Department of Manufacturing Engineering
and Operations Management

Expectations of safety:

Realising ergonomics and safety in product design

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A product is defective if 'the safety of the product is not such as persons generally are entitled to expect'.

(Consumer Protection Act, 1987: Part 1, Section 3)

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Abstract

This research considers the role of ergonomics in consumer safety. The aim was to encourage and improve the input of ergonomics, and thus safety, into the design process. The research has resulted in a series of publications targeted specifically at designers and producers of consumer goods, with the aim of encouraging their adoption of ergonomics principles, data and methods. These publications have been produced and distributed to industry by the Department of Trade and Industry (DTI) Consumer Safety Unit:

- CHILDATA: The Handbook of Child Measurement and Capabilties - Data for Design Safety
- Designing Safety into Products: Making ergonomics evaluation a part of the design process (presented as an appendix to this thesis).

The background to the research is a review of the influences on consumer safety, and the exploration of a role for ergonomics. European consumer legislation states that to be safe a product must meet the expectations of the user, hence the title of this thesis. This user-centred premise indicates the importance of product design and ergonomics in consumer safety, within the context of the other influences on safety such as safe-guarding, mitigation of accidents and education. Theoretically this places ergonomics as a central influence on safety. A review of the existing contributors to safety, such as governance, standards and education was undertaken and again design was found to be central. With the potential contribution of ergonomics to safety demonstrated, evidence of a formal relationship between ergonomics and the design process was sought from the literature. Despite many years of calls for improvements in the input of ergonomics to design, little evidence was found in the ergonomics literature of support or guidance for designers of consumer products on either of these aspects. Two main routes to improving this input of ergonomics to design were identified: the use of ergonomics data and guidelines, and the use of ergonomics evaluation methods. This research focuses on

these two routes to product design safety with the hypothesis that these inputs could be improved, eventually allowing better design safety to be realised. The aims of the research were therefore to investigate and improve these inputs.

The first stage of the research considered the use of ergonomics data and guidelines in design. The limitations of ergonomics data and the barriers to effective knowledge transfer were identified. Work was undertaken to address these problems, in the first instance specifically for designers of children's products. This resulted in the production of '**Childata**', a handbook of ergonomics data on children, and its production and content are described. Four thousand copies of this handbook have been published and distributed free of charge to industry by the DTI. The success of Childata has resulted in sibling publications on adults (now published) and the elderly (in preparation).

The next stage of the research was to consider the use of ergonomics evaluation methods by designers. A review of the literature on ergonomics methods and on guidance for their use found that there was a dearth of practical advice for designers. Also, that most guidance on evaluation methods concentrates on usability with very little reference specifically to safety. The feasibility of producing guidance for designers to encourage their use of evaluation was therefore considered. A series of four product safety evaluations were undertaken, presented here as case studies, and these form the major experimental part of the research. The aim of the case studies was to investigate the most useful and common methods for evaluating product safety and to generalise these into guidance for designers, as well as producing formal reports and recommendations for improvements in the safety of the individual products. The products investigated were swimming pool covers, carbonated drinks bottles, all terrain bicycles and stepladders.

The case studies showed however that a diversity of methods were needed to carry out the evaluations, many of which were novel methods or which drew on a mixture of ergonomics, technical and market research expertise. The only commonality found was in the sequence of stages that each evaluation followed, namely the identification

of the products' users and hazards, the setting of performance criteria and selection of measurement variables, and the subsequent choice of methods. The initial concept behind the fundamental research to producing prescriptive advice on methods was therefore rejected. Instead a framework for a generic evaluation process was developed, based on the findings from the case studies and with reference to the literature. This framework formed the basis of a guidance document for designers: **'Designing Safety into Products'**. This was also published and distributed to industry by the DTI. The publication establishes and encourages a generic evaluation process, but also concentrates on embedding ergonomics principles into the design process by exploring the relationship between evaluation and safety and stressing the need to move past the use of ergonomics data, as well as providing methodological guidance.

The research reported in this thesis has shown that the problems with the transfer of knowledge and methods from the ergonomics discipline are long standing. The reasons for this are discussed and recommendations are made to improve the link between design and ergonomics, including furthering this pragmatic approach to empowering designers by the production of similar design tools.

The research programme has been a pragmatic approach to improving ergonomics and safety in design: improving the accessibility of ergonomics data for designers and promoting ergonomics evaluation methods during the product development process. The publications that have resulted from the research represent pragmatic steps which it is hoped may make some contribution to the realisation of safety.

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This thesis is for my family -

for mum, dad, Jude, Nigel, Nicholas, Stewart and Melissa,

and for nan and bamps.

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10.1 Designing Safety into Products

Chapter 1 - Accidents with consumer products

Chapter 1 considers the need for research to reduce the number of accidental injuries in the home and at leisure, and finds that there are more accidental injuries and deaths associated with the use of consumer products than occupational and traffic accidents combined. Some definitions of accidents, hazard and risk are offered to set the boundaries for the research. In order to explore the potential relationship between ergonomics and consumer safety, accident causation models and accident research are reviewed, identifying the contributory factors in consumer accidents and particularly the role of the 'product'. The need for an impetus for improvements is discussed and the aims of the research described.

1.1 The need for research

Four thousand people die every year in the United Kingdom and at least three million are injured seriously enough to seek hospital medical attention (DTI, 1995).

Across the European Commission this has previously been estimated as 30,000 deaths and 40 million injuries annually, across the (then) twelve member states (Falke, 1989).

These phenomenal numbers of deaths and injuries are not caused by road traffic accidents, dangerous work environments or malicious acts, but are accidents happening at home and at leisure. The Consumer Safety Unit (CSU) of the Department of Trade and Industry (DTI) defines home as: 'any type of dwelling and

its boundaries except hotels, hospitals and prisons' and leisure as: 'any environment or activity other than the home, paid work, motorised vehicles on the public highway but includes public transport, cycling, shopping and sport' (DTI, 1995). Accidents in the home and at leisure account for far more medically treated injuries (including those also treated by GPs) than injuries at work *and* on the road combined and accidents in the home alone account for around 40% of all fatal accidents in Great Britain (DTI, 1995).

In 1989 the cost of home and leisure accidents to the twelve members of the European Community was then estimated to be 60 billion ECU (Rogmans, 1989). Regardless of any moral duty to protect people from injury, it might be assumed that these economic implications would be impetus for remedial action.

1.2 Definitions of relevant terms

This Chapter will consider accident causation, but prior to any analysis of accidents some definitions are required.

Definitions of an accident vary according to the domain of interest:

- *'a mishap, an unforeseen event or one without apparent cause'* (Collins English Dictionary, 1990)
- *'an unintentional injury or suspected injury, no matter how caused, except deliberately self-inflicted or by physical attacks by other persons'* (DTI, 1992)
- *'the occurrence of immediate personal injury or personal damage during the use of a product'* (Weegels, 1996, *after Leplat 1984 and Surry, 1974*)

It may be of use to further define the following components of accidents[1]:

- hazard:

[1] Further discussion of these definitions is given in Chapter 10.

- *'an act or phenomenon poses a hazard when it has the potential to produce harm or other undesirable consequences to a person or thing'* (NRC, 1989)
- *'a set of circumstances that has associated with it the potential for injury or death'* (Christensen, 1980)
- *'the disposition to produce harm'* (EC Machinery Directive 89/392)

- risk - *'the probability that harm will be realised'* (NRC, 1989)
- injury - *'the effects of an external energy source on the body, such as mechanical, electrical, chemical or radiation energy'* (DTI, 1992)

It is recognised that not all accidents will result in injury, but for the purposes of this thesis, an accident will be considered as *'an unplanned and harmful event associated with the use of a consumer product'*.

If injury is the effect of an external energy source on the body, the sources of this energy are suggested as 'the products that surround people in their everyday lives - architectural features, furniture, tools, domestic goods, toys' (DTI, 1992). So injuries in the home and at leisure can be considered to be associated with **consumer products**. These have been defined as:

- *'goods and services.....with which the general public come into contact'* (Wilson, 1983a)
- *'ordinarily intended for private use or consumption'* (except for food, medicines, unprocessed agricultural products and motor vehicles - Consumer Protection Act 1987)

Safety can be interpreted in a number of ways. A product is safe if it:

- *'meets consumers' expectations, during use and misuse'* (Consumer Protection Act, 1987)
- *'can be used without reservation*[2]*'* (Thomas et al, 1990).

[2] Criterion for the 'GS' mark in Germany, equivalent to the BSI Kitemark in the UK.

1.3 Accident causation

Before ways of improving consumer safety can be explored, the process of accident causation should be given some consideration. There has been much analysis and there are many theories about this process.

The contributory role of any product in an accident frequently remains unproven despite costly accident monitoring systems (see Chapter 2) and the efforts of accident investigation (see Weegels, 1992). Wilson (1983a) said that at the root of all accidents is a product-person interaction which has in some way failed, and either the product, person, circumstances or environment has precipitated this failure. Unfortunately, the vast majority of the work analysing accident causation from an ergonomics perspective is concerned with occupational accidents, such as that of Ramsey 1985 whose model of accident causation in shown in figure 1.1 (see Pimble and O'Toole 1982, , Woodcock Webb 1988, Kusukami and Ikeda 1989, Reason 1995). There is less work on accidents with consumer accidents, a view supported by Kanis and Weegles (1990) and Weegels (1992).

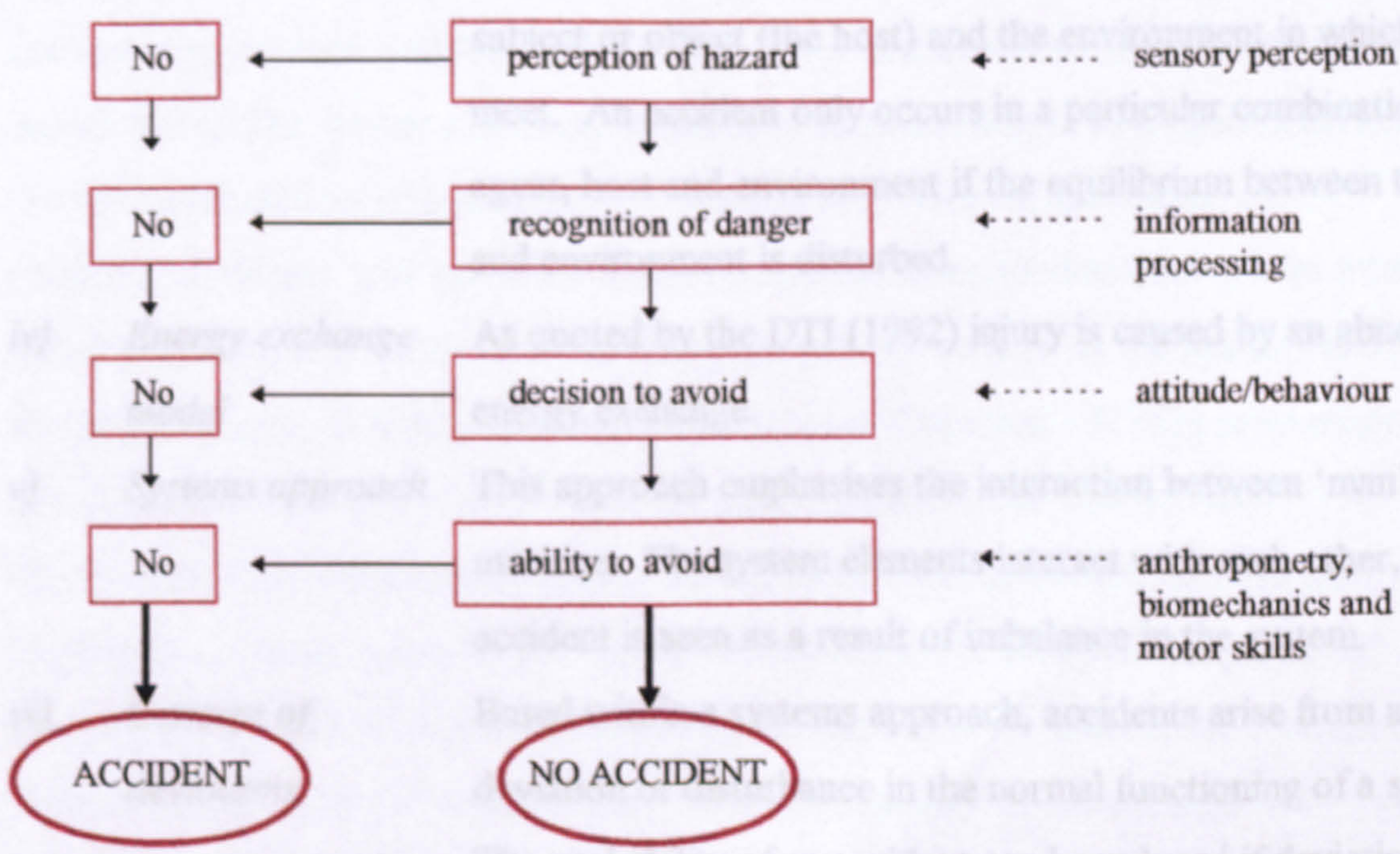


Figure 1.1 - Ramsey's accident sequence model (after Ramsey, 1985)

Given the lack of accident causation models applicable to consumer safety, Weegels (1996) examined the popular theories of accident causation with a view to applying them to consumer accidents. She interprets and summarises the available theories and perspectives into the following list:

i)	*Mono-causal*	Accidents have only one cause, such as accident proneness or failure of the product.
ii)	*Chain of multiple events*	These theories recognise that accidents have more than one cause, and in particular a chain of events. A most well recognised one of these is the domino theory developed in the 1950's by Heinrich (1959). The chain of events or 'dominoes' are, in the following order: social environment; personal influence; an unsafe act /mechanical and physical hazards; resulting in an accident and then injury. Accident prevention is achieved by removing one of the dominoes or events; the unsafe act/mechanical and physical hazards are the easiest to remove according to Heinrich.
iii)	*Epidemiological perspective*	An accident is the result of the interaction of three factors: the inflicting agent (physical, chemical or biological), the recipient subject or object (the host) and the environment in which they meet. An accident only occurs in a particular combination of agent, host and environment if the equilibrium between the host and environment is disturbed.
iv)	*Energy exchange model*	As quoted by the DTI (1992) injury is caused by an abnormal energy exchange.
v)	*Systems approach*	This approach emphasises the interaction between 'man' and machine. The system elements interact with each other, and an accident is seen as a result of imbalance in the system.
vi)	*Concept of deviations*	Based within a systems approach, accidents arise from a change, deviation or disturbance in the normal functioning of a system. The probability of an accident can be reduced if deviations can be eliminated or controlled.

vii)	*Technical approaches*	These comprise a systems perspective but identify technical failures.
viii)	*Behavioural approaches*	These emphasise the relevance of the information processing, decision making and cognitive aspects of behaviour. The human is seen as an information processor with limited capacity, and the probability of an accident increases if a deficiency in one of the information processing phases occurs.
ix)	*Combinations of the above*	

Kanis and Weegels (1990) have suggested that these theories, while much quoted, are divergent, fragmentary, difficult to 'operationalize' and vary in their applicability and Weegels (1996) concludes that a single approach to accident causation is unsatisfactory and that an approach more attuned to consumer products is needed.

1.4 Human error theory and 'misuse'

Schoone-Harmsen (1990) categorised accident theories into two approaches: theories concentrating on technical failures leading to unwanted situations and those based on human error. The former allows probabilities of technical failure to be quantified and the latter probabilities of human failure. Ryan (1983), looking specifically at consumer accidents, said that traditional accident causation models (and quotes from the 1930s through to 1980) all identified 'improper human acts' as the primary factor in personal injury. Schoone-Harmsen however cites Wagenaar's (1983) proposition that estimates of the probability of human failure are unrealistic and that as ergonomists we maintain that products should be adapted to the user and therefore are opponents to the human-error theory. This leads to the idea that design should account for the ways in which a product is used and misused. Indeed, the concept of design accounting for foreseeable misuse has been adopted in current legislation (see Chapter 2). Ryan (1983) offers a definition of this as: 'the reasonable ways in which a product can be used, or misused, by a prudent person'. Importantly, Weegels

(1996) says that the preoccupation with the term 'misuse' in consumer safety, which is rarely used in other safety fields, demonstrates the lack of recognition of the freedom of use surrounding consumer products, factors such as the diversity of the user population and the lack of control over where, how and by whom the products are used. These factors are common to consumer accidents but are often ignored or irrelevant in the analysis of other accidents (traffic or occupational) from which many accident causation theories originate. Designers therefore need to be encouraged towards a user-centred approach, although the realisation of design safety is difficult because as Baber and Mirza (1996) point out, the model of how a product works is often different in the mind of the user and the mind of the designer.

1.5 Accident investigations

While theorists argue about the accident causation model most appropriate to consumer products, a more pragmatic approach may be to look for *evidence* of causation in order to find a starting point for remedial action by designers and producers. As well as accident causation theories, Weegels (1996) also assessed available accident investigation methods for their applicability to investigating accidents with consumer products. She found that most techniques are not explicit on the causes or contributory factors and set out to produce a method to assist product designers in identifying accident causes and so set safety criteria for their products.

Weegels investigated forty-two accidents using a number of methods: interviewing victims within two weeks of injury; assessing the accident scene, product and user involved in the incident; and using these to re-construct accidents. The important differences between this and other methods were the lack of delay between the incident and the follow-up and the lack of reliance on the victim's interpretation of the cause of the accident. Possible limitations of the study were cited as the small number of accidents investigated; that the method was concerned with existing products only and could not be used in prospective design; and that the accidents

studied were biased as the sample was self-selected victims who agreed to participate. The method of analysis was considered costly in terms of time and money because each accident analysis was detailed and, in the author's own words, laborious, with no obvious way of cutting time without losing validity.

Based on this method, Weegels here and previously (1992) produced a list (with albeit limited examples) of contributory factors in accidents with consumer products, which echoed the contributory factors identified previously by Wilson (1983a). These have been adapted here as follows:

- **user** — eg physical characteristics, perceptual and cognitive factors, temporary and permanent conditions
- **use** — eg appropriateness of task, combination with other products
- **product** — eg structure, moving parts, power sources, controls, displays, packaging, instructions, fixings, maintainability, ancillary equipment
- **environment** — eg physical (eg noise, lighting, temperature) and social (eg home versus playground)

Weegels found that in most accidents more than one of her five factors (user, use, product, situation and social conditions) were indicated, no particular combinations were predominant and when the factors were considered separately, all featured only in a minority of cases. The most consistent finding was that 'there is no consistency in the causes of accidents', they are 'largely unpredictable', with Weegels concluding that accidents are intractable (p198).

Of relevance here is the theory of risk homeostasis, which states that a person's behaviour reflects the acceptance of a fixed level of risk (Cushman and Rosenberg, 1991). As products become 'safer' the way in which they will be used will be less safe. Most of this work has addressed driving behaviour, with the example of the effect of wearing seat belts on driving aggression (Wilde, 1984). With regard to consumer safety, a similar issue is the effect of child resistant containers (CRCs) for

medicines on the attitudes of carers' to the storage of medicines. The potential child resistance benefits of the packaging could be said to encourage carers to be less concerned about storing medicine containers away from children and would allow children to have increased exposure to the packaging, with the possibility of the child exploring the packaging and eventually gaining access. Another example would be the inherent safety of a product such as a bath seat, which allows an infant to be supported in a bath for easier washing but does not prevent them toppling over, but the perceived level of increased safety from the product could encourage a carer to momentarily leave the child when they would not do so if the product was not used. This theory suggests that any attempts to improve safety will probably become ineffective over time, and could be seen to negate the need for this research, however while its relevance is not underestimated it should not rule out the need for attempts to understand accident causation and is possibly most constructive in the economic assessment of intervention strategies.

1.6 The role of the product in accidents

Weegels found that of the five factors she quotes as contributing to accidents, the 'product' was indicated in the fewest. The aim of this research is to examine whether product design, and ultimately ergonomics, can be used to reduce accidents at home and at leisure. The role of the product in accident causation is therefore of interest.

Other authors have similarly found the product to be 'the cause' in a minority of accidents:

- ***'10% of product-involved injury episodes are attributable to 'unsafe products'*** (Somers, 1994); a study of 16,000 injuries recorded by the National Injury Surveillance and Prevention Project NISPP in Australia carried out by the Industry Commission and supporting earlier estimates by the Australian Consumers' Association.

- ***12% of injuries in all home and leisure accidents could have been prevented if the product had not been at fault'*** (Abbott and Tyler, 1997); investigations of Accident and Emergency admissions in the UK, USA and Netherlands.
- ***in '20% of all accidents faulty appliances were a 'potential cause', but in practice only 2% of injuries were due to 'faulty' appliances and only 0.5% if old appliances and incorrect usage were disregarded'*** (Mertens, 1986); a study by insurance companies in the Federal Republic of Germany using interviews with victims.

Schoone-Harmsen (1990) also asserts that only a small number of consumer product accidents are due to technical failure alone. Ryan (1985) quotes but disputes the '85/15% ratio of accident causation' - that 85% of accidents are caused by human error and 15% by product or environmental defects - and suggests instead that a 'primary causation factor' in consumer product injury is a lack of product safeguarding.

While the research reviewed here suggests that the majority of accidents are not attributable to one single factor and that 'the product' (or deficiencies in the product) is not the primary cause of injury, the methods of accident investigation on which these results are based have been criticised for their reliance on victims' interpretations of the accident scenario and the likelihood that blame is often self-attributed (Weegels, 1996). Moreover, the research above does not distinguish between accidents due to product 'construction' defects and defects in product design. Accidents due to product construction defects are linked to inadequacies in materials, structures and manufacturing quality procedures. Accidents due to design 'defects' are due to the product not accommodating the user, or how the product will be used, including human error. To achieve safety, product development must account for both of these aspects of the product's presentation, but *product design safety* is the focus of this research.

1.7 Impetus for improvements

The sheer numbers of home and leisure injuries should be argument enough that improvements in the consumer safety are necessary; according to the National Consumer Council three percent of the UK population claim that they have been injured by an 'unsafe' product, excluding cars (NCC, 1995). There must however be an impetus for improvements. Ergonomists have been suggesting for some time that consumers are increasingly intolerant of poor design, and look for indicators of good design (Bullock, 1994, Thomas et al 1990, Wilson and Whittington 1982). If we assume safe design to be a component of good design, then safety should be an expectation and a purchase criterion. Safety is much more of a 'visible' entity in vehicle design than in consumer products - safety is now one of the primary selling points of cars. The impetus for these improvements in vehicle safety could be one of many - legislation, competition or consumer demand. Yet the very real risk of injury or even death in the home and in our leisure time, demonstrated by the statistics, does not appear to have had such an impact on the design safety of consumer products. This may be due to the perception that one is less likely to be injured at home than on the road or any injury would be less severe. Also the NCC suggest that consumers are likely to attribute blame for an injury at home to their own actions, suggesting a greater 'locus of control' (one's perceived ability to exert control over circumstances and events) over domestic accidents than those outside the home.

Whatever the reasons - familiarity with domestic products and tasks, the perception of less severe potential injuries, or lower unit cost - it appears that the impetus for improvements in safety is unlikely to be consumer driven. Schoone-Harmsen (1990), in discussing the potential for improvements in product safety, points out that concerns by manufacturers for safety should always have been justified because of ethical motives, but that recent product liability legislation should provide an added economic motive for them to scrutinise product safety. However the NCC suggest that under the present legislative system consumers are unlikely to take action against a manufacturer of a product if that product injures them, as their awareness of consumer safety legislation is low. Without this threat of litigation, perhaps the only

impetus for manufacturers, and even for government, to work towards improvements, would be competitive advantage.

1.8 Aims of the research

A need for improvements in home and leisure safety is demonstrated by the high number of injuries in these domains. This Chapter has considered the mechanisms of accident causation and although a plethora of accident models have been produced, few appear to have been found useful in consumer safety. Instead a combination of factors have been identified as contributing to an accident: the user, the product, the use of the product or task, and the environment. An ergonomics approach to consumer safety is concerned with ensuring that product design has accounted for the interaction of these factors, yet the accident investigations reviewed in this Chapter implicated product 'defects' in only a minority of cases, suggesting that ergonomics interventions are likely to have little impact on safety. However, the reliance of these investigations on victims' perceptions of accident is recognised as an important limitation, as well as potential biases in those responsible for accident records. The possible contribution of product design to safety is explored in detail in the next Chapter.

The research reported in this thesis is underpinned by the issues raised in this Chapter and had the following aims:

1. to investigate the routes and contributions to improvements in consumer safety and identify a role for ergonomics in these improvements
2. to specify the ways in which ergonomics can contribute to design
3. to investigate the limitations of the ergonomics inputs to product design safety
4. to identify remedies for these limitations
5. to improve the input of ergonomics to product design safety.

The research carried out in this thesis was funded by the Department of Trade and Industry Consumer Safety Unit[3]. The research included investigations of specific product safety issues and the feasibility of prospective safety initiatives. As a result of this work reports were distributed to industry on the results of the product safety evaluations and two major publications have been produced as part of an overall proactive approach. The production of these publications is described in this thesis and they are submitted in support of this research. The publications are:

Beverley Norris and John R Wilson. *CHILDATA: The Handbook of Child Measurement and Capabilties - Data for Design Safety*. Department of Trade and Industry, London. June 1995. ISBN 0 9522571 1 4.

Beverley Norris and John R Wilson. *Designing Safety into Products: Making ergonomics evaluation a part of the design process*. Department of Trade and Industry, London. October 1997. ISBN 0 9522571 2 2.

These publications represent a proactive initiative on behalf of the government to encourage ergonomics and safety within design and industry. They have been produced and distributed by the DTI world-wide and free of charge to the design community, manufacturers, research organisations, standards bodies, safety groups and other interested bodies.

[3] Except the first two phases of the production of Childata which was funded by the European Commission DG XIV: Directorate General Consumer Policy.

Chapter 2 - Contributions to consumer safety

With a need for improvements in consumer safety identified, the potential contribution of product design and ergonomics needs to be considered. This Chapter investigates the theoretical routes to consumer safety and the existent contributors, such as governance and education. The Chapter concentrates on these influences and suggests a model of their interactions. Their effectiveness is discussed, and as a result, product design is established as the most influential factor in safety. By establishing the importance of design, a potential role for ergonomics is identified.

2.1 Routes to safety

A number of theoretical routes to improving safety have been suggested in the literature, as shown in figure 2.1:

Hale and Glendon, 1987	**Wilson, 1983b (after Haddon, 1973)**	**Cushman and Rosenburg, 1991**
• eliminate the hazard • isolate the hazard • protect against injury and damage • reduce injury and damage • improve system recovery after hazard	• remove or isolate the hazard • remove the user • barrier • reduce the consequences • education or training	• design • isolate • barrier • active/passive warning • instructions/training

Figure 2.1 - Routes to consumer safety

These routes have been consolidated here by this author as follows:

- eliminate the hazard (*through design)*

- isolate the hazard *(or protect the user)*
- mitigate the consequences of an accident
- educate the users to be aware of the hazard and how to avoid it.

It is suggested that the primary route to consumer safety should be eliminating the hazard through product design. Isolation of the hazard is also achieved through design measures. All others are secondary approaches, to be used in situations when product design can only reduce risk, such as products with inherent hazards, for instance knives or stairs. Design is therefore the central route to safety.

2.2 Model of consumer safety

With this system of potential routes to improved safety in mind, a review of the existent contributions to, or influences on, consumer safety was carried out, to assess their effectiveness. A model of the factors influencing the safety of people in their homes and at leisure is proposed and is shown in figure 2.2.

There are three immediate influences on consumer safety:

- the product design
- the behaviour of the consumer (how the product is used)
- the conditions in which it used (where and when it is used and the product's condition).

It is suggested that the latter two are at a 'micro' level of influences in that they vary from one instance of use to another and, beyond a certain level, are difficult to predict or control. This is an important aspect of consumer safety which distinguishes it from, say, occupational or transport safety.

The product design - its form, materials, construction and presentation - is a central contributor in that it is influenced by each of the 'macro' level contributors. The 'macro' influences on consumer safety can be thought of as

those activities that are remote from the actual use of the product. They exert a direct influence on design, and on the general level of safety in which the consumer market operates, and indirectly on the consumer. These macro influences are from governance (in the general sense), product safety standards, manufacturers, and, as a subsidiary of all these, safety information.

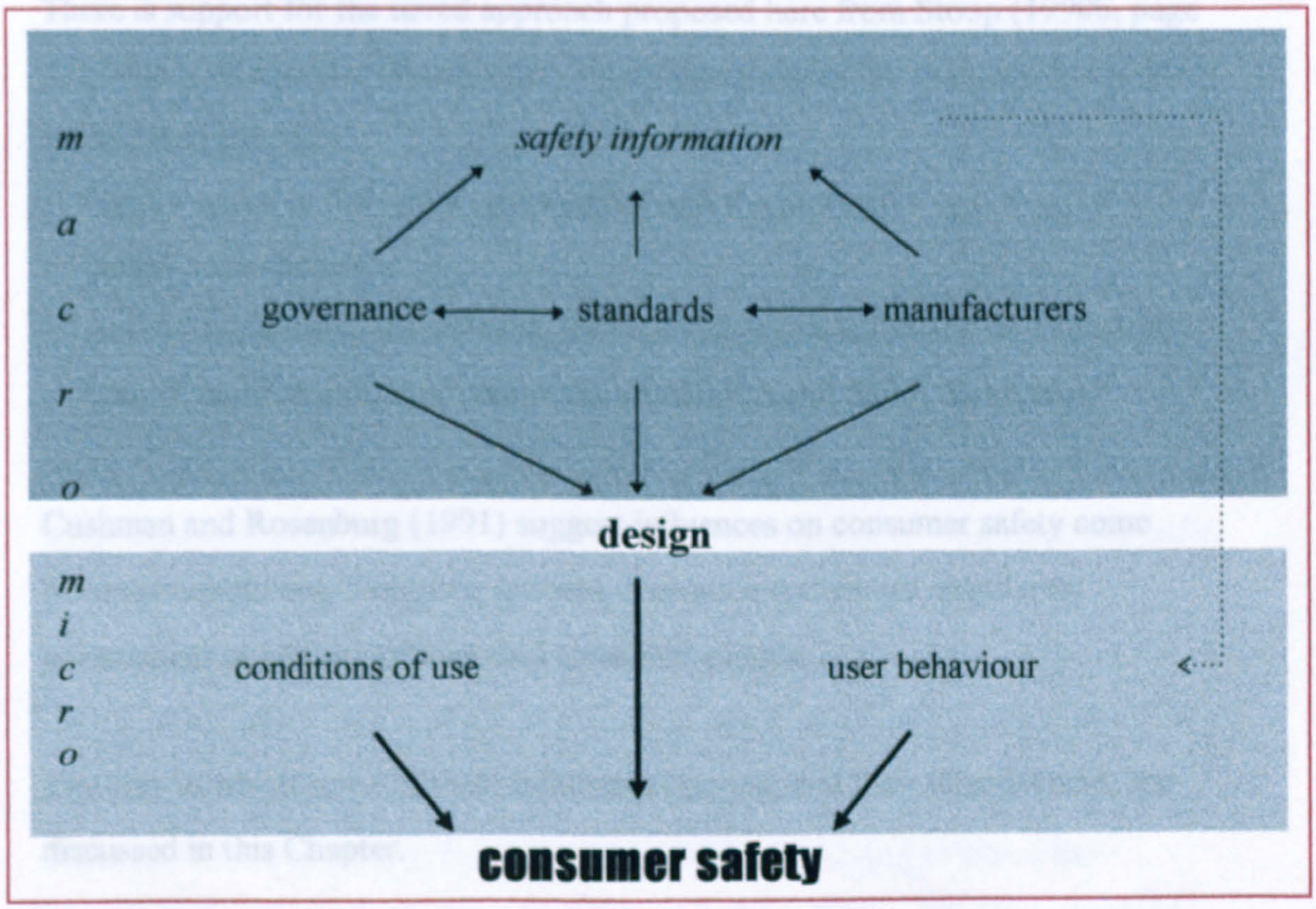


Figure 2.2 - Influences on consumer safety

Manufacturers have an obvious role to play in the level of safety they decide to design and build into their products, the pressure they exert on governance, the level of safety they foster generally in the market and the influence on standards. Standards are considered a separate function since they directly influence design and are not a responsibility of governance. They are however directly influenced by both governance and manufacturers.

Safety information can be produced or influenced by all these bodies - governance, standards bodies and manufacturers - and can include general public awareness through to instructions and labelling. Safety information, or knowledge, affects the micro-level of safety in that it can influence each instance of use, differences occurring between users and between each time of use.

There is support for the tiered approach proposed here from Stoop (1990b, page 53), who uses a similar classification but defines three rather than two levels of safety intervention:

- micro - users, in their direct interaction with the product
- meso - manufacturers
- macro - legislators, government, professional organisation and an 'industrial branch' such as insurance companies and Health and Safety Executive.

Cushman and Rosenburg (1991) suggest influences on consumer safety come from manufacturers, designers, lawyers, insurance companies, standards, government regulatory offices, and consumer groups.

The way in which some of these influences operate, and their effectiveness, are discussed in this Chapter.

2.3 The role of governance in consumer safety

Governance can be considered to consist of anything influencing the consumer market: legislation, government activities such control and monitoring of the market, public training and awareness initiatives, through to consumer groups.

The effectiveness of legislation and the monitoring of safety are considered the main activities and are discussed here.

2.3.1 Legislation

Consumer safety legislation in the UK operates on both generic and specific levels. Specific legislation is in the form of regulations relating to particular groups of products, such as the Pedal Cycle Regulations (1984). Generic legislation was introduced in its present form in 1987 (the Consumer Protection Act or CPA) and followed by the 1994 General Product Safety Regulations (GPSR), both enacting European directives and a result of a move towards harmonisation across the European Union (85/374/EEC and 92/59/EEC respectively). Legislation has changed radically in the last ten years and the importance of this new generic approach is twofold; the CPA introduced for the first time a **comprehensive general safety requirement** - for all products to offer 'a reasonable level of safety'- and introduced **strict liability.**

Strict liability - Part 1 of the CPA introduced civil liability for consumer products, allowing manufacturers (or suppliers or importers) to be sued directly by any person injured by a 'defective' product - a product being defective when '*the safety of the product is not such as people generally are entitled to expect*' (Section 3). This introduced the concept of 'strict liability' for the first time in consumer law: that damages could be sought without having to prove the manufacturer negligent, the onus now being on the manufacturer to prove their product was safe and that they were not negligent.

General safety requirement - In Part 2, the CPA extended the existing criminal liability for product safety by introducing a new concept in safety legislation which had only been used once before in the UK, under the Health and Safety at Work Act. This concept was a new, broad approach, that all consumer goods should satisfy a test of being 'reasonably safe'. The specification and interpretation of the concept of reasonably safe is obviously crucial. The Act defines safe as:

> *'no risk, or no risk apart from one reduced to a minimum, that the goods, their keeping, use or consumption, or assembly, etc,*

will (whether immediately or after a definite or indefinite period) cause the death of, or personal injury to, any person whatsoever.'

In interpreting this requirement the manufacturer was to take into account any relevant published standards of safety and the existence of any reasonable means for the goods to have been made safer. The GPSR followed in 1994 to 'fill the gaps' (Abbott and Tyler, 1997) that remained after the CPA. This extended the CPA to include second hand goods and extended the definition of a safe product as (Article 2b):

'Safe product shall mean any product which, under normal or reasonably foreseeable conditions of use, including duration, does not present any risk or only the minimum risks compatible with the product's use, considered as acceptable and consistent with a high level of protection for the safety and health of persons, taking into account the following points in particular:

- *the characteristics of the product, including its composition, packaging, instructions for assembly and maintenance;*
- *the effect on other products, where it is reasonably foreseeable that it will be used with other products;*
- *the presentation of the product, the labelling, any instructions for its use and disposal and any other indication or information provided by the producer;*
- *the categories of consumers at serious risk when using the product, in particular children.*

The feasibility of obtaining higher levels of safety or the availability of other products presenting lesser degree of risk shall not constitute grounds for considering the product to be 'unsafe' or 'dangerous'.

Of importance here is that the feasibility of making safer products is now excluded as a reason for deciding if a product is safe or not. Also compliance

with standards can be disregarded as a defence if products don't meet the level of protection that consumers are entitled to expect. The emphasis on vulnerable users, especially children, is also of interest.

The CPA introduced another important concept, which was expected to cause manufacturers most difficulty, that of *foreseeable misuse* (Jenkins and Davies, 1989). This meant that the level of safety a product attains should account for how the product could be reasonably used, and for all intended and potential users. This new requirement was hoped to instil in manufacturers a 'greater and continuing responsibility and for their products and encourage more attention to the design, product testing and assessment stages' (Jenkins and Davies, 1989).

In the United States, litigation now relies heavily on the ability of the manufacturer to warn of potential hazards as what the user knows about the product is considered critical. The perception of what is 'reasonable' is fundamental to the legislation there also, whether it be what is a reasonable consumer, reasonable use or what is reasonably dangerous. Courts issue guidelines to juries to consider in personal injury cases:

1. the degree of risk acceptance by consumer
2. the state-of-art in the product
3. the technical and economic feasibility of eliminating or minimising the risk of injury
4. the extent to which the manufacturer warned the consumer of the hazard (including specific aspects of warning design)
5. the likelihood and seriousness of injury
6. the usefulness and availability of a safer replacement product
7. the consumer's expectation and general knowledge of the product in reasonable and foreseeable use
8. the bargaining power of the manufacturer compared to that of the consumer,

Legislation to improve the safety of products has moved forward considerably in the last twenty years, with product safety legislation raised as an area in need of

attention by the European Council in the early 1970's, apparently driven by concern over the requirement that under existing legislation fault had to be proven although it took until 1985 for the Product Liability Directive to emerge (it is interesting to note that while the UK had implemented this directive under the Consumer Protection Act by 1987, France still have not - Abbot and Tyler, 1997). It has been commented that the drive has come from the European single market and the need for a harmonised legislative framework across Europe, with 'consumer policy only being formally recognised as an end in itself after the 1992 Maastricht treaty' (Abbott and Tyler, 1997, page 81). This is considered by some working in consumer safety as long overdue, coming much later than regulations governing industrial or traffic safety (Rogmans, 1989) and only now catching up with that of pharmaceuticals, chemicals and food (Abbott and Tyler, 1997). Meanwhile consumer organisations have criticised the reliance of the legislation on standards with no evidence of improvements in safety (NCC, 1995).

2.3.2 Monitoring of consumer safety

The Government monitors consumer safety and uses the results to highlight areas of concern, to stimulate standards activity, prioritise public awareness initiatives, influence manufacturers and even legislate on specific products (eg Fireworks Regulations, October 1997). The monitoring system (HASS - the Home Accident Surveillance System) was developed in the UK in 1976 by the Consumer Safety Unit (CSU) of the DTI (Warne, 1982), following the example of the United States (Hayward, 1988). The DTI have added to it LASS (the Leisure Accident Surveillance System) and HADD (the Home Accident Deaths Database). The UK was the first country in Europe to produce statistics on home accidents and the format of HASS has been the basis for other systems developed across Europe. The European Home Accident Surveillance System (EHLASS) collates statistics from the comparable systems in the European Union. Summary statistics of recorded and estimated injury and fatality rates from HASS, LASS and HADD from 1984 to 1995 are shown in table 2.1.

year	injuries (HASS and LASS)		deaths (HADD)
	recorded cases	national estimates	
1984	n/a	n/a	4,593
1985	n/a	n/a	4,485
1986	99,489*	1,999,000*	4,388
1987	156,227**	5,026,000	n/a
1988	226.388	5,694,000	n/a
1989	249,157	6,242,000	3,968
1990	249,513	5,587,000	3,949
1991	251,969	5,865,000	3,870
1992	216,557	5,424,000	3,841
1993	209,526	5,845,000	3,663
1994	185,363	6,387,000	3,569
1995	217,303	5,442,000	n/a

* *HASS only*

** *LASS data estimated from 6 months data*

Table 2.1 - HASS, LASS and HADD statistics for the period 1984 - 1995

The data are collected as follows:

H/LASS: HASS and LASS record medically attended injuries reporting to hospital Accident and Emergency (A & E) departments. Recorded cases and estimates of national injury rates according to product types are published annually based on a sample of eighteen hospitals in the UK out of an eligible 300 (routinely rotated for the first eleven years of the system but not now).

HADD: The Office of National Statistics (ONS) publishes death statistics. Since 1983 the DTI has filtered deaths in the home in England and Wales into HADD, which uses information from death certificates.

EHLASS: This was established in 1986 to provide a comparative and standardised cross-European monitoring of consumer safety. Only the UK and the Netherlands had a surveillance system before this. Each of the twelve member states at that time took part [1] except Germany whose system is based on interviews in the home. Only a selection of the systems' hospitals in each country are used, for instance 11 out of the 18 UK

[1] UK, Luxembourg, Ireland, Denmark, Greece, Belgium, Portugal, Netherlands, Spain, France, Italy, Federal Republic of Germany

hospitals, giving different recorded statistics to the national systems although the national estimates are the same.

There are other, somewhat less comprehensive accident-monitoring systems. Trading Standards authorities investigate product-related incidents but it is not a monitoring system and Royal Society for the Prevention of Accidents (RoSPA) collates press reports of accidents.

H/LASS monitors medically attended injuries only and this leaves important gaps in the monitoring of consumer safety, notably GP or self-treated injuries and non-injury accidents, for which expensive prospective recording systems would be required. The data provided by H/LASS are often too brief to allow any more than a superficial study of product type and involvement and there is a significant delay in producing annual data (usually twelve months after the year's end), which means that detailed investigations of accidents by following up incidents are difficult because of victims' poor recall of events. There is also a suspected bias in the sample as A & E staff have reported confidentially to the author that there is some informal pre-selection of interviewees, caused by a reluctance to interview some A & E attendees, such as parents of injured children or aggressive male patients.

There are serious shortcomings in the monitoring and analysis of accidental deaths in the home or at leisure in the UK. Any death in the UK due to unnatural causes is subject to a coroner's inquest. The coroner's report can provide information on the possible involvement of any consumer product but they are not routinely open to the public. Coroners' reports are an obvious medium for recording and centralising details of accidents, however as has been pointed out by Levene (1991), there are barriers to using the information in consumer safety. There is no central data collection and area coroners have to be contacted individually. Not all coroners allow access to their records and some that do levy a charge. There are gaps in the information available such as lack of victims' details and the use of safety measures and safety training (as identified by Levene in an investigation of

children's accidents). Research described in this thesis found that it is often difficult to tell what type of product was involved, the location of the incident, what tasks were being carried out, and if the accident was occupational or domestic (see Chapters 6 to 9). Levene calls for a contribution to safety by coroners opening their records and Hayward (1988) in describing the development of HADD called for a fundamental change in the method of data collection on fatal home and leisure accidents.

EHLASS is continuing to be evaluated, but it has been found that, counter to one of its objectives, third party data analysis has been excluded and access is by European Commission staff only (Mulder and Rogmans, 1991).

2.4 Standards

Standards for products are thought to date back to the 15th Century (prescribing methods for processing wool), but it was not until the 1920s (at least in the United States) that the conformity of standards recognised today developed (Ryan 1985). Comprehensive product safety standards now exist at national and international levels with the aim of bringing about a comparable and minimum level of safety across a product group, but these are still developing. Safety standards are diverse and can comprise specifications for the design, materials, construction, labelling and performance of a product, for test methods and the definitions and classifications of products.

A committee of those considered expert in a product will be assembled to draw up a standard. Experts will consist of representatives of manufacturers, government and consumer/safety/scientific bodies, although this latter group are reportedly included only on an ad hoc basis and upon the request of the other parties (Rogmans, 1989).

Standards are voluntary, unless referred to specifically in legislation - for example the Pedal Cycle Safety Regulations (1984) in the UK requires that all bicycles meet the British Standard for Pedal Cycles (BS6102). However, they have in effect become mandatory as a result of the 1987 CPA's requirement for all products to be 'reasonably safe' as existing standards serve as a reference for the minimum level of safety expected of that product.

Standards for a product will often differ between countries in their requirements for testing, materials or performance, as is the case for swimming pool covers (Chapter 6) and stepladders (Chapter 9). The effort of international standards organisations such as ISO[2] and CEN[3] is to harmonise product development and to provide a benchmark where countries do not have their own national standards, although this can produce conflict (see Chapter 9). This lack of co-operation between countries has been identified as a barrier to harmonisation by Van Weperen (1993).

As well as the problems of harmonisation, shortcomings in the standardisation process in general have been identified. Rather than serving to protect consumers, some consider that standards are often written to be most useful to their prime users - manufacturers, certification bodies and test houses - who are the ones invited to draft the standard (Van Weperen, 1993). The role that standards could play in consumer protection has apparently been recognised by both government and consumers for some time now (Rogmans, 1989), however, while it is important to have industry represented on standards committees so that standards are easy to apply, it is suggested that these representatives alone may not be sufficient to impartially apply the rigour, and push the criteria for safety, that consumers might expect.

With regards to the inclusion of ergonomics in standards, few references to ergonomics criteria are thought to be made. Baber and Mirza (1996) surveyed

[2] ISO - International Organisation for Standards
[3] CEN - Commité Européen de Normalisation

the procedures used in test laboratories (which test products for standards certification) and found that no ergonomics factors were tested.

2.5 Public information and labelling

Some products pose intrinsic hazards and the options for safety to be improved through design are limited; for instance, stepladders take users away from ground level, cookers have hot surfaces and knives have sharp edges. In these cases the other approaches to safety may have to be employed: isolating the hazard (guarding for hot surfaces) or mitigating the consequences of a hazard being realised (over-reaching on a stepladder leading to a topple rather than a fall), but when residual risk remains educating or informing consumers is a common approach to the management of consumer injuries.

In the UK, the majority of consumer safety education is undertaken by public agencies such as government and campaigning consumer groups (for example the DTI's recent initiative on stepladder safety produced as a result of work described later in this thesis (Chapter 9). Industry (either individual manufacturers or representative organisations) is rarely seen to carry out public awareness initiatives and certainly not on a national scale. Rare examples may be a recent initiative by the Baby Products Association to alert consumers to the hazards of second hand goods (BPA 1997) or safety leaflets distributed to consumers by the Association of Cycle Traders (ACT, 1994).

By far the most frequently used medium of consumer education is on-product information, such as warnings. The impetus for manufacturers to provide warnings is thought unlikely to be a concern for safety, but rather a fear of litigation (Lehto, 1992). This is particularly so in the United States, where strict liability has existed for much longer and providing warnings has been seen an easy route to avoiding or reducing liability. Research literature suggests that the drive to provide warning labels often comes from the legal profession and the concern

to exhaustively warn against all hazards. This is despite research which indicates that warnings applied in this way are likely to lose their effectiveness (Lehto and Miller, 1986). However the reliance on warnings to compensate for product risk has been much criticised (McCarthy et al, 1995), not least because of the debate over warning effectiveness. A whole body of research has focused on warnings effectiveness, identifying their limitations and the conditions under which they can and should be used to best effect. Warnings are aimed at modifying users' behaviour in some way, and the concept of warning effectiveness should therefore be considered in terms of whether or not an appropriate change in behaviour is achieved. Research has shown that effectiveness is difficult to measure, and a variety of measurement methods have been developed, namely (Dejoy, 1989):

- comprehension - the level of understanding of a conveyed message
- warning detection - the time to notice a warning message in-situ on packaging
- reading time/rate - the time to understand or the rate of processing of a warning message
- recall - the retained learning of a warning message over time
- hazard perception - the awareness of a hazard and likelihood to comply with a warning
- behavioural compliance - a measure of changed behaviour as a result of a warning.

A 1989 review of research into the effectiveness of consumer product warnings found that the majority of studies had been based on laboratory research using college students, there had been comparatively few field studies, and work examining existing warnings through representative user populations was non-existent (Dejoy, 1989).

Even with these limitations in mind, research has shown that just because a warning is provided it shouldn't be assumed that people will change their behaviour accordingly (Ayres et al, 1989). The factors suggested as contributing towards the effectiveness of a warning are:

- users' perceptions of the risk associated with a product - it has been suggested that the more hazardous a consumer thinks a product is, the more likely that a warning will be looked for, noticed, read, recalled, and acted upon (Trommelen, 1994). Perceived risk can be thought of consisting of the perceived *severity* of injury and the perceived *likelihood* of injury (Vaubel & Young, 1992).
- familiarity - the more familiar someone is with a product the less likely they are to see it as hazardous and take notice of a warning (Wogalter et al, 1986)
- the cost of compliance - there is evidence, although limited to specific circumstances, that compliance is increased if the effort involved is decreased such as supplying gloves where their use is recommended (Jaynes and Boles, 1990).

There is certainly a 'drop-off' effect for warnings. A number of studies have shown that of those who notice a warning, only some will read it and even less will act on it (Friedmann, 1988). Also as the amount of consumer information presented increases, the likelihood of reading and complying with warnings decreases due to information overload (McCarthy et al, 1995). However no research presently exists to identify what is a reasonable number of warnings and equally when too many have been provided. It has been argued therefore that warnings should be used judiciously, with priority given to those that involve the most serious risks and where there is a reasonable chance of changing users' behaviour (McCarthy et al, 1995). Supplementary to this, and sometimes overshadowing the fundamental question of whether or not warnings work, is the debate over warning design (see for example Mayer and Laux, 1989; Lehto 1992; Lehto & Miller 1986). Within warning design is the concern over the recent proliferation of pictograms as a warning medium and their effectiveness (Davies et al, 1998; Norris 1997; Lehto and Miller, 1986; Freidmann, 1988; Easterby and Hakiel, 1981; Cairney and Sless, 1982; Akerboom, 1993).

2.6 Discussion

This Chapter considered the theoretical routes to consumer safety: removing the hazard through product design, isolating the hazard through design, mitigating the consequences of the hazard or educating/training. Design was seen to be a primary route to consumer safety. These are however theoretical models. The existent contributors which operate to influence consumer safety in the 'real world', such as the activities and influences of governance, standards and safety information were reviewed to assess their effectiveness.

Governance, in its wider sense, has the potential to influence and control consumer safety in the UK, through legislation. Consumer safety legislation has been seen to move forward substantially in the last ten years, offering more protection to consumers, and it is interesting to note that it has concentrated on *design* as a route to improving safety. The anticipation of the effects of the legislation was well documented (eg Jenkins and Davies, 1989; Falke, 1989), although it is thought that consumers are still loathe to take civil action against manufacturers and there appears to have been little subsequent assessment of the impact of legislative changes. A cursory review of UK accident statistics (see table 2.1) shows that there is no evidence that changes in legislation have made an impact on safety. Ryan (1983) suggested that in the United States in the ten years since the US Consumer Protection and Safety Act there had not been a reduction in personal injury cases associated with consumer products and Moll et al (1985) suggested that there was no way of knowing whether the changes in products liability law made there over the preceding 20 or 30 years had made any impact. Steps to improve safety cannot be assessed without adequate monitoring systems, needed to provide an overview of safety. The monitoring of consumer safety in the UK is limited to Accident and Emergency admissions, and serious gaps and limitations to the monitoring systems have been described, most notably a lack of information in HASS/LASS records, the lack of monitoring of non-A&E accidents, ineffective European co-ordination of comparable data, a lack of

information from coroners' and the need for coroners' data to be centrally processed.

Product standards have developed internationally to offer a benchmark of minimum safety requirements for consumer products, but there is common misunderstanding of the fact that these are minimum requirements only and are not a guarantee of safety (as recognised by Ryan, 1983 and Cushman and Rosenburg, 1991). They are seen by some to be slow to react and perhaps to be compromised by manufacturers interests. Some of the problems of product standardisation and its influence on safety may be combated by the 'New Approach' adopted by the European Union (Rogmans, 1989). Under this approach, product safety legislation specifies the safety requirements to be met in general terms only - the 'essential requirements' - increasing harmonisation of standards across the Union. This horizontal approach would mean that standards addressing specific hazards (such as entrapment or choking) would be drawn up to apply across, rather than within, product groups (Van Weperen, 1993). Rogmans has also called for the increased participation of consumers in the standards making process. However, Ryan (1985) has said that manufacturers need to go beyond minimum safety standards and says that this is now recognised in legislation, where conformance with standards is no longer recognised as a defence against a product found to be defective. He suggests that safety standards should be improved by the inclusion of human factors principles.

The role of safety information, particularly in the form of on-product warnings, has been the focus of much research, and results are inconclusive on the effectiveness of warnings to affect an behavioural change. Warnings should be used selectively when no other routes are available to avoid 'information overload' as the proliferation of warnings will only serve to negate the effect of those already in use, and they should not be used to compensate for deficiencies in design, akin to 'bolting the stable door'.

There is one other main contributor to safety which has not been discussed and this is the role played by manufacturers and the level of safety they design into their products. Government and standards have been seen to set minimum safety requirements but these cannot be expected to keep pace with technological developments and new product trends, therefore manufacturers can be seen to have its own potential independent contribution. Evidence (in Chapter 1) suggests that deficiencies in product design are responsible for only a minority of accidents, but in the models of both the *routes* (figure 2.1) and the *contributors* (figure 2.2) to consumer safety presented in this Chapter, product design has figured as the most central influential factor. However Weegels (1996) in Chapter 1 suggests that in most cases there is a combination of more than one of her 'five factors' (product, user, use, environment and circumstances of use) indicated in any accident and similarly Wilson's (1983a) tenet, that a failure in the product-person interaction is the root of all accidents, suggests that product design cannot be considered an independent element in accident causation but that the four elements of the interaction are inter-dependent. Product design, and the interaction of the product with the user and the environment is the remit of ergonomics; ergonomics can therefore be seen to have a pivotal influence on consumer safety. How this influence can be realised is therefore the focus of this research.

Chapter 3 - Ergonomics and product design: a review of literature

Chapter 2 argued that product design, and therefore ergonomics, are significant potential contributors to consumer safety. Chapter 3 now looks at the relationship between ergonomics, safety and design, as demonstrated by the literature, to review the extent to which ergonomics is realised in product design. The Chapter looks at the theoretical links between ergonomics and design, at reasons for a lack of recognition of ergonomics and at attempts that have been made to transfer ergonomics to design generally and especially to formalising its input to safety. The Chapter ends with a proposed model of the design process, with ergonomics contributions, and suggests that there are two main inputs to the design process: the use of ergonomics data and guidelines, and ergonomics evaluation methods. The feasibility of improving and formalising these inputs is identified as the hypothesis of the research.

3.1 Product design

Before the realisation of ergonomics in design is considered, a brief review of what is meant and understood by product design is presented. This reviews the definitions of design, the design process, consumer products and product design safety, as well as reviewing available models of the design process.

3.1.1 A definition of design

The design process has been the subject of much analysis and published research. Definitions of design and the design process are varied, and Cross, Christiaans and Dorst (1996) highlight the somewhat revered and abstruse nature of design:

'Design activity encompasses some of the highest cognitive abilities of human beings, including creativity, synthesis and problem solving'.

3.1.2 A definition of the design process

Numerous definitions of the process of designing consumer products have been offered, including:

'Product design is the process of devising and laying down the plans that are needed for the manufacturing of a product' Roozenburg and Eekels (1995) page 3.

'Designing a product is a goal-directed thinking process by which problems are analysed, objectives are defined and adjusted, proposals for solutions are developed and the quality of those solutions is assessed' also Roozenburg and Eekels (1995).

'Engineering design is the use of scientific principles, techniques, information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency (Feilden, 1963).

Design is '*the process of establishing requirements based on human needs, transforming them into performance specification and functions, which are then mapped and converted (subject to constraints) into design solutions (using creativity, scientific principles and technical knowledge) that can be economically*

manufactured and produced' Evbuomwan et al (1996), taking key words from definitions in a review of design philosophies and methods.

Referring specifically to the design of consumer products, Roozenburg and Eckels, 1995, page 4) talk of the product *development* process rather than the product *design* process, and it perhaps within a development context that an ergonomics input would be better put. McClelland (1990) interprets a description of the product development process from Carroll and Rosson (1985), originally applied to computer applications:

Design is a process, a dynamic socio-technical activity, involving both 'bottom up and 'top down' approaches; the process is 'radically transformational', involving the development of interim or partial solutions which may never be part of the final design'; designing to a particular set of goals almost always results in different goals emerging as a final design solution evolves'.

3.1.3 A definition of consumer products

In Chapter 1 consumer products were defined according to a legislative perspective. Galer and Page (1996) suggest a product can be anything from a television to an investment plan. For the purposes of analysing the design process a more specific definition is required. Roozenburg and Eekels (1995) describe products as... *'artefacts conceived, produced, transacted and used by people because of their properties and the functions they may perform'*. Butters and Tetra-Dixon (1998) say that consumer products have to cater for the broadest range of users. Meyer (1979), quoted in Wilson (1983a), categorises consumer products into the following categories:

- those for the satisfaction of human wants and needs, but not used for further production (eg household appliances, furnishings)
- specialised products (eg toys)
- dual role of capital or consumer products (eg hand tools, transportation)

A detailed but not exclusive categorisation of consumer products is suggested in table 3.1.

Category	Examples
transport	cars, bicycles, buses (although transport safety may also be considered as separate from consumer safety)
architecture and fittings	windows and locks, cupboards, stairs, steps, electric sockets
furniture	chairs, beds, tables
powered	'white' and 'black' goods, power tools, kitchen appliances, heating
do-it-yourself products	tools, stepladders,
leisure products	sports equipment, camping equipment
products for further production	kitchen appliances, hand tools, materials
capital products	furnishings, ornamental products
products for special groups	toys, products for the elderly or disabled
safety products	stair gates, residual circuit devices (RCDs), fire guards
associated products	cycle carriers, swimming pool covers

Table 3.1 - Categories of consumer products

3.1.4 Product design safety

Ryan (1983) says that to ensure safety, as opposed to functionality, efficiency and usefulness, design must integrate the following criteria:

- reliability - the probability that the product will perform its intended function for a specific interval of time under stated conditions
- maintainability - the probability that the product will be retained in, or restored to, a specific condition within a period of time
- quality - the totality of properties, features and characteristics of a product which bears on its ability to satisfy the consumer's need.

He quotes Shooman (1968) who states that catastrophic product failures can occur in three stages of product life:

- early (because of design defect)

- middle (because of environmental stresses)
- late (because of material wear-out).

Design defects are said to be related to inadequate strength or improper materials, and Ryan says that injury can be caused by improper material, material failure caused by lack of strength and a lack of, or inadequacy of, safeguarding. However it is suggested here that these causes of injury are considered as material failures or lack of safeguarding. Ryan's list importantly omits injury caused by design, which from an ergonomics perspective would be considered due to a fundamental mis-match between the design and either the user, the task or environment to which it is exposed. A distinction is therefore made for the purposes of this research between aspects of product safety, namely product design safety and construction safety:

- design safety - the concept and presentation of a product should provide anyone who may come in contact with it a level of safety that might reasonably be expected
- construction safety - the materials, components, construction and functioning of a product, including chemical and electrical components, should meet the requirements of the design throughout the product life.

3.1.5 Models of the design process

The analysis of the cognitive processes that take place during design dominate the design literature, which is littered with models of the design process. The methods used to produce these models are themselves the subject of research, for instance the use of protocol analysis by Cross et al, (1996), the focus of this work being how best to interrogate what is, as earlier defined, a cognitive process. Evbuomwan et al (1996) review the many available models of the design process. They interpret the models in terms of design activities, which they say represent the different facets of the design process, the design activities being:

- opportunistic
- incremental
- exploratory
- investigative
- creative
- rational (logic based)
- decision making
- iterative
- interactive.

They categorise the available models of the design process as either prescriptive or descriptive, the former being algorithmic, systematic, describing how the design process should be carried out and the latter focusing on designers' actions and activities.

Roozenburg and Eekels (1995) comment that while the variety of models can give the impression that there is disagreement on the structure of the design process, the differences are actually mostly terminological. They distinguish three types of model. These have been interpreted here as:

1. Cyclical - a series of problem-solving steps describing the most logical sequence; the most fundamental type of model
2. Abstraction - the design is worked out in different levels of abstraction, each level relating to a different form in which the product can be represented
3. Phase - these are activities of the design process and represent the problems the designer has to solve and the best sequence in which to solve them.

Roozenburg and Eekels also use the prescriptive/descriptive distinction of models, suggesting that descriptive methodology is a way of explaining the structure of the design process and prescriptive methodology is a way of approaching the design process to make it more effective and efficient.

There are numerous models of the design process which could be reproduced here, but some of these are summarised in figure 3.1. However, this Chapter is not intended to be a review of the design process, but an examination of how the design process can be made to focus on safety, and how ergonomics can contribute. An alternative model of the design process is therefore proposed, and presented at the end of this Chapter based on this review.

3.2 Evidence of ergonomics in design

We have been told that manufacturers recognise the potential benefits of ergonomics. Abedini (1989) quoted an article nearly ten years ago in 'Newsweek' (14/3/88) in which industrial design firms said the use of human factors leads directly to better quality products which are readily acceptable by their general market and Thomas et al (1990) said that poor design was becoming less tolerated. This recognition of the *potential* of ergonomics is not however evidence of its realisation. Unfortunately the use of ergonomics in product design is often more recognisable by its absence than presence. Even so, isolated products would not be evidence of ergonomics being formally established as part of the design process. Roozenburg and Eekels (1995) suggest that design requires a multi-disciplinary approach and that while different products require different disciplines they nearly always involve engineering design, industrial design, ergonomics, marketing and innovation management. This recognition of the involvement of ergonomics in design is encouraging, however the issue of lip service to ergonomics has been much discussed (eg Chapanis, 1995).
It is suggested here that the principles of ergonomics were not invented with the term, a view supported by the likes of Van Cott et al (1978, page 3). Function has always been a requisite of design and a product that doesn't take account of its user is unlikely to be successful. Ergonomics is therefore a concept, but as a *discipline* came about because the process of applying its principles was informal and unsupported. The reasons for the lack of formality of ergonomics in design have often been laid at the feet of the ergonomics discipline.

TEXT BOUND INTO

THE SPINE

Haubner (1990)	**definition**	→	**concept**	→	**realisation**	→	**evaluation**	→	**application**	
Stanton and Young (1995)	concept	→	flowsheeting	→	design	→	prototyping	→	commissioning & maintenance	→ operation
Chapanis (1995)	**recognition of a need**	→	**utilisation concept**	→	**concept exploration**	→	**concept validation**	→	**engineering development**	→ **production & distribution** → **operation & maintenance**
USERfit (1996)	problem definition	→	development of a functional specification	→	building phase	→	testing or evaluation phase			
Pikaar (1990)	**feasibility study**	→	**definition of design problem**	→	**analysis of design problem**	→	**development of solutions**	→	**detailed design and** implementation	
Straker (1994)	acquire background info	→	specify the problem	→	generate possible solutions	→	select a suitable solution	→	develop final design	

Figure 3.1 - Models of the design process

If we consider some definitions of ergonomics (of which Goldsmith (1985a) suggests there are almost as many as authors), a common factor is usually the transfer and application of knowledge to design:

> *'ergonomics is the study of human abilities and characteristics which affect the design of equipment, systems and jobs....with the aim of improving efficiency, safety and operator well-being'* (Corlett and Clarke, 1995, page 2)

McClelland (1995, page 249) suggests that ergonomics is based on two principles, that *'the interaction between people and the products, equipment and services they use can be measured and in ways which can be used to guide the specification, design and evaluation of that interaction'*.

It is not necessary, or probably practical, to list here the authors that have identified the relationship between design and ergonomics but by definition a **transfer of knowledge** is intended. It is suggested that if ergonomics knowledge is not being used during the design process (as McClelland says) then it is not achieving its goals. This is not a new concern.

Chapanis (1995), writing on the subject of using ergonomics methods in product design differentiates between ergonomics as a discipline and what ergonomists do. He defines ergonomics as 'a body of knowledge' as opposed to the practice of ergonomics, 'the application of that knowledge to the design of products'. He states that ergonomics, unusually as an academic discipline, has the aim not to just add to a body of knowledge but to apply it. He considers those adding to the body of knowledge as carrying out 'basic ergonomics research'. Chapanis suggests that only a minority of ergonomists are probably involved in actually applying ergonomics techniques to the process of designing or improving products. Instead, the outcome of the 'basic ergonomics research' activities are 'general statements which wind up in any of a large number of published guidelines'. Examples of these are given as reach limits, control-display relationships and guidelines on the use of colour. He states

however that for design purposes these generic guidelines are 'not good enough' and that more precise information and specification is needed.

3.3 Encouraging ergonomics in product design

Two conference series took place in the 1980s concerned with integrating ergonomics into the design process - Interface (in the USA) and Ergodesign (in Europe); the latter apparently seen as a step towards integrating the ergonomics and design professions (Grandjean, 1984). In the early 1980s, Wilson and Whittington (1982) talked of the evident growth over the preceding ten years of 'consumer ergonomics' (which they defined as 'research, and application of that research, such that the goods and services used by the general public are safe, convenient, efficient, comfortable and aesthetically satisfying, under conditions of normal use and foreseeable misuse, and in the light of economic, technical and legal criteria' page 25). They said that at that time in the UK the discipline had failed to get ergonomics systematically applied in the design process and that overt human factors input into design of most new products was minimal, criticisms being levelled at the quality of research and the lack of adequate methodologies, techniques and data. Their recommendations to redress this were to:

- promote an integrated approach to design and convince manufacturers that ergonomists should be involved as early as possible in the design process
- promote an adequate interface with other professionals (eg designers)
- generalise research
- evaluate studies (eg for cost effectiveness, to improve methods)
- provide data in a usable form and improve communication.

While they said that there was little evidence that the impact of ergonomics was changing, the need for ergonomics was likely to grow because of increasing technological complexity of products, increasing consumer expectations, and the possible introduction (although it was still five years away) of strict liability for

consumer goods; in fact, the authors predicted that the introduction of strict liability would make ergonomics input to the design process 'imperative'.

Ward (1994), less positive about the growing role of consumer ergonomics, commented that the majority of ergonomics research was oriented to occupational safety and performance, and the explanation for this was that the relationship between designers and ergonomists was uneasy, a view supported also by Kanis (1987). Kanis' reasons were that:

- teamwork training between ergonomists and designers was needed
- there was a lack of a common language between designers and ergonomists
- there was a lack of understanding between the professions with no mechanism to learn.

Interviews with designers gave him evidence that when it comes to ergonomics issues most rely on intuition and common sense, which has been suggested elsewhere (eg Bullock 1994) . He suggests that testing for ergonomics should be incorporated into the product testing procedure, maintaining that most products are 'tested' during their development and that incorporating tests for ergonomics aspects would be simple.

Kanis also identified the following reasons for the difficulties that designers experience in applying ergonomics:

- lack of a common language
- lack of easy to use data sources
- doubts about the applicability of research to practical problems
- a mismatch between the design data needed and research output.

McClelland (1987) recommended, from the perspective of a large organisation (Philips), that the solution to encouraging ergonomics is designer and ergonomist working together in a common environment. Dockery and Neuman (1994) also suggested that it is organisational structure - management support and accountability,

concurrent engineering, appropriate time and resources - that is needed to ensure ergonomics is represented in design.

3.4 Designing for safety

Wilson and Whittington (1982) said that consumer products should be safe, convenient, efficient, comfortable and aesthetically pleasing; safety being the first criterion on their list. Whilst safety may be a proffered criterion for a successful product, it may not always be an priority in design, for practitioners or theorists. For example, Roozenburg and Eekels' text (1995), purportedly on the fundamentals and methods of product design, has no entry in the subject index for safety.

A review of the design and ergonomics literature has found little evidence of attempts to formalise the relationship between product design and product safety, and in the 'consumer ergonomics' literature most reference was made to designing for usability. The concept of usability has been around for at least 25 years (the first authors to write about it were Eason (1984) and Shackel (1986), quoted in Jordan, 1998) and it has now been formally recognised as a criterion by ISO with respect to office environments and specifically visual display terminals (ISO DIS 9241-11). ISO define usability as:

'the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments'.

Stanton and Baber (1996) have been concerned with defining usability, particularly they say since it has now become a legal requirement for some products (presumably referring to ISO 9241). While they say that most evaluators will define usability according to what they are doing (which is true surely of all definitions) they define the scope of usability, based on what they say is a decade of work by others (such as Shackel, Eason and Booth), as including eight factors:

1. Learnability - reach an acceptable performance within a specified time
2. Effectiveness - acceptable performance (defined proportion of users, specified range of tasks, specified range of environments)
3. Attitude - performance achieved within acceptable human costs (fatigue, stress, frustration, discomfort and satisfaction)
4. Flexibility - deal with a range of tasks beyond those first specified

   (1 to 4 criteria referred to as the LEAF precepts)
5. perceived usefulness or utility - a product must be used
6. task match - match between the functions of the system and user needs and requirements
7. task characteristics - frequency with which a task can be performed and degree to which it can be modified
8. user characteristics - knowledge, skills and motivation of users.

Safety is most noticeably omitted from this list.

A 1994 conference aimed specifically at producing practical guidance for industry to incorporate usability into design brought together practitioners from industry with experiences of human factors work (Jordan et al, 1996a). The resulting proceedings contains twenty-six papers, none of which address evaluation methods for safety and the only reference to safety is in the editors' introduction. Jordan et al (1996b) proposes that usability should be expanded to recognise the attitudinal components of usability, and goes on to promote 'pleasure' as an important and ignored component of usability (also Jordan, 1998), yet safety is ignored by the whole discipline of practitioners as represented in these proceedings. Galer and Page (1996) define usability as 'ease of use, comfort and acceptability' only. They suggest that trying to define usability was difficult but if compared to a definition of intelligence it would be 'that measured by intelligence tests'; which can be interpreted that, without a measure, safety cannot be defined.

The limited work that has been published on designing for safety in consumer products has however been reviewed and is summarised in the following sections.

3.4.1 'Safety and the design process' (Stoop, 1990b)

Stoop (1990b) attempted to structure the input of safety to the design process, particularly for application to the design of consumer products. The method proposed was 'a dynamic decision making process' involving the application of 'use-scenarios and hazard patterns'. His approach was based on a basic problem solving model by Hale (1985), shown in figure 3.2.

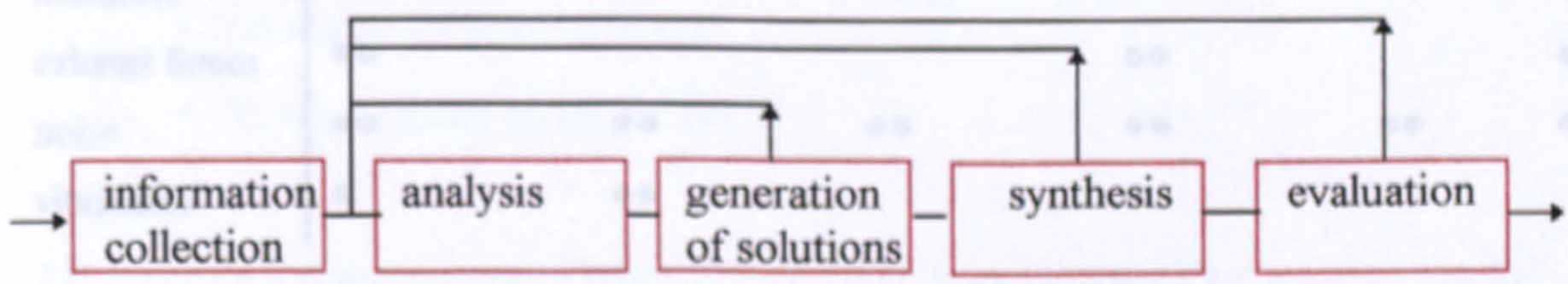


Figure 3.2 - Basic cycle of problem solving (Stoop 1990, after Hale, 1985)

He suggests that 'selection of solutions is facilitated by ordering through a matrix scheme which links technical design options and measures of a social and organisational nature into a set of coherent safety measures'. This is taken to mean that a systematic and ordered approach is needed, to ensure that all relevant factors are considered, whether they be technical, social or organisational. Stoop then attempts to elucidate the steps in the problem solving cycle as they relate to design, his description requiring substantial interpretation:

1. Information collection

   An information collection strategy is needed, to produce a model of the system in which the product is used. The information to be collected should consist of:

   - historical (of the product's development)
   - the product life cycle (development through to disposal)
   - use
   - the system in which the product will be used.

2. Analysis

   This should generate a set of relevant accident factors. Stoop comments here that a problem description is often lacking; these may be a lack of detailed accident information, a lack of specific knowledge on a particular accident mechanism, or

an accident description that is too broad. He proposes two main approaches to these problems: 'use-scenarios' and hazard patterns. Use scenarios are used to break the problem into manageable 'sub-problems'; an example for a chain saw is shown in table 3.3, where identified hazards are matched to potential uses.

HAZARDS	USE SCENARIOS					
	forestry	public green	construction	fruit-growers	farmers	DIY
posture	••	•	•			
accidents	•	••	••	••	••	••
exhaust fumes	••			••		••
noise	••	••	••	••	••	••
vibrations	•	••		•		

Table 3.2 - Use-scenarios for a chain saw (from Stoop, 1990)

The 'hazard pattern' concept is used to identify the precise sequence of events, the mechanism and causality of accidents, and is based on ideas by Drury (1983).

Stoop brushes over the methods and techniques that might be used to realise these outcomes. In a sentence each he describes the way in which these 'concepts' are produced:

- use scenarios - accident data bases, expert opinions functional and task analysis
- hazard patterns - observation, film or photographs, questionnaires, checklists, on-the-spot investigation, expert opinions, task and product analysis and 'dose-effect measurements'.

3. Generation of solutions

   A matrix is used to organise possible solutions according to levels of intervention (he uses Hale and Glendon's (1987) 'routes to safety' - shown in Chapter 2) and to aid selection. Solutions are generated by 'literature survey, expert consultancy...known principles and experience'.

4. Synthesis

   This is where, according to Stoop, 'safety becomes explicitly visible in the design process'. It becomes visible in the selection of relevant use-scenarios, which

technological principle and energy source to select for further investigation, and which hazards are to be dealt with. Again, no techniques are offered. This appears to be a decision making process, aided by the use of a matrix.

5. Evaluation

   The solutions can be rated for their effectiveness:

   - which hazards are eliminated?
   - is there any foreseeable misuse?
   - are there any new hazards introduced?
   - what are the residual risks?
   - how can these be coped with?

Taken from a consumer products design perspective, Stoop offers a method with which to introduce safety into the design process, but is predominantly an academic exploration of the design process which offers little practical, usable guidance for the designer or design management.

3.4.2 'The Product Safety Method' (Schoone-Harmson, 1990)

Schoone-Harmsen (1990) published the 'Product Safety Method', a method to detect and solve product safety problems. The criteria for her method were that it was to predict hazards and identify solutions. The method she proposed has four stages and is shown in figure 3.3. The method operates as a schema which can be used to stimulate and structure the consideration of safety in the design process and offers a taxonomy of potential solutions, akin to the approaches to product safety listed at the start of Chapter 2. The crucial process of identifying hazards is not addressed; the system relies on accident data which Schoone-Harmsen admits is not available for new products. For these she suggests instead that hazards must be predicted and for this she adapts the accident analysis tool of Kanis and Weegels (1990). This is the 'Product Safety Matrix' in which hazards are broken down into those associated with the product, the actions of the user and the situation of use, according to each phase in the use of the product (see table 3.4). This again, serves as a schema for de-constructing the use of the product.

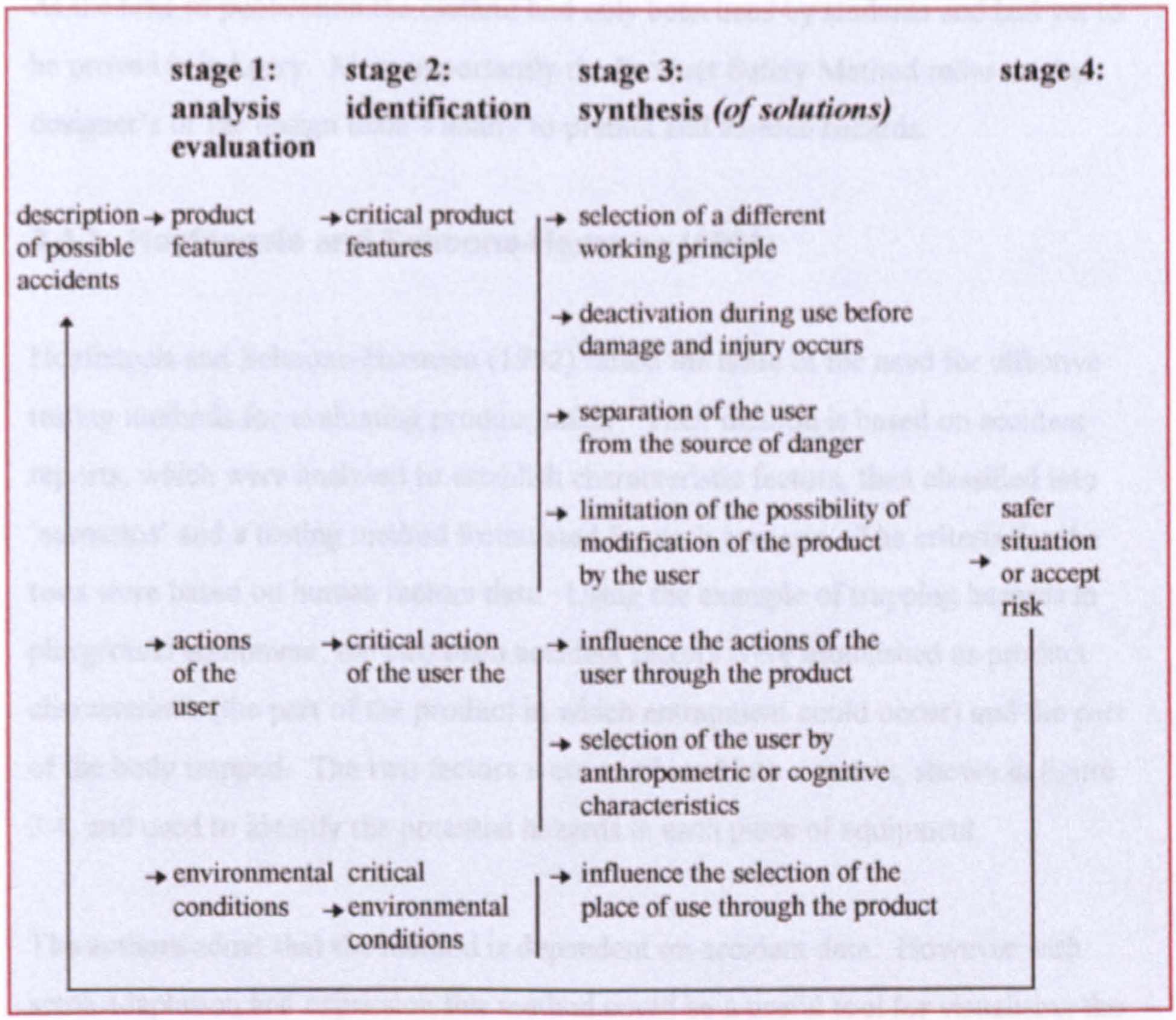


Figure 3.3 - Product Safety Method (adapted from Schoone-Harmsen, 1990)

	Relevant factors connected with:		
Phases in the use of the product:	**product**	**actions of user**	**situation**
fetch product			
bring product to place of use			
make product ready for use			
use product			
interrupt task			
refill product			
clean product			
store product			

Table 3.3 - Product Safety Matrix (from Schoone-Harmsen, 1990 and Kanis and Weegels, 1990)

At the time of publication the method had only been used by students and had yet to be proved in industry. Most importantly the Product Safety Method relies on the designer's or the design team's ability to predict and foresee hazards.

3.4.3 Hoefnagels and Schoone-Harmsen (1992)

Hoefnagels and Schoone-Harmsen (1992) raised the issue of the need for effective testing methods for evaluating product safety. Their method is based on accident reports, which were analysed to establish characteristic factors, then classified into 'scenarios' and a testing method formulated for each scenario. The criteria for the tests were based on human factors data. Using the example of trapping hazards in playground equipment, the two main accident factors were established as product characteristic (the part of the product in which entrapment could occur) and the part of the body trapped. The two factors were combined into a matrix, shown in figure 3.4, and used to identify the potential hazards in each piece of equipment.

The authors admit that the method is dependent on accident data. However with some adaptation and expansion this method could be a useful tool for visualising the possible combinations of factors contributing to accidents. It is suggested that all possible features of a product, features of use, environment and the user can be combined in matrices similar to this to identify the combination of factors likely to lead to hazards.

3.4.4 Zurwelle (1993)

Zurwelle (1993) suggests the following steps in designing-in safety for existing or similar products:

- identify all users
- test the product with members of the design team
- gather all user reports such as customer complaints.

Figure 3.4 - Hazard matrix for trapping hazards associated with playground equipment (from Hoefnagels and Schoone-Harmsen, 1992)

- identify positive design features of similar/competitor products for minimum design criteria
- compare all features in user trials
- evaluate new design with focus groups
- compare new design with the best of existing designs in user trials.

3.5 Discussion

This Chapter has considered the relationship between ergonomics and product safety. There has been much published analysis of the design process, resulting in the production of many models. Ergonomics has long since established a potential role for itself as a contributing to design, and with the design process the subject of so much analysis it is suggested that the input should by now be formal. Little evidence of this has been produced. It has been found also that in much of the published research on ergonomics and product design, safety is rarely a focus of either practical research or theoretical models, the discipline and literature concentrating on usability rather than on safety. In fact it has been suggested that safety is often seen as a negative or constraining factor in the creative design process (RoSPA 1987; Fraquelli, 1996). The attempts at structuring safety in the design process that have been described in this Chapter offer little in the way of techniques or methods.

Ergonomics is a vehicle by which safety could be promoted. McClelland (1990) sees ergonomics as a 'product' to be marketed to designers. He has suggested that while there is a marketable product and the potential for contribution to design was excellent, there was need to look further and to understand how the ergonomist's skills can be used to complement those of designers. He advocated that ergonomics should be developed as part of a design strategy, to change it from that of a remedial role to a more prospective, process oriented way of thinking. Problems in the adoption of ergonomics have been described and recommendations to improve this have included:

- promote an integrated approach to design

- ensure ergonomists are involved as early as possible in the design process
- promote an interface between designers, ergonomists and other professionals to improve understanding and a common language
- generalise research and improve applicability to practical problems
- provide applicable, usable data
- improve evaluation methods studies.

Building on these considerations, and on the analysis of the design process earlier in the Chapter, a model of the design process with a provision for ergonomics input and focused on safety is proposed in figure 3.5. Referring to the analyses of design models earlier in section 3.1.4, the proposed model is prescriptive in that it is attempting to improve the design process by formalising the inclusion of ergonomics and safety considerations. It is a phase model in that it is a series of problem solving steps as well as indicating the necessary activities.

Market research and intelligence, and a specification of user and safety needs clarify the objectives of the design brief. Requirements and constraints are considered in terms of manufacturing and engineering processes, safety protocols (standards, regulations and legislation), accident statistics and a user profile. The concept design is framed by a hazard analysis (produced by a detailed study of accident statistics and scenarios). It is at this stage that ergonomics effort is first incorporated, by inputting ergonomics data and guidelines and carrying out initial ergonomics evaluation. Evaluation can be carried at this stage, but is most vitally carried out during detailed design, when all aspects of the design can be incorporated.

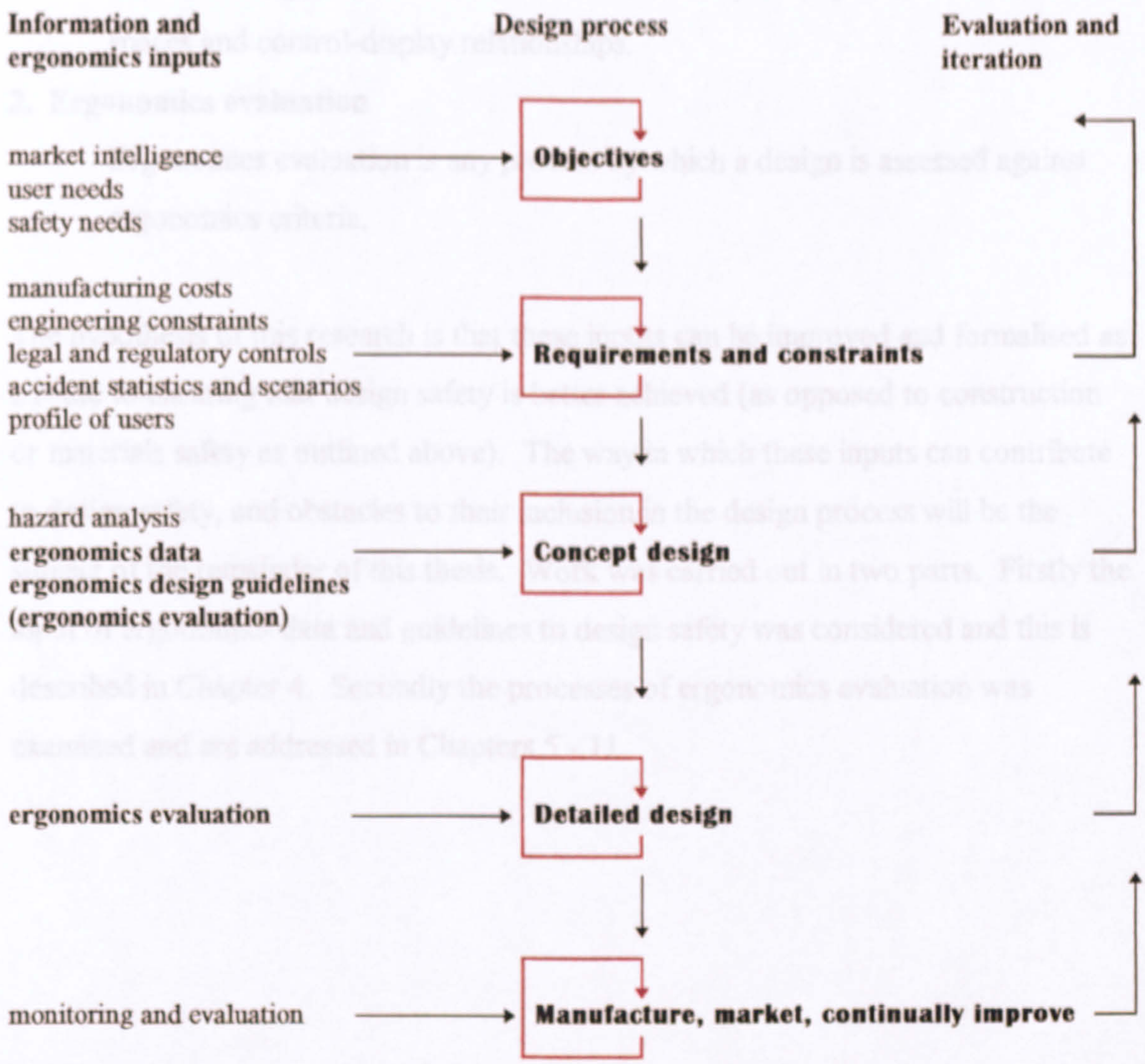


Figure 3.5 - Simplified consumer design process focused on safety and ergonomics

Based on this model there are two main ergonomics inputs to the design process:

1. Ergonomics data and guidelines

Ergonomics data should be the building blocks of design; anthropometric, strength, psychological and performance data describing human characteristics and abilities should be the starting point for a safe design. Ergonomics guidelines are the output of ergonomics studies which rather than measure human functioning they describe it in a way that is intended to most

useful to designers, such as recommended workplace layouts, movement spaces and control-display relationships.

2. **Ergonomics evaluation**

   Ergonomics evaluation is any process by which a design is assessed against ergonomics criteria.

The hypothesis of this research is that these inputs can be improved and formalised as a route to ensuring that design safety is better achieved (as opposed to construction or materials safety as outlined above). The way in which these inputs can contribute to design safety, and obstacles to their inclusion in the design process will be the subject of the remainder of this thesis. Work was carried out in two parts. Firstly the input of ergonomics data and guidelines to design safety was considered and this is described in Chapter 4. Secondly the processes of ergonomics evaluation was examined and are addressed in Chapters 5 - 11.

THE BOOK OF FIGURES THAT GETS TO THE BOTTOM OF MR AND MRS BRI

Are you Average?

Average measurements

Characteristic	Man	Woman
Height	[illegible]	[illegible]
Weight	12st 8lb	10st 7lb
Chest	[illegible]	[illegible]
Waist	[illegible]	4.2in
Hips	[illegible]	[illegible]
Thigh	4.7in	2.3in
Knee	[illegible]	[illegible]
Ankle	[illegible]	[illegible]
Head	[illegible]	[illegible]
Neck	[illegible]	[illegible]
Shoulder	[illegible]	[illegible]
Arm	[illegible]	[illegible]
Wrist	[illegible]	[illegible]
Hand	[illegible]	[illegible]
Finger	[illegible]	[illegible]
Nose	[illegible]	[illegible]

The Observer 31 May 1998

Now we know exactly how they are in Middle Engl

How do you measure up to Mr and Ms Average?

The average man

79.75kg (12st 8lbs)	
175.51cms (5'9")	
57.50cms	HEA
6.39	
11.88	FACE
14.07	FACE
6.35	DI
5.22	
39.89	
41.17	
133.72	
64.10	
32.30	
182.87	
18.45	

By Marie Woolf

ARE YOUR trouser legs too short? Do you bump your head on the door frame of your car? Do you panic about opening pill boxes or reaching alarm bells on trains?

If you do and you think it is your own fault, think again and point an accusing finger at the designers. For years, they have been guessing at how long our legs are, how strong our grip is and even the size of our cuffs, or they have relied on surveys based on the size and shape of fit soldiers in the Fifties and Sixties.

Now to relieve us from pinching shoes, uncomfortable chairs and shoddy safety features, the government has produced a definitive guide to Mr and Ms Average.

The 400-page document laying bare the nation's anatomical secrets has been compiled by civil servants and Nottingham University researchers. They have spent a year collating the sizes of our ischias and elbows, noses, leg lengths and finger strengths and those vital ear-to-ear proportions required by the makers of sunglasses — although more intimate measurements [illegible]

- The Observer, 31st May 1998
- The Daily Mail, 1st June, 1998

Chapter 4 - Improving the use of ergonomics data in design

Chapter 3 proposed that there are two main ergonomics inputs to the design process: ergonomics data/guidelines and ergonomics evaluation methods. Chapter 4 now discusses the way in which ergonomics data can contribute to product design safety and identifies some of the problems with the input of data to the design process. The Chapter then describes research carried out to remedy some of the problems identified, namely the production of ***Childata: The Handbook of Child Measurements and Capabilities***, a publication aimed at encouraging the use of ergonomics data in designing safer products for children and one of the outputs of this research.

4.1 Ergonomics data in design

Ergonomics begins with studies of how people interact with their environment, the products and tools they use, the buildings they work and live in, the information they receive, and of how all of these activities are organised. The aim of ergonomics is to improve every level of this interaction, to enhance people's safety, comfort, satisfaction and the usability and effectiveness of their tools, products and environments. The product of these studies are 'ergonomics data' - qualitative and quantitative information on human characteristics and abilities which are fundamental to ensuring that products and environments 'fit' their users. These data are the 'building blocks' of design. The types of data that can be used in product design are shown in table 4.1, and examples of the ways in which such data can be applied to product safety are shown in table 4.2.

Type of ergonomics data	Examples
SEX	
AGE	
ANTHROPOMETRIC CHARACTERISTICS	• static body measurements eg stature, weight, limb lengths, head size, hand size, centre of gravity • dynamic anthropometry eg reach, movement
STRENGTH	• static (against a fixed object) eg grip strength, bite strength • dynamic (force combined with movement) eg opening strength, punching strength
ENDURANCE	momentary or sustained forces that can be exerted or withstood
BIOMECHANICAL CHARACTERISTICS	• gross motor skill eg movement, balance • fine motor skills eg hand-eye co-ordination, psychomotor skills • manual handling
SENSORY CHARACTERISTICS	• oral • aural • olfactory • tactile • thermal • vibratory
PSYCHOLOGICAL CHARACTERISTICS	• perceptual abilities eg visual and auditory sensitivity and processing • cognitive abilities eg information processing, decision making • personality eg motivation, risk taking, perseverance, inquisitiveness • intelligence eg problem solving, literacy and numeracy
SKILL, BEHAVIOUR AND PERFORMANCE	at tasks specific to a product eg keyboard skills, use of tools, equipment and machinery
CULTURAL DIFFERENCES	physical, social, lingual
DISABILITIES	physical and mental abilities of all potential users include permanent and temporary conditions (eg pregnancy, fatigue, alcohol, drugs etc)
EXPERIENCE AND EXPOSURE	to the product, environment or tasks eg years of driving, use of tools

Table 4.1 - Ergonomics data to be used in product design

Child interacts with:	Examples of products or environments	Possible application of ergonomics data	Data to be used include:
PRODUCT	medicines and packaging	make child resistant (inoperable or unattractive) whilst accessible to adults, elderly and disabled	opening strength, psychomotor skills, cognitive abilities of all potential users
	infant soother or pacifier	prevent swallowing by child	mouth and throat size
	bicycle	reach to pedals and handlebars, size of handlebars	arm length, leg length, sitting height, hand size
PERSONAL SPACE	machine guarding	prevent access to hazard through or around guard	maximum and minimum adult finger size, hand size, pushing and pulling strength
	stairs	prevent tripping and falls	step height, balance, foot length
	fireguard	prevent access or operation of catch by children	children's finger size, hand strength, pushing and pulling strength, specific abilities related to mechanism
PHYSICAL ENVIRONMENT	window and door handles	make usable by adults, elderly and disabled but inoperable by children	overhead reach height, opening strength, specific abilities related to window handles
	public movement areas	optimal movement space for general use and in emergencies	general ergonomics guidelines for general guidelines and national building regulations
SOCIAL ENVIRONMENT	supervision	recognition of child hazards by adults, warning systems	adult's and children's safety knowledge and behaviour
	shift work	changes in performance at inspection tasks	attention changes during shift work
INFORMATION	safety signs	recognition and comprehension by all users	understanding of colour codes, symbols, perception of hazards
	warning alarms	recognition and comprehension by specific occupational users	auditory perception

Table 4.2 - Application of ergonomics data to the safe design of products

4.2 The need for knowledge transfer

As stated in Chapter 3, Chapanis (1995) has differentiated between ergonomics ('a body of knowledge') and the practice of ergonomics ('the application of that knowledge to the design of products') and suggested that only a minority of

ergonomists are probably involved in actually applying ergonomics techniques to the process of designing or improving products. One would assume from this that the majority of ergonomists are involved instead in producing ergonomics data and that the major output of the discipline are ergonomics data and guidelines, to be used in the design of products or environments. With a presumably large output of data, we would hope to see these fundamental 'building blocks' of good and safe design used by designers. Unfortunately it has been generally recognised and accepted that the transfer of knowledge from the ergonomics discipline to the design profession has never fully materialised (Van Cott et al 1978; Wilson and Whittington, 1982; Wilson, 1984; Kanis, 1987; Norris and Wilson, 1988; Wilson and Norris, 1992), and is at best inconsistent and unreliable. If, as Chapanis (1995) suggests, few ergonomists are involved in applying ergonomics in design, then it is presumably incumbent on designers to seek out, interpret and apply data.

One of the main causes of the lack of transfer of information has been suggested to be intrinsic problems with the data themselves, such that data are difficult to use and do not match the needs of designers. In 1970 Chapanis said that experimental criteria examined in ergonomics research had little bearing on design criteria, and could not be related (p344). A survey of Australian industrial design courses found that much of the data that could be used for design projects was lacking or was in a form difficult to use, the only exceptions being Dreyfuss (1971) and Diffrient et al (1974), although these contain old, out of date data and were compiled by designers themselves (Ward, 1994). Much ergonomics advice is in the form of 'general statements which wind up in any of a large number of published guidelines', such as reach limits, control-display relationships and guidelines on the use of colour and for design purposes more precise information and specification is needed (Chapanis, 1995).

Because of these problems of transfer of knowledge, a need was identified for work to address the barriers to the application of ergonomics data to the design of consumer products, and specifically to designing for safety. This was addressed as part of this research. Work to produce a resource of ergonomics data for use by

designers was proposed and funded by the Directorate General XI of the European Commission and managed in conjunction with the Child Accident Prevention Trust, a charity promoting research aimed at reducing children's accidents. A subsequent 12 month period research was funded by the UK Department of Trade and Industry. The work was to produce a handbook of data on children, as it was felt the need for work to improve the safety of children's products was greater than other age groups due to their vulnerability to injury[1]. The remainder of this Chapter describes this research:

Section 4.3	describes survey work to establish which data were already in use by designers
Section 4.4	describes the requirements of the handbook on children
Section 4.5	describes the procedure to produce the handbook
Section 4.6	describes the findings of the work
Section 4.7	describes the format of the handbook
Section 4.8	describes the gaps in data which were identified.

4.3 Survey of the use of ergonomics data in designing for children

A questionnaire survey was carried out in 1993 to examine the use of ergonomics data by producers of baby and children's products (see Appendix 4.1 for a copy of the questionnaire). Seventy three UK companies manufacturing and designing child care products and toys were contacted. They were selected to represent a range of sizes of company and type of products. Seventeen completed questionnaires were returned and just eight of the designers who responded said that they were in possession of and used ergonomics data resources. Three had acquired the resources as a result of working on standards committees, one happened upon the data by chance, one had the information already on file in the company when they arrived,

[1] The production of has been followed by subsequent research to produce sibling publications on adults and the elderly, *Adultdata and Elderlydata,* but these are not reported here.

and two had sourced the information themselves. The resources used were as follows:

- BSI publications (used by two designers)
- a publication from TNO (a Dutch research institute)
- Dreyfuss (1971)
- 'data from the USA'
- Brockoff et al (1976) (anthropometric dimensions for seat restraints)
- Bioastranautics Data Book (Parker and West, 1973)
- Tanner and Whitehouse growth charts
- information kept from a University course.

All but five of the designers said that they had experienced difficulties finding data and that they were still unable to find some data that they needed. One of the respondents used an ergonomics consultancy to provide data as and when it was required.

These results, together with the low response rate, provide some evidence that the problems of under-use of ergonomics data, reported by other authors for other domains, exist similarly in the domain of designing for children, as had been anticipated (Wilson, 1984).

4.4 Requirements of an ergonomics resource for designing for children

As long ago as the early 1960s calls were being made by the Human Factors Society for improvements in information transfer (Ronco, 1963) and in 1978 Van Cott et al (1978) called for an co-ordinated information dissemination system to be established - the Standard Ergonomics Reference Data System (SERDS).

Successful communication of not only data but also underlying ergonomics principles (how the data are applied) requires careful consideration of the needs of the potential

end user. This relies on clients being able to express such needs. In addition, the form and content of data often set their own constraints on communications mechanisms. Added to these intrinsic difficulties in meeting data needs is the reported scepticism and ignorance of data by designers, which means that any knowledge transfer mechanism has to be palatable to a profession potentially recalcitrant about any data that limits their creativity. Wilson (1984) suggests the reasons for low utilisation of ergonomics data are:

- ignorance of the existence or potential value of ergonomics data
- a perception of them as irrelevant (half of Wilson's sample of manufacturing companies and designers named instinct, experience or common-sense as their source of 'ergonomics')
- apparent cost of use
- confusion with market intelligence or test data
- inadequacy of the data or their presentation in terms of application.

At the time of writing there is still no accepted central reference system for ergonomics data. The lack of a data resource has particular repercussions in the case of designing products for children, where design safety is ever more important because of children's increased vulnerability to injury. Ergonomics data have a relevance to a particularly wide range of products when child safety is of interest:

- products used actively by children eg toys
- products used passively by children eg cots
- products used non-exclusively by both adults and children eg furniture
- products used to prevent children's access to a hazard eg fire guard
- products used to enhance safety eg soft playground surfaces
- environments used by children eg stairs, playgrounds.

The aims of the research described here were therefore to:

1. identify, collect and collate the existing data on children's physical, perceptual and sensory characteristics, relevant to design
2. assess the data collated in terms of reliability, validity and applicability to design

3. classify and present the assessed data in a way that will increase its usability and applicability
4. increase the accessibility of the information by distribution as a hard-copy data resource.

4.5 Procedure for production of a handbook of children's ergonomics data

A systematic literature search was carried out covering the period 1980 to 1992 using on-line database systems. Scientific Indices were used for before 1980. Literature from the ergonomics, medical, psychological, engineering, child development, education, occupational therapy and physiotherapy fields was trawled, and publications back to the 1940's were collated. Contact was made with individuals and organisations world-wide working in the field of ergonomics, child development, child safety and design to identify the 'grey' or unpublished literature, such as in-company, commercial and student research. Publications and reports were reviewed for inclusion in the handbook, collated, and data classified hierarchically into a computer database (using FoxBase-Mac).

A draft structure and format of the handbook was proposed and reviewed. The review process involved regular liaison with the Child Accident Prevention Trust and the sponsor. The handbook was reviewed by other ergonomists and most importantly designers, the intended users. Designers were those contacted in the survey described in section 4.3 plus those who had contacted the author during the production of the handbook requesting data.

4.6 Findings

The production of the handbook highlighted some important deficiencies in ergonomics data which have repercussions for the successful transfer of knowledge from the ergonomics discipline to the design profession.

One of the objectives of the work was to translate repetitious but often conflicting sources of data (for instance, five sources of hand-grip strength) into usable generic design parameters, with the intention of increasing the usability of the data collated. A number of difficulties were found in attempting to collapse data from different sources into succinct design criteria, some of which had been anticipated (Wilson 1984). Some of these problems could be described as inadequacies in the original data, as described in the following sections.

4.6.1 Lack of reporting

What can only be deemed a lack of responsible reporting of research details and of foresight of the possible applications of data are responsible for a range of problems. Reports often lack details of the way in which a measurement was collected or of the sample on which it was collected. Specific omissions are, for example, the posture or the number of hands used in strength testing. All of which means data are difficult to apply and their validity and reliability cannot be assessed.

4.6.2 Lack of standardisation

Non-conformity and lack of standardisation between authors makes comparison difficult. This demonstrates itself in differences in units of measurements, classification of age groups, definition and execution of measurements and presentation of results.

4.6.3 Difficulties in application to design

Difficulties were found in using the data contained in many reports which supposedly pertained to an aspect of human functioning with potential for ergonomics applications. This was often because the data had been collected without consideration of other applications. Examples of this are studies that are primarily methodological to compare measurement techniques, tools or equipment where the data produced will be a cursory adjunct to the report. The data are collected are often ignored, or results collapsed into incremental changes and not related to age. Performance is often measured in arbitrary or abstract units, particularly in the measurement of motor skills in children, where scoring systems will be devised and reported (perhaps to assess an impairment) rather than demonstration of concrete existence of a developmental skill. Strength data may be difficult to apply because often only 'classical' measurements are recorded, dictated by the established instrumentation available, for instance in the measurement of hand grip strength. (Chapters 6 and 7 demonstrate the lack of applicable strength data on children). Developmental studies often use subject groupings that render the data unusable, such as longitudinal data (ie changes in individuals over time), skeletal age rather than chronological age (used in growth studies) and comparing full-term and early infants.

4.6.4 Specific versus generic data

The conflict between producing specific and generic data is a characteristic of ergonomics research generally. Data produced in highly specific contexts are difficult to generalise as the conditions in which data are collected have to be the similar to those in which they will be applied - environmental conditions (eg lighting, temperature, noise) and task conditions (eg size and position of controls). For instance, torque strength measured on a 50 mm diameter horizontal door handle cannot be applied with confidence to assessing the torque required to open a 20 mm screw-top on a drugs container. Yet it is this very sort of product-related performance data (for instance opening torque) that is much requested by designers. The other extreme is research which is either summarised or generalised to make it

widely applicable, such as guidance on force capabilities, but end up too generic to apply with any confidence. Indeed, Chapanis (1995) comments that much ergonomics knowledge ends up as general guidelines.

4.7 Format of the handbook

As a result of these difficulties with data, and the lack of confidence in collapsing data into general guidelines, it was decided that the format the Handbook would take would be to strictly reproduce original data from original reports, but in a consistent format and with enough supplementary information to aid their interpretation and application. In June 1995 '*CHILDATA: The Handbook of Child Measurements and Capabilities*'[2] was published (figure 4.1). The handbook contains data on 187 measurements on children aged from birth to 18 years: 140 antropometric measurements and 40 strength, performance and psychological attributes. World-wide data are included, with the main sources being from the UK, USA, Netherlands, Germany and Australia. Data are organised in sections according to a hierarchical classification and anthropometric data according to body part. Data on the sample size, age range, mean, standard deviation, 5th and 95th percentiles are presented. Figure 4.2 shows sample pages from CHILDATA and the Handbook's introductory information on the interpretation and application of ergonomics data on children is reproduced in Appendix 4.2.

[2] Published by the Consumer Safety Unit of the Department of Trade and Industry and distributed free of the charge to industry, research organisations, standards bodies and safety organisations. To date 4,000 copies have been published.

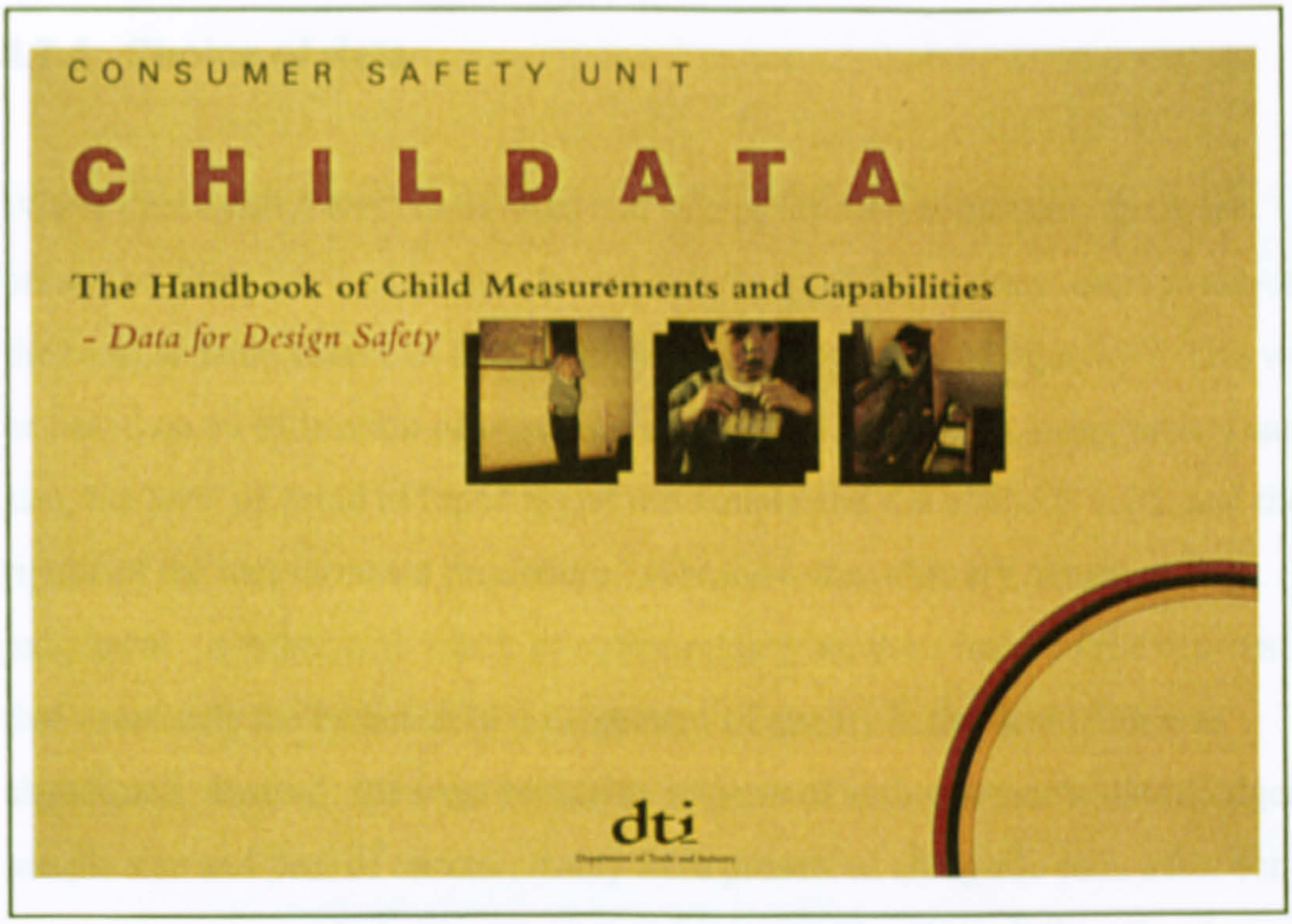


Figure 4.1 - Childata

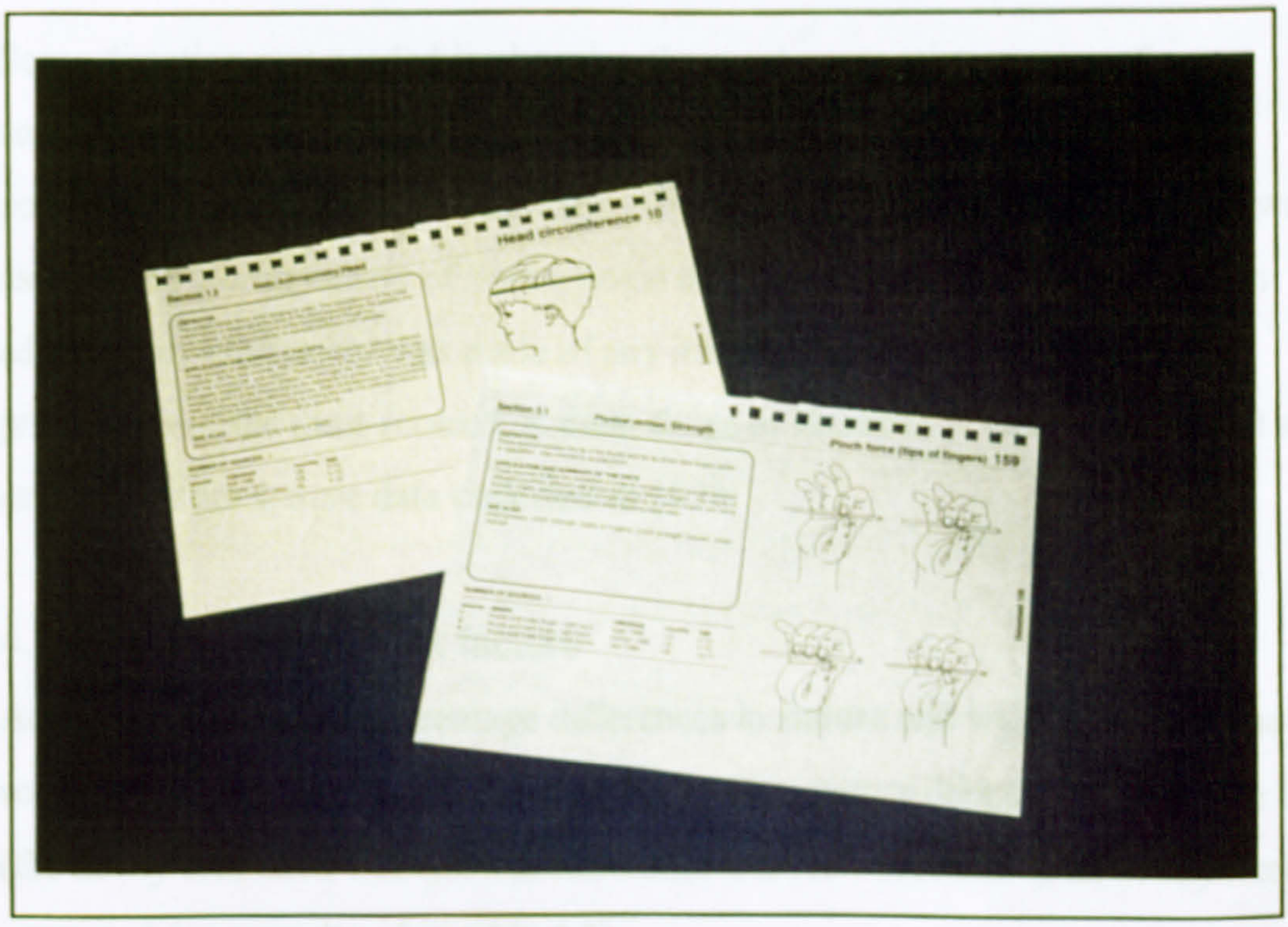


Figure 4.2 - A sample of the contents of Childata

4.7.1 Choice of data

Where data existed from more than one source for a measurement, these are presented alongside each other. It was initially intended to assist users in choosing the most suitable source of data by providing a judgement of 'quality'. This was to be based on an estimation of reliability and validity of the data, using mainly sample size, the level of detail of reporting of the sample and the methods used, and the rigour of the measurement procedure. However, the arbitrary nature of this judgement, together with a lack of comparability between many of the sources meant that eventually the inclusion of a judgement of quality in the handbook was abandoned. Instead, the most reputable sources of anthropometric data (judged on sample size and year of measurement) were presented alongside each other for the user to compare, and an attempt was made at assessing the validity of each anthropometric source for use with a UK population, as described in the next section.

4.7.2 Validity of anthropometric data

Some direction was needed in choosing the most appropriate source of anthropometric data when data on the target country did not exist (the target population being the UK). The validity of the data sources for use in the UK was assessed by a comparison of international differences in stature and weight. In addition, an assessment was made of any influence of secular trend since the production of the most recent UK data, those of Pheasant (1986). His dataset was estimated from stature data collected in 1970.

4.7.2.1 Adjustment factors

Adjustment factors of percentage differences in stature and weight between the major sources in the handbook and the most up-to-date stature data available for the UK (the newly estimated UK Growth Reference Curves - Freeman et al, 1995) were presented (as reproduced in table 4.3).

Country	Source	Age (years)	% difference from current UK data:			
			Stature		Weight	
			male	female	male	female
Britain	Pheasant 1986	2-18	-1.40%	-1.27	+0.99	- 0.31
Britain	BSI 1990	5-16	- 0.97	- 0.37	- 1.14	- 2.49
USA	Snyder 1977	4-19	- 0.31	- 0.31	+4.42	+1.02
Germany	DIN 1980	3-17	+1.44	+1.79	n/a	n/a
NL	Steenbekkers 1993	2-12	+3.17	+3.16	+8.07	+7.14

-ve value = data are smaller than current UK population
+ve value = data are greater than current UK population

Table 4.3 - Comparison of mean stature and weight between major Childata sources and most recent UK stature and weight

4.7.2.2 Secular trend in stature

The secular trend in stature had been thought to have halted in UK children (Chinn et al, 1989; Chinn and Rona, 1994), however increases have been found from the mid-1980s to early 1990s in Scottish girls and boys and in English girls (Chinn and Rona, 1994). The 1970s stature data used by Pheasant to produce his estimated dataset (probably the most widely used anthropometric data on children in the UK before Childata) was found to be around 1% smaller than children measured in 1990, the real differences in stature at age 11 being approximately 20 mm and 14 mm (boys and girls mean stature respectively). (Similarly, a secular increase in UK adult stature had been assumed to have halted [Pheasant, 1996]. Current work by this author to produce a sibling publication to Childata on adults has shown that the secular trend is continuing in the UK: mean adult stature has increased by 17 mm and 12 mm from 1981 to 1995 [Peebles and Norris, 1998]).

4.7.3 Choice of percentile values

A decision was made to present 5th and 95th percentile values data in the Handbook, rather than more extreme percentiles, which might have been considered more appropriate for safety applications. This decision was based on the format of the

original data, most of which presented 5th and 95th percentile values. Advice and guidance was given on the implications of choosing the most appropriate percentile values and how to calculate more extreme percentiles.

4.8 Lack of data

The production of the handbook highlighted serious gaps in the data available to designers. There was a paucity of data on dynamic anthropometry, strength and perceptual, cognitive and sensory capabilities. Generally there were few functional, product-related or performance-related measures which could be directly related to design. Exceptions and good examples of the sort of data needed were those produced by Nixon et al (1979) on the height of barriers that children could climb and by McClelland and Thompson (1976) on the height at which in-situ window handles could be operated by children. Reasons for the lack of data have been cited by Norris and Wilson (1988) and Wilson and Norris (1992). For instance, many studies could produce data with potential design implications but the focus of the research often negates this: medical research is often concerned with the aetiology and treatment of disease, illness and injury rather than normal function and behaviour; psychological research may be concerned with the quantification of abstract phenomena rather than design-related skills; occupational therapy research often concentrates on the assessment of abnormal rather than normal motor function. Even so, data produced within the ergonomics discipline itself often lacks functionality, highlighting the difficulty of relating classical, laboratory-based data to real life situations. For instance, the data produced by McClelland and Thompson (1976) specifying the placement of window handles measured children's performance with their feet held flat on the floor, obviously an unrealistic scenario. This is a classic example of the conflict between the need for control (and so give high reliability of results) and the need for realism (and thus validity) in the collection of human performance data.

4.9 Assessment of *Childata*

In spring 1997, the DTI carried out a survey of users of Childata to assess its usability and questionnaires were sent to recipients of the handbook (shown in Appendix 4.3). Seventy responses were received. The DTI said there was '*an overwhelming endorsement for the format and data contained within Childata.*' The response was such that a similar approach was recommended by the DTI for the production of *Adultdata* and *Elderlydata*, the sibling publications which have followed. The full results of the survey are shown in Appendix 4.4 and are summarised as follows:

- 90% of users said they found Childata easy or very easy to use
- 89% said they found Childata easy or very easy to understand
- 83% said Childata met their needs.

4.10 Discussion

Twenty years ago, Van Cott et al (1978), in discussing the needs for a co-ordinated ergonomics data reference system, said that traditionally the human sciences have pursued information exchange traditions suited to the needs of the academic community only. As well as problems with dissemination, they said data collection efforts were uncoordinated and un-standardised. Data were of uneven quality, contained inconsistencies, inaccuracies and gaps, and were often unsuitable for general reuse. In trying to address ergonomics data needs, their findings were:

- a definitive survey of user needs and priorities was necessary to define the scope of any data system
- standards were needed for the collection and reporting of data
- alternative technologies for the collection of data need to be assessed in light of cost
- all data should be critically evaluated before they are systematically compiled and disseminated

- any data system would need to be assessed, developed and managed to ensure its responsiveness.

The findings of the work reported here support their recommendations, and suggest that their recommendations for standardised data collection and reporting, now 20 years old, are still not addressed. The result is that much of the research effort which has the potential to lead to improvements in design and safety remains untapped. The paucity of data on some important aspects of children's design-related abilities show that there is a lack of co-ordination and dialogue, not only between academic disciplines, but also within the research communities.

Still the most recognised type of ergonomics information is anthropometric data, and it has been suggested that some designers may think of ergonomics in terms of anthropometrics only (Fraquelli, 1996). Even within anthropometrics, there are limitations to the applicability of the data to design, caused to an extent by poor dissemination but also by a lack of validity of the data. The secular trend in stature (and therefore other body dimensions) which has been identified above, is possibly unexpected or under-estimated by some, even within the ergonomics community, and is of particular importance where anthropometric datasets are estimated from stature, which is now common practice (after Pheasant, 1982 and Barkla, 1961). The need for appropriateness of the sample population is probably more well understood, given the tendency for early anthropometric sets to be based on military populations (Pheasant, 1996), but while there may be an awareness of this limitation these data are still used when faced with no other easily accessible or disseminated alternatives, as demonstrated by the continued popularity of sources such as Dreyfuss (1971) (Fraquelli 1996; Ward, 1994). The lack of cross-fertilisation between research communities again causes problems with the dissemination of anthropometric data, when large scale anthropometric surveys are conducted for, say, medical or clothing purposes and withheld from other disciplines such as ergonomics. This was discovered during the work on Childata described in this Chapter.

The production of Childata means that some progress has been made towards the dissemination of critically evaluated data in the particular case of designing for children and, with the subsequent stages of work not reported here, eventually for designing for adults and for the elderly. The hard-copy format of the Handbook means that its development and management may be limited, but a computer-based system would improve this aspect.

A co-ordination of research within and between disciplines is still needed to avoid wasteful replication of funds and expertise, and to ensure the widest application of research output. Also the problems of specificity and generalisabilty of ergonomics data remain, and can only be addressed by the co-ordinated production and dissemination of more performance-related data.

This Chapter considered the barriers to using ergonomics data in the design of safe products, and described work to overcome some of these barriers in designing for children. The use of data was just one of the two routes to improving product safety identified in Chapter 3 and this Chapter has demonstrated some of the potential problems of the ergonomics discipline relying on designers seeking out and using ergonomics data alone. The other route was the use of ergonomics evaluation methods, and the remainder of this research was focused on examining the feasibility of encouraging ergonomics evaluation in the design process, and is described in the subsequent Chapters.

Chapter 5 - Ergonomics evaluation in the design process - a review of literature

Chapter 4 demonstrated the difficulties encountered if we rely solely on using ergonomics data and guidelines as an approach to ensuring safety in product design. The other potential approach to using ergonomics to improve product design safety proposed in Chapter 3 was the inclusion of ergonomics evaluation within the design process. Since the generation and transfer of ergonomics data has limitations, if evaluation can be carried out effectively during design this is obviously of great importance. This Chapter reviews the literature on methods used in ergonomics evaluation, specifically those related to product design and to safety, and looks specifically at what methodological guidance is available to designers to encourage them to carry out ergonomics evaluations during product development. This will be used in conjunction with experimental work to try to produce guidance for designers on how to carry out ergonomics evaluations.

5.1 Ergonomics methods

As well as ergonomics data, another major output of ergonomics research is a plethora of methods. Methods have been developed, for example, for contribution to the design process, for the collection of human performance data, or for use in the design and evaluation of products, work organisation and workplace layout. Stanton and Young (1998) note a 'growing number of texts in recent years describing, illustrating and espousing a plethora of ergonomics methods'. They cite collections of methods from Corlett and Clarke, 1995 (workspaces), Diaper, 1989 (human

computer interaction), Jordan et al, 1996a (on usability), Kirwan and Ainsworth, 1992 (task analysis) and Wilson & Corlett, 1995 (evaluation of work). Some ergonomics methods are adapted from other disciplines, others developed specifically for ergonomics work (Chapanis, 1995). A huge number of methods for testing and evaluation have been developed for application to the design of large systems, and particularly military systems (for example see Meister, 1985) but comparatively few have been developed and documented specifically in the domain of consumer products. Of the texts cited above by Stanton and Young as 'guides' to ergonomics methods, only two (Jordan, Wilson and Corlett) refer explicitly to either consumer products or to safety. It is doubtful also if any of these texts would be picked up by those in the manufacturing or design industries, and so are unlikely to be used to guide evaluation in industry. A review of literature was therefore undertaken to assess the guidance available to designers on how to incorporate ergonomics methods and evaluation into design, specifically of consumer products and specifically for safety.

5.2 Summary of available methods

First of all the ergonomics literature was reviewed for useful evaluation methods, applicable to consumer products. Chapanis (1995) differentiates between ergonomics methods according to purpose:

i) descriptive methods (of observation, description, analysis, explanation) concerned with describing what has happened in the past

ii) predictive methods used to assess whether or not a design will meet its objectives, concerned with development and future or novel designs.

A number of recent reviews or summaries of ergonomics methods relevant to design have been published:

- Stanton and Young (1995) reviewed methods proposed for usability evaluation of consumer products and found over sixty published methods.

- Usability evaluation in industry was reviewed in a 1994 conference and the Proceedings describes current practices in industry (Jordan et al, 1996a).
- The UK Consumers' Association have summarised the methods they use to carry out comparative testing of consumer products (Butters and Tetra-Dixon, 1998). The CA operate under commercial pressures which serve to make their testing procedures probably more akin to a real industrial design setting than most research organisations.
- Chapanis (1995) draws on considerable experience of ergonomics and product development to describe methods that he has found most useful in what he calls 'the practical business of developing products', proffering a potentially practical guide to ergonomics methodology, specifically for product design.

A summary of the methods reviewed by these authors is shown in table 5.1.

Stanton and Young (1995)	Chapanis (1995)	Butters and Tetra-Dixon (1998)	Jordan et al (1996a)
Checklists	Analysis of similar systems	User trials	DIY
Observation	Activity analysis	User panels: Lay, specialist or trained	TAFEI
Interviews	Critical incident study	Checklists	FACE
Questionnaires	Functional flow	Expert appraisals	SUS
Heuristics	Decision/Action analysis	Discussion groups	SUMI
Link analysis	Action/Information requirements analysis	Convenience diaries	Private cameras
Layout analysis	Functional allocation		Co-discovery
HTA	Task analysis		
PHEA	Failure mode and effects analysis		
Repertory grids	Time line analysis		
KLM	Link analysis		
	Simulation		
	Controlled experimentation		
	Operational sequence analysis		
	workload assessment		

DIY - Do-It-Yourself Usability Evaluation
TAFEI - Task Analysis for Error Identification
FACE - Fast Audit based on Cognitive Ergonomics
SUS - System Usability Scale
SUMI - Software Usability Measurement Inventory
HTA - Hierarchical Task Analysis
PHEA - Predictive Human Error Analysis
KLM - Keystroke Level Mode

Table 5.1 - Summary of methods used in the evaluation of consumer products

Each of these methods is described in Appendix 5-1, except those from Chapanis, which are summarised in table 5.2 in this Chapter.

5.2.1 Usability of ergonomics methods

As well as reviewing methods, Stanton and Young attempted to assess the acceptance and practice by ergonomists of these abundant methods. They asked members of the Ergonomics Society to consider a list of twenty-seven methods from the sixty they had identified. Just eighteen chose to respond to their survey. The results showed a limited utilisation of the methods; only eleven were used by six or more of the ergonomists surveyed. They found that questionnaires, interviews and observation are the principle methods used for data collection. Simulators, computer simulation, interviews and repertory grids are used largely for design activities. Stanton and Young suggest from this that 'most methods are used by their inventors only', although the motivation of the target sample to respond and provide detailed information on the techniques they use should obviously be borne in mind when considering these results. Stanton & Young also asked respondents to judge their methods on a number of criteria. Some methods appeared to be significantly easier to use than others - checklists were found easier than simulation; guidelines easier than proto-typing; interviews easier than mock-ups. From this work they suggested the criteria an ergonomist may use to choose a method are:

- the appropriateness of a method
- time to train people to use the method
- time to apply
- relative benefits of one method over another.

In a previous paper (Stanton and Baber, 1996) the influences on the selection of methods is reduced down to four basic factors:

- stage of design process
- form product takes
- access to end users

- pressure of time.

These analyses were limited to experienced and motivated ergonomists only. To compare findings to what might be reported by inexperienced users, the authors looked at the training involved in using the methods, using nine engineering students. Four hours training in each method was given, plus practice, and then the methods were applied to the evaluation of radio-cassette players. The students' were asked to judge the methods on seven criteria:

- acceptability
- auditability
- comprehensiveness
- consistency
- theoretical validity
- resource usage
- usefulness.

Results suggested that methods will differ in their acceptability because of the time taken to learn them, the time to apply them and the degree of consistency they offer. Questionnaires, observations, checklists, interviews and heuristics were quick to learn while the first three were also quick and flexible to apply. Interviews, observation, and heuristics were all rated highly in terms of overall acceptability. Checklists, HTA, PHEA and KLM were rated as the most consistent methods to use with heuristics rated the least consistent. Link analysis, layout analysis, repertory grids and KLM all offered good overall utility when compared with other, more commonly used methods.

The authors combine this assessment of novice users with the judgements of the experienced ergonomists in accordance with the criteria for selection of methods listed earlier. The authors conclude that there is an almost random match of methods to applications.

Stanton and Young's investigation suggests that any practitioner is likely to 'settle' into using a small number of favoured methods, and that the plethora of methods actually available are likely to remain unused by those under commercial pressures of time and cost. These conclusions do not, however, assist the selection of methods for use by designers or industry.

In a review of the use of ergonomics methods by designers Baber and Mirza (1996) found product designers tend to restrict methods to interviews, observation and checklists, choosing these because they say they are easier to use. They rated methods easier to use if they are not software-supported; even though software support can make things more efficient long term, they can be seen to make methods complex and cumbersome in the short term. Perceived ease of use also appeared to be dependent on the amount of training the person has had; suprisingly if no training had been received the method may be perceived as easier than those in which informal training had been given, a potential danger in the practice of ergonomics by the naïve or unwary.

5.3 Guidance for designers on methods

Since there is such a large variety of methods available to ergonomists, and ergonomists themselves report that only a limited number of methods are widely accepted and many admit that they have difficulty in applying methods, a review was conducted to find guidance to help designers and other professionals over the barriers it appears ergonomists find difficult to overcome. Three primary sources of advice were found, Chapanis (1995), USERfit (1996) and The Consumers' Association (Butters and Tetra-Dixon, 1998) which were reviewed individually, followed by other sources.

5.3.1 USERfit

USERfit (1996) is a 600 page handbook aimed at achieving user-centred design in Assistive Technology (Assistive technology, also known as rehabilitation technology, addresses the needs of elderly and disabled people, especially the need to maintain independent living, and has two main themes -enabling access to new technologies and harnessing these technologies to fulfil the needs of everyday life [TIDE, 1993]).

The handbook is aimed at designers and is intended to be a design tool. The handbook presents a general approach and framework to design and presents design and evaluation methods as 'tools'. A hierarchical structure of 'summary' tools is developed, within which they then describe 'design' tools', shown in figure 5.1.

'summary tools'		**'design tools'**
user analysis		user mapping
activity analysis		brainstorming
product analysis		task analysis
environmental context		direct observation
product environment	→	expert opinion
functional specification		diary methods
usability evaluation		questionnaires
		interviews
		group discussions
		empathetic modelling
		user trials
		field trials

Figure 5.1 - Evaluation framework (from USERfit, 1996)

Each of the summary tools is a pro-forma checklist, of questions and information to be collected. The design tools are described and two full worked examples are given which take up around 80 pages of the handbook. The USERfit manual is a comprehensive reference document for designers and its modular approach makes it probably the nearest thing to a 'designer's guide' for evaluating usability, or in its own words, a 'user-centred' approach. Its unwieldy size does make it difficult to handle. Also, although the organisation and layout of the document have obviously

been given much consideration, the structure is complex: the 'summary tools' do not lend themselves to easy incorporation into the design process, although the information that they are prompting the designer to produce is important. Their labelling as 'tools', and their disparate presentation make them difficult to use. They would be better presented together as stepped checklists. The problem of producing prescriptive advice on methods is well demonstrated by the difficulty of making this method or approach to evaluation 'usable' in itself.

5.3.2 Chapanis

Chapanis (1995) developed a model of ergonomics methods and offers this as a guide to the practical application of methods to the product development process (figure 5.2). Each method in this model is then described (as shown in table 5.2).

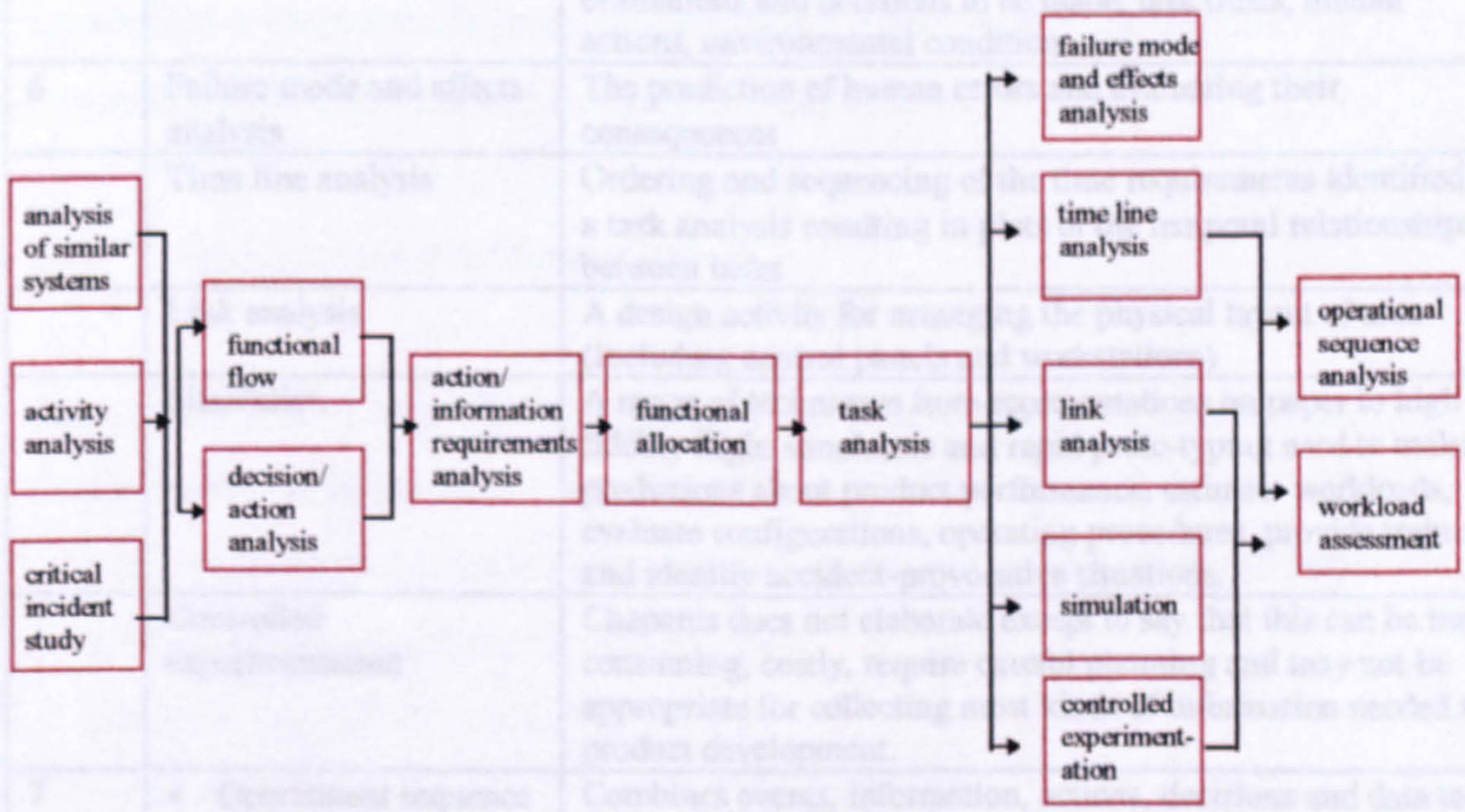


Figure 5.2 - Model of methods for product development (after Chapanis, 1995)

Chapanis stresses that the model of methods is sequential, some methods depending on methods earlier in the process. Also methods should be used selectively, they are not all applicable to all situations. He promises to demonstrate the model and methods by applying them to the design of a related group of products - an automatic bank teller, and automated ticket machine or an automated point of sale terminal and

taking the reader through a sequence as if designing a small system. Reference to the examples promised is made only minimally in the discussion of four of the fifteen activities (functional flow, decision/action analysis, functional allocation and briefly in link analysis) and these use the example of an automated bank teller only.

Stage	Activity	Description
1	• Analysis of similar systems • Activity analysis • Critical incident study	Activities performed at any stage and used to provide suggestions about the functions that the product must serve
2	• Functional flow • Decision/Action analysis	Procedures for i) decomposing or identifying the sequence of functions and actions to be performed by the product ii) identifying functions/actions that can be dealt with as questions with yes/no choices
3	Action/Information requirements analysis	Identifies the information needed for each action or decision to occur.
4	Functional allocation	The allocation of functions and decisions to hardware, software, people or combinations.
5	Task analysis	Production of an ordered list of the things people will do with a product, including information on information requirements, evaluations and decisions to be made, task times, human actions, environmental conditions.
6	Failure mode and effects analysis	The prediction of human errors and evaluating their consequences
	Time line analysis	Ordering and sequencing of the time requirements identified in a task analysis resulting in plots of the temporal relationships between tasks
	Link analysis	A design activity for arranging the physical layout of area (including control panels and workstations)
	Simulation	A range of techniques from representations on paper to high fidelity flight simulators and rapid proto-typing used to make predictions about product performance, estimate workloads, evaluate configurations, operating procedures, provide training and identify accident-provocative situations.
	Controlled experimentation	Chapanis does not elaborate except to say that this can be time consuming, costly, require careful planning and may not be appropriate for collecting most kinds of information needed for product development.
7	• Operational sequence analysis • Workload assessment	Combines events, information, actions, decisions and data to produce a graphic presentation of user tasks as they relate to equipment and other operators. Particularly appropriate for complex systems with several operators and equipment (no discussion of workload assessment techniques).

Table 5.2 - Methods for use in product development (from Chapanis, 1995)

Chapanis concludes that :

- methods are not interchangeable and cannot be substituted for one another
- the methods flow from one to another (the sequential nature of the model)
- the methods do not follow precisely definable procedures
- most methods involve judgement, and so are highly dependent on the skill of the ergonomist
- collectively the methods are indispensable tools for the production of safe, comfortable and effective products.

Chapanis makes a number of very important points but does not provide the suggested practical guidance to methods. He talks of the preoccupation of the ergonomics discipline with the proliferation and promulgation of a body of knowledge, the 'lip service' paid to the application of ergonomics to design, yet this paper does not contribute to moving forward to a useable methodology. The lack of application of the methods to examples perhaps demonstrates the difficulty in producing a generic yet useable process of application.

5.3.3 The Consumers' Association

Butters and Tetra-Dixon (1998) describe the evaluation methods they use as:

- user trials - at home or in controlled laboratory situations, usually employing rating scales that are statistically analysed or else producing anecdotal information
- user panels: lay, specialist or trained users
- checklists
- expert appraisals
- discussion groups
- convenience diaries - to assess factors of long term use.

Choice of methodology in any particular situation is governed by:

- time
- cost
- characteristics of the product

- trade-off between experimental control and realism
- methods used in past assessments
- where the product is in its 'life-cycle'
- frequency of testing
- the intended focus of the magazine article (all testing is carried out to produce material for the organisation's magazine *Which?*).

Some details of choices between methods are given. For instance: they suggest that user trials may be impractical for some complex products, and checklists based on existing guidelines would be used instead. The impracticalities are not explained, but it is assumed that complexity suggests that there are too many factors to be assessed simultaneously by one 'usability' criterion. Comparative assessments are easier if objective data are collected, such as the force to operate controls. They suggest however that this can be difficult as many data and guidelines are incomplete, out-of-date and not applicable to modern products. Checklists may therefore often have to concentrate on subjective assessment. Notably they say that often more than one method is used to assess a product. For instance a user trial may be supplemented by expert appraisal from an ergonomist or a group discussion may take place before a user trial. Also, arbitrary methods may be developed and used. They suggest, for instance, that rather than employing a user-characteristic such as handedness as a variable in trial, which would add to the number of trials conducted, the product may be assessed additionally by say a left-handed member of the staff.

5.3.4 Other guidance on evaluation

Stanton and Baber (1996) provide a useful guide to the selection of ergonomics methods, based on the criterion questions:

- at which stage of the design cycle are you?
- in what form does the product exist?
- do you have access to end users?
- how tight are time pressures?

The guidance is in the form of a heuristic chart (shown in figure 5.3) and is intended to assist designers in choosing methods for usability evaluations. The chart is based only on the methods they have discussed, and they do say the list is not meant to be exhaustive.

Lamb (1985), Rennie (1981) and Meyer (1994) classify ergonomics evaluation methods as they apply to product design and produce three comparable classifications:

Lamb (1985)
- user trials
- expert appraisal
- performance test

Rennie (1981)
- user trials
- expert appraisal
- human simulation tests

Meyer (1994)
- user trials
- expert appraisal
- performance tests

Rennie suggests that decisions on what tests should be carried out are governed by preliminary steps - task analysis, hazard analysis and injury analysis - and that there are no rules on how to decide between evaluation techniques. The evaluation process is usually a case of blending, mixing and adapting methods and text book methods are not always appropriate for product evaluations. She also differentiates between technical and ergonomics tests and emphasises that both are often necessary.

Dockery and Neuman (1994) give simple advice in that a user profile needs to be reviewed at every stage of the design process (also Fisher, 1991).

Drury (1989) attempts to produce a 'standard methodology' for comparative evaluations, based on an evaluation of cooking pans. Stating that ergonomics evaluations of consumer products are usually ad-hoc affairs the aim was to produce a method that had a sound theoretical background and an intuitive appeal, as well being used to teach methodology. However, rather than producing a model of evaluation the study simply identified comparative task parameters (in this case parameters such as velocity of movement and controllability) and developed measures of these (such as attaching a pen to the pan as it was moved over a prescribed path), without extrapolating the potential to other product evaluations.

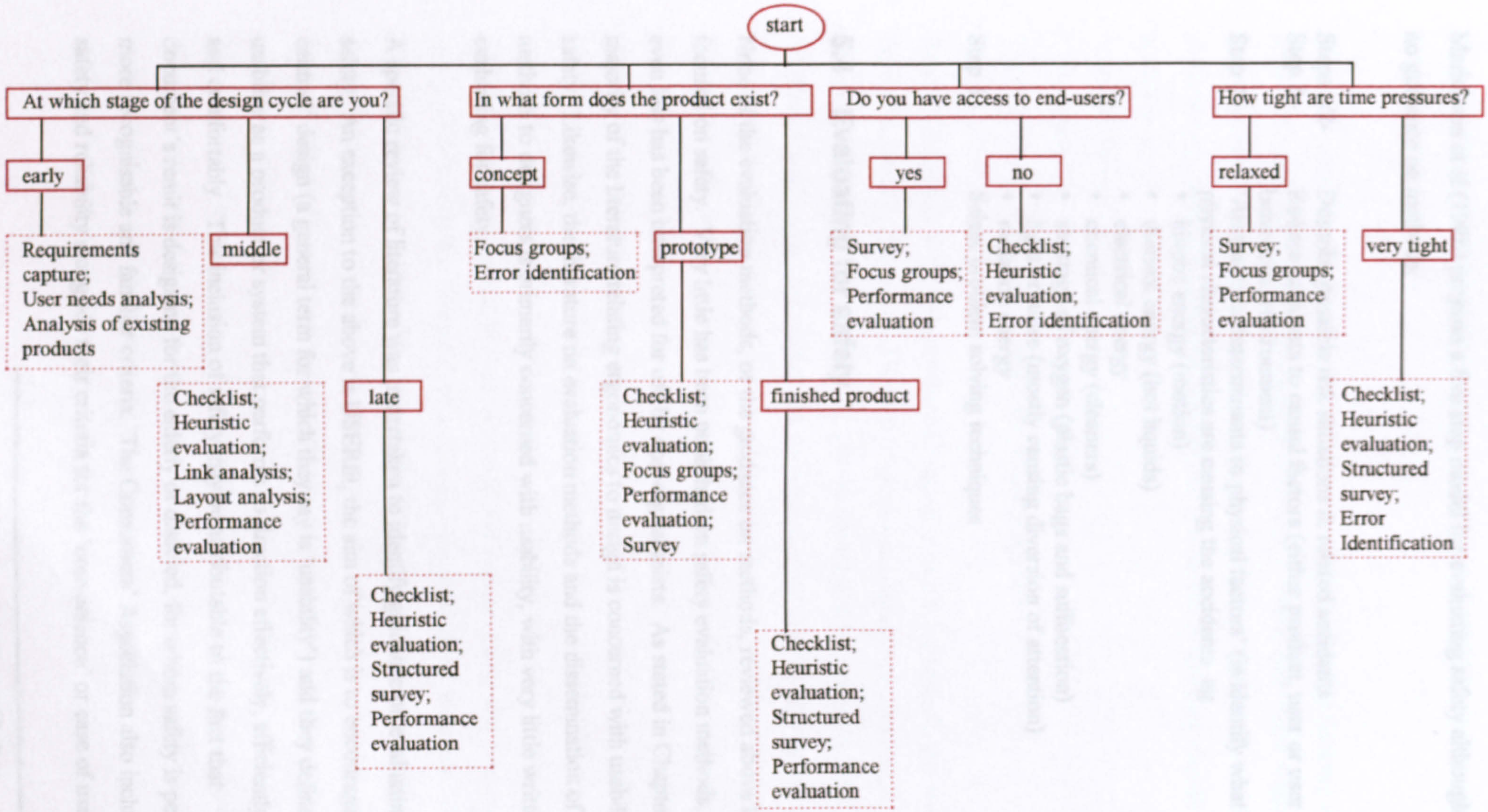


Figure 5.3 - Heuristic chart for the selection of usability evaluation methods and techniques (from Stanton and Baber, 1996)

Marinissen et al (1986) propose a five step model for evaluating safety although offers no guidance on methods:

Steps 1/2-	Describe possible risk situations & related accidents
Step 3 -	Reduce accidents to causal factors (either product, user or user behaviour, environment)
Step 4 -	'Abstract the determinants to physical factors' (ie identify what physical characteristics are causing the accidents eg • kinetic energy (motion) • thermal energy (hot liquids) • electrical energy • chemical energy (cleaners) • shortage of oxygen (plastic bags and suffocation) • light or noise (mostly causing diversion of attention) • radiation energy
Step 5 -	Select problem solving techniques

5.4 Evaluating for safety

None of the evaluation methods, or the guidance on methods, reviewed above have focused on safety. Very little has been published on safety evaluation methods, and even less has been interpreted for use by non-ergonomists. As stated in Chapter 3, the majority of the literature relating ergonomics to design is concerned with usability, not safety. Likewise, the literature on evaluation methods and the dissemination of methods to designers is primarily concerned with usability, with very little written on evaluating for safety.

A specific review of literature was undertaken to identify guidance on evaluating for safety. An exception to the above is USERfit, the aim of which is to encourage 'user-centred' design (a general term for which they say is 'usability') and they define usability as a product or system that performs its function effectively, efficiently, safely and comfortably. This inclusion of safety may be attributable to the fact that document's remit is designing for the elderly or disabled, for whom safety is perhaps a more recognisable and familiar criteria. The Consumers' Association also include safety and reliability alongside their criteria for the 'convenience' or ease of use of a

product. However neither the Consumers' Association or USERfit address *evaluating* for safety.

Hoefnagels and Schoone-Harmsen (1992) (reviewed in Chapter 3) attempted to produce a method for evaluating specifically for safety. While their paper suggested that evaluation is an integral stage in designing for safety (see figure 3.2), their bias is towards test methods in standards only and this is reflected in how they classify test methods:

- safety distances
- user panel - eg child-resistant packaging
- performance - small parts cylinder and finger probe test.

Benedyk and Minister (1998) propose an evaluation method specifically for product safety. The BeSafe (Behavioural Safety) Method was adapted from the PHEA (Potential Human Error Audit) method, and was developed by British Coal for targeting accident prevention initiatives. It is based on an original assumption that most accidents at work are due in some part to human error, and when applied to consumer products this is a method for systematically addressing human behaviour with products. It is intended for use by non-ergonomists following a short training course. It is an 'integrated set of ergonomics-based procedures (analysis techniques, checklists, questionnaires) which are designed to enable an auditor to identify systematically the potential for human error'. The BeSafe process is shown in figure 5.4, and the main adaptation between its use in occupational safety and consumer safety is re-defining the 'Scenario', to account for the user, the environment of use and the way the product is used. This scenario is followed by an ergonomic audit and an instructional/behavioural audit. The ergonomics audit is intended to identify all design features that pre-dispose human error, and involves a long list of checks. The second audit attempts to identify the individual or social factors that predispose 'violations'. The stages involve questioning and observation of users. Although some of the stages of the original method are recognised to be less relevant than in assessing safety within an organisation, one of the benefits of the method is suggested as the structuring of the safety evaluation process.

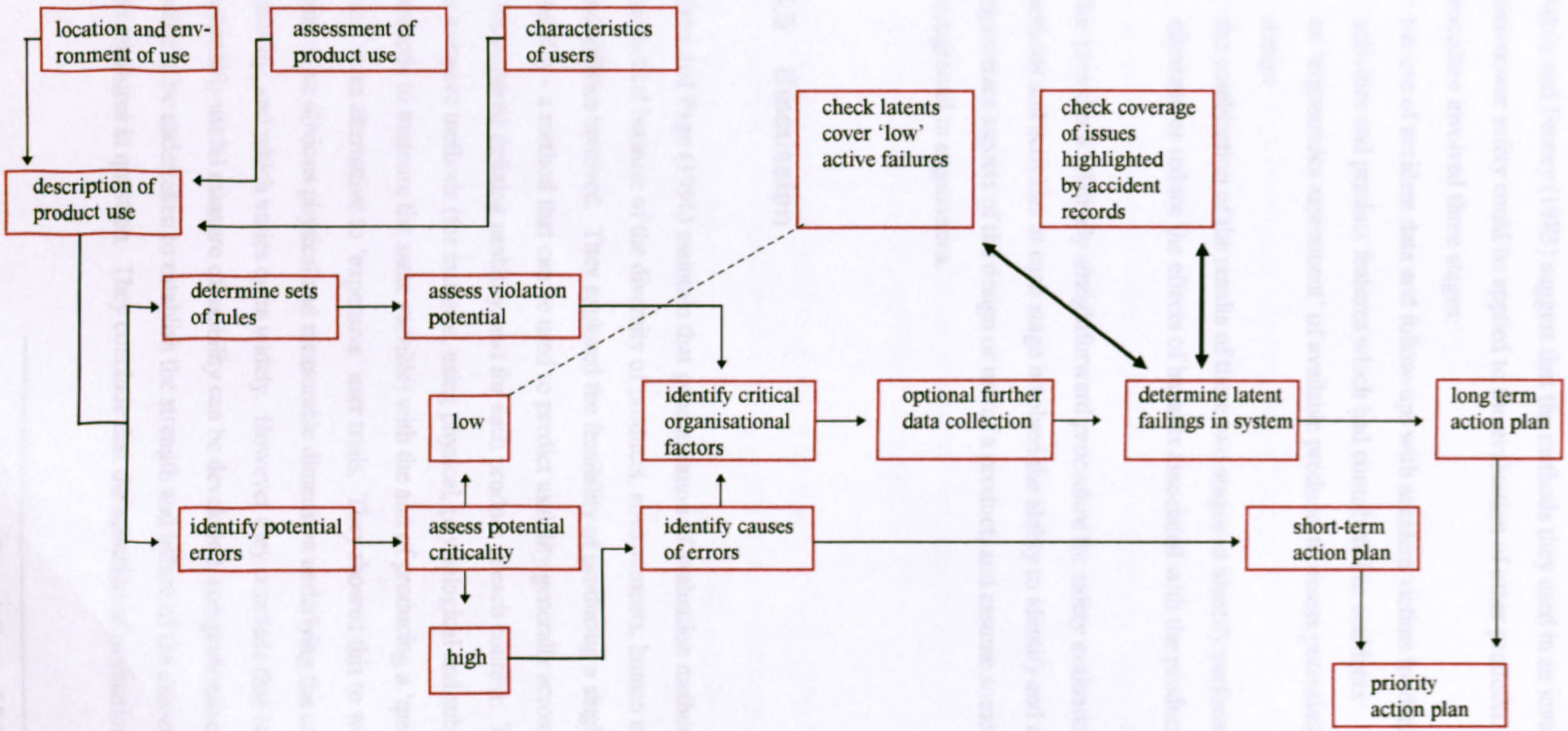


Figure 5.4 - The BeSafe Approach for consumer products (from Benedyk and Minister, 1998)

Fulton and Feeney (1983) suggest that the methods they used in an investigation of lawnmower safety could be applied to the evaluation of other products. Their procedure involved three stages:

- the use of accident data and follow-ups with accident victims to identify user activities and product features which had contributed to accidents
- an 'ergonomics assessment' of available products to assess potentially hazardous design
- the combination of the results of these two stages to identify performance criteria to eliminate or reduce the effects of hazards associated with the products.

This provides a relatively straightforward *procedure* for safety evaluation, however the methods and activities at each stage involved the ability to identify and assess the ergonomics aspects of the design or use of a product, and assume some training or background in ergonomics.

5.5 Discussion

Galer and Page (1996) maintain that generalisation of evaluation methods is impractical because of the diversity of products, environments, human characteristics and abilities involved. They explored the feasibility of producing a single index of usability - a method that can be used to predict usability generally across products. This required defining usability, and for each product in each context. They attempted to compare methods (for instance, using physical, physiological and subjective methods to measure the same variable) with the aim of producing a 'quick assessment tool' as an alternative to 'expensive' user trials. They showed this to work best where there is an obvious physical and measurable dimension underlying the concept of usability, and which varies quite widely. However they conclude that before any potentially useful measure of usability can be developed, comprehensive basic research needs to be undertaken to establish the strength and nature of the association between the measures in question. They conclude that the selection of evaluation method

depends on the level of precision required, the resources available and the type of information that is being sought.

This Chapter has demonstrated another serious gap in the transfer of knowledge from ergonomics to designers, in that the methods developed by ergonomists for evaluation are still difficult to 'sell' amongst the ergonomics discipline and especially are not being translated into a format usable by designers or industry. Also they have generally not yet been produced to adequately address the evaluation of safety.

Of the two approaches identified in Chapter 3 for encouraging ergonomics and safety into design, both have been shown to be in need of improvements. Chapter 4 described work carried out as part of this programme of research to address the barriers to transferring and encouraging the use of ergonomics data to design. The rest of the thesis now explores the possibilities for addressing the failures in the second route, namely encouraging ergonomics evaluation.

A programme of experimental research was instigated. The aim of the research has been to assess the methods used in each investigation and from this produce practical and usable guidance for designers to help encourage evaluation in the product development process. Practical investigations of safety across a diverse range of products were undertaken.

Chapters 6, 7, 8 and 9 describe these safety investigations. Each one is a case study describing the methods used to evaluate each product and hazard. Following the case studies, Chapter 10 is an analysis of the series of case studies and will assess the feasibility of using them to produce guidance for designers.

Introduction to the case studies

Chapters 6 to 9 describe four case studies of product safety investigations. The products investigated and their associated hazards are as follows:

Chapter 6 - Swimming pool covers - access of children under the covers

Chapter 7 - Carbonated drinks bottles - closures missiling from bottles during opening

Chapter 8 - All Terrain Bikes (ATBs) - falls from bicycles and failure of the product

Chapter 9 - Stepladders - falls from stepladders and failure of the product.

Each of the case studies was undertaken on behalf of, and funded by, the Department of Trade and Industry Consumer Safety Unit. In each case the outcome of the case studies was a formal report to the government outlining potential routes for improvements in safety. These reports were published by the government as public consultation documents and used to initiate discussions with manufacturers, trade representatives, standards bodies and/or consumer groups on feasible action to be taken to reduce injuries. As well as producing formal reports on individual product safety, the case studies have been used here to examine the feasibility of producing a generic evaluation methodology.

The research projects which formed the case studies were all proposed, co-ordinated and managed by the author. All planning work including preparation of reports was the author's. All ergonomics and survey work was carried out by the author, however technical work was carried out by a number of colleagues and their contribution to this work is gratefully acknowledged:

Swimming pool covers -	Materials tests were carried out by Helen Pretty
Carbonated drinks bottles -	Pressure tests were carried out by Neil Hopkinson
All Terrain Bikes (ATBs) -	Neil Hopkinson carried out the impact tests and field trials and analysed the data.
Stepladders -	Neil Hopkinson carried out the analysis of the distribution of loads and Neil Hopkinson and Karen Lawrence ran and analysed the user trials.

KEEP YOUR POOL SAFE

Many tragic accidents occur in unattended pools, the victims are in the main children under five.

The DRI Pool Cover completely seals the pool. Manufactured from Polyester reinforced PVC, it is incredibly strong, it floats on the water enabling it to carry enormous loads, thanks to our old friend Archimedes and his Principle.

- DRI Pool Cover manufacturers, Southampton

Chapter 6 - Case study: The design and safety of swimming pool covers

6.1 Introduction and aims

Around thirty six children under five years old die every year in the UK through accidental drowning (RoSPA, 1990) and drowning is the third commonest cause of accidental death of children in the UK (OPCS, 1992). Domestic pools are the fourth commonest site of drowning and near drowning, after open water (rivers, canals and lakes), the bath and the sea (Kemp and Sibert, 1992). Although these figures may not highlight domestic pools as a priority area for child safety activities in the UK, in countries such as like Australia where domestic pools are more prevalent, drowning is the commonest cause of accidental death (among children under three) and most of these deaths occur in domestic pools (CAPFA, 1991). There is therefore concern over the safety of domestic swimming pools as a consumer environment or product. There are a number of approaches to reducing the problem, and these can be interpreted in terms of the approaches to safety referred to in Chapter 2:

- eliminate the hazard - *make the pool itself safe*
- isolate the hazard - *through the use of barriers*
- mitigate the consequences of immersion - *through alarm systems, life saving equipment, CPR training for carers*
- educate - *children and carers of the hazards of swimming pools.*

A swimming pool, or any body of water has a inherent hazard - drowning - and the only possible design-based approaches to reducing the problem are by isolating the hazard, possibly through the use of barriers or covers. Some Australian states have

legislated that domestic pools must be fenced, and give fencing requirements based on human factors testing with under fives carried out by Nixon et al (1979). The research carried out for this thesis suggests later that such legislation is likely to be unpopular in this country. Pool covers could therefore be a potential route to reducing immersions.

Conversely however, concern had been raised that pool covers may actually be playing a contributory role in these accidents (Sulke, 1990). Kemp and Sibert (1992) investigated 33 immersion incidents in domestic pools in 1988 and 1989 and found that over half of the incidents occurred in pools with covers on. Given that domestic swimming pools in the UK are unregistered and are not subject to any specific design or safety standards, the potential role of the role of swimming pool covers (SPCs) in childhood immersion incidents, and the ergonomics issues surrounding their design were of interest. An investigation was therefore carried out on behalf of the Department of Trade and Industry (DTI) Consumer Safety Unit (CSU). The aims of the research were to:

- identify the types of SPC involved in immersion incidents
- identify the user profile at risk from immersion incidents with SPCs
- assess the risk of each hazard and each type of SPC
- identify possible routes to improve SPC safety.

6.2 Definition of the products and the SPC market

6.2.1 Types of pool covers

SPCs are multi-purpose: to prevent the evaporation of heat and chemicals; to keep the pool clean and/or to seal the pool and render it safe. They fall into three broad categories and possible hazard scenarios were identified for each type:

- **Floating covers** are made of blue foam or plastic bubble sheeting (see figures 6.1 and 6.2). They are free floating and used solely to preserve heat and chemicals.

"Bubble" covers, the commonest and cheapest, also act as a solar heat trap on outdoor pools. Floating covers may make the pool surface appear solid and would probably obscure anything in the pool. They are not designed to support any weight and are likely to hinder any attempt to get out of the pool.

- **Winter covers** are secured over outdoor pools to keep them clean. They are made of either open nylon mesh with buckled straps pegged into the ground (figure 6.3) or a PVC sheet held down at the edges by PVC sacks filled with water (figure 6.4). Winter covers depend on successfully denying access to the pool. The winter mesh cover relies on a child's inability to pull out a peg or undo/loosen a buckle (figure 6.5). If not installed carefully however the edge can be easily lifted. "Waterbag" covers depend only on the removal of the bags around the edge.
- **Safety covers** are usually automatic, expensive and fulfil all three functions of a cover outlined above. There are two common designs. Flexible safety covers are made either of strong, flexible PVC stretched across the pool in hidden tracks; they can collect rainwater on top and some have a free flexible end that can be lifted to gain access to the pool (figure 6.6). Rigid safety covers consist of a series of interlocking plastic slats resting on a rail above the water level (figure 6.7); they can let water through from the pool if depressed and the edges can be lifted. Both designs offer a risk of entrapment if left partially open.

6.2.2 Standards

There is no UK legislation or standardisation regarding the design or installation of SPCs. There are however standards in the USA and Australia (ASTM ES 13-89 and A2020 respectively) where domestic pools are more prolific and these are described in Appendix 6.1. The main provisions of the standards are that a child's face should not be submerged in water, either through falling between the edge of the cover and the pool, or falling in water on the surface of the cover, and performance criteria for these are described.

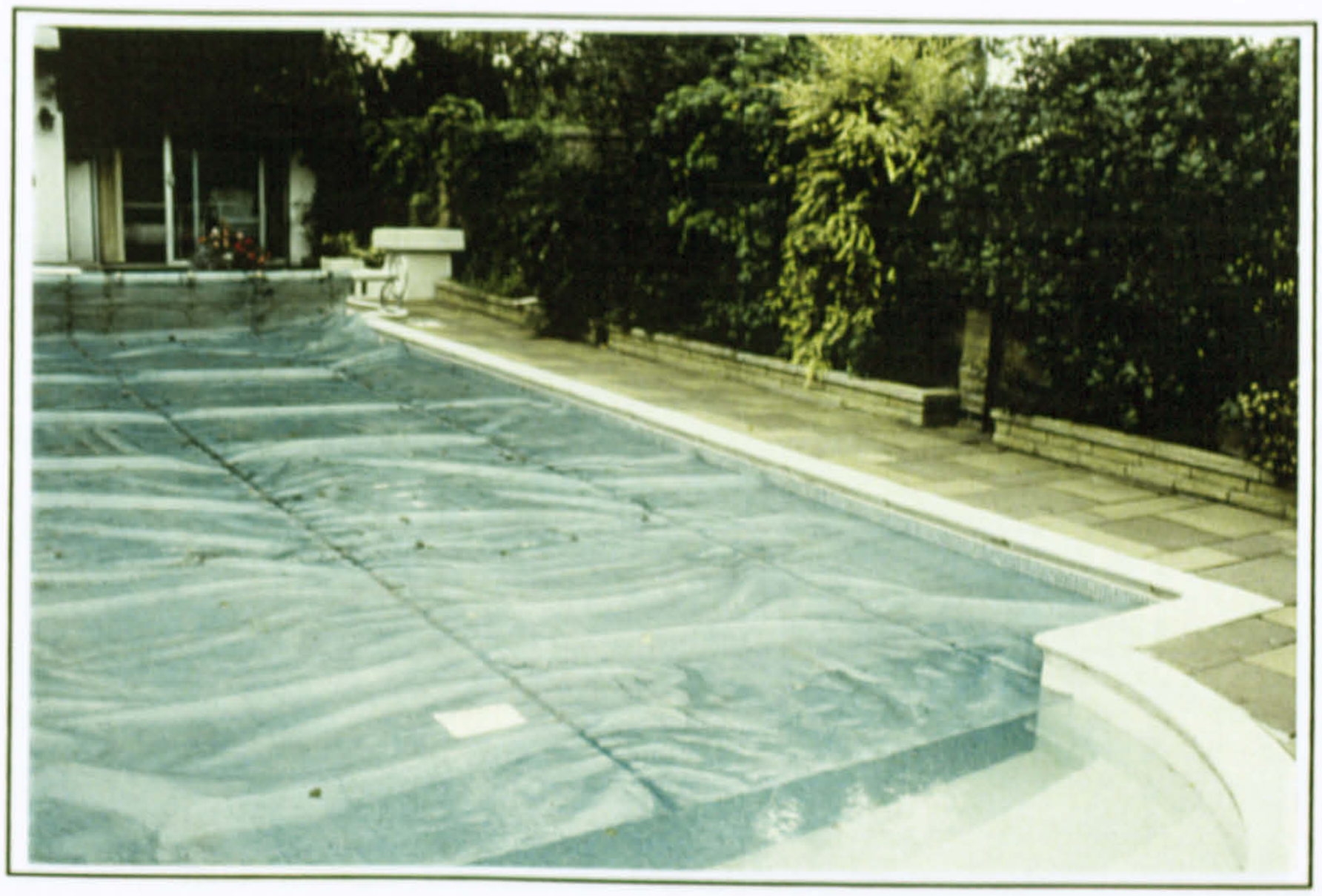


Figure 6.1 - Floating 'bubble' cover

Figure 6.2 - Floating foam cover

Figure 6.3 - Winter 'mesh' cover

Figure 6.4 - Winter 'water-bag' cover

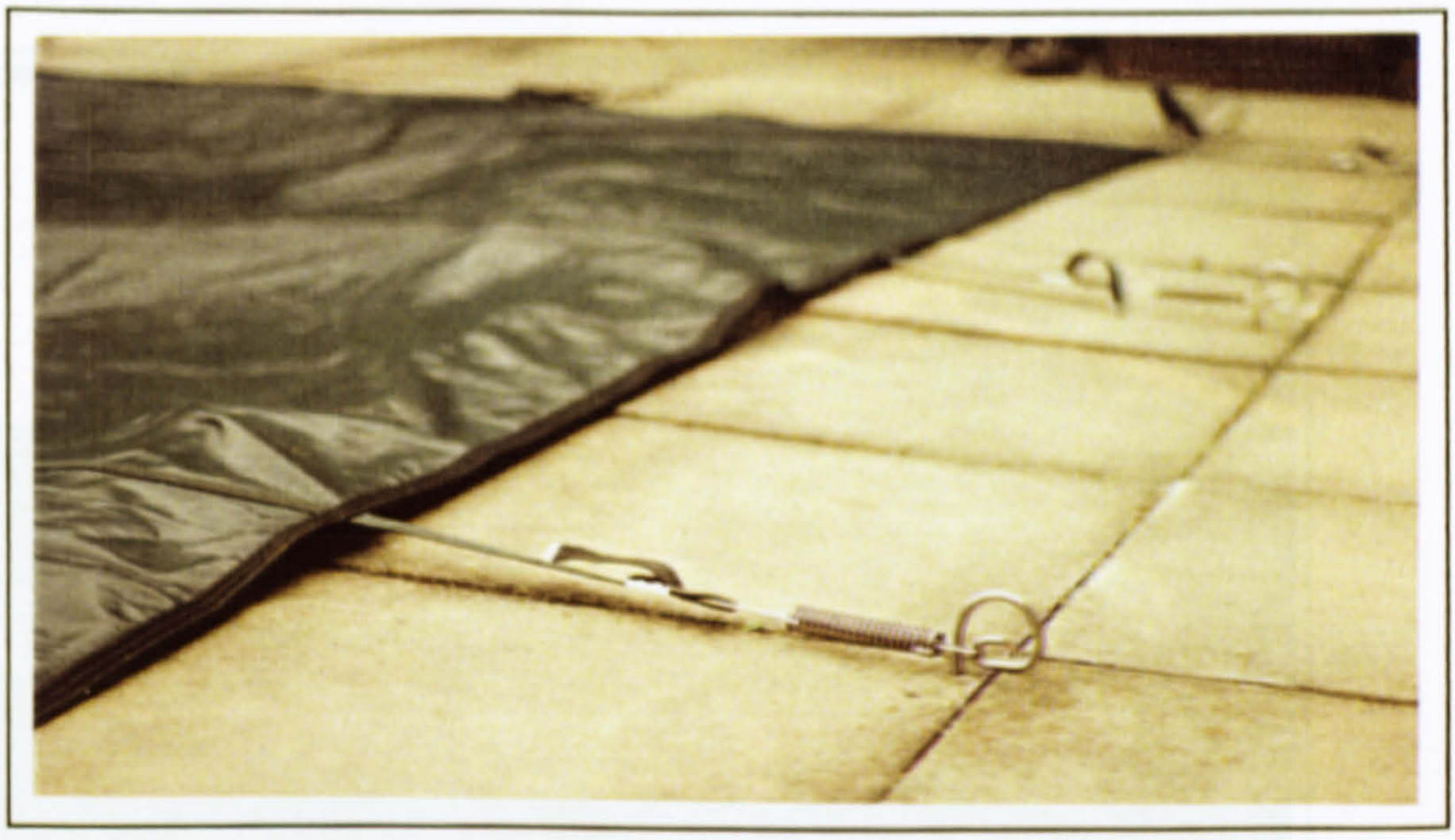


Figure 6.5 - The securing system used on winter mesh covers

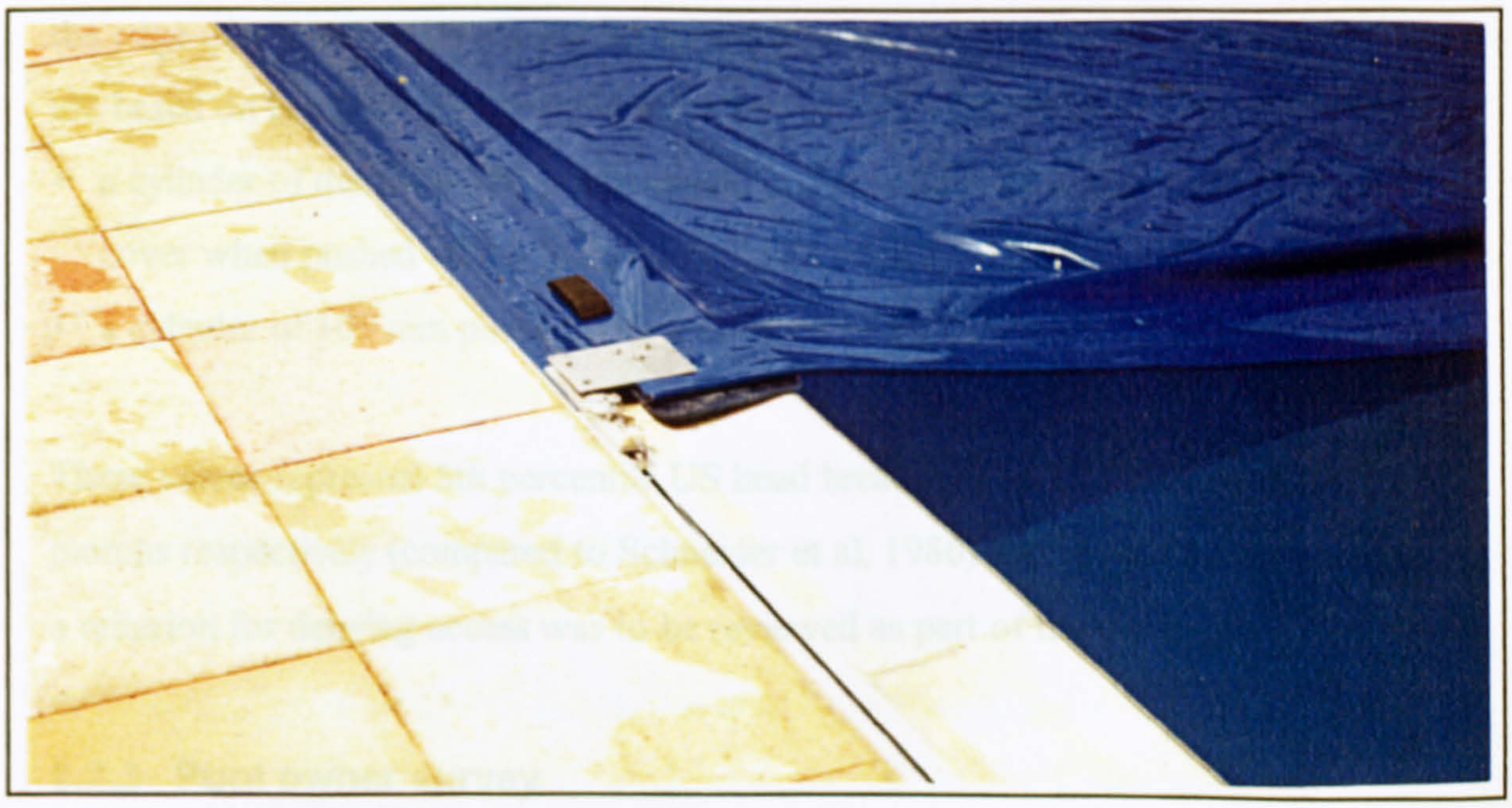


Figure 6.6 - Flexible safety cover

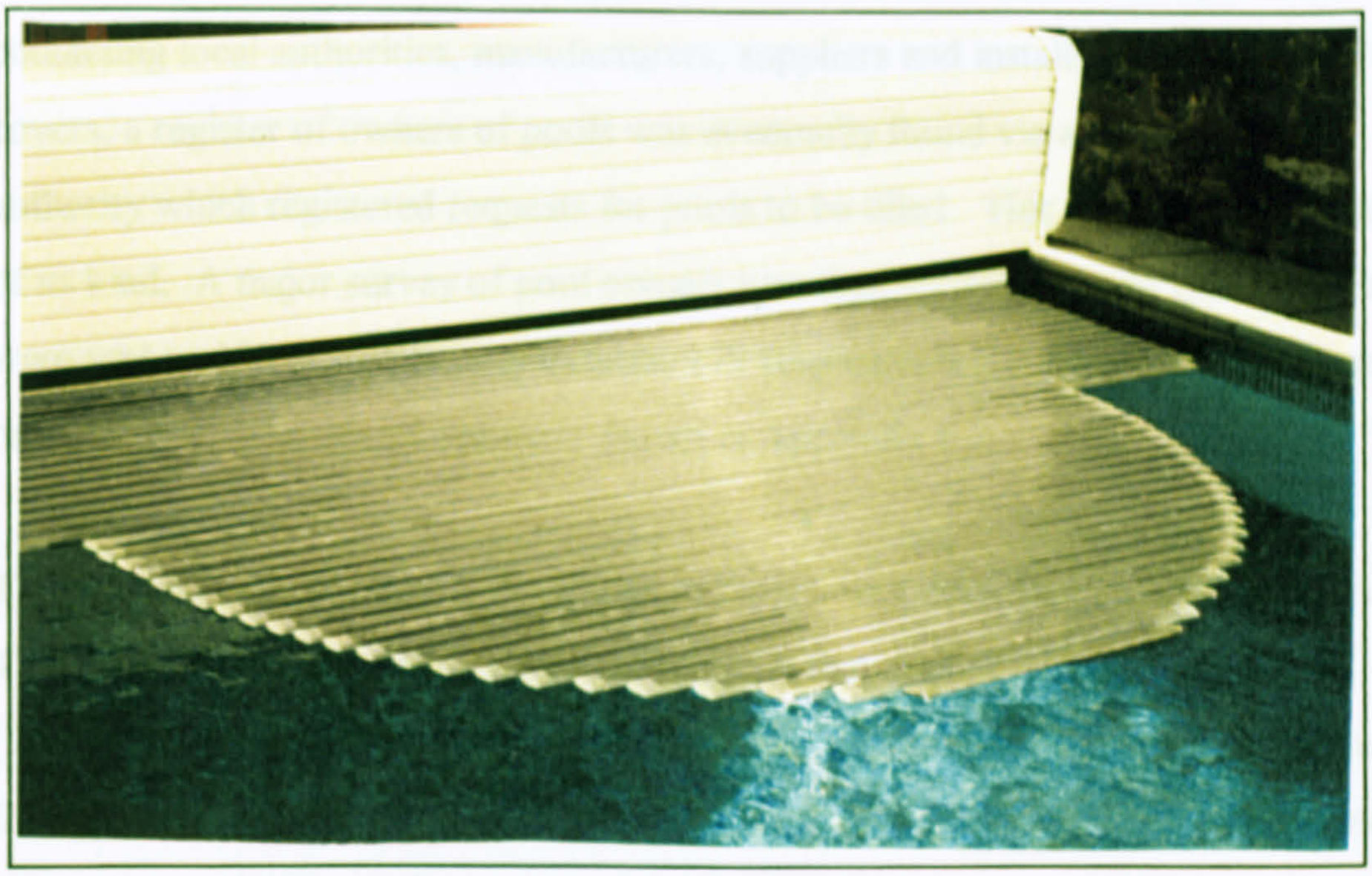


Figure 6.7 - Rigid safety cover

Of particular interest were the test methods used to assess the aperture produced at the edge of a cover. The criteria for access through an aperture for both standards are based on head size and pushing force but use different values:

- a cylinder of diameter 114.3 mm should not pass through a gap at the edge of the cover when pushed with a force of 18 kg (ASTM ES 13-89 - USA)
- a cylinder of 105 mm pushed with a force of 15 kg (AS 2020 - Australia).

These values represent 5th percentile US head breadth at either 10-12 months or 4-6 months respectively (compared to Schneider et al, 1986) and the use of head size as a criterion for denying access was to be reviewed as part of the evaluation.

6.2.3 Pool owner survey

Very little information was available on the numbers or types of domestic swimming pools installed in the UK, as pools do not need to be registered and planning permission is required in only certain situations. It was felt important to establish

information on the types of pools and covers in use to investigate exposure rates, to establish a profile of owners and in particular owners' attitudes to safety. After contacting local authorities, manufacturers, suppliers and installers of pools and covers, a register of owners of pools was eventually found via a regional water authority which registered requests for pools to be filled. This was the only register of its kind. A major survey of pool owners was then undertaken and questionnaires were sent to 450 domestic pool owners; 179 responses were received (a response rate of 40%). The questionnaire is shown in Appendix 6.2.

The full results of the survey are shown in Appendix 6.3 and are summarised here. The survey found that nearly all pool owners in that area of Britain used an SPC (92%) and that bubble covers were by far the commonest (80% of pool owners used this type of cover). Half of the sample used a winter cover and a total of 253 covers were used by the respondents as most used more than one cover. When asked about safety, half of the covers used by the sample were considered to make the pool safer, including even bubble covers. Yet few SPCs are marketed as safety covers. Winter mesh covers in particular were considered to offer safety as a function. In general, pool owners did not consider their pool a hazard: 99% said they thought their pool was safe for members of their household; 95% said it was safe for visitors; and 73% said it was safe for children in the neighbourhood. When asked their opinion on mandatory pool fencing, as has been introduced in some Australian states (Ashby et al, 1998, Pitt and Balanda, 1991), just 30% said they agreed with its introduction.

6.3 Accidents involving SPCs

A number of agencies and organisations were contacted to try to establish the number and details of immersion incidents in the UK involving swimming pool covers.

Table 6.1 shows the total number of deaths by drowning in the UK from 1982 to 1991, the number in swimming pools (according to RoSPA) and those involving

SPCs. The two sources quoted (RoSPA and OPCS) give differing numbers for children under five - this exemplifies the lack of a satisfactory method of recording drowning incidents in the UK - and the statistics can only be considered as a minimal estimation of the total numbers involved. This was suggested also by a study of drownings in Wales (Sibert et al, 1988) which had to use information and data from the Royal Life Saving Society, Chief Constables of Welsh police forces, the Office of Population, Census and Surveys (OPCS), coroners as well as major coastguard stations.

Year	all ages		under fives				
			all drownings		in swimming pools	in domestic swimming pools	domestic pools with a cover on
1981		783		35			
1982		823		39			
1983	657	786	34	34			
1984	535	717	40	38			
1985	599	712	44	42	7	6	4
1986	563	699	28	32	5	3	2
1987	461	677	33	34	4	4	1
1988	571	656	33	34	7	5	2
1989	528		29		7	7	5
1990	496		35		6	6	1
1991	446		33				

Table 6.1 - UK drownings by age and location. *Source: RoSPA (except italics - OPCS)*

Data from RoSPA and OPCS identified fifteen fatal incidents involving SPCs over the period 1985-1990. Using additional information sources (such as HADD and the Child Accident Prevention Trust) the scenarios of a total of 25 immersion incidents involving SPCs were finally constructed (23 drownings and 2 near-drownings). Detailed information on the circumstances of the incidents was difficult to acquire; newspaper reports of accidents are collated by RoSPA but gave often only journalistic information. All accidental deaths are subject to a coroner's inquest and so coroners' reports should be able to provide fuller details of the incidents however reports had to been requested from individual coroners offices and were not made available by all of the offices. The reports varied greatly in the details they documented about the product involvement. In some instances information was only

acquired when victims' families contacted the researcher when they became aware of the study and provided the information needed. Contact was not however sought with families due to moral considerations.

Table 6.2 summarises the details of the known drowning and near drowning incidents involving swimming pool covers between 1982 and 1990 and shows the incompleteness of the information available.

Nearly all of the victims were under five years (23 out of 25) and the modal age of drowning was 2 years old. More than twice as many male children as female children were involved. The commonest accident scenario involved a child crawling under a 'floating' cover (see previous section for descriptions of covers). In the cases where the type of cover involved was known, floating covers were the most frequently cited; nine referred specifically to bubble covers and seven to a floating plastic sheet. One incident occurred with a secured winter cover, one with a secured plastic cover and one other with a "wooden" cover. There were no details of the covers involved in the other six incidents. Of the cases where the location of the pool was known, eight occurred when the victim was visiting a relative's or friend's home, seven involved children drowning in neighbours' pools, three occurred when the children were visiting private pools (a holiday camp and private schools) and only one occurred in a pool at the victim's own residence; six were unknown. All of the incidents occurred in the summer (April to September). In all but two of the cases the victim was found underneath the cover and in sixteen of the cases it was stated that discovery of the victim was delayed because the victim was not visible when the pool was first inspected but was subsequently found concealed underneath the cover. Using the information from the accident investigations and an examination of the products, detailed hazard scenarios were developed for each of the most common types of cover, and are listed in Appendix 6.4.

Date	County	Sex	Age	Cover	Location	Other details
drownings						
1990 July	Nottm	m	2	floating polythene	neighbours	underneath, delay
1990 June	Devon	f	2	bubble	neighbours	underneath, delay
1989 May	Hants	m	1	floating blue plastic	friends	underneath
1989 May	Hants	m	2	floating plastic	neighbours	underneath, cover folded over
1989 Aug	Bucks	m	3	bubble	private school	underneath, delay
1989 June	Hants	m	2	bubble	neighbours	underneath, delay
1989 Sept	Kent	f	1	n/a	n/a	stepped on cover
1988 June	Essex	m	3	bubble	friends	underneath, delay
1988 July	Shrops	m	1	bubble	n/a	underneath, delay
1988 Aug	Beds	f	78	n/a	relatives	underneath
1987 May	Essex	m	73	bubble	relatives	underneath, collapsed and fell in pool
1987 Aug	Kent	m	1	plastic sheet	relatives	underneath, delay
1987 Apr	n/a	m	24	wooden	n/a	cover fell and knocked victim unconscious and trapped in pool
1986 June	Bucks	m	2	bubble	neighbours	underneath, delay
1986 Aug	W.Suss	m	2	bubble	neighbours	underneath, delay
1985 July	W.Suss	m	2	plastic sheet	friends	underneath, delay
1985 Apr	Bucks	f	<5	pegged winter cover	own home	underneath, pegs loosened
1985 May	E.Suss	m	4	secured plastic	private school	fell through gap in cover
1985 June	Gt.Man	m	2	blue plastic	relatives	underneath, delay
1985 June	W.Mid	m	2	n/a	n/a	crawled under cover
1985 Aug	Essex	m	1	n/a	n/a	walked on cover to retrieve toy
1984 June	Devon	f	2	bubble	holiday camp	underneath, delay
1982 July	London	f	2	floating blue plastic	friends	underneath, delay
near-drownings						
1985 May	E.Suss	m	2	n/a	neighbours	got under cover
1985 June	n/a	f	1	n/a	n/a	crawled under sheet

n/a = no information available
underneath = victim found underneath the cover
delay = discovery of the victim was delayed by the cover

Table 6.2 - UK drowning and near drowning incidents involving swimming pool covers

6.4 Evaluation methodology

The diversity of SPC designs and functions resulted in a range of potential accident scenarios, mainly children falling under the edges of floating covers and access by children under the edges of winter covers. A combination of ergonomics, engineering and materials testing methods were therefore necessary to evaluate the safety of the range of SPC designs.

Swimming pools pose an inherent hazard (in the form of open water) regardless of the presence of a cover, and so the methods used in the evaluation were restricted by ethical considerations as the users at risk were children, and they could not be exposed under any circumstances to the potentially hazardous environment in which the products are used. Very young children (the high-risk age of two years old) could not be exposed even to simulations of the product, due to the risk of raising their interest in the product, its mechanisms or the pool environment. Test methods using simulations of both the product, user, task and environment were devised, plus isolated tests of product and material performance. A series of multi-disciplinary test protocols are described together with a series of empirical performance tests on children, as they were used to evaluate each of the main hazard scenarios of each type of cover.

6.5 The supporting strength of floating covers

The majority of incidents investigated in the study had involved a floating cover and the circumstances of the incidents had suggested that floating covers would fail to support anyone venturing onto a cover. Falling under the edge of a floating cover was therefore one of the commonest hazard scenarios. A variety of tests were considered to quantify this risk: tests of material strength (such as burst and tear strengths) and performance tests. Material tests would provide comparative data between materials but strength was not considered a product characteristic likely to indicate safety as the covers were not secured to the pool at any point. An

evaluation of performance would therefore require some tests of the user-product interaction, but these would be limited due to ethical considerations described above.

6.5.1 User trials with adults

A qualitative assessment of the covers' behaviour under the weight of an adult was made in user trials with adults. An adult male weighing 69.4 kg (32nd percentile[1]) walked onto the cover at various points around the edges. Video analysis showed that the cover was pushed down into the water by the subject's weight as he stepped onto it and the subject immediately fell into the pool. The pressure of the surrounding water caused the cover to 'wrap' around the subject's body as it was immersed, constraining his movement. For safety, the subject only allowed the lower half of his body to be immersed so that he could hold the edge of the pool and prevent falling completely under the cover. In the second part of the user trials the ability to climb out from under the cover was evaluated. The subject tried to swim underneath the cover and lift it up to gain air. This was possible near the edge but not towards the middle of the pool.

6.5.2 Simulation tests with children

It was not possible to carry out these tests with children and so some method of simulation was required. Simulation of the product was impossible since water and size were vital to the natural behaviour of the product, so methods to simulate 'the user' and test the products in-situ were investigated.

6.5.2.1 Equipment

The available methods of simulating children in the age range at risk (1 to 5 years) were compared. The following is a summary of the simulation methods considered.

[1] compared to UK data from Pheasant (1996)

i. Crash-test mannequins

There are a number of anthropometric and biomechanically accurate mannequins available, such as those used in vehicle testing. TNO in The Netherlands produce a range of mannequins including new-born, 9 months, 3, 6 and 10 years old. However the sensitivity, electronics and mechanics of these mannequins prohibited their use in or near water.

ii. Retail display mannequins

Retail display mannequins were considered but were anthropometrically unrealistic and available only in limited age ranges.

iii. Diving/resuscitation mannequins

A range of articulated mannequins are produced by Laerdal as training aids for resuscitation and/or diving rescue practice (as 'adult', 'junior' and 'baby'). The 'baby' mannequin was unsuitable for complete immersion in water and so could not be used. The 'junior' mannequin is intended to represent a five year old male child, but it was found that it varied in size from 0.001 to 99.95 percentile values compared to UK anthropometry (as shown in table 6.3) and was too light (its dry body weight was 7.2 kg and a fifth percentile UK five year old male child weighs 15.5 kg[2]). The mannequin had drainage holes so that when immersed it takes on water in order to 'sink realistically' (Laerdal, 1991). Despite these concerns it was decided to use this mannequin as it was the best available that could be exposed to water. It was used both as designed and with the drainage holes sealed so that no water was taken into the mannequin when immersed. This would allow the body mass to be adjusted. The mannequin was used with a mass of 15.2 kg (5th percentile) with and without clothing by securing 0.5 kg weights along its length.

Some other forms of simulation were needed however as these were far from satisfactory and to cover the range of children at risk. Two 'test models' were manufactured, one to compare to the diving mannequin and the other to extend the range of ages simulated. The waterproof models were designed to the dimensions

[2] compared to data from Pheasant (1996)

(height, shoulder breadth and chest depth) of a fifth percentile 12-18 month old child (unspecified sex) and a ninety-fifth percentile five year old male child. These offered the advantage of variable mass, variable weight distribution and durability. The models and mannequin are shown in figure 6.8 and their dimensions in table 6.3. The 'models' were simple waterproof bags filled with 0.5 kg and 1 kg weights and polystyrene chips. The volumes of the models were not representative of a child, but surface area in contact with the cover and the mass of the models were considered adequate and these were considered the critical factors in the simulation of a child falling/stepping onto the cover. In particular the mass of the models was considered the most crucial factor since the body surface area in contact with the cover will vary greatly depending on how the child 'enters' the pool. It was therefore considered that the bags offered an acceptable form of simulation, but the performance of the larger model and the resuscitation mannequin as methods of simulation would be compared as an assessment of the two forms of simulation.

dimensions	UK children		diving mannequin		'test model' dimensions	
	5th %ile 12-18mo.	95th %ile 5yrs male	dimensions	corresponding %ile value	small	large
stature (mm)	690	1195	1100	42.5	690 (length)	1195
weight (kg)	15.2	24.5	7.2		8.5	24.5
volume (litres)	8.2[1]	24.5[1]			9.8	47.8
bideltoid breadth	185	305	330	99.95	150 (width)	250
hip breadth (mm)	140	235	230	91.0		
chest depth	94[2]	160	125	0.5	95 (depth)	160
arm length	305	535	420	1.5		
upper leg length	170	380	260	0.01		
lower leg length	175	370	240	0.001		

Anthropometry according to Pheasant (1996) except:
[1] body volumes calculated assuming body density to be 1kg/litre
[2] according to Snyder (1975)

Table 6.3 - Comparison of anthropometry of UK children and the dimensions of the mannequin and models used to assess the supporting strength of floating covers.

6.5.2.2 Procedure

The models and mannequin were used to simulate a child either falling, stepping or jumping onto the two types of floating cover (bubble and foam), as shown in figure 6.9. Qualitative and quantitative measurements were taken, including whether the mannequin was supported, the time to 'sink' if not, the depth of water collected around the mannequin if it was supported and the general behaviour of the cover and mannequins and models.

6.5.2.3 Results

It was shown that the covers would support a child placed gently onto the edges of the cover at 90° to the pool edge (figure 6.10). However, in all of the simulations - from 5th percentile twelve month old child to 95th percentile five year old male - the covers did not support the mannequins when placed 'feet first' either on the edges of the cover or up to 1 metre in from the edge, simulating a more realistic scenario of a child stepping onto the cover. The mannequins slipped under the edge of the cover and the cover floated back to the surface concealing the mannequin and showing no signs of disturbance. The corners of the covers reacted quickest. When placed 'lying down' parallel the edge of the cover, simulating a child rolling onto the cover, the largest mannequins rolled off the cover but the small mannequin was supported. However water from the pool seeped on top of the cover and collected around the mannequin and the water level was enough to cover the mannequin.

Figure 6.8 - Mannequin and model used to test the supporting strength of floating covers

Figure 6.9 - Testing the edges of floating covers with the test models

It was difficult to systematically simulate dynamic forces on the covers, for instance representing a child jumping onto the cover, and the majority of the tests were static. However the static tests carried out (in which the test pieces were lowered onto the cover) represent the lowest risk situations and thus this was a test of a minimum safety criterion. The two methods of simulation provided comparable results although a need was highlighted for a range of robust and adaptable child mannequins.

6.6 Access to the pool under the edge of winter covers

The next commonest hazard scenario was children gaining access under the edges of winter (secured) covers. Again ethical restrictions governed the way in which access was evaluated. User trials could not be used, as children could not be used to test access with the SPCs in place over pools. Simulation was used, this time the user was simulated to measure the size of apertures that could be gained at the cover edges, and the product and environment were simulated to assess children's' performance with the covers, and the results compared.

6.6.1 Size of aperture measured on covers in the field

Firstly the size of the aperture that could be made at the edge of covers in-situ was measured in field trials. Aperture size is the design parameter used to assess safety in the US and Australian standards (see 6.2.2 above), and head size and pushing force are used as test criteria. The use of these criteria were to be validated by this evaluation.

6.6.1.1 Equipment and procedure

Two novel methods were developed to measure aperture size, simulating different behaviours: i) a pulley and spring balance system (figure 6.11) lifted the edge of the cover midway between adjacent securing pegs, simulating a child of standing age lifting the edge to crawl under the cover, and the incremental lifting force and the

Figure 6.10 - Mannequin supported on a floating cover at 90° to the pool edge

Figure 6.11 - Testing the apertures at the edges of winter mesh covers with the lifting rig

height of the cover's edge from the ground was recorded; ii) a graduated cone was pushed with an incremental horizontal force under the edge of the cover (figure 6.12), simulating a child forcing its way through head first, and the aperture diameter and pushing force were recorded using a reverse spring balance. Field trials were conducted and measurements made at five similar covers on pools around Nottingham.

6.6.1.2 Results

Both of the methods developed for this test indicated that aperture size and therefore the safety of winter mesh covers depended on how the covers were installed, as the size of apertures at the edges varied greatly both between and within covers. Measurements were made at up to twenty points around five similar covers, and results showed that with a vertical lifting force of 5 kg the mean minimum height any cover edge could be lifted was 207.5 mm (range 125 and 370 mm) and the mean maximum height was 264 mm (range 145-370 mm). When lifted with a force of 20 kg the minimum height any cover was lifted was 490 mm. Using the 'cone test', the maximum diameter of the cone (200 mm) passed under the edges of all the covers, using a minimum horizontal pushing force ranging between 2 to 8 kg. Comparison of results showed that both of the methods developed for this test were satisfactory although the 'cone test' was simpler and more portable. Comparison to Standards criteria showed that all of the covers tested would have failed the US and Australian standards for safety covers.

6.6.2 Size of aperture children can crawl through - user performance tests

In order to assess whether or not children would have been able to gain access under the covers measured in the field, and to validate the use of head size as an access criterion, the minimum aperture under the edge of a cover through which a child could crawl was measured in laboratory user trials. Ethical restriction meant that the cover edge and pool surround had to be simulated in the safety of a laboratory

setting, and the resemblance of the test equipment to a swimming pool or cover was controlled to reduce learning effects and avoid raising any interest in the products.

6.6.2.1 Equipment

The edges of the covers were simulated by clamping samples of cover material was to a board at two points 1520 mm apart, which is the largest spacing between securing pegs on winter mesh covers. The amount of cover material between the clamps could be varied in order to vary the size of the aperture gained by lifting the edge. The aperture size was calibrated using the two methods described in 6.6.1 above.

6.6.2.2 Subjects and procedure

Twenty four subjects aged from 20 months to 7 years took part in the user trials and their details are described in Appendix 6.5. Subjects were encouraged to repeatedly pass under the edge of the cover as shown in figure 6.13. The trials started with a large aperture and each time the amount of material between the clamps was decreased until the smallest aperture through which they could or would pass was found. The trials were repeated on materials used to make winter mesh covers and safety covers. The method of limits was rejected as an experimental procedure after pilot trials showed that the younger children were unwilling to attempt to pass through very small apertures because of a fear of becoming stuck, and if trials started in this way children would not carry on with the tests. Qualitative and quantitative measurements of the subjects' behaviour were recorded: the willingness of subjects to pass through such an aperture, their method of doing so as well as the minimum aperture size.

6.6.2.2 Results

All but three of the twenty five subjects performed this test: three refused to pass through the aperture and could not be coaxed but most of the children were attracted to the test. The results are shown in table 6.4. All but one of the subjects went

Figure 6.12 - Testing the apertures at the edges of winter mesh covers with the cone test

Figure 6.13 - Measuring the size of aperture through which children can pass

through the aperture head first. Aperture size was negatively related to age (and therefore body size); the smallest apertures passed through were by the two eldest subjects. From video analysis the size of aperture through which a child can crawl appeared to be related to the child's willingness to squeeze themselves through a tight gap, and the development of certain motorskills such as the ability to hold up the edge of the cover whilst crawling underneath it. The smallest aperture through which a subject passed was 190 mm diameter, measured by lifting the edge of the cover with a vertical force of 18 kg, and this was by the eldest subject (aged seven). The mean smallest aperture passed through by the under fives was 218 mm (standard deviation 16.7 mm). Comparison of user trials results with the field measurements showed that all of those subjects tested would have been able to crawl under the edges of the covers tested.

sex	age (mo/yr)	head breadth	child's method				smallest aperture (mm)	
			head first	feet first	supine	prone	unaided	cover held up
f	20/1	134	✓			✓	-	255
f	30/2	154	✓			✓	-	290
f	32/2	135	✓			✓	225	
f	36/3	144	refused					
f	36/3	148	✓		✓		213	
f	37/3	130	✓			✓	-	225
f	37/3	131	✓			✓	187	
f	37/3	142	✓			✓	290	
f	41/3	143	✓			✓	225	
f	44/3	145	✓			✓	213	
f	45/3	144	✓			✓	242	
f	46/3	138	✓			✓	-	213
m	44/3	147	✓			✓	213	
m	45/3	138	✓			✓	213	
m	46/3	141	✓			✓	213	
f	48/4	142	✓			✓	242	
m	48/4	142	✓			✓	242	
m	48/4	147	✓			✓	267	
m	51/4	155	✓			✓	213	
f	54/4	147	✓			✓	225	
f	56/4	149		✓		✓	255	
f	59/4	155	refused					
m	61/5	142	✓			✓	187	
m	87/7	153	✓			✓	205	

Table 6.4 - Size of aperture children passed through and the method they used

6.7 Access to the pool by removing or loosening winter covers

Certain features of the winter covers were identified which, if they had been designed according to ergonomics criteria could have made access underneath the edges of winter covers difficult, namely the mechanisms used to secure the covers around the pools. The 'child resistive' nature of these securing mechanisms were therefore evaluated.

The first method used to evaluate the securing methods was to compare the designs to ergonomics data and guidelines. It was suggested in Chapter 4 of this thesis and elsewhere (eg Norris and Wilson, 1988; Wilson and Norris, 1992) that there is a paucity of applicable, product-related performance data on children. A search of the data gathered in the production of Childata (see Chapter 4) and specifically related to the products and systems under evaluation supported this, and no data were found which could be related directly to these product features or used to assess children's likely ability to operate them. User trials were therefore required to produce these product-related data and to assess children's performance directly with the securing mechanisms. Again, due to ethical considerations, simulations of the products and product features were employed, using varying degrees of realism. The user trials were conducted in the laboratory using the subjects described in section 6.6.2.2. Data were collected on children's vertical pulling strength, ability to remove the pegs, ability to undo the buckles and ability to move the waterbags.

6.7.1 Vertical pull strength

Children's likely ability to remove the securing pegs used in winter mesh covers was evaluated by measuring vertical pulling strength, as there were no data published on pulling strength at ground level. Strength was measured by pulling on a real peg but in a disguised setting - at ground level but isolated from any SPC features (figure 6.14). Subjects were told to 'pull as hard as you can' on the peg. Verbal feedback was given from the experimenter to encourage maximal exertion. The indicator of

the spring balance was visible to subjects and older subjects were encouraged to use this to judge their efforts. Pilot tests with younger children showed they were unable to relate the indicator to their efforts. Three maximum efforts were recorded. The subjects were given no instructions on how to pull the peg and no restrictions were placed on the subject's posture or whether they used one or two hands. This was to ensure realism in the task and also to give information on how children carried out the task. Video recording was used to record the results.

6.7.2 Ability to remove a securing peg

Ability to remove the securing pegs was not dependent on strength alone; if correctly installed, a spring attached to the peg caused the peg to twist such that the peg was easier to remove if pulled at an angle away from the cover rather than straight up. A realistic simulation of the securing pegs was necessary in order to assess whether children could learn this technique (figure 6.15). It could be removed from a paving slab when pulled with a 12 kg vertical force or a 2 kg force at 135 degrees. Subject behaviour was recorded with video.

6.7.3 Ability to undo a buckle

A buckle used to tighten winter mesh covers was disguised and the subject's time and ability to undo the buckle were recorded (figure 6.16).

6.7.4 Ability to move waterbags

The ability of children to move the waterbags used to secure PVC winter covers and gain access to a pool was assessed (figure 6.17). Two common sizes of waterbags (900 x 300 mm and 1500 x 300 mm, weighing 8.5 kg and 22.5 kg respectively) were

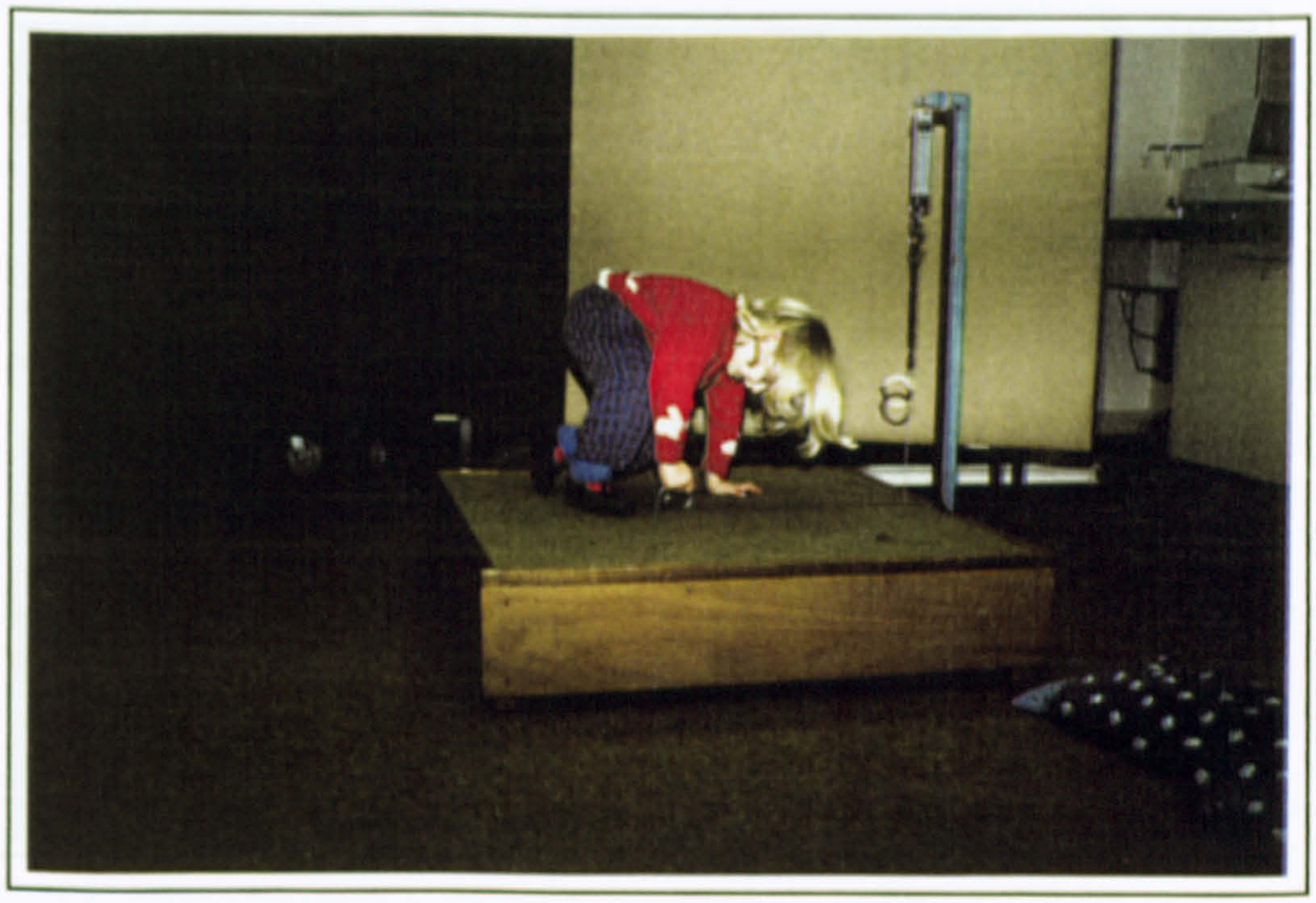


Figure 6.14 - Measuring the pulling strength of children on the securing pegs of winter mesh covers

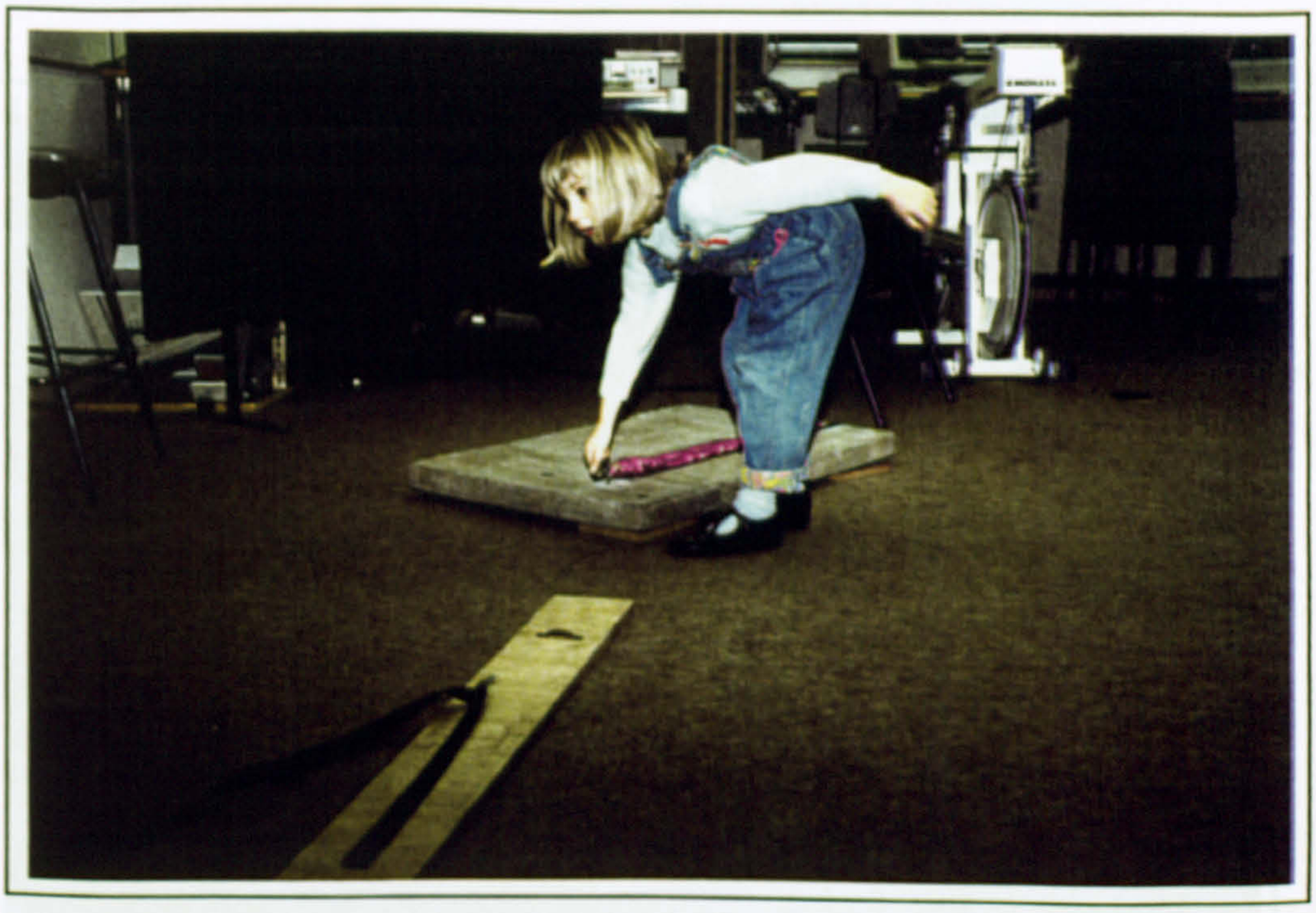


Figure 6.15 - Assessing children's technique used to remove the securing pegs on winter mesh covers

Figure 6.16 - Assessing the ability of children to undo the securing buckles on winter mesh covers

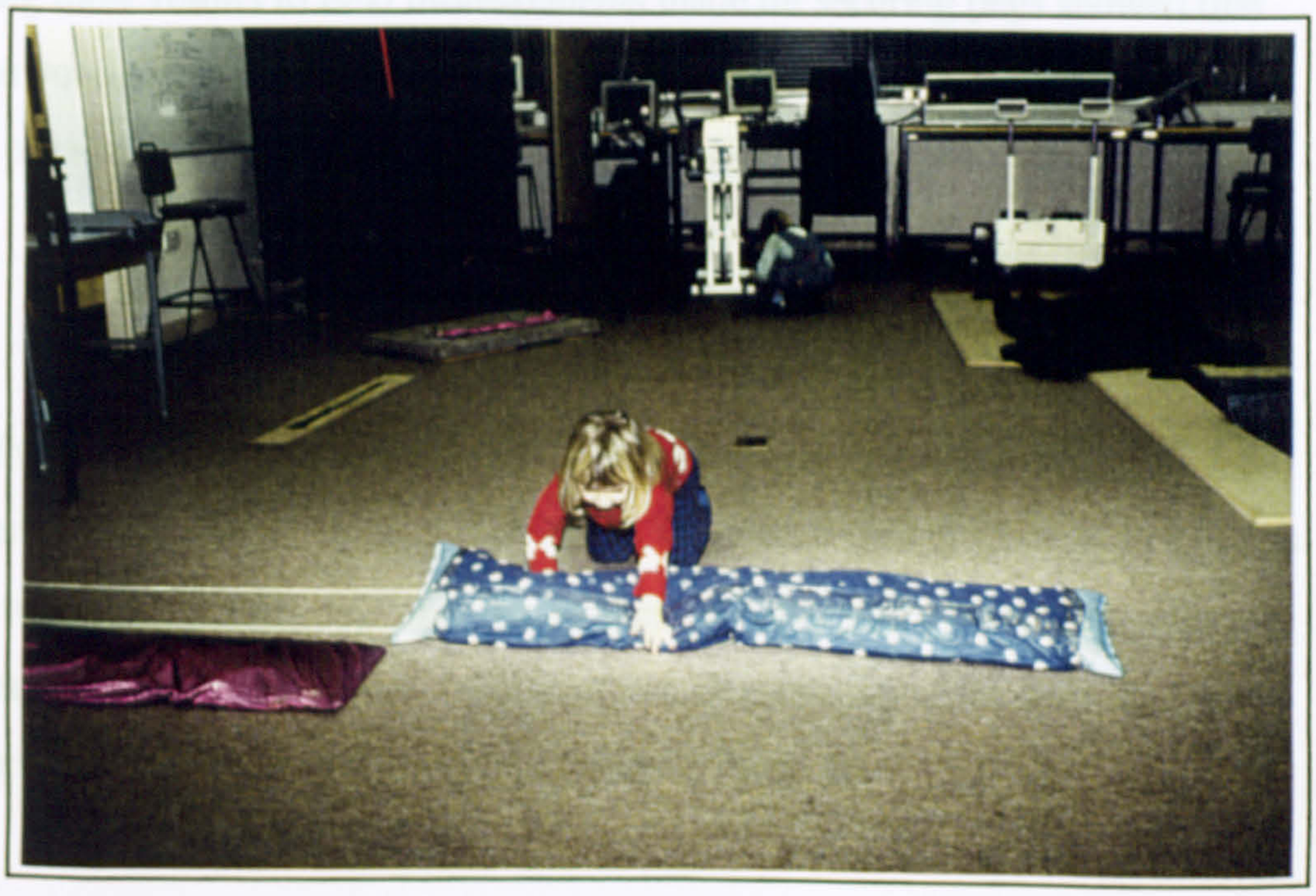


Figure 6.17 - Measuring the distance children can move 'water-bags'

disguised. The subjects were asked to move the bags across a distance of 200 mm and their ability and method used were recorded.

6.7.5 Results

The battery of tests were presented to the child subjects as a series of games and no reference was made to swimming pools or covers. The majority of the subjects were easily motivated to carry out the tests and only one subject (aged two years) refused to carry out any of the tasks. A summary of the results is as follows:

6.7.5.1 Vertical pulling force

The mean of the mean vertical pulling forces recorded in the under fives was 5.5 kg, with a standard deviation of 2.9 kg, and the range of maximum pulling forces was 1-13 kg. The tests themselves and the variability of the results demonstrated the difficulty of collecting reliable strength data from children under five years of age. The maximum pulling force in the whole group was 29 kg (age seven years). Comparing these results to field measurements made on securing pegs showed that all but the youngest subject (aged 20 months) would have been able to remove some securing pegs at all of the sites tested.

6.7.5.2 Ability to remove the securing peg

Twenty four subjects attempted this task and fourteen subjects, aged from 2 to 7 years, were able to remove the peg (table 6.5). A vertical pulling force of 12 kg, was required to remove the peg and only five of these subjects had a maximum pulling force greater than or equal to this, indicating that the majority of the subjects had been able to acquire the technique need to remove the pegs.

sex	age (yrs)	no of subjects	no of subjects able to remove the peg			mean time (secs)
			completely	partially	not at all	
f	1.5 - 2	1	0	0	1	40
f	2.5 - 3	2	1	0	1	23
f	3 - 3.5	6	1	1	4	41
f	3 - 3.5	3	3	0	0	13.6
m	3.5 - 4	3	2	0	1	20.5
f	4 - 4.5	1	0	1	0	76
m	4 - 4.5	3	2	0	1	25.5
f	4.5 - 5	3	1	0	2	7
m	5 - 5.5	1	1	0	0	27
m	7 - 7.5	1	1	0	0	19
total		24	12	2	10	

Table 6.5 - Ability and time to remove the winter cover securing peg

6.7.5.3 Ability to undo the buckle

Twenty three subjects attempted to undo the buckle and fourteen subjects (aged 3 to 7 years) undid it completely while a further two loosened the buckle a minimum of 3 mm. None of the subjects under three years of age were able to undo the buckle.

6.7.5.4 Moving the waterbags

All twenty four subjects who attempted to move the small bag (weight 8.5 kg) were successful and only one failed to move it the full 200 mm. Twenty subjects attempted to move the large bag (weight 22.5 kg) and eighteen (aged 18 months to 7 years) were successful. It was too heavy for most of the children to lift yet the majority simply rolled the bag effortlessly past the line. This demonstrated that these bags were unlikely to successfully seal the pool to children as young as eighteen months.

6.8 Product performance tests

In addition to the ergonomics evaluation methods described above, the evaluation of safety of the range of covers also included product performance tests: these were

tests of engineering and materials aspects of the products' performance related to safety. These tests were extensive and space does not allow their full documentation here. A summary of the tests is as follows:

6.8.1 Floating bubble covers

- The concealment of anyone falling underneath a floating cover was highlighted as a contributory factor in many of the fatal incidents involving SPCs. Immediate discovery of a small child is important as there is a suggestion that they can survive longer immersion than adults, particularly in cold water (Kemp and Sibert 1991). Possible improvements in the visibility through these covers was therefore investigated. The effect of transparency on visibility through covers was assessed using a specially manufactured half blue and half colourless cover and judging the visibility of the mannequin through the cover. Detection was much easier through the colourless cover when the mannequin was floating on the surface of the water (figure 6.18) but little improvement in detection was found if the mannequin was at the bottom of the pool, at a depth of around 1500 mm (figure 6.19).
- The effects of weathering on transparency and visibility were assessed by simulating six months of weathering (8 hours sunlight per day at 50°C). Little change in visibility was noted but the cover had become weaker.

6.8.2 Winter mesh covers

- The burst strength of the material used to make winter covers was measured to assess the likelihood of the cover failing if someone walked across it. It was tested as per BS 3424: Testing of coated fabrics.
- The tear strength of the material was measured using a tensile testing machine to assess the spreading of faults (as per BS 4443).
- The force required to remove securing pegs was measured (figure 6.20) and compared to children's pulling strength to assess if they could remove the pegs.

Figure 6.18 - Visibility of a mannequin through a coloured/colourless floating cover (mannequin on the surface of the water)

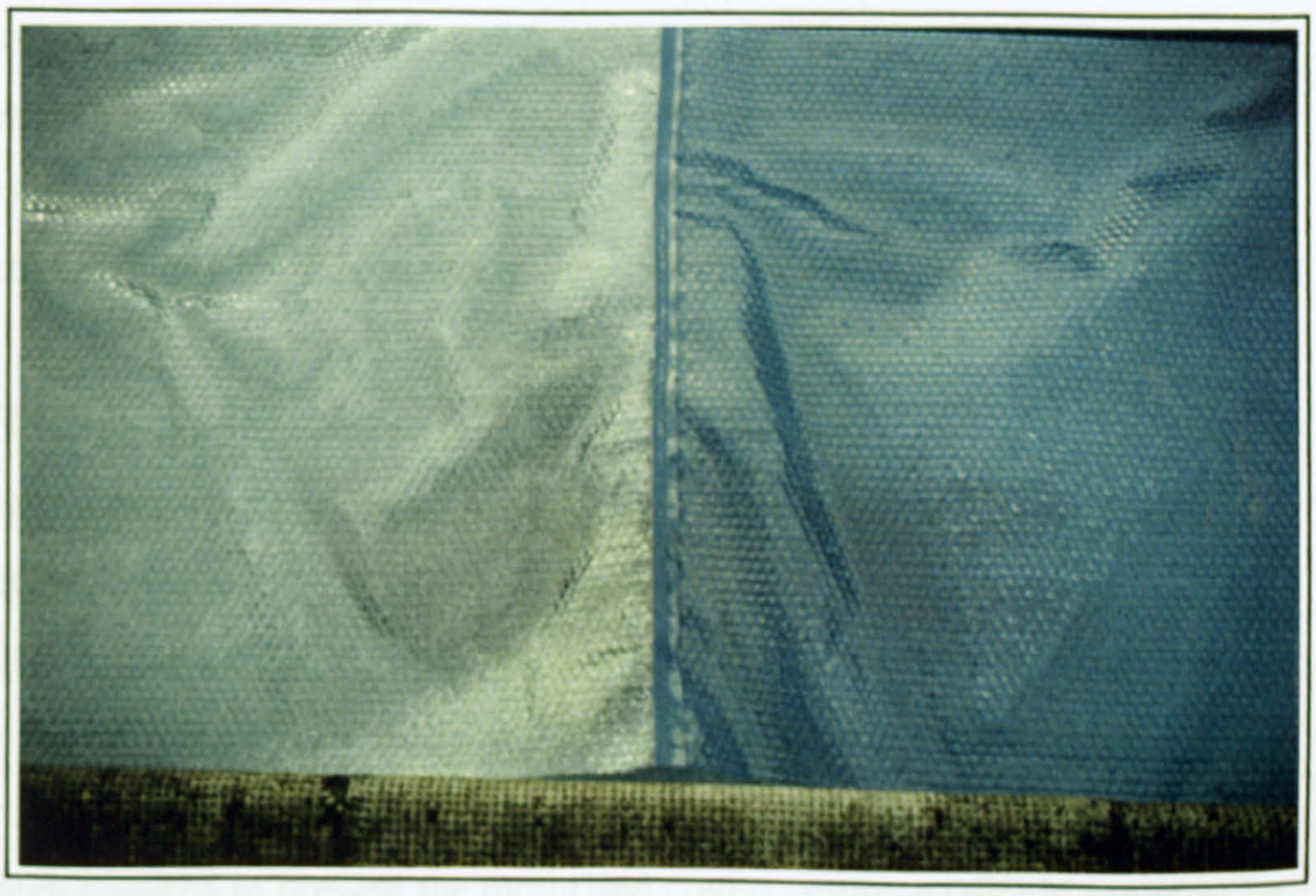


Figure 6.19 - Visibility of a mannequin through a coloured/colourless floating cover (mannequin at a depth of 1500 mm)

Figure 6.20 - Measuring the force to remove the securing pegs on winter mesh covers

6.8.3 Waterbag covers

- The ability of the material to resist snagging was measured to assess material strength.
- The weight supported on the cover before the cover collapsed into the pool was assessed using the mannequin, models and human subjects.
- The stability of the water bags was assessed by measuring the horizontal pulling force needed to move the bags from around the edges of the cover and to identify the optimum filling level for stability.

6.8.4 Flexible safety covers

- The burst strength, tear strength and resistance to snagging of the material were measured to assess strength of the covers.
- The force to pull the edges of the cover from the tracking was measured using a tensile testing machine assess the likelihood of the cover coming loose if someone walked across it.
- The force required to prevent the motorised covers stopping (should someone be in the pool as the cover closes) was measured using a reverse spring balance.

- The depth of water collected around a mannequin placed on top of the cover was measured to assess the risk of drowning in collected water.

6.8.5 Safety rigid covers

- The depth of water collected around a mannequin was measured to assess the risk of drowning in collected water.
- The force required to lift the edges of the cover was measured to assess access under the edges.

6.9 Discussion and conclusions

The process of accident analysis and product definition helped identify specific SPC hazard scenarios for evaluation. A mixture of product and user performance tests were then necessary to produce important design criteria.

The results of the study showed, through simulation, that floating covers would not support a 12 month old child stepping onto the edge. Considering that they are implicated in most accidents but offer little scope for human factors improvements bubble covers were highlighted as a priority area for regulatory activity.

The evaluation of secured winter mesh covers produced design data on the minimum vertical pulling force on the pegs which should be used to prevent removal, but it was shown that strength was not the critical design criterion; realistic simulation of the actual task showed that technique and performance at this task to be as important as strength. This simulation, together with the user evaluation of water bags and buckles, showed that the securing systems on winter covers are unsatisfactory to deny access to the pool by children, which is of concern as these covers are perceived by owners as a method of sealing pools and making them safe.

The use of head size and pushing force as criteria for assessing aperture size at the edges of secured covers in US and Australian standards was validated. However,

user trials showed that up to the age of five the ability to pass through flexible apertures depends not only on head size and strength but on motor abilities and motivation as well. Measurement methods were developed to measure aperture size at the edge of covers and by comparing field data and human performance data from the laboratory simulation tests it was possible to demonstrate that all children tested would have been able to crawl under the edges of all the covers tested. All of the covers would have failed the US/Australian standards and the amount of access at the edge of covers was shown to be too dependent on careful installation by the owners.

As a result of the study a formal report was made to the DTI CSU and this was used by them to guide policy decisions on whether action was needed by government, standards bodies or the industry. The recommendations in the report highlighted the above issues for improvements in SPC and pool safety. Labelling and information to owners were also highlighted as areas where possible improvements could be made. Few covers had warning labels and the labels used did not give explicit warnings. In the absence of product re-design, instructions to owners of winter covers should at least state the importance of careful installation to make access under the edge of the covers more difficult. However, the survey of pool owners illustrated that domestic pools are perceived as safe by their owners and that SPCs are mistakenly seen as making pools safer. The study has shown that generally SPCs have not been designed to improve safety and may even be adding to the intrinsic hazards of domestic pools. Despite this, a safety leaflet given to all new pool owners produced by SPATA (the Swimming Pool and Allied Trades Association), and endorsed by RoSPA, advises owners to fit a winter/debris cover as a way of sealing the pool and making it safe (SPATA, 1992). Given that bubble covers, the most frequently used covers in the UK, offer few options for re-design, an improvement in swimming pool safety is unlikely to be achieved through attention to swimming pool covers alone and other measures such as mandatory pool fencing, which have been proven to reduce drowning rates in Australia, New Zealand and the US (Kemp and Sibert, 1992; Pitt and Balanda, 1991; Nixon et al, 1979; Pearn and Nixon, 1977) should be

pursued, although owners' opposition to these measures need to be considered (as shown by this study and Wintemute and Wright, 1990).

A mixture of novel product performance and user performance tests and methods of simulation were developed to evaluate the safety of this range of products. Although piecemeal, the diversity of products and hazards that fall under the umbrella of 'swimming pool covers' meant that this mixture of test methods was needed, and were successful in producing the user performance data needed to set necessary design criteria.

DTI investigate potential hazards associated with carbonated drinks bottles.

Tops of the Pop

A woman is rushed to a hospital A&E Unit. She has been hit in the eye by a missiling bottle cap while trying to open a soft drink. Fortunately no permanent damage is done, but she still needs to attend a specialist eye hospital for treatment. Although such accidents are rare, they do happen.

Concerned about accidents of this kind and particularly the potential for serious injury, DTI commissioned Nottingham University to research the phenomenon of caps flying off PET plastic bottles. The aim of the study was to establish the extent of the risk from carbonated drinks bottles and to identify the specific conditions under which missiling occurs.

The study found that missiling was highly unlikely to happen under normal conditions. However, an analysis of accidents suggested that consumers resorted to using inappropriate tools, such as nutcrackers or door frames, with bottles they had difficulty in opening.

This was confirmed in consumer trials, which also showed that consumers using tools tended to turn the cap in the wrong direction. The research showed that the use of inappropriate tools, together with failure to keep bottles cool, greatly increases the risks of caps missiling.

The advice to consumers is never use inappropriate tools to open bottle caps. Bottles should be kept cool and care taken not to agitate the contents. Never open a bottle with the cap facing you.

The industry has responded positively to the problem by providing clearer opening instructions on bottles, reducing the torque with which caps are applied by at least 5%. It has also introduced a code of practice for tests on plastic closures to be undertaken by closure suppliers and bottle fillers.

A copy of the research report "Potential Hazards from Carbonated Drinks Bottles" can be obtained from the address on page 6.

- 'Safety Net', Department of Trade and Industry, London, Summer 1997

Chapter 7 - Case study: Investigating a potential hazard of carbonated drinks bottles

7.1 Introduction and aims

Around five million carbonated drinks bottles are sold every day in the UK (BSDA, 1993) and drinks bottles are an everyday item in many households. With such high exposure of the public to these products, and particularly children, they should offer a high level of safety. Concern was raised however over a potential hazard of carbonated drinks bottles, the propulsion of caps at high speeds from bottles during opening, a phenomenon which had become known as 'missiling'. Although only a very small number of incidents had been reported, particularly in comparison to the rate of exposure of the products, the injuries were of a serious nature and a number of people had suffered facial or ocular injuries through this previously unheard of hazard. Prior to this study some research had been conducted into the possible causes of this hazard but it had not been possible to recreate the phenomenon consistently under controlled conditions, suggesting that the risk of the hazard could not be assessed (BRDC, 1993). This study was commissioned by the Consumer Safety Unit of the Department of Trade and Industry to establish whether or not this phenomenon could be recreated. The objectives of the study were to:

- identify technical factors likely to contribute to cap missiling
- identify any behavioural factors likely to contribute to cap missiling
- assess the likelihood of missiling and thereby specify the risk of injury.

The nature of the hazard and its likely dependence on both technical factors and user behaviour required a multi-disciplinary approach and this was achieved by a mix of ergonomics and engineering tests.

7.2 Definition of the product

Over the ten years prior to the study there had been a switch in the UK from glass to plastic bottles (Poly[ethylene] Terephthalate or PET) for carbonated drinks. At the time of the study 1.5 litre was the commonest size bottle and a standard bottle shape, neck and thread design for 1.5 litre bottles had been adopted across the industry (Appendix 7.1). This neck and thread design was also standardised across all size bottles. The standard bottle thread has four vertical slots which line up with similar slots on the cap during opening to allow 'venting', a gradual release of carbon dioxide from the bottle as the cap is unscrewed. This system of venting had been introduced to prevent another phenomenon known as 'tailing', in which caps could fly off while being unscrewed as they reached the (tail) end of the threads on the bottle (Willhoft, 1986). This differed from 'missiling' in which caps were apparently propelled from the bottles at the start of opening before venting could take place, therefore with the full pressure and energy of the contents of the bottle. Pressure and energy is created inside a carbonated drinks bottle when carbon dioxide which is dissolved in a liquid state within the beverage is released into the headspace at the top of the bottle. This internal pressure provides a potential energy that could, theoretically, propel a closure from a bottle (Willhoft, 1992; Bowles, 1976).

7.3 Accidents involving missiling caps

The hazard scenarios of missiling caps were difficult to establish due to a lack of detailed accident reports. An examination of accidents associated with carbonated drinks bottles recorded by HASS showed that the majority of injuries appeared to be caused by exploding glass bottles (HASS, 1993; Dunn et al 1990), which were

caused by exploding glass bottles (HASS, 1993; Dunn et al 1990), which were outside the remit of the study. In the four years prior to the study there were 4,540 accidents associated with bottles recorded by HASS, of which 79 appeared to be related to 'explosions' and only five of those appeared to involve missiling closures. The details of these incidents were sparse. In addition to the HASS cases there were a few high profile incidents which had received media attention (eg Today, 1993; Watchdog, 1993). In at least two cases, and where details were known, the use of a tool to open a bottle was implicated, either a dedicated tool designed specifically for opening bottles (Today, 1993) or improvised tools such as a nutcracker (Willhoft, 1992) (see figure 7.6 later). However few other details were known and there were suggestions by some that the use of mechanical aids would not increase the risk of missiling (Wilson and Breeze, 1990; BDRC, 1993). The use of tools suggested that users were experiencing difficulty opening bottles and that this was likely to be a factor in the safety of the product. This scenario became the focus of the study and a number of issues surrounding the use of tools were to be evaluated:

- the contribution of the use of tools to missiling
- the likelihood of tools being used
- the contribution of other environmental or behavioural factors to missiling.

7.4 Evaluation methodology

The study consisted of two main stages of work, a technical evaluation which aimed to identify the product, task or environment factors leading to cap missiling and an ergonomics evaluation intended to investigate the normal use of bottles and to assess the likelihood of those factors arising.

7.5 Technical evaluation

The first objective in the technical evaluation was to establish whether or not internal pressure in a bottle cause a cap to missile, without any influence of user behaviour or

external factors. This involved trying to produce missiling by incrementally increasing pressure only and comparing this to the pressures actually found in bottles. A number of factors had been suggested as likely to increase the internal pressure of carbonated drinks bottles, namely increased headspace (the space at the top of the bottle), agitation and increased temperature (Willhoft, 1992), and these would subsequently be manipulated to assess their effects on the precipitation of missiling. The influence of bottle/closure design and behavioural factors (i.e. opening behaviour) would also be investigated. The technical evaluation therefore consisted of the following tests:

- measurement of the internal pressure required to 'missile' closures, including a comparison of the security of different closure designs
- measurement of the internal pressure found in bottles, including the effect of headspace, bottle size, product type, temperature and agitation
- assessment of the effects of opening behaviour and closure design on the likelihood of missiling
- measurement of the missiling velocity of closures.

7.5.1 Measurement of internal pressure required to cause missiling

Research carried out elsewhere prior to this study had suggested that under 'normal' conditions closures were secure and that missiling was difficult to reproduce under laboratory conditions. In order to verify this, closures were subjected to increasing levels of internal pressure.

7.5.1.1 Equipment

Although there was a standard bottle thread across all bottles, a number of different cap designs were available and three types of cap were tested. Within these, prototype variations of two of the caps - with a hinge connecting the tamper evident band to the cap - were tested to assess any effects of hinges on missiling. The hinged caps were provided by the manufacturers and were applied to the bottles to a torque of 2.034 Nm (18 inch pounds), the torque to which closures are applied by industry.

A test rig was designed and manufactured to hold the neck sections of 1.5 litre PET bottles, cut approximately 25 mm below the support ring (figure 7.1).

7.5.1.2 Procedure

The rig held the necks of the bottles in a sealed system and hydraulic pressure was administered incrementally to the neck and closure until the closure failed. Failure was classified as either:

- *leakage* - any increase in applied pressure was released through the cap threads without any change in the status of the cap
- *missiling* - the cap was propelled from the bottle in one piece
- *exploding* - the cap shattered and was propelled from the bottle in more than one piece.

7.5.1.3 Results

Twelve closures were tested in their 'off-the-shelf' state. Seven of these closures leaked pressure and five missiled or exploded. However the lowest internal pressure at which a closure missiled or exploded was 400 psi, which according to knowledge in this area was a pressure highly unlikely to be encountered inside a carbonated drinks bottle (see table 7.2 later).

7.5.2 Measurement of internal pressure in unopened bottles

Given this target figure of 400 psi needed to cause missiling, measurements were made of the internal pressure in a range of bottles under different conditions, to investigate the influence on internal pressure of bottle size, headspace and the environmental factors of temperature and agitation.

Figure 7.1 - Rig designed and manufactured to test the pressures at which bottle closures fail (holds the neck sections of 1.5 litre PET bottles)

Figure 7.2 - System to measure the pressure inside carbonated drinks bottles

7.5.2.1 Equipment and procedure

Internal pressure was measured using a sealed hypodermic needle inserted through the caps of unopened bottles (figure 7.2). The vacuity of each bottle (the volume of the headspace as a percentage of the volume of the bottle) was recorded. A sample of 111 bottles ranging from 0.25 litres to 3 litres and containing 25 different drinks products were tested: 62 in their normal 'off-the-shelf' state and 49 that had been exposed to a variety of conditions. These were:

- *temperature* - bottles were placed in a kiln with an ambient temperature of 70°C for up to 3 hours in order to raise liquid temperature (the temperatures quoted below and in table 7.1 refer to liquid temperatures)
- *agitation* - bottles were shaken vigorously by hand for between 30 seconds and two minutes immediately prior to measuring the internal pressure
- *temperature and agitation* - bottles were heated and then agitated as above.

7.5.2.2 Results

Table 7.1 shows the results of the internal pressure measurements. Internal pressure in 'off-the-shelf' bottles ranged between 26 and 57 psi (mean 44.7 psi); bottle size, product type and vacuity appeared to have little effect on internal pressure at ambient temperature. Agitation increased internal pressure slightly with mean recorded internal pressure in 2 litre bottles rising from 46.4 to 48.3 psi. Increased liquid temperatures caused more notable increases in internal pressure with a maximum internal pressure of 69 psi in a 2 litre bottle with liquid temperatures raised to between 40 - 59°C. However the combination of increased temperature and agitation caused the greatest increase in internal pressure, and the mean internal pressure in 2 litre bottles rose to 86.2 psi (standard deviation 15.6) as a result of heating and agitation. The maximum internal pressure recorded in the study was 118 psi, in a 2

litre bottle agitated with a liquid temperature of 59°C. None of the bottles reached the internal pressure of 400 psi required to cause missiling or explosion of caps as indicated by the first stage of the technical evaluation suggesting that missiling was unlikely to occur due to environmental factors only.

Conditions	Bottle Size (litres)	n	mean	sd	min	max
Off-the-shelf	0.25	8	38.1	1.5	37	41
	1	8	42.4	5.7	34	51
	1.5	8	45.2	9.4	35	57
	2	30	46.4	6.5	26	56
	3	8	46.4	1.8	44	49
Agitation (at room temperature)	2	10	48.3	6.4	35	56
Increased temperature [1] (20-39°C)	2	10	55.2	6.7	46	66
(40-59°C)	2	10	58.4	7.5	46	69
Agitation & temperature [1] (40-59°C)	2	10	86.2	15.6	69	118

* liquid temperatures

Table 7.1 - Internal pressure (psi) in PET bottles according to bottle size, increased temperature and agitation

7.5.3 Effect of opening behaviour and closure design on the likelihood of missiling

Given these results it was decided to investigate the possible role of opening behaviour and closure design in the risk of missiling. In particular, the use of tools to open caps was of interest as accident scenarios had already implicated their contribution to missiling.

7.5.3.1 Equipment and procedure

The first stage of the evaluation was therefore repeated using closures that had been subjected to a number of possible use scenarios:

• *loosening*	eighteen closures were opened (turned anticlockwise) through thirty degrees
• *over-tightening by hand*	twenty closures were over-tightened (turned clockwise) to a torque of approximately 3.39 Nm (30 inch-pounds)
• *over-tightening with tools*	sixteen closures were over-tightened using either a dedicated bottle opening tool or nutcrackers, to a torque of 3.39 Nm and leaving visible damage to the outside of the closures
• *temperature*	twelve bottle necks and closures were heated in water between 35 and 50°C for 10 minutes
• *temperature plus over-tightening with tools*	thirty one closures were heated and then subjected to over-tightening with tools as described above

7.5.3.2 Results

Table 7.2 shows the pressures at which caps failed under each of the above conditions, and when 'off-the-shelf'. Loosening the closures meant that even higher pressures were required to cause failure, and most of the caps leaked rather than missiling or exploding. Over-tightening closures with the hand meant that closures were more likely to missile/explode than to leak and this occurred at a minimum pressure of 325 psi. This is still an unlikely pressure to be reached inside a bottle. An increase in temperature reduced the minimum pressure to missile/explode further again, to 200 psi, but again this is unlikely to be encountered inside a bottle. Also, more caps leaked than were propelled from the bottle necks. Over-tightening closures with a tool dramatically reduced the pressure to missile, to a minimum of 125 psi. This is slightly higher than the pressure recorded inside the bottles tested in this study. Over-tightening closures with a tool combined with an increase in temperature did, however, cause closures to fail at pressure well within the range of internal pressures recorded in off-the-shelf bottles. Four caps missiled at pressures lower than the threshold value of 118 psi, at pressures of 50, 66, 76 and 100 psi. All of these had been over-tightened with grippers or nutcrackers and had been heated to temperatures of 38-40°C.

Conditions	N	Leak				Missile/explode				% failed
		n	mean	min	max	n	mean	min	max	
'off-the-shelf'	12	7	311	150	500	5	455	400	500	42
loosened	18	16	227	25	350	2	563	425	700	11
hand tightened	20	7	298	175	400	13	427	325	525	65
tool tightened	16	7	314	100	500	9	286	125	500	56
heated	12	8	206	100	375	4	306	200	350	33
heated & tool tightened	31	15	150	0	300	16	271	50	500	52

Table 7.2 - Range of pressures (psi) required to cause failure of PET bottle caps under various conditions and the percentage of the sample that failed

Some differences in the propensity to missile were noted between the different types of closures tested (table 7.3). Only one type of the closure designs (type 'a') missiled or exploded at pressures below the threshold value of 118 psi, although one of the second type (type 'b') did explode at 125 psi which is only slightly above the threshold value of 118 psi. In addition, all type 'a' caps missiled in one piece whereas all other closures (types 'b' and 'c') exploded into a number of pieces rather than missiling.

The tests with prototype hinged caps suggested that 'hinging' would not prevent closures missiling. The mean internal pressures at which hinged closures missiled were slightly higher than those at which the non-hinged versions missiled. The lowest pressure at which a hinged cap missiled was 100 psi, compared to 50 psi for a non-hinged cap but this is still lower than the threshold value of 118 psi. However, perhaps more importantly, the two hinged caps that missiled at 100 psi had been over-tightened with a tool but had not been exposed to increased temperature, suggesting that missiling might even be more likely. Also hinging on type 'b' caps caused some of them to missile rather than explode which was the case when this design of cap was not hinged.

Cap	Conditions	N	Missile				Explode				%
			n	mean	min	max	n	mean	min	max	
'a'	hand tightened	4	2	350	325	375					50
	tool tightened	7	5	185	125	275					71
	heated & tool tightened	15	7	196	50	275					47
'b'	'off-the-shelf'	8					5	455	400	500	63
	hand tightened	11					9	453	400	525	82
	loosened	10					2	563	425	700	20
	heated	8					3	342	325	350	38
	tool tightened	8					4	413	325	500	50
	heated & tool tightened	15					9	330	125	500	60
'c'	hand tightened	5					2	375	375	400	40
	heated	2					1	200	200	200	50

Table 7.3 - Range of pressures (psi) required to cause closures to explode or missile according to cap type and the percentage of the sample that failed

7.5.4 Measurement of the missiling velocity of closures

The speed and direction with which closures are propelled from bottles is likely to affect the severity of any potential injury. Therefore the study also attempted to estimate the speed and behaviour of missiling caps. A high frequency (300 Hz) strobe light was used to provide successive images of missiling caps on a single video frame (figure 7.3). Speed could be calculated by measuring the distance between successive images of the cap. Only four out of twenty missiling caps filmed using this method provided images clear enough to allow calculations of velocity. It had been suggested previously (Willhoft, 1992) that headspace dictates the potential energy in a missiling cap and therefore its potential speed, and a reduction in headspace had

been proposed as a possible route to reducing the risk of injury from missiling. As the tests carried out in this study were independent of headspace (tests were on neck portions removed from bottles) no experimental evidence was produced regarding the relationship between headspace and missiling velocity.

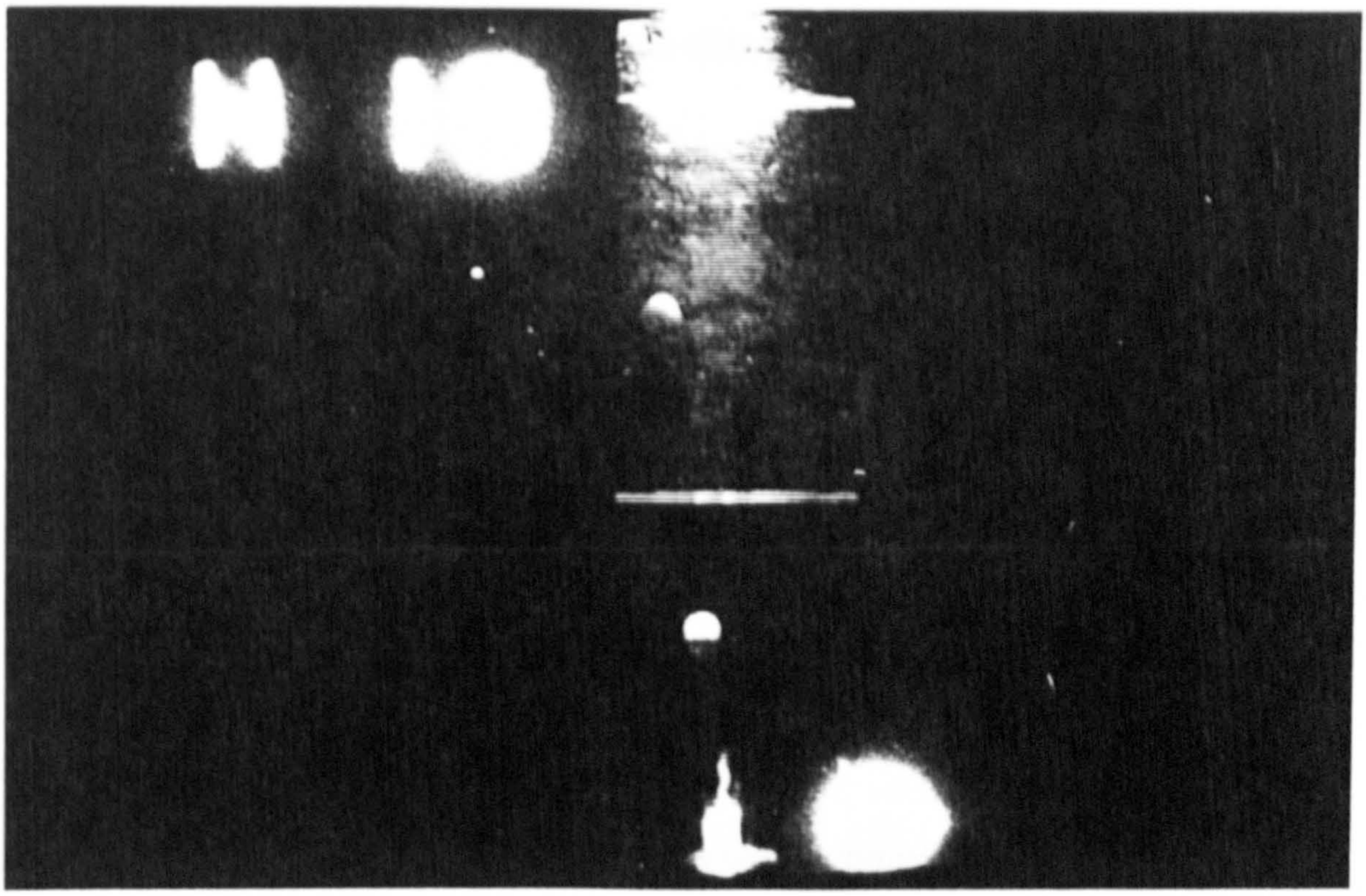


Figure 7.3 - Still image taken from video footage of missiling caps used to measure cap velocity

7.6 Ergonomics evaluation

Having identified that the use of tools and over tightening were the main risk factors of missiling the aim of the ergonomics evaluation was to investigate user behaviour and determine how likely these risk factors were to occur during 'normal' use. The objectives of the ergonomics evaluation were to:

- identify the need for tools by comparing opening strength to the torque required to remove caps

- identify the propensity of people to use tools
- study any aspects of opening behaviour, with and without tools, likely to contribute to the risk of injury
- identify the propensity to over-tighten caps either with or without tools.

The ergonomics evaluation included a mix of methods, namely laboratory user trials and a field study in which 'in-the-home' use of bottles was investigated.

7.6.1 User trials

User trials were conducted to collect user performance data (opening strength) and to allow the observation of users interacting with the product. Sixty eight adults, children and the elderly (aged 4 - 86 years) participated in the user trials (subject details are shown in Appendix 7.2). The latter two groups were included because these were expected to be the groups of consumers most likely to experience difficulty in opening bottles and because children were expected to be frequent users of bottles.

Opening behaviour was observed and the following information recorded from observation and interviews:

- the direction bottles were pointed during opening
- how bottles were held during opening
- which hand(s) and grips were used
- what difficulties if any were experienced in opening the bottles
- the direction caps were turned
- the extent to which tools were used.

Subjects were observed opening four bottles (two 3-litre and two 1.5-litre) and their behaviour recorded using video (figure 7.4). Two of the bottles had normal caps and two were fitted with the new prototype hinged caps, which had been proposed as a possible design solution to missiling. A balanced experimental design was used to avoid any order effects. The caps were fitted to a torque of approximately 2 Newton

metres (18 inch pounds). Subjects were then interviewed to find out whether or not they had any difficulties opening bottles at home and whether or not they admitted to using tools. Those who admitted to using any sort of tool were observed doing so.

Opening strength was measured on a replica bottle specially manufactured in aluminium to the dimensions and weight of a full 1.5 litre bottle (figure 7.5). The cap on the bottle was attached to a fixed central member instrumented with strain gauges and was restrained so that any torque applied to the cap was measured against the external walls of the bottle. The output from the strain gauges was recorded via a small cable from the bottom of the bottle which meant that it could be picked up and handled in a realistic manner. Subjects performed three maximum and three comfortable strength measurements, with a two minute rest period between each measurement. Comfortable opening force was described as a force which did not hurt the hand, and maximum force as the highest force one could possibly exert without injuring oneself (after Berns, 1981).

In a second stage of the trials maximum opening and tightening torque was recorded on a second sample of ten adults aged 22- 32 years, this time using tools as well as their hands. The tools used included a rubber cone (a device specifically designed for the disabled), a rubber mat and a pair of nutcrackers (shown in figure 7.6).

No restrictions were placed on subjects' posture or technique in performing any of the tasks, either opening bottles and particularly when measuring opening strength, in order to record realistic maximum strength. Subjects were free to sit or to stand, to rest the bottle on a work surface or hold the bottle, and in any orientation.

Given that the reason for the study was to evaluate the risk from missiling closures there were ethical considerations about exposing subjects, especially children who are

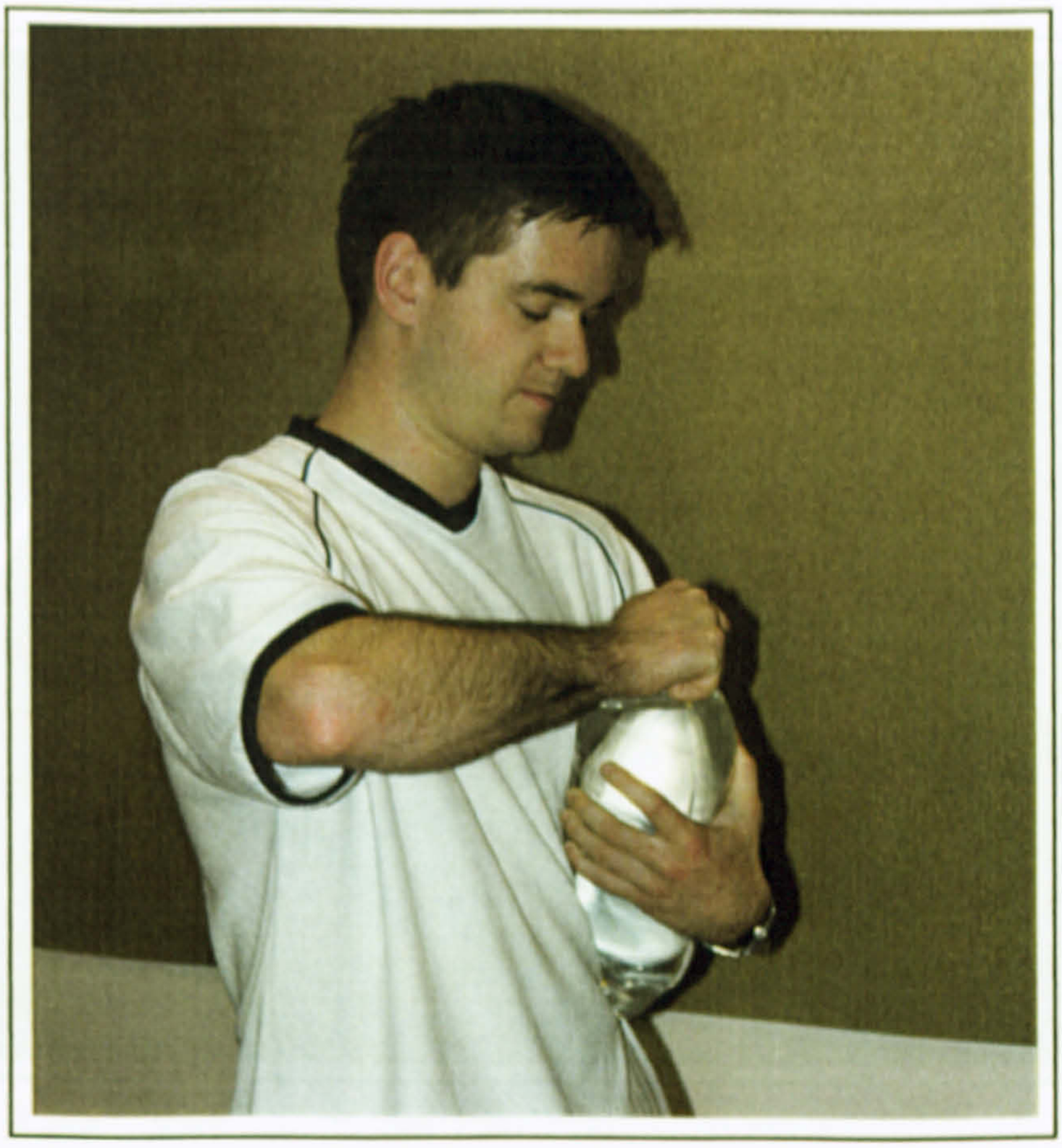


Figure 7.4 - Observation of opening behaviour

Figure 7.5 - Replica aluminium bottle with strain gauges used to measure opening strength (3 litre bottles shown)

Figure 7.6 - Tools used to open carbonated drinks bottles

unable to give informed consent, to any risk during user trials, however small. After ethical review it was decided that any bottles to be opened by children or by adults using tools would be filled with water to remove any risk. Bottles containing carbonated drinks were used for the other subjects. Pilot trials revealed that bottles filled with water were less rigid than those filled with carbonated drinks due to the lack of pressure acting on the bottle walls but this was likely to have a negligible effect on the results.

7.6.2 Field study

The field study took the form of a disguised 'in-home' study from which it was hoped to gain *evidence* of whether or not consumers used tools to open bottles. This 'evidence' was considered necessary as without it the only data on the use of tools would be from interviews and therefore subjects' reported behaviour, which can be unreliable, particularly if it is related to safety. The field study would therefore

provide empirical data to corroborate information reported by subjects during interviews. In addition, there was concern that the prototype hinged caps under evaluation may be difficult to open and encourage consumers to cut the hinge or tamper-evident band, perhaps with a knife thereby introducing a secondary hazard, and evidence on this was also sought.

Evidence of the use of tools was to be recorded by inspecting returned caps for marks left by tools and hinged caps were to be inspected for whether or not the hinges had been cut. Households that consumed a 'substantial' number of bottles of carbonated drinks were recruited and the study was disguised as a study of recycling to deflect attention away from safety and design issues. A sample of 450 homes randomly selected from around Nottingham were asked to partake in the study and 51 responded. They were asked to save all of their usual carbonated drinks bottles and closures over a period of three to five weeks for recycling, the supposed aim to see how easy or likely households were to start recycling plastic bottles as well as glass. Households were offered free bottles of drinks as an incentive for taking part in the study, fitted with the new prototype hinged caps. In order to find out who in the household had opened each bottle, and therefore who had possibly used tool(s), a 'diary' system was developed. Labels were provided to be attached to each bottle in order to record who opened, used and disposed of each bottle. A questionnaire was subsequently used to establish information on bottle use and explicitly whether any members of the household ever use nutcrackers, grippers, teeth door jambs or anything else to open bottles (shown in Appendix 7.3).

7.6.3 Results

7.6.3.1 Opening strength

7.6.3.1.1 Opening strength using hands

Table 7.4 presents the peak (best of three) maximum and comfortable opening torques recorded in this study.

ages	males					females					males and females				
	n	mean	sd	min	max	n	mean	sd	min	max	n	mean	sd	min	max
5-9	5	1.6	0.2	1.2	1.8	5	1.5	0.2	1.1	1.7	10	1.5	0.2	1.1	1.8
10-14	5	2.2	0.7	1.4	3.0	7	2.6	0.9	2.0	3.7	12	2.4	0.6	1.4	3.7
15-19	4	2.8	0.8	2.0	3.9	2	3.0	0.3	2.8	3.2	6	2.9	0.6	2.0	3.9
20-39	5	4.1	1.4	2.1	5.5	7	2.5	0.6	1.5	3.5	12	3.1	1.3	1.5	5.5
40-59	5	3.0	1.0	1.9	4.0	5	2.2	0.6	1.5	2.8	10	2.6	0.9	1.5	4.0
60+	3	2.3	0.7	1.8	3.2	11	1.7	0.6	1.0	2.5	14	1.5	0.7	1.0	2.5

Table 7.4.i - Peak maximum opening torque (Nm)

ages	males					females					males and females				
	n	mean	sd	min	max	n	mean	sd	min	max	n	mean	sd	min	max
5-9	5	1.0	0.2	0.9	1.4	5	1.0	0.2	0.8	1.4	10	1.0	0.2	0.8	1.4
10-14	4	2.0	0.4	1.6	2.5	7	2.0	0.4	1.5	2.5	11	2.0	0.4	1.5	2.5
15-19	4	1.8	0.5	1.5	2.4	2	2.4	0.4	2.1	2.7	6	2.0	0.5	1.4	2.7
20-39	5	3.1	1.0	1.6	4.1	7	2.2	0.7	1.4	3.2	12	2.6	0.9	1.4	4.1
40-59	5	3.2	1.2	2.2	4.8	5	2.2	0.5	1.4	2.6	10	2.7	1.0	1.0	4.8
60+	3	1.9	0.3	1.6	2.2	11	1.1	0.3	0.7	1.6	14	1.3	0.5	0.7	2.1

Table 7.4.ii - Peak comfortable opening torque (Nm)

A literature search was carried out to establish whether other strength data were available to assess the appropriateness of the application torque and for comparison to the data recorded in this study. Research has shown that the characteristics of grip and of the object being turned (such as diameter) directly affect exertable torque (Pheasant and O'Neill, 1975) and these factors had to be considered when comparing published and recorded hand strength for this application. Table 7.5 presents a comparison of published torque strength, the results of this study and the application torque.

All of the studies reviewed, except Imrhan and Loo (1986), measured torque on lids removed from bottles and attached via a shaft to a torque meter fixed to a work surface. Imrhan used caps still attached to the bottles but with the bottles still fixed to a work surface. Strength is known to be dependent on posture and orientation of the joints and so it was felt that realism in the collection of all of these data, particularly the person's ability to move the bottle to their preferred orientation for maximum exertion, was lacking. The study by Berns (1981) measured torque strength on a 28 mm cap fixed to a replica bottle placed on a worktop and it is assumed from the report, although it is not stated explicitly, that the bottle was not fixed to the worktop and could therefore be moved. However the results from this study were only presented graphically and the 50th percentile values presented here

had to be estimated. Although not directly comparable because of the measurement techniques and age groups, the results from the present research are either of similar magnitude or are slightly higher than the published data. This is likely to be due to the fact that the bottle was movable and allowed different postures and grips to be used.

Age group	Age (years)	Source of data	Cap diameter (mm)	Method	Mean torque (Nm)
children	4	Rohles et al 83	27 & 29	cap only	0.58 - 0.63
	5-9	This study	29	movable bottle	1.51
	10-14	This study	29	movable bottle	2.43
elderly	60-97	Imrhan & Loo 86	31	bottle fixed to table	1.62
	62-92	Rohles et al 83	29	cap on torque meter	0.92 - 2.04
	60-86	This study	29	movable bottle	1.53
teenagers	students	Konz & Ravishankar 89	28	cap on torque meter	2.44
	15-19	This study	29	movable bottle	2.86
adults	20-70+	Berns 81	28	movable bottle	1.18
	20-39	This study	29	movable bottle	3.12
	40-59	This study	29	movable bottle	2.59
		Industry applied torque	29		2.03

Table 7.5 - Comparison of published torque strength to that recorded in this study and applied torque

Some interesting findings from published research however included differences in exertable force due to cap surfaces: mean torque in the elderly measured by Imrhan was slightly higher on a 'rough' (undefined) lid compared to a 'smooth' lid and Konz and Ravishankar (1989) found differences in students' torque strength according to differences in knurling. Rohles et al (1983) found sex and age differences in torque strength: four year old children were not as strong as 'older' adults (62 - 92 years) and amongst this older group the males were much stronger than females (mean torque 2.44 Nm and 0.92 Nm respectively). The study also demonstrated that the direction of turn (opening versus tightening) did not significantly affect torque strength. The use of tools was investigated by Nagashima and Konz (1986) who found that use of a rubber gripper significantly increased torque, although this was on jar lids, the smallest diameter of which was 48 mm, much larger than a bottle closure.

Comparison of the results with the application torque showed that of the 68 subjects measured in this study, nearly half (46%) had peak maximum torque strength less

than 2.034 Nm, the value quoted by industry as the applied torque on bottle closures (table 7.6). Of these, most were children or the elderly: none of the children under 10 years and nearly seventy percent of those over 60 years did not have the required torque strength to remove caps; only in the 20-39 age group were there more than seventy percent with the required opening strength.

age (years)	N	no with peak strength < 2.034 Nm	% of sample
5-9	10	10	100
10-14	12	4	31
15-19	6	2	29
20-39	12	1	8
40-49	10	3	30
60-86	14	10	67
total	64	31	46

Table 7.6 - Number of subjects with peak strength less than the application torque

7.6.3.1.2 Opening strength using tools

The results of the missiling tests indicated that a significant factor in the risk of missiling was the combined effect of over-tightening closures and using tools. The closures that missiled had been over-tightened to a torque of approximately 3.4 Nm (30 inch pounds) using either nutcrackers or special grippers. If this magnitude of force was not achievable during everyday use then this hazard scenario was unlikely to occur. The maximum exertable torque using tools was therefore measured in the second part of the user trials on ten adult subjects (mean age 27 years). Torque was measured in both directions (opening and tightening) using the hands, a rubber mat, a rubber cone and nutcrackers and the results are shown in table 7.7. Hand strength in this group of subjects was comparable to the same age subjects used in the first stage of the user trials. The use of tools increased both opening and tightening strength compared to using the hands only, with the exception of the rubber cone which actually reduced opening torque, particularly in men, even though this tool is specially designed as an aid for the disabled. Using nutcrackers had the greatest effect, increasing both opening and tightening torque. All of the subjects tested were able to exert an over-tightening torque greater than that required for the caps to missile (3.39 Nm) when using either the rubber mat or the nutcrackers, as highlighted in table 7.7.

	males					females					males and females				
Opening	n	mn	sd	min	max	n	mn	sd	min	max	n	mn	sd	min	max
hand	5	3.5	2.0	1.8	6.8	5	2.4	0.3	2.1	2.9	10	2.9	1.5	1.8	6.8
rubber cone	4	2.0	0.5	1.3	2.5	5	2.1	0.5	1.4	2.6	9	2.1	0.5	1.3	2.6
rubber mat	5	6.9	1.7	4.0	8.2	5	4.3	1.1	2.5	5.4	10	5.6	1.9	2.5	8.2
nutcrackers	5	9.7	4.2	5.2	14.5	5	5.8	1.5	3.4	7.2	10	7.8	3.6	3.4	14.5
Tightening															
hand	4	2.2	0.5	1.45	2.7	5	2.3	0.5	1.5	2.3	9	2.3	0.5	1.45	2.99
rubber cone	4	6.2	2.3	4.1	8.6	5	3.7	0.6	3.0	4.5	9	4.8	2.0	3.0	8.6
rubber mat	5	6.9	2.3	3.9	9.1	5	4.7	0.7	3.85	5.8	10	5.8	2.0	3.85	9.1
nutcrackers	5	11.0	4.2	5.9	15.8	5	6.5	1.95	4.5	8.6	10	8.8	3.9	4.5	15.8

Table 7.7 - Peak maximum torque strength (Nm) according to direction and use of hands or tools

7.6.3.2 Opening difficulty

The assessment of opening difficulty was based on observed behaviour from the user trials and reported difficulty from both the field study and user trials. Of over 100 people interviewed in the user trials and field trials, nearly half reported that they always had difficulty opening bottles and 65% of all subjects said they had experienced difficulty (table 7.8).

	N	always	sometimes	never	no answer
home study	40	57.5%	20	22.5	-
user trials	68	37	20	34	9
total	108	44.4	20.4	29.6	5.6

Table 7.8 - Percentage of respondents who said they have difficulty opening bottle closures

The observation of subjects opening bottles in the user trials supported this. Over a quarter of subjects (19 out of 68) failed to open at least one of the four bottles they were given. All but one of these were children and adults aged over sixty. One subject (a female in her seventies) failed to open any of the four bottles. Most of the bottles that couldn't be opened had caps put on by the manufacturer, as opposed to the hinged caps which had been applied by hand, although ostensibly to the same torque.

7.6.3.3 Use of tools

7.6.3.3.1 Reported use of tools

Subjects were asked in both the field study and the user trials about their use of tools, and the results are shown in table 7.9. Subjects in the home study were given a questionnaire with a multiple choice question on whether or not they had ever used grippers, nutcrackers, teeth or a door jamb to open difficult bottles. In the user trials, subjects were asked an open-ended question on what they did to open difficult bottles. Out of more than a 100 respondents over half admitted to using tools such as grippers or nutcrackers, or misuse such as teeth or a door jamb. Comparison between the results of the home study and the user trials show little difference between results obtained from interviews and questionnaires, or from open-ended versus multi-choice questions, apart from the 'use of a cloth/rubber mat' and 'asking someone else', which could be attributed to the inclusion of the elderly and children respectively in the user trials but not in the home study.

	User trials	Home study	% of total sample
Use nothing	7	8	13.9
Ask someone else	17	-	15.7
Cloth or rubber mat	13	2	13.9
Door	17	18	32.4
Teeth	9	8	15.7
Nutcrackers	4	4	7.4
Special grippers	6	10	14.8
Any misuse or tool (ie door, teeth, nutcrackers or grippers)	31	26	52.7
Total	68	40	

Table 7.9 - Number of subjects who admit to using tools or other methods to open difficult closures

7.6.3.3.2 Evidence of the use of tools

The bottle closures returned from the home study were inspected for evidence of the use of tools. The aim was to provide comparative data between reported use of tools

and evidence of use. The closures were inspected for marks likely to be caused by tools such as grippers, nutcrackers, teeth or door jambs. Over a quarter of the returned closures (122 out of 408) were marked (figure 7.7). It was not possible to confirm that these marks were made by tools, however they were unlikely to have been made by the hands. These results support the reported data.

Figure 7.7 - Marked closure indicating the likely use of a tool to open the bottle

7.6.3.4 Opening technique

Four main types of grip were observed to open bottles. Nearly half (33) of the subjects used just one type of grip and a further 25 used only two types of grip, suggesting that opening technique is habit-forming. Subjects using more than one or two grip types were usually experiencing difficulty opening bottles.

Most subjects rested bottles on the available work surface during testing. As a result, bottles were usually opened with the cap pointing towards the subject's face, either vertically into the face or tilted slightly. Even when the bottle was lifted from the table and held in the hands, bottles caps were usually pointing towards the face.

7.6.3.5 Turning closures the wrong way

7.6.3.5.1 Turning closures the wrong way with the hand

Ten out of the sixty eight subjects in the user trials turned at least one cap the wrong way. Most of these eventually realised their mistake and turned the cap the correct way but a few, particularly children, persevered and had to be told to turn it the other way when they continued to fail to open the bottles. During the collection of opening strength data when there was no feedback from the bottle or cap because the cap was fixed to the bottle, four subjects consistently turned the caps the wrong way and a further eleven turned the cap the wrong way at least once. Children and the elderly seemed most likely to turn the cap the wrong way.

7.6.3.5.1 Turning closures the wrong way with tools

The thirty one subjects in the user trials who had said that they had at some time used tools were observed doing so. Ten subjects were observed using a 'handled' tool, such as grippers or nutcrackers, and all of them placed the bottle on the work surface and turned both the bottle and the cap at the same time. One adult female subject repeatedly tried to open the bottles by over-tightening the caps although she had turned the caps the correct way when opening the bottles with her hands. She eventually said that the caps were too tight to open and gave up.

7.6.3.6 Cutting the tamper-evident band

Seven out of the 108 people interviewed about their use of carbonated drinks bottles volunteered the information that they often use a knife or scissors to cut the tamper-evident band already in use on caps. These tamper-evident bands are at present designed to either stay with the cap when it is removed or to be retained on the bottle neck and should not need to be cut. This has some bearing on the proposed use of caps that are hinged or tethered to the tamper-evident band and would be more likely to be cut. Perhaps more importantly, over two-thirds (69%) of the sample of prototype hinged caps which were distributed in the home study were returned with the hinge either broken or cut.

7.7 Discussion

The main factor found to contribute to missiling was the use of a handled tool to over-tighten a cap, combined with agitation and exposure to temperature of around 40°C, such as those likely to be encountered in a car during summer. Results suggest that over-tightening on its own could possibly lead to missiling although is less likely than when the bottles have also been exposed to increased temperatures. Some differences were found between different designs of cap in their propensity to missile and a prototype hinged cap did not appear to offer a solution to missiling. Given that the use of tools and turning the caps the wrong way are pre-requisites of missiling, the actual risk of this hazard depends on whether or not these were realistic behaviours with bottles. The factor most likely to dictate the need for tools is difficulty in opening bottles. Bottle closures are applied to a target wet torque of 2.034 Newton metres (18 inch pounds), which apparently drops to around 15 inch pounds when dry. A sample of 26 closures were tested in this study and the mean dry removal torque was higher than this, 17.15 inch pounds (standard deviation 1.95, range 14-20). According to the industry (BSDA, 1993) the application torque used is based on strength data measured in Spanish subjects opening metal closures, which would appear to be inappropriate now that most caps are plastic (given the different coefficients of friction between metal and plastic caps) and possible population differences. There had been some suggestion, although based on limited data, that bottle closures were difficult to remove (Wilson and Breeze, 1990). However, prior to this study there was a lack of realistic torque data applicable to this task to allow this to be fully assessed. These data have now been made available by this study. Comparison of this torque strength with the torque used to apply caps to bottles showed that the elderly and children under ten (who are also likely to be frequent users of carbonated bottles) will experience difficulty opening bottles. This was supported by observed data which showed that children and the elderly experienced most difficulty opening bottles and actually failed to open some bottles they were given. Reported data suggests that adults also experience difficulty and half of the sample interviewed for this study reported that they do use tools to open bottles.

Given that the tools are in use, the secondary pre-requisite for missiling is over-tightening caps. Nearly a quarter of the subjects observed opening bottles and recording strength measurements turned caps the wrong way when using their hands, suggesting that it can be a common mistake, particularly amongst children. Turning caps the wrong way is probably more likely when using a handled tool, due to a change in the usual interface between the user and the bottle. This was suggested when one subject experienced confusion when using a tool but not when using her hands. As well as demonstrating a potential need and propensity to use tools, the study showed that adults had the required strength with tools which had been used to over-tighten caps and caused them to missile in the technical stage of the study.

7.8 Conclusions

A multi-disciplinary study was necessary to assess the risk of this potential hazard of carbonated drinks bottles. While technical investigations identified the specific conditions to cause missiling, an ergonomics approach was necessary to identify the likelihood that this combination of mainly behavioural factors were to occur. Under 'normal' environmental and behavioural conditions caps are unlikely to missile suggesting that the risk from this product is low. However strength data collected in this study suggests that caps are currently applied with too great a torque for some user, particularly children and the elderly, to be able to open carbonated drinks bottles without some difficulty. This could encourage the use of tools which together with the risk of turning caps 'the wrong way' is the main predisposition to missiling.

7.9 Recommendations and outcome

As a result of the study a formal report was issued to the DTI CSU. This was used by them to initiate discussions with the packaging industry on routes to reduce the risk of injury from missiling closures. The following recommendations were made to the DTI CSU in that report:

7.9.1. The relatively small number of reported accidents compared to the high exposure rates for these products indicated that missiling incidents are likely to be rare. However, given that specific risk factors have now been identified it was considered that it may be appropriate to inform industry and/or the public of these specific risks.

7.9.2. It may be possible to reduce the likelihood of tools being used or caps being turned the wrong way by making closures easier to open. This could be achieved either by slightly reducing the torque with which closures are applied or through re-design of the cap to provide better grip, but the need for contents integrity and security may rule out a substantial reduction in closure torque.

7.9.3. The study provided some evidence that closure design/material may effect the likelihood of missiling. Further work was recommended in order to specify more closely the particular design features which lead to these differences in missiling probability.

7.9.4. The printing of arrows on the tops of caps indicating the direction of opening would help prevent confusion over opening direction such as when tools are used.

7.9.5. The use of warning labels to inform users of the potential hazard of missiling caps was rejected after consideration of literature on warning efficacy, given the low probability of the hazard and the high exposure of the public to the product, two factors which suggest that a low level of compliance with warnings would be likely.

As a result of the study the DTI initiated discussions with the soft drinks and packaging industries on possible routes to reducing the risk injury from cap missiling.

The industry accepted recommendations that the torque with which closures are applied to PET carbonated drinks bottles needed to be reduced and at the time of submission of this thesis an acceptable reduction in application torque is being discussed by the industry. In addition to a reduction in torque, some sectors of the industry have adopted a labelling approach to the problem, and have printed directional arrows and instructions '*open by hand*' on bottle closures (figure 7.8).

Figure 7.8 - Closures with arrows and instructions developed as a result of the study

A bumpy ride for mountain bike riders

Research into the safety of mountain bikes points the way to reduce accidents

All terrain bikes or mountain bikes, as they are now commonly known, have become increasingly popular over recent years. They now account for two out of every three bikes sold and over 20% of adults in this country own a mountain bike.

Around 10,000 cyclists are injured every year riding mountain bikes.

- In the years 1990 to 1994 three fatalities were recorded.

Aware of the rising accident figures, the DTI commissioned Nottingham University to examine the range of mountain bikes on the market, to assess their safety and to look into consumers' riding habits, attitudes to safety and what expectations they have of their bikes.

Professor Wilson said: "Our research showed that bike failures were reassuringly low, and that consumers' behaviour, in buying, riding or maintaining bikes was the major factor in causing accidents."

Factors influencing accidents include the

- level of a rider's expertise
- difficulty of terrain
- weather conditions
- degree of protective equipment worn
- condition of the bike

The research showed that mountain bike riders should always wear a helmet and depending on the severity of the terrain, should wear additional protective clothing such as gloves, elbow pads, knee pads and eye protection. Their regularly maintained bikes must be given the more testing conditions of off-road riding.

With mountain bikes ranging in cost from £100 (or less) up to £3,000 the actual purchase can be confusing for newcomers to off-road riding. Choosing the right bike for the job is essential. Consumers need to consider carefully the type of terrain on which they intend to use the bike and to seek guidance from their retailer on appropriate bikes to match their needs.

As there are no standards to distinguish mountain bikes from road bikes, research suggests categorising all terrain bikes to help guide purchasing decisions. Three broad categories of bikes are suggested

- bikes suitable for road use only
- bikes suitable for moderate off-road conditions
- bikes suitable for more rugged terrain such as quarries and the mountain tracks

The longer term answer, thus, lies with the development of safety standards for mountain bikes that will set appropriate requirements for the different levels of terrain and enable consumers to readily distinguish the different categories of mountain bike. Standards along these lines are currently being prepared by the International Standards Organisation. The research report will be published shortly.

- 'Safety Net', Department of Trade and Industry, London, Summer 1997

Chapter 8 - Case study: Accidents with All Terrain Bicycles

8.1 Introduction and aims

'Mountain bikes' were first 'invented' in California in the late 1970s by a group of cyclists who wanted to make bikes able to withstand fast downhill cycling and racing on rough terrain (Rosen, 1994). The first mass produced mountain bike (the 'Stumpjumper', made by Specialized) appeared in the USA in 1981 and 'All Terrain Bikes' (or ATBs) appeared here a few years later, although views vary on when they were first mass produced in the UK (Kelly and Crane, 1989 and Mintel 1991). Unlike previous bicycle developments such as BMX, the first mass produced ATBs were aimed exclusively at an adult market. Indexed gears[1] and cantilever brakes were developed along with the ATB to make them 'easier' to ride and have now been introduced onto other types of bikes. The upright riding position, efficient gears and brakes and the robust appearance of ATBs have made them so popular that at the time of this study they accounted for around 60% of all new adult bicycle sales in Britain (BAGB, 1994; Keynote, 1992; Euromoniter, 1991; Rosen, 1994).

Immediately prior to this study there was concern over an apparent rise in accidents associated with ATBs, recorded by the DTI Consumer Safety Unit's HASS/LASS systems and an investigation was carried out into their safety. The aims of the research were to assess the extent to which the design, marketing or use of ATBs may be contributing to accidents and whether action was needed to improve their safety. The study included the following stages of work:

- an examination of the bicycle and ATB markets

[1] See Appendix 8.1 for a glossary of ATB-related terms

- an assessment of the feasibility of producing a classification of ATBs to guide policy decisions
- an analysis of accidents involving ATBs
- surveys of ATB ownership and of the cycling practices and attitudes to safety amongst cyclists, especially those riding ATBs
- a technical evaluation of the safety and performance of a selection of bicycles sold as ATBs or mountain bikes.

8.2 Definition of the products and the ATB market

ATBs have been defined as *'bicycles designed for genuine off road riding... capable of being ridden over rough tracks and down steep and rocky down-hills'* (United Leisure Magazines, 1994). However ATBs vary considerably, in design, price and use. The term 'mountain bike' is now an ubiquitous cycling term used to refer to a range of bikes, from highly refined bikes costing up to £3,000 through to children's bikes *styled* like ATBs. The original ATB market has also now fragmented to include the initial adult off-road-riding sector, an upgrading market for those who want to do more serious off road riding, an older sector who are re-discovering cycling and the 'general' cyclist.

8.2.1 ATB market share

ATBs dominate the UK bicycle market and are considered by some in the industry as the conventional adult bicycle of today. They are considered as responsible for a general increase in overall bicycle sales during the late 1980s, with sales reaching over £300 million in 1992 (BAGB, 1994). The increase in sales has been met almost exclusively by imports, which account for just over half of the market (Euromoniter, 1991). The majority of ATBs are imported, mainly from the Far East.

In 1990 it was estimated that around 14 million adults in the UK (32% of adults) owned a bicycle and this had increased from 23% in 1985 (British Market Research

Bureau, 1990). Just over half of all households have a bike although they are not all used regularly (Mintel, 1991), with about 17% (7 million) of adults thought to be regular cyclists; in 1990, just three to four years after their introduction, around two million homes (9%) had ATBs although the commonest bikes were road/racing bikes and conventional 3-speed bikes (General Household Survey, 1990). ATBs were expected to retain that share of the bicycle market for the foreseeable future and if anything its profile was likely to increase following the exposure of mountain biking as a sport and its introduction as an Olympic event at the Atlanta Games in 1996.

8.2.1.1 Ownership surveys

Two surveys of the general public were carried out as part of this study to further investigate the size of the ATB market. An on-street survey was commissioned in summer 1994 and face-to-face interviews of 1,753 adults carried out. The survey found approximately 17% were regular cyclists, two thirds of which cycled at least two or three times a week. This agreed with the findings of the General Household Survey of 1990. ATBs were by far the most popular type of bicycle and half of the *regular* cyclists interviewed had ATBs (around 9% of the adult population). A second survey was commissioned as part of an omnibus survey in March 1995 (by the British Market Research Bureau). 2,201 adults were interviewed over the telephone and found that 21% of all adults owned an ATB.

8.2.2 ATB prices

The 1994 bicycle market was reviewed in detail and found that bicycles marketed as 'mountain bikes' or 'ATBs' ranged in price between £100 and £3,000. The average price of an ATB was thought to be very much towards the lower end of this price range, although there were very few published data available to support this. The only information was on bicycles in general and not specific to ATBs; the average price of all bicycles in 1991 was £115 (Euromoniter 1991). The omnibus survey of ATB owners carried out for this study and described above was therefore used to also provide information on sales figures related to retail price (table 8.1). Three

hundred and ninety eight adult owners of new (rather than second hand) ATBs were interviewed and nearly three quarters of ATBs (74%) had cost less than £250 (the informally recommended threshold price for ATBs to be used off-road - see next section), and just over a quarter had cost under £150. Nearly all the remaining ATBs had cost under £500, with only 4% of all ATBs costing more than this. There was a tendency for males rather than females to purchase the more expensive ATBs (30% against 21% paid over £250), but little difference by age. The majority of the bicycles had been purchased within the last three years.

	Purchase price					
age	<£150	£150-249	£250-499	£500-999	>£1000	total
15-24 years	26	71	31	5		133
25-34	34	37	25	7	1	104
35-44	39	39	18	2		98
45-54	15	20	11	2		48
55-64	4	4	3			11
65+		4				4
sex						
male	64	106	57	14	1	242
female	54	69	31	2		156
total	118	175	88	16	1	398

Table 8.1 - Purchase price of ATBs according to owner's sex and age *(Omnibus survey of 2,201 adults owning 398 ATBs - March 1995)*

8.2.3 Marketing of ATBs

ATB marketing literature was reviewed. ATBs were commonly depicted being ridden over off-road terrain, although only a small number of brochures (around 16%) used images of stunts and trick riding. No limits or recommendations about use were suggested in the brochures, although a few companies had disclaimers in their warranties excluding certain types of riding. Nearly all of the images showed riders wearing helmets. This was also true of images in the ATB press, which is where the majority of ATB advertising is concentrated. The ATB press has a strong

influence and is read by a large proportion of enthusiastic mountain bike riders, who say they use product reviews to influence their purchase decisions (see section 8.4 later).

8.2.4 Classification of ATBs on the market

Despite attempts to define ATBs (see 8.2 earlier) the bikes sold as ATBs varied considerably, in design, price and use. Despite having similar features such as thick tyres, chunky treads, larger diameter frame tubes, smaller frames and straight handlebars (Appendix 8.1 contains a description of ATB features, a glossary of common terms in use for ATBs, and description of the other bikes on the market which were excluded from the study), the suitability for off-road riding of many of these bicycles was unknown, and was considered at least doubtful. To address this, some retailers and the cycle press had begun to recommend a retail price of £250 for an entry level ATB suitable for off-road riding (United Leisure Magazines 1994, Halfords, 1994). This led to suggestions that there may be two tiers of ATBs, those suitable for off-road riding and 'ATB-style' bikes which are not; another suggestion is of three tiers, with those suitable for off-road riding divided into those suitable for 'severe' and those for 'moderate' off-road conditions.

An exhaustive review of the ATB market in 1994 was undertaken and a database established containing the specifications of 455 models of ATB on sale in the UK during that year, including imports. Given the wide variation of bikes on sale an attempt was made to classify ATBs, to provide a framework within which to carry out the rest of the study. A large number of features of ATB design and construction were considered as potential criteria for classifying the market, shown below.

Retail price Frame material Tube thickness Transmission system Wheel rim material Handlebar material	Bar ends Number of gears Brake types Weight Dropout angles Tyre type Pedal type	Method of construction Rear suspension Type of gear shifters Seat type Number of wheel spokes	Fork material Suspension forks Range of frame sizes Quick release levers wheels Type of bottom bracket Type of wheel hub

Some of these features proved difficult to use as potential classification criteria, either because information was difficult to acquire or because there was too much variation in each feature. A discussion of each potential criterion and their variation according to price and frame material is contained in Appendix 8.2.

Consideration of all the ATB features and extensive consultation with retailers, media and trade associations suggested that a useful initial classification of ATBs on the market could be constructed on the basis of retail price and frame material. Price is dictated mainly by materials and components and is considered to be an indication of suitability for good off-road handling, indeed almost as the *de facto* criterion. Using information from specialist magazines the following price categories appeared to reflect different sections of the market:

<£250	ATBs and ATB style bikes below the threshold purchase price recommended for off-road use
£250 - 499	Entry level ATBs used by new off-road riders
£500 - 999	ATBs for enthusiasts and experienced off-road riders who will be familiar with the ATB market (possibly a second purchase)
£1000-2500	Probably a second or even third purchase ATB and used by experienced off-road riders and for competitive riding.

As for materials, frame material emerged as the most important technical criterion for ATBs; it is commonly used to promote certain ATBs in marketing literature and is an indicator of performance and safety in off-road use. The higher performing bikes will be constructed from materials which have high strength/weight ratios and modulus (stiffness)/weight ratios and which allow the use of smaller tube diameters and wall thickness, albeit at higher cost. Characteristics of the different materials which may be used in ATB frames are summarised in table 8.2.

Frame material	Cost	Yield Strength σ_y (MN^{-2})	Young's Modulus of Elasticity E (MNm^{-2})	Density (Mgm^{-3})	Specific strength σ_y/ρ	Specific modulus $E/\rho \times 10^3$
Low alloy high tensile steels	Low	300 - 950	205,000	7.8	38.5 - 122	26.3
Alloy steels Cro-Mo and Mn-mo	Low/ Med	350 - 1480	200,000 - 210,000	7.8	44.9 - 190	46.2
Aluminium alloys	Med.	100 - 627	75,000	2.6	38.5 - 241	28.8
Titanium alloys	High	440 -1320	80,000 - 130,000	4.3	100 - 307	18.6 - 30.2
Carbon fibre composites	High	600 - 1000	70,000 - 200,000	1.5	400 - 667	46.6 - 133

Table 8.2 - Mechanical property specifications, of ATB frame materials

A 'price/frame material' classification was produced and is shown in table 8.3. This allowed relatively clear-cut market segments to be distinguished and could be used to predict the presence of many other ATB features (such as method of construction or fork and handlebar materials).

Frame material	Retail price				
	<£250	£250-£499	£500-£999	£1000-£2500	N
Low alloy steels	65	11	0	0	76
Cro-mo alloy steels	5	96	87	31	219
Reynolds 500	2	17	3	0	22
Reynolds 600	0	0	4	4	8
Aluminium alloys	0	7	11	14	32
Aluminium 7000	0	2	26	22	50
Aluminium 6000	0	0	6	14	20
Titanium alloys	0	0	4	4	8
Carbon fibre	0	0	4	4	8
Other	0	1	0	7	8
N	72	137	150	96	455

Table 8.3 - Classification of 455 models of ATB available on the UK market (1994) according to retail price and frame material

Table 8.3 shows that nearly all bikes under £250 had low alloy steel frames but only 11 out of the 383 bikes over £250, suggesting its unpopularity as a higher performance ATB frame material due to excess weight. Most 'entry level' bikes had cro-mo alloy steel frames and cro-mo was the most common frame material in all price ranges. Above £500, where high performance of the bike off-road is important, lightweight aluminium alloys were the second most common frame material, and were the commonest materials over £1000. Titanium alloys, although the most expensive and lightweight frame material, was only found in the £250 - £1000 price range and not in bikes over £1000; although these frames were likely only to have one or two tubes made of titanium alloy and the remaining tubes of cro-mo. Frames made wholly of titanium were likely to cost over £2500. With the exception of bikes under £250 which were nearly all low alloy steel, the whole range of frame materials can be found in each price category, indicating that neither price nor frame material could be used on its own to classify the ATB market and so a two way classification was necessary, together with subsequent performance tests.

8.3 Cyclists and mountain bikers

The cycling practices and attitudes to safety of both the population as a whole and also of those who ride ATBs as a regular sporting or recreational activity were considered important factors in the safely of ATBs. Surveys of general cyclists and mountain biking enthusiasts were therefore undertaken.

8.3.1 Sample

A number of methods were used to firstly contact members of the general public and thus the general cycling population. Questionnaires were handed out at cycle retailers (N = 150) and a random mail-shot to homes in the Nottingham area was carried out (N = 200). The response rates were low, between 3 and 12.5%. Also, the samples contacted were not considered to be representative of the general public as the response appeared to be from those with a particular interest in cycling or

safety, which is more likely with this form of self-selected sample. The general public were therefore contacted through on-street interviews, carried out in three Midlands cities, Nottingham, Sheffield and Leeds. A target sample of 300 people who owned or rode a bicycle was set and 1753 members of the general public were approached in order to meet this target. The age and sex of the sample of general cyclists interviewed is shown in table 8.4.

Next, a questionnaire survey of mountain bike club members was carried out. A total of 37 clubs were contacted and 810 questionnaires were sent to their members. The clubs were representative of rural and urban areas throughout the country and all organised recreational off-road rides. A total of 71 responses were received, of which two thirds competed or had competed in mountain bike races.

age	males	females	total
16-24	81	27	108
25-34	78	18	96
35-44	54	9	63
45-54	20	6	26
55-64	4	3	7
65+	-	-	-
total	237	63	300

Table 8.4 - Age and sex of general cyclists interviewed

8.3.2 Results

Cycling, and mountain biking, is male dominated and is most popular amongst 16 to 44 year olds. ATBs are the most popular bikes amongst general cyclists and over half now ride them. There were four equally popular reasons which emerged for buying ATBs: to go off-road riding; because they are fashionable and people like their style; because they appear strong and robust; and because they look comfortable and easy to ride. *Mountain bikers*, who regularly ride off-road, pay much more for their bikes and very few ride ATBs which have cost less than £250; on the other hand more than half of the *general* cyclists ride bikes costing less than £300 and most of those who ride ATBs pay less than £250. Over two thirds of general cyclists have

ridden off-road, even those without ATBs and a third say they regularly ride off-road. Everyone who rode an ATB considered that their bike had been designed for off-road riding. The most popular places for off-road riding were country parks, open countryside and bridle-ways. In terms of safety, far more mountain bikers wear helmets: 86% always wear a helmet compared to only 24% of general cyclists. Mountain bikers are more likely to wear a helmet when cycling off-road than when on roads; in contrast, there is a slight tendency for general cyclists to wear helmets more often when cycling on roads than when off-road. Mountain bikers carry out much more maintenance and care on their ATBs, regularly replace worn out or damaged components and are more likely to have them serviced, although two thirds of general cyclists do claim to maintain their bikes.

8.4 Accidents involving ATBs

A number of sources of information were used to identify accident rates and scenarios with ATBs. These were:

• *Literature*	Published research and commissioned reports
• *OPCS*	Annual statistics of cyclists killed in road accidents in England and Wales, taken from death certificates.
• *Department of Transport*	Annual statistics of cyclists killed on the roads in Great Britain, taken from police reports.
• *HASS/LASS/HADD*	Accident and death statistics and follow-up interviews.
• *RoSPA*	Reports of accidents from other safety organisations, cycling organisations, press cuttings and the public.
• *Trading Standards*	Notification from the public of incidents involving ATBs, particularly where failure of the product has occurred.
• *CPSC (USA)*	Monitors consumer safety and operates NEISS (The National Electronic Injury Surveillance System) but does not publish annual accident rates.
• *PORS (The Netherlands)*	The Dutch Home and Leisure Accident Surveillance System.

- Surveys of cyclists — Information on accident rates and scenarios was collected from the general public and from 'mountain bikers' in the surveys described in the previous section.
- *Cycling organisations*[2] — None of these organisations operate an accident monitoring system.

8.4.1 Cycling fatalities

Approximately 250 adults are killed in cycling accidents every year (OPCS, 1992) and nearly all of these accidents happen on the roads. However there is no comprehensive method for recording deaths other than on public highways and so it is not known how many cyclists might be killed while cycling off-road. There was information available from OPCS however, who commissioned a special report into sporting/leisure fatalities during 1992. They found five of these were cycling fatalities (all adults), three of which were during time trials (OPCS, 1993). None of these systems or studies recorded the type of bicycle being ridden.

Reports of three fatal incidents involving ATBs were received by Trading Standards offices between 1990 and 1994. One was caused by a quick release front wheel becoming loose, one as due to poor maintenance combined with cycling near a canal and the third was caused by hitting a log while riding off-road. Eight ATB deaths were reported in the USA between 1985 and 1993.

8.4.2 Cycling injury rates

Likewise the sources of information on cycling *injuries* were conflicting and incomplete. The Department of Transport recorded 3742 serious and 20,256 minor injuries to cyclists on the road in Great Britain in 1992, based on police reports (DoT,

[2] ACT - *The Association of Cycle Traders*
BAGB - The Bicycle Association of Great Britain
BCF - The British Cycling Federation
BMBF - The British Mountain Bike Federation

1993). A report by the Transport Research Laboratory (TRRL, 1989) however found that 68% of cycling injuries treated in A & E departments had not been recorded by the police. This would put the annual injury rate in Britain at around 75,000 per year. National estimates from LASS for the UK (ie including Northern Ireland) put the injury rate even higher than this, at around 100,000 in 1995 (table 8.5). Table 8.5 also shows that according to LASS around 10 per cent of all cycling injuries were sustained on ATBs, and while there was no noticeable increase in the annual rate of cycling accidents on all bicycles, the number of injuries sustained on ATBs increased dramatically from 1987 to 1995.

	HASS	LASS			
	all bikes	all bikes		ATBs only	
Year	no. of records	no. of records	National Estimates	no. of records	National Estimates
1980	582				
1981	690				
1982	602				
1983	820				
1984	878				
1985	666				
1986	644				
1987	776	1,764	94,000	1	n/a
1988	983	4,231	148,000	15	n/a
1989	1,169	4,755	168,000	139	4,907
1990	1,029	4,628	126,000	338	9,193
1991	1,036	5,367	153,000	513	14,621
1992	728	4,886	139,000	532	15,108
1993	893	2,622	132,152	500	12,425
1994	990	2,490	102,840	490	9,981
1995	1,093	2,872	105,000	586	10,712

Table 8.5 - Number of UK cycling injuries recorded by HASS/LASS and consequent national estimates according to bicycle type.

8.4.3 Accident scenarios

The details of all ATB accidents recorded by LASS between 1987 and 1992 were reviewed - a total of 1538 injuries. The majority of injuries were attributed to rider

error, road surface conditions or unexplained 'falls', and just under 5% (72) were assigned to problems with the bicycle or its components. Of 532 ATB injuries recorded in 1992, approximately four times as many males than females were injured on ATBs (84% males) and the majority (67%) were children. Most accidents occurred on the road although a higher proportion of children were injured on the roads than adults: 82% of children were riding their ATBs on the road compared to 57% of adults, and 27% of adults were injured riding in parkland or open countryside compared to 12% of children.

A more in-depth analysis of accidents was then made by interviewing a sample of those injured during 1992. 128 of the 532 people recorded by LASS that had given their permission to be contacted after their accidents and were sent postal questionnaires (shown in Appendix 8.3). A response rate of twenty eight percent gave 36 incidents available for analysis. Three quarters were regular cyclists who cycled at least once a week and for a minimum of three hours a week; a third of the sample cycled every day. Sixty percent had ridden their ATB off-road and most of those were regular off-road riders: 'off-road riding' included bridle-ways, national parks, woodland, cross-country and 'tracks'.

Over a third of the 36 accidents investigated occurred while 'mountain biking'. These included:

- cycling off-road - five accidents happened while cycling in open countryside, two in country parks and one on a dirt track
- trying tricks - two accidents happened while trying to do jumps and one while riding over a BMX ramp
- mountain bike races - two accidents occurred during races.

Just over half of the incidents investigated were due, in the opinion of the injured person, to either lack of skill, not paying attention or going too fast. Five were caused by problems with the bike: three were failing brakes, one because something became caught in a wheel and lastly a rear wheel came loose. Nearly two thirds of the sample (21) had experienced more than this one cycling accident.

8.4.3.1 Accidents amongst general cyclists

In order to elucidate the information from LASS victims, the sample of 300 adult regular, 'general', cyclists (contacted in the survey described in the previous section) were asked about any accidents they had been involved in. This gave information on accidents resulting in injuries other than those likely to be treated and hospital A & E departments.

A third of the sample (36%) had had a cycling accident within the last five years. Most of these (73%) were on roads. The remainder had happened off-road, and on all types of bike. The cyclists were asked to describe any accidents that they considered to be serious. Of a total of 104 accidents, 44% had happened while riding ATBs. Of the ATB accidents, 30% were caused by other vehicles (including cars and other cyclists), 26% were due to a lack of experience or skill and 24% were due to the type of terrain being ridden or hitting obstacles. Of the accidents that happened on other bikes, a larger proportion were due to other vehicles (36%) and to inexperience and skill (31%) while less were due to the terrain (15%). Three accidents were caused by problems with the bikes (a broken fork, a broken wheel and a slipped stem) but none of these were ATBs.

8.4.3.2 Accidents amongst mountain bikers

The survey of members of mountain bike clubs (described in the previous section) also provided information about accidents. The majority of the riders (84.5%) had had accidents while cycling off-road compared to 39% while cycling on roads. Not all the accidents had resulted in injury: nine had what they considered serious accidents off-road, and four had had serious accidents on roads.

Accidents occurring off-road were mainly due to terrain, for instance, hitting obstacles, catching wheels in ruts, slippery surfaces, foliage and so on. Other causes, in descending order were: a lack of skill (not being able to control the bike, feet caught in pedals etc); trying tricks or stunts (such as jumps) and excessive speed.

Accidents on roads were most commonly caused by cars or other traffic. Three accidents had been caused by product failures; a loose stem, failed brakes and a split front wheel.

8.5 Evaluation methodology

The review of the ATB market and attitudes of cyclists suggested that ATBs were now the most popular style of bicycle, and that riding all types of bicycle 'off-road' or on rough terrain had become common place. Accident analyses had not indicated any accident scenarios specific to ATBs. The evaluation of safety therefore concentrated on assessing the suitability of the range of ATBs for this change in cycling behaviour and the type of cycling terrain for which they were now being used. The aims of the evaluation were to:

- assess whether certain types of bike would present a risk to off-road use as a result of product failure
- identify how failure might arise
- identify which type of activities would be most likely to cause failure.

A range of ATBs were chosen to be subjected to typical off-road activities. The stresses produced in the bike frame would be recorded and used to indicate which elements of the frame, and which bikes, might be susceptible to damage. This was done in two stages of tests. Firstly field trials with experienced ATB riders were used to measure the stresses produced in a top-level ATB during a variety of typical off-road riding scenarios. The results were to be used to set the parameters for laboratory simulations of these activities. Laboratory simulation tests were then used to systematically replicate and repeat these activities and allow systematic, reliable and reproducible assessments of off-road impacts across the full range of test bikes.

8.5.1 The test ATBs

Seven models of bicycles sold as ATBs were tested, ranging in price from £100 to £860 and considered to be representative of the ATB market according to the classification produced in table 8.3. The details of the bikes tested are shown in table 8.6

Bike no.	Frame material	Handlebar material	Construction	Price
1	Cro-mo	Aluminium	TIG welded	£860
2	Titanium/Cro-mo	Titanium	Bonded	£565
3	Aluminium	Aluminium	TIG-welded	£400
4	Cro-mo	High Tensile steel	TIG welded	£350
5	High Tensile steel	High Tensile Steel	TIG welded	£189
6	High Tensile Steel	High Tensile Steel	TIG Welded	£169
7	High Tensile steel	High Tensile steel	TIG welded	£100
8	High Tensile steel	High Tensile steel	TIG welded	£100

Table 8.6 - The test ATBs

8.5.2 Field trials

The field trials were undertaken by an experienced rider taking the bike over a closely specified, simulated course of obstacles, set after discussions with experienced off-road riders and designed to represent many situations faced in off-road riding (figure 8.1). Table 8.7 lists the activities undertaken. The rider weighed 66 kg (23rd percentile adult male[3]) to provide a conservative level of 'rider loading'. Loads typical of those encountered in off-road riding were measured using three strain gauges (for longitudinal, rotational and shear directions calibrated from measured forces) at fifteen points on the bike (shown in Appendix 8.4) and related to activity by using videotape of the trials. Results from the field trials were used to identify bike parts which suffer highest loading and the activities which produce the high loading, and to set loads which could be replicated consistently in laboratory tests across the whole sample of ATBs.

[3] compared to data from Pheasant, 1996

	Activities during the field trials
1	Front Braking (sharp front braking from 15 kmh^{-1} to a stop)
2	Rear Braking (sharp rear braking from 15 kmh^{-1} to a stop)
3	Rear wheel vertical impact from a height of approx. 240 mm
4	Front wheel vertical impact from a height of approx. 240 mm
5	Two wheel vertical impact from a height of approx. 180 mm
6	Front wheel horizontal impact (ride into a wall at) 12 kmh^{-1}
7	Front wheel horizontal impact with obstacle (ride over 100 mm obstacle at 15 kmh^{-1}) (obstacle was a roadside kerb)
8	Ride down shallow steps at 10 kmh^{-1}
9	Uphill sprinting from 0 - 20 kmh^{-1}

Table 8.7 - Activities during the field trials

The field trials identified the following activities as producing consistently high stresses:

- Front wheel horizontal impact (ride into a wall) at 12 kmh^{-1}
- Front wheel horizontal impact over obstacle (ride over obstacle) at 15 kmh^{-1}
- Front wheel vertical impact
- Two wheel vertical impact

Much higher stresses were generated by the impact activities than by riding down steps for instance. Examples of the greatest stresses were: 540 MPa in the down tube, 396 MPa in the forks and 414 MPa in the seat stays, all in the horizontal impact into a wall at 12 kmh^{-1}, and 216 MPa in the handlebar stem and 144 MPa in the down tube during a front wheel vertical impact from about 240 mm.

8.5.3 Laboratory trials

Laboratory simulation tests followed the field trials and a number of activities were simulated and replicated across the sample of ATBs, mainly vertical and horizontal

Figure 8.1 - The field trials

impacts. The aims of the laboratory tests were to identify if and when failure of the bikes would occur so as to provide comparative performance data between bikes and possibly suggest limits to use. It was important to replicate the off-road riding activities evaluated in the field trials as closely as possible in the laboratory while using a system which could perform the activities repeatedly and accurately. Therefore special testing equipment was developed.

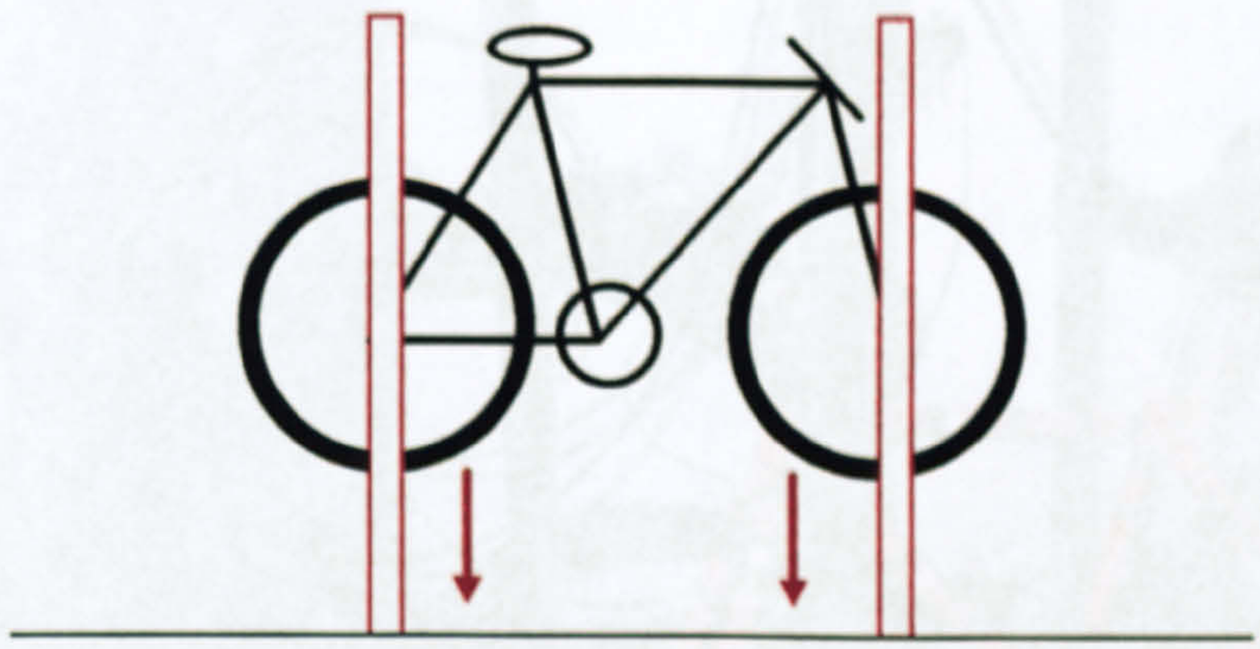
8.5.3.1 The vertical impact rig

This was designed and manufactured to replicate the rear wheel impact, front wheel impact and two wheel vertical impact (figure 8.2 and 8.3). This allowed either the front, rear or both wheels of the bike to be dropped from a given height. The rig was adjustable so that bikes of different sizes could be tested and a variety of dropping heights could be used.

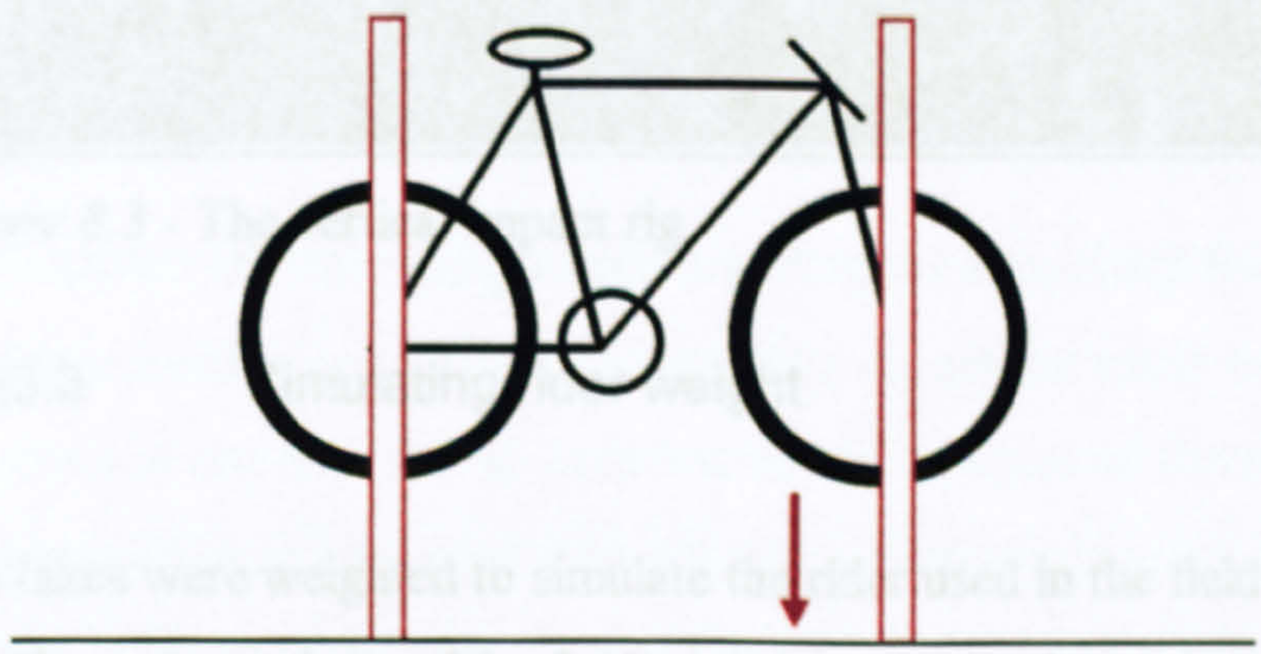
The bike was held by the handlebars and by the seat with specifically designed grippers. A special T-shaped attachment was used in place of the seat. The grippers were withdrawn simultaneously by a pneumatic system allowing the front and rear ends of the bike to drop simultaneously for the two wheel vertical impact test.

8.5.3.2 The horizontal impact rig

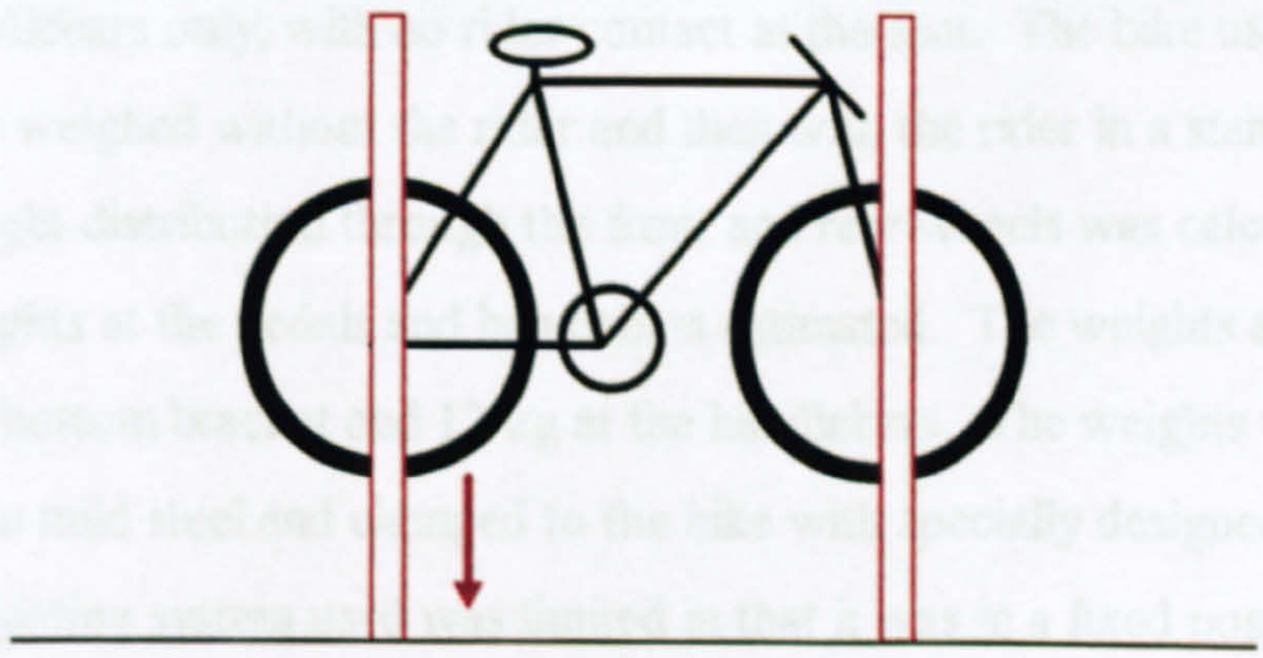
This was used to replicate horizontal front wheel impacts into a wall and riding over an obstacle on the ground. The bike was propelled by means of an elasticated rope which was fed through the main triangle of the frame so that it pulled the bike towards the wall from the head tube. It was possible to achieve consistent impact speeds by withdrawing the bike specified distances. Horizontal impacts over an obstacle were also performed on this rig. For these tests the obstacle was a concrete block of similar dimensions to the roadside kerb used in the field trials. To keep the bike stable a set of stabilisers were manufactured and an attachment fitted into the seat tube.



two wheel impact



front wheel impact



rear wheel impact

Figure 8.2 - The vertical impact rig

Figure 8.3 - The vertical impact rig

8.5.3.3 Simulating rider weight

The bikes were weighted to simulate the rider used in the field trials, who weighed 66 kg. From the analysis of the field trials it was established that in all of the off-road riding activities the rider was in a standing position to ensure stability and control. Weights were therefore applied through the pedals at the bottom bracket and on the handlebars only, with no rider contact at the seat. The bike used in the field trials was weighed without the rider and then with the rider in a standing position. The weight distribution through the front and rear wheels was calculated and the correct weights at the pedals and handlebars estimated. The weights applied were 54 kg at the bottom bracket and 12 kg at the handlebars. The weights were manufactured from mild steel and clamped to the bike with specially designed fixtures. The weighting system used was limited in that it was in a fixed position on the bike. It is acknowledged that during riding the centre of mass of the bike and rider changes during different activities. Also the centre of mass was lower than it would be with a real rider as the body's centre of mass is above the bike.

8.5.3.4 Test parameters

For the horizontal impact tests (into the wall and over the obstacle) it was decided to use lower speeds than the 12 kmh^{-1} and 15 kmh^{-1} used in the field trials as damage had been caused to the field trial bike during these activities. Impact speeds of 3 kmh^{-1} were achieved by withdrawing the bike 640 mm from the wall or obstacle.

In the vertical impact rig, the dropping distance from the bottom of the tyres to the floor for the two wheel impact was 180 mm. For the front and rear wheel impacts the bike was held at the same height but the angle of the bike made the distance from tyre to floor around 240 mm. These distances replicated the impact heights in the field trials but generally resulted in higher stress recordings.

8.5.3.5 Order of activities

The number of strain gauges used was reduced from forty-five (used in the field trials) to twenty-four. The data recording equipment could only record eight channels at one time and so each test had to be repeated three times. Ideally a new bike should have been used for each test carried out but this was not economically viable. The activities were carried out sequentially according to the procedure shown in table 8.8.

Test no.	Sequence of tests in the laboratory simulations
1.	Rear wheel vertical impact from 240 mm
2.	Two wheel vertical impact from 180 mm
3.	Front wheel vertical impact from 240 mm
4.	Repeat 1, 2 and 3 with next set of gauges
5.	Repeat 1, 2 and 3 with final set of gauges
6.	Horizontal impact over obstacle at 3 kmh^{-1}
7.	Horizontal impact into wall at 3 kmh^{-1}
8.	Repeat 6 and 7 with next set of gauges
9.	Repeat 6 and 7 with final set of gauges
10.	Repeat 1, 2, 3, 4 and 5 with heights increased by 50 mm
11.	Repeat 6, 7, 8 and 9 with impact speeds of 6 kmh^{-1}

Table 8.8 - Order of activities carried out in laboratory simulations

Most of the bikes failed by being damaged beyond use before the full set of activities had been completed. All of the tests were recorded on video and photographs were taken regularly during testing to record any visible damage to the bikes. Dimensional measurements were taken to quantify physical damage.

8.5.3.6 Results

The highest stresses recorded via resistance strain gauges across the whole sample of bikes are shown in table 8.9. Quantitative results showed that certain parts of a bike tended to be subjected to higher stresses than others and that activities influenced the type and magnitude of the stresses. In all of the bikes, stresses were measured which exceeded the Yield Stress (YS) and Ultimate Tensile Stress (UTS) estimated for the frame material, indicating the risk that deformation, damage or failure of the frame members might arise (table 8.10). (It should be noted that detailed mechanical specifications of frame materials were not available from most of the manufacturers and so estimated values for the mechanical properties of each frame material had to be used).

	Activities				
Bike Part	Rear wheel vertical impact	Two wheel vertical impact	Front wheel vertical impact	Horizontal impact over obstacle	Horizontal impact
Handlebars	630	810	-810	-378	-306
H'bar Stem	-630	-1260	-864	-74	-128
Down Tube	-630	-900	-378	1580	1800
Right Fork	-450	-1026	-396	900	3150
Left Fork	-324	-1440	-756	-666	-1800

Note: -ve values are tensile stresses and +ve are compressive stresses

Table 8.9 - Gauge positions and activities resulting in the highest stress recordings in laboratory trials (all values in MPa)

	Bike number							
Bike Part	1	2	3	4	5	6	7	8
Handlebars								*
H'bar stem	*							
Down tube		*	*	*	*	*		*
Right fork			*	*		*		*
Left fork			*	*		*	*	*

Table 8.10 - Parts of bikes where the stress exceeded the yield stress (suggesting potential damage to the bike member)

Horizontal impacts over an obstacle resulted in high levels of stress and these increased with more severe impacts (into a wall at 3 kmh^{-1}); stresses were recorded above the estimated UTS values in five out of the six bikes tested in this way. The highest priced bike was the only bike not to exceed the estimated YS or UTS in this activity. Vertical impacts from heights of 180 to 230 mm caused stresses above UTS values in four of the seven bikes with higher stresses generated from the greater heights. In terms of the location of the stresses within the bike, in all but one of the bikes the highest stresses were recorded in the forks and in the down tube. In the highest priced bicycle (bike 1), high stresses were recorded in the forks and down tube but the largest stresses were measured in the handlebar stem (see table 8.9). The performance of the bikes is compared in table 8.11 which shows the number of trials each bike survived before damage precluded any further tests.

		Bike no. & price							
Test number	Type of impact	1 (£860)	2 (£565)	3 (£400)	4 (£350)	5 (£189)	6 (£169)	7 (£100)	8 (£100)
1-9	vertical							8	9
10-15	horiz								
16-24	vertical						18		
25-29	horiz	30	30	24	30	30			

*Note - **bold** numbers indicate the number of trials completed before bike failure or severe damage*

Table 8.11 - Comparison of bike performance in laboratory trials

In addition to stress measurements, damage was observed in all of the bikes (figures 8.4 to 8.7). Three bikes failed when forks bent upwards away from the frame by up

to 120 mm (figures 8.4 and 8.5). The others exhibited failure either in the frame (figure 8.6) or in the front of the top and/or down tubes which caused the front dropouts to be pushed back towards the frame (figure 8.7).

The results have indicated a high degree of variability between bikes. In terms of the 'materials/price' classification of ATBs, there were notable differences in performance related to price, particularly at the high and low ends of the price range. The most extreme damage for all bikes was produced in the two lowest price bikes (£100) following just eight and nine vertical impacts, while the highest price bike appeared to suffer little damage and only recorded stress over the UTS in one part of the bike (the stem). Within these price limits the performance of the bikes varied, and there was less relationship to price; one model retailing at £189 resisted severe damage while another at £565 sustained damage in the top and down tubes. This could be attributable to differences in the performance of the materials. In addition, differences in design, namely in fork design, were noticed. Unicrown (one piece) forks failed at the bend near the top whereas bikes with straight forks resisted damage in the forks with damage being transferred to the front of the frame.

8.6 Discussion

ATBs now account for two thirds of all new bicycles sold in the UK and their popularity appears sustainable. The market has expanded from the initial specialist market of adults who wanted to ride off-road, to being today's conventional bicycle. With the popularity of ATBs and the publicity surrounding mountain biking, cycling off-road is increasingly common-place amongst the general cycling population and it should be expected that all ATBs might be used on rough off-road terrain. Although most cycling accidents still occur on roads, it has been suggested by this study and elsewhere that those who regularly cycle off-road are likely to have a higher number of accidents than those who cycle on roads, even if these are not necessarily more severe.

Figure 8.4 - Damage to bikes following the laboratory tests (severe deformation of the forks)

Figure 8.5 - Damage to bikes following the laboratory tests (severe deformation of the forks)

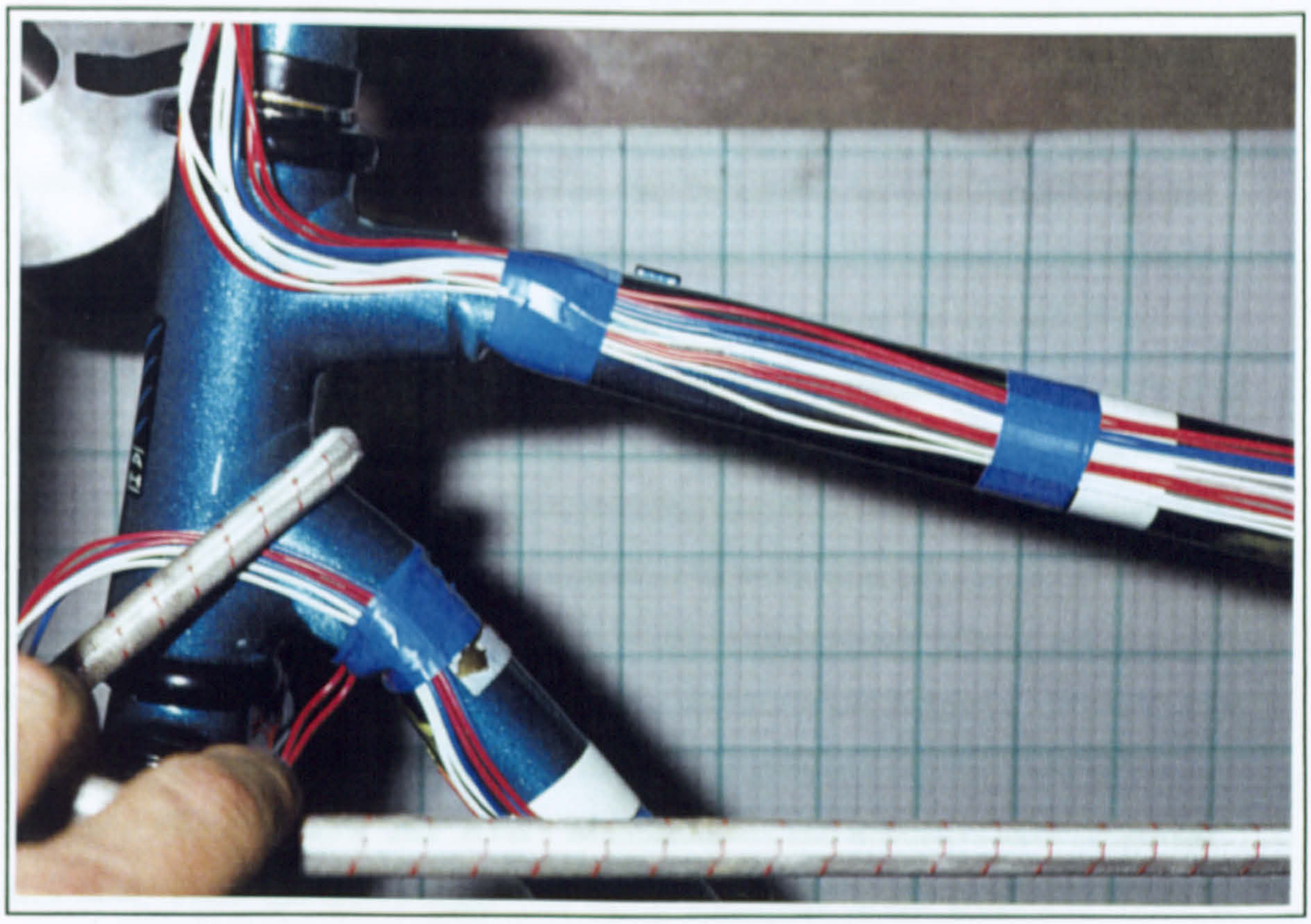


Figure 8.6 - Damage to bikes following the laboratory tests (damage to the top and down tubes)

Figure 8.7 - Damage to bikes following the laboratory tests (front forks pushed backwards)

While there has been an increase in the number of non-RTA injuries involving ATBs, only a small number of injuries have been associated with bike failure. There is however some concern that not all ATBs may be suitable for extended off-road use. The ATB market is wide and varied; bikes sold as ATBs are present in the low end of the general cycle market and there is rapid development at the top end of the market with the introduction of new, lightweight frame materials. Some classification of the market is therefore necessary but this should be robust enough to cope with its changes. Price has been proposed as a potential classification criterion although it is acknowledged as possibly a transitory criterion in terms of policy decisions. However price is used by the retail trade to differentiate classes of bike and is used likewise in purchase advice in the cycle press. Both sources suggest a threshold price for ATBs intended for regular off-road use, which leads to a possible view of two tiers of ATB, ATB style and ATB . Manufacturers and importers have supported this view. There has been a suggestion also of a possible further grading of ATBs, as suitable for different levels of off-road use, perhaps moderate and severe.

This study has produced methods for performance testing. Laboratory replications of off-road use have been used successfully to compare the performance of a range of ATBs tested under impact conditions. The most likely modes of failure of ATBs under these conditions have been identified as deformation of the forks and of the front of the top and down tubes. Differences in the performance of the bikes were noted, to some extent related to price, in that the lowest price bikes (£100) failed quickest and the most expensive bike (£860) suffered least damage. However, between these price limits differences in performance were not strongly related to price. In terms of design, some differences in performance were noticed between the two primary fork designs - unicrown (one piece) and non-unicrown - particularly in vertical drops, in that the former tended to bend at the top of the forks.

The activities most likely to produce failure of the bike were identified, as impact into a wall, impact into and over a low obstacle, and vertical impacts onto the front or onto both wheels. All of the activities simulated in the trials are likely to be infrequent for inexperienced riders, but were considered to be moderate off-road

impacts by experienced off-road riders. It is acknowledged that impacts into a wall are likely to be rare, but these tests were carried out conservatively at low speeds and with low weight riders.

The test programme has been successful in comparing a range of ATBs and similar programmes can be used to suggest some limits to ATB use. However test protocols to be incorporated into standards may require three elements: technical laboratory simulations with repeated impacts and systems of weights to simulate a range of riders; limited and controlled field trials with force measurement (and stresses) directly linked to particular activities undertaken by test riders; and extended field performance tests over longer "standardised" test tracks.

8.7 Conclusions and recommendations

A formal report was issued to the DTI CSU on this investigation. A number of recommendations were made to reduce the number of injuries associated with ATBs and the report was used by government to assess these potential routes to improvements in safety.

8.7.1 Standards

Standards bodies should address off-road bicycles with a thorough review, and either replacement or strengthening, of BS 6102, which was produced without ATBs in mind. It is largely recognised as inadequate in a number of respects, since it does not allow for the different design of ATBs, the more demanding stresses put on all the various components or the type of terrain encountered off-road. New standards should also include impact performance tests, whether in field track conditions or in the laboratory. Finally, a new standard should allow for a graded or tiered system of performance requirements and approaches, as suggested above.

8.7.2 ATB design

The design of ATBs, especially as it relates to the performance of brakes and gears and the ease of use of adjustment mechanisms, should be re-examined by producers in the light of increased demands from off-road riding being taken up by a more 'naïve' public.

8.7.3 Manufacturer and retailer guidance

As a first step, consideration should be given to the range of bicycles now being sold as ATBs, particularly those 'ATBs' or 'ATB-style' bikes which are unlikely to be suitable for off-road use. There are a number of options to address this issue. As a minimum, information and guidance should be given at the point of sale on the suitability (or not) of bicycles for off-road use. An industry-wide voluntary performance-based grading system of ATBs/ATB style bikes might be introduced, perhaps leading to a safety standard, to indicate suitability and safety for off-road use.

8.7.4 Maintenance of ATBs

Most of the accidents reported as caused by technical problems with the bike are attributed to problems with brake and gear systems. These often fail due to poor set up and poor maintenance, although this is not specific to ATBs. There could be some consideration given to ensuring correct set up and maintenance of brakes and gears throughout the ATB life cycle, perhaps as part of a promotional service from manufacturers or retailers to the public.

8.7.5 Publicity

Publicity is needed to inform the general public on the specific risks of off-road riding, including information on the frequency of accidents off-road and the potential mode of failure of bikes under impact conditions (ie forks and down/top tubes). This information should be directed to ensure that bikes are inspected and maintained

regularly, that riding is adjusted according to bike standard, rider ability and terrain, and to highlight those specific off-road activities that may cause failure (impacts into walls or low obstacles, two wheel and front wheel drops even from low heights). Helmets are important when riding off-road, not least because of the possible high frequency of accidents; the lack of severe injury amongst regular off-road riders may be due to a high rate of helmet wearing and this should be strongly encouraged, along with other protective clothing. Most importantly, intending purchasers should be informed about the wide variability, and thus suitability, of ATBs on the market.

8.8 Outcome

In parallel with this research, but without our prior knowledge, relevant bodies (eg ISO and the Bicycle Association of Great Britain) have been exploring the use of performance standards rather than construction/dimension standards for bicycles used in off-road riding. An ISO committee (ISO TC 149/SCI) has now been established to look at off-road bicycles, with working groups looking at Fatigue and Impacts (WG4), Brakes (WG5), and General issues (WG8). WG8 have identified the following components as needing more stringent requirements than presently exist if we are to have a standard appropriate for off-road riding: frames, forks, handlebars and stems, seat pillars, saddle assemblies, crank assemblies, wheel assemblies, literature/instructions, tyre clearance, and chain wheel guarding. WG4 are assessing the use of performance tests and tests have taken place in the UK, France, USA and Japan with an experienced 'standard weight' rider over a 'normal' route with recording of impact forces at the fork, handlebar, saddle-pillar and pedal/crank and videotaped performance for comment and analysis. The incorporation of performance tests into bicycle standards would, at a minimum, provide a technical input to the grading of ATBs thereby allowing a better matching of ATB to the user's expectations and intended use.

Chapter 9 - Case study: The safety of stepladders in the home

9.1 Introduction and aims

One person is killed nearly every week in the UK using ladders and stepladders around the home (HADD, 1995). It is unknown how many of these deaths are stepladder accidents, due to the way fatality data are classified by OPCS, but most are assumed to be accidents with leaning ladders. However if non-fatal accidents with ladders and stepladders are considered, nearly three times as many people are injured in falls from stepladders than from leaning ladders with approximately 14,000 people treated at hospital Accident and Emergency departments each year (HASS, 1995). This suggests that accidents in the home with stepladders are much more common than accidents with leaning ladders, although when accidents happen they are less likely to be fatal. In fact, stepladders have one of the highest rates of accidents associated with any product in the home; the only products associated with more accidents in the home (excluding furniture and architectural features) are knives and hammers (DTI, 1995). Concern over this extremely high number of injuries prompted an investigation into the design and safety of stepladders for use in the home, funded by the DTI Consumer Safety Unit.

The aims of the research were to:

1. define and classify the stepladder market
2. identify accident trends and scenarios
3. specify typical use of stepladders

4. identify accident causation mechanisms
5. identify possible routes to improvements in stepladder safety.

9.2 Definition of the products and the stepladder market

An analysis of the stepladder market was carried out to establish the range of products available in the UK. Information on materials, design, standardisation, recommended use and safety was acquired through a nation-wide survey of manufacturers, suppliers, retailers and the trade association.

9.2.1 Stepladders in the UK

Aluminium stepladders dominate the UK retail market. Stepladders are also manufactured in steel, fibreglass and wood but in much smaller numbers, and the latter two are used mainly for trade use. There are two principle designs of stepladders: 'one-way' stepladders (the commonest, usually with a platform to stand on and usable only as a stepladder) and combination stepladders (which can be used as a stepladder or leaning ladder).

Eight or nine manufacturers dominate the UK market. There are few imported stepladders, imports being financially prohibitive due to their bulk. There is only a small hire market for stepladders because they are such a common and relatively inexpensive household product. The volume and variety of sales is concentrated through the large DIY multiples. At the time of the study a domestic aluminium stepladder ranged in price from around £15 to £100.

9.2.2 Standards

Two standards have UK jurisdiction for the manufacture of ladders and stepladders: BS 2037:1994 and BS EN 131:1993. The British Standard has two Classes of stepladder: Class 1 for industrial use and Class 3 for domestic use. A third Class (Class 2) was withdrawn around 1993 due to the introduction of BS EN 131, the European Standard. This has no Class rating system but it is considered to be similar to the withdrawn British Standard Class 2. A comparison of the British and European standards found that they use similar test techniques but both lack stability, fatigue and performance based tests (for example the test of static loading is not representative of realistic loading). The European Standard appears more rigorous in terms of testing than the British Standard but has a major deficiency in that it does not contain any requirements for safety labelling, unlike the British Standard.

The majority of stepladders available in the UK conform to the British Standard and the majority are manufactured to the Class 3 duty rating. Class 1 stepladders are more expensive and manufactured in smaller numbers. Very few were found manufactured to the European Standard.

9.2.3 Labelling and product information

The majority of the stepladders sold in the UK are labelled with safety information. The British Standard, to which most stepladders conform, lists the following seven messages which must be permanently labelled on the stepladder:

1. Never use damaged equipment
2. Ensure firm and level base
3. Check for hazards at top
4. Avoid electrical hazards
5. Avoid over-reaching
6. Keep a secure grip
7. Never stand on the top rail

Additional guidance, although not required as part of BS 2037, is found on most UK stepladders:

8. Select the correct stepladder for the job
9. Don't use sideways on to a job - always face the work
10. Check stepladder is correctly and safely assembled and locked into position
11. Regularly check your stepladder and check for damage or wear
12. Don't use to reach another level or greater heights - always have both feet on the stepladder
13. Don't exert sideways pressure
14. Don't use when folded (closed)
15. Always store properly
16. Ensure treads are clean
17. Ensure stepladder feet are in place and replace if worn
18. Wear flat, firm soled shoes

The British Ladder Manufacturers Association (BLMA) produce a ten point safety label for stepladders (figure 9.1) although most manufacturers use their own labels (figure 9.2). Other than these standardised labels there is little other information on the products, on the packaging or at the point of sale. In particular there is no information explaining the Class rating system or about purchasing the correct stepladder for the correct job. Packaging on one model showed the user in a sideways position on the stepladder contrary to advice in the safety labelling.

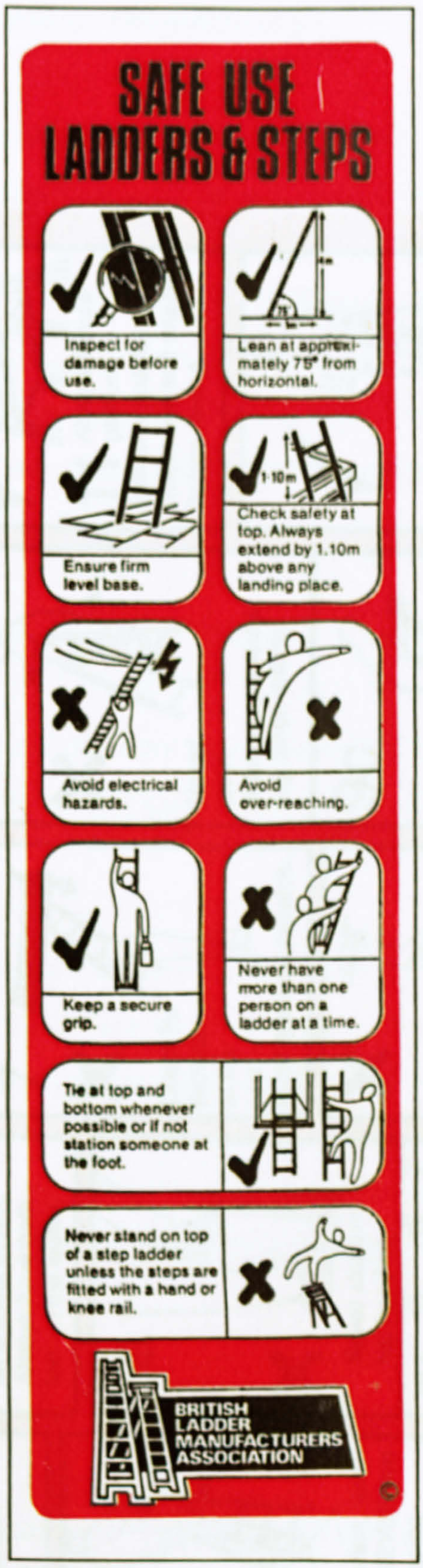


Figure 9.1 - British Ladder Manufacturers' Association (BLMA) stepladder label

STEPLADDER SAFETY INSTRUCTIONS

BS2037:1994
LICENCE No. 3806

1 NEVER use a damaged stepladder. ALWAYS ensure that treads are dirt and grease free. ALWAYS ensure that all feet are in place and replace if worn. ALWAYS ensure that your stepladder is of sufficient height for the job in hand and that you ALWAYS wear flat bottomed and firm soled shoes.

2 Ensure firm, level base, NEVER use on soft or sloping ground.

3 Do not modify or repair this product in any way.

4 Never have one foot on the ladder and one on another object. Always have both feet on the ladder.

5a Never stand on top handrail.

5b Never stand on back crosstube.

6 Never have more than one person on a stepladder at a time.

7 Check for hazards at top and avoid electrical hazards.

8 Never use a stepladder to access greater heights e.g. lofts.

9a Do not overreach otherwise you risk losing your balance or damaging ladder.

9b Never exert sideways pressure e.g. when drilling.

9c ALWAYS use the stepladder facing your work.

10 Never use the ladder in closed position.

LOCK & RELEASE

11 Always ensure platform is locked in position before use and release before closing.

12 Keep a secure grip when climbing up and down the stepladder.

CLASS 3 DOMESTIC DUTY RATING 95kg. (15 STONE)

Figure 9.2 - Individual manufacturer's stepladder label

9.3 Domestic use of stepladders

A survey of consumers was undertaken to investigate the extent of stepladder ownership and frequency of use, with the aim of estimating exposure rates. The survey was in two parts: an omnibus telephone survey of 1,023 British adults was commissioned to identify the percentage of UK homes owning a stepladder (carried out by the British Market Research Bureau) followed by on-street, face-to-face interviews of 329 users of stepladders (defined as using a stepladder at least once a year) to investigate patterns of use. These interviews were carried out by trained interviewers in three cities around the UK.

9.3.1 Numbers of stepladders in use

The omnibus survey found that over three quarters (77%) of British households have a stepladder. Over half are used at least once a month and the majority (93%) are used at least once a year.

Most people buy stepladders from new, although around 17% had second-hand stepladders which had either been bought or given to them. The average purchase price was £27. Two-thirds of stepladders in use were 'one-way' stepladders (with a top platform designed for standing on) and the rest were combination stepladders. Five or six treads were the commonest although a third had seven treads or more. They were either aluminium (69%) or wood (20%); wooden stepladders were likely to be older than the aluminium ones.

9.3.2 Stepladder users

Males and older respondents were more likely to be the main user of the stepladder in the home. Males said they used the stepladder twice as much as females and the 55-64 year old age group used the stepladders the most (three times a month).

9.3.3 Stepladder uses

Stepladders were most commonly used for painting and decorating and over half the respondents said they used them for this. A third of the sample said they used a stepladder for DIY, a third for cleaning and another third for access to a loft or to different levels. Two thirds said they had at some point used the stepladder in the garden.

9.3.4 Safe use

When asked how they used their stepladders the majority of respondents (80%) said that they had used them side-on to the task (which is warned against in current safety labelling) and over a quarter said they had stood backwards on the treads; both of these behaviours were more common in men than in women (41% compared to 14%). Of the 208 users who owned one-way stepladders, 13% had used it as a leaning ladder, that is, unfolded against a wall. Most respondents had never carried out any maintenance or repairs to their stepladder.

9.3.5 Safety labelling

Only a third of users were aware of any safety labelling or instructions on their stepladder. Seventeen percent of these said that they had never read them and just over a third said they had read them only once. Of those that said they had read them, the most frequently recalled messages were 'make sure the stepladder is locked into position / make secure' (54%) and 'use on an even surface' (16%). Most answers were general in nature, such as 'general safety tips' or 'what you can and can't do with them'.

Over half the total sample were not aware, or could not remember, if their stepladder complied with any standards. Similarly the majority of respondents did not know if their stepladder had a class rating and three quarters did not know what this meant.

9.4 Accidents involving stepladders

To investigate stepladder accident mechanisms a review of published literature and an analysis of UK, European and USA accident data were undertaken.

9.4.1 Review of literature

Stepladder accidents have been divided into two types, mechanical and stability failures. It has been suggested that the majority of falls seem to be associated with stability failure, and that although mechanical failure has been indicated in some incidents it has proven difficult to determine whether or not this was causative or occurred during the accident (Goldsmith, 1985b).

A study in the USA by Cohen and Li (1991) of over one hundred industrial stepladder accidents found over-reaching to be one of the most common causes of falling. Other causes included:

- lifting objects overhead
- using the ladder on uneven floors
- wearing incorrect footwear
- applying excessive force to surfaces and losing balance
- use of hand tools
- inappropriate use eg as a straight ladder against a wall
- standing on the top step (on a product not designed for this)
- climbing from the stepladder to another structure such as a roof
- mis-stepping or slipping on rungs

Falls during ascent and descent were most often associated with the ladder overturning or moving. This was attributed to the horizontal force created by the user getting on and off the ladder but contributory factors were identified such as a lack of appropriate handholds or rails, using stepladders which are not the correct height for the job and poor environmental conditions (such as poor lighting, confined space and surface slipperiness). Falls occur more frequently during descent than ascent of the stepladder

and that the final step is particularly hazardous as it is difficult to make the transition from the stepladder to the floor surface, possible because the distance between the floor surface and the bottom rung tend to be consistently less than the standard distance between the remaining rungs (Axelsson and Carter, 1995). Some have suggested that the majority of stepladder and ladder falls were preventable, possibly by consumers following safety guidance (Muir and Kanwar, 1993). A study by von Wolff et al (1989) of over two hundred cases in East Berlin from 1978 to 1983 found the majority of accidents were due to safety regulations not being obeyed.

Research has also looked at the potential for improvement in stepladder safety through design (Cummings and Nevitt, 1994). For instance, rung spacing has been studied and it has been shown that if spacing is too great, climbing is harder, more tiring and more dangerous in descent (McIntyre, 1979). Different shapes of rung have been suggested as a means of improving balance, as the foot is the optimal channel through which to supply feed-back information as it constantly adjusts and affects balance. Experimental work found that a rung curved at the sides improved feedback to the user that they were reaching the boundaries of their 'reach envelope' (Juptner, 1976). Other suggestions have been extending handrails over the top steps (Goldsmith 1985b, Ermon 1986) and making the bottom of stepladders broader (Bjornstig and Johnsson, 1984).

9.4.2 Accident analysis

A review of UK stepladder accidents was carried out using information from HASS, Trading Standards offices and interviews with accident victims, to establish rates of accidents and accident scenarios.

9.4.2.1 Accident rates

A review of HASS data over a six year period showed that there had been no noticeable change in the annual rate of injuries, suggesting that there had been no significant change in the use or design of stepladders in that time (table 9.1). People

aged over fifty-five were most likely to be involved in a *fatal* ladder or stepladder accident, but no particular age group appeared prone to injury. Twice as many men as women were injured, which corresponded to exposure data described above (table 9.2). However, USA data from 1994 showed that men and women had an equal number of accidents and in the Netherlands data from PORS (the Dutch home accident surveillance system) showed that females were twice as likely to have a stepladder accident as males.

Of the 329 stepladder users interviewed in the consumer survey described above, only 18 (5%) had had an accident with a stepladder.

Year	Stepladder injuries
1993	14363
1992	14409
1991	14516
1990	12778
1989	14914
1988	13690

Table 9.1 - Annual rate of stepladder injuries treated at A&E departments (*source: HASS national estimates*)

Age range (years)	males	females	Total
0-4	6	1	7
5-14	10	3	13
15-25	22	13	35
26-35	51	20	71
36-45	55	19	74
46-55	56	27	83
56-65	66	27	93
66-75	35	30	65
75 +	12	10	22
Total	313	150	463

Table 9.2 - Stepladder injuries treated at A&E departments by age and sex, 1992 (*source: HASS*)

9.4.2.2 Accident scenarios

HASS case listings for 1993 were examined for details of falls from stepladders. A total of 560 accidents involving stepladders were recorded that year, of which 493 were falls. Few details were recorded and by far the majority of the accident descriptions were simply 'falls' with no further information given. A survey of accident victims was conducted to try to establish detailed accident scenarios. Questionnaires were sent to 212 individuals recorded by HASS as having fallen from a stepladder in that year. These were expected to provide the most detailed information available on accidents. However only thirty-five questionnaires were returned and this poor response rate (16.5%) was attributed to the time delay between contact and the date of the accident (around 18 months), which is a symptom of the way HASS data are collected. The information on the questionnaires was often vague and inconclusive, and few conclusions could be made because of the small sample size.

It was therefore difficult to determine exact causes of accidents. As well as contact with HASS accident victims, many other data sources were examined, including published research, HASS accident rates, HASS case listings of specific accidents, information from consumers, Trading Standards, Environmental Health Officer, manufacturers, the trade organisation (BLMA), safety organisations such as RoSPA and from subjects in user trials (described later).

Trading Standards and Environmental Health Officers were surveyed nationally and around twenty cases of stepladder accidents were reported to the study. All of these cases involved apparent mechanical failure of the stepladder, the most commonly reported damage being buckling to the bottom of the stile(s), consistent with a sideways fall, either from over-reaching or using the stepladder sideways. However some doubt remained over whether such damage would occur before or during a fall and led to concern over how suitable stepladders are for sideways use. In most cases

the main cause of accidents was eventually reported as misuse, 'misuse' being interpreted as using the stepladder sideways to a task or on an uneven ground. Combining all of this information, the most common accident scenarios appeared to involve the user mis-stepping, slipping and over-reaching, using the stepladder sideways and/or the stepladder slipping or tipping.

9.5 Evaluation methodology

The accident analysis had suggested that task factors(ie the way the stepladder is used) were contributing to the risk of stepladder accidents, and in particular, 'misuse', as interpreted by manufacturers and the British Standard in their safety labelling requirements.

The first aim of the evaluation programme was therefore to identify how realistic the 'safe rules of stepladder use' were and how closely they were followed. If the rules can not be practically adhered to and common or 'typical' use was leading to accidents then some concern would be raised over the effectiveness of stepladder labelling, the suitability of the products for their intended use and therefore their design safety.

A second aim of the evaluation programme was to investigate the likelihood of mechanical failure (namely buckling of the stiles) which had been raised as a possible cause of falls, and to identify the conditions required for this to happen.

The evaluation programme consisted of two testing programmes. The first was user trials, in which *typical* use of stepladders was analysed to establish the frequency and extent of certain types of unsafe behaviour and misuse. This was done by observing inexperienced subjects using stepladders in a 'disguised' study. The second programme was a technical/materials investigation in which *critical* use (over-reaching to produce a sideways fall) was simulated. Falls through over-reaching were closely observed and

analysed to detect the onset of buckling and measurements were made of the distribution of loads through the feet of the stepladders during the fall. This enabled a comparison of the performance of different stepladders.

9.6 User trials

9.6.1 Methodology

The aim of the user trials was to try to quantify components of safe behaviour during 'normal' stepladder use. The components were identified as: the notice given to safety labelling, ease of assembly, extent of over-reaching, sideways use, repositioning of a stepladder, position on the stepladder, amount of grip and so on. It was important that the data collected in the user trials represented normal and natural behaviour with stepladders. Such data are difficult to collect, as the effect of being observed invariably changes people's behaviour. Methods used to combat this can include hidden observation, such as concealed cameras or two-way mirrors. There were practical difficulties in using these methods for this study; for instance, finding a location where stepladders were being used regularly enough to collect enough data, and by a wide enough range of users to give valid results. Also we were interested in domestic use, which meant observation of use in the home. The methodology finally developed involved users being openly observed but where they were under the assumption that their use of the stepladder was incidental and not being recorded. This hopefully detracted their attention away from the stepladder and issues of safety.

Forty subjects took part in the trials, all of whom were casual stepladder users (ie did not use a stepladder as part of their job). Half of the subjects were observed using a one-way stepladder and the other half using a three-way combination stepladder. The stepladders were chosen to be representative of the most popular models on the market, ie aluminium stepladders with five treads. The subjects were told that the aim of the experiments was to record biomechanical data on their movements while

performing household tasks such as cleaning. To support this, electronic goniometers, which record data on the positions of the joints, were fitted to their arms (figure 9.3). No mention was made of stepladders or safety. In line with experimental ethics that stipulate that subjects should not be put at any risk during experiments, the subjects were also fitted with a safety harness to save them from injury should they fall from the stepladders during the experiment (this was a possibility and something the research wished to observe, if it occurred). Subjects were told that this harness was necessary to carry the wires from the goniometers up and away from their body without restricting their movement. It was hoped that this would not suggest to the subjects that they would be expected to use the stepladder as part of the experiment.

The first task was cleaning a white board with a board rubber. This was intended to replicate cleaning windows. The area to be cleaned was 2.4 metres wide and reached from 1.5 to 3.9 metres from the floor. Subjects were told to clean only the area they felt comfortable with. A stepladder was left at the side of the task but was not referred to and subjects only used this of their own accord (figure 9.4). The cleaning task was essentially a one-handed task which mean that the subject could keep a secure grip on the stepladder at all times if desired. The aim of this task was to observe the extent of over-reaching, sideways use of the stepladder and re-positioning. The second task involved placing two boxes on two shelves of different heights. This was essentially a one handed task but could be performed more easily with two hands; the aim was to observe whether subjects kept a secure grip on the stepladder (figure 9.5).

Each user trial lasted around thirty minutes. It was accepted that this represented only initial and short term use of a stepladder and did not give any information on how it would be used over longer periods of time, such as for decorating. It was anticipated that the care taken while using a stepladder may change over a longer period of use. In order to assess extended use, eight of the forty subjects took part in extended trials and performed each task five times to see if the way they used the stepladders changed over this extended period.

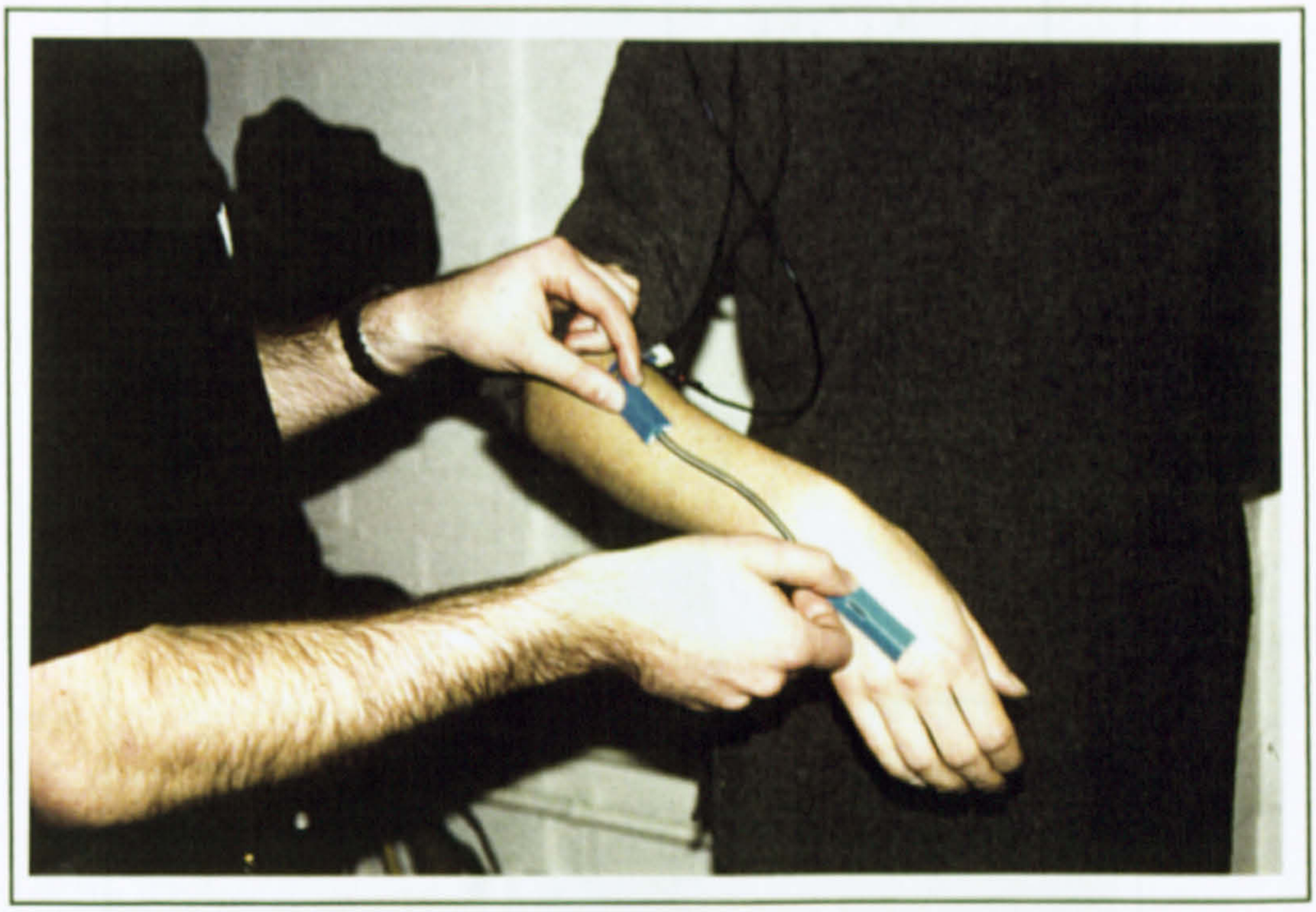


Figure 9.3 - Fixing electronic goniometers to subjects arms for the user trials

Figure 9.4 - Subjects carrying out user trials with voluntary use of a stepladder

Figure 9.5 - Placing boxes on shelves in the user trials (two-handed task)

9.6.2 Results

9.6.2.1 Qualitative analysis

The following is a summary of the observed behaviour:

- None of the subjects read the instructions before they used the stepladder and no one checked for damage.

- More males than females were prepared to go to the top of the stepladder (to the top platform on the one-way or to the fifth tread on the three-way stepladder).
- The majority of subjects (80%) used both stepladders sideways to the tasks.
- Most subjects seemed to over-reach but this was difficult to assess accurately and to quantify.
- The extended trials showed that the subjects' behaviour did not alter over increased use; only one (male) subject started to reposition the stepladder less over the trial.

9.6.2.2 Quantitative analysis

An attempt was made to quantify subjects' safety-related behaviour. Each subject was given a safety score or rating for each task. The scores were based on the following safety-related aspects of use:

- reading the instructions
- inspecting the stepladder for damage
- correct assembly
- correct positioning of the stepladder with respect to the task (ie facing the task)
- keeping a secure grip
- placement of feet
- over-reach distance
- number of times the stepladder was repositioned

The various permutations of these factors were recorded from the videos taken of the trials. Each permutation was given a score according to how safe the behaviour was considered to be. For example repositioning of the stepladder three times or more carried a score of zero and was considered the safest; repositioning it one or two times carried one point and not repositioning the stepladder at all carried two points. The scores were summed for each subject to see how they performed in each task.

Overall the three-way stepladder showed lower safety scores than the one-way stepladder. Subjects generally seemed to be more careful due to a lack of familiarity with combination ladders.

9.7 Simulation of critical use - over-reaching and falls

9.7.1 Methodology

The aim of the second part of the evaluation program was to examine 'critical' use, over-reaching to precipitate a fall. This would be used to indicate the likelihood and mechanism of buckling and to compare the performance of different types of stepladders. Ten subjects (five male and five female) were used ranging in weight from 57 kg to 89.5 kg (7th and 89th percentile values[1]) and in height from 1660 mm to 1830 mm (10th to 87th percentile values [1]).

Subjects were asked reach out to one side along a wall until the stepladder tipped (figure 9.6). This was done with the stepladder facing the wall and with the subjects stood at two heights on the stepladder. Consistency between the trials was achieved by ensuring that the subjects reached specified distances along the wall, increasing the distance at set time intervals. Subjects were free to interact with the stepladders in any way they wanted. To ensure safety of the subjects a harness system was used to arrest any falls.

All of the activities were recorded using a video camera to relate the point of tipping to the extent of over-reach and the postures adopted by subjects and to observe the behaviour of the stepladder during over-reaching and falls. A variety of stepladders ranging from three treads to seven treads and including eight different designs produced by four different manufacturers were used, to allow comparisons between designs and use at different heights to be made. The effect of floor surface was investigated as the point of contact between the stepladder and the ground could be crucial with respect to the method and likelihood of stepladders tipping. Two different

[1] compared to data from Pheasant, 1996

floor types were used: hard floors were replicated by a flat steel surface which was part of the housing for the load cells in half of the tests while a carpeted surface was used for the remainder.

In addition to observing falls, transducers were used to measure loads developed in the structural members of stepladders by measuring the forces transferred through the feet of the stepladders during falls. To measure the forces transferred throughout the feet of the stepladders independently, piezo-electric load cells were housed in each of the four corners of an adjustable platform on which different stepladders could be placed. A 30 Hz sampling rate was used and the output from each load cell was adjusted by a calibration factor in Newtons and graphs showing the simultaneous forces recorded under each of the feet of the stepladder were plotted.

9.7.2 Results

9.7.2.1 Stability

There were no obvious differences in stability between stepladders in terms of the distance that could be reached by the subjects before the stepladder tipped. There were differences between heights of stepladders: subjects were able to reach furthest before falling on a five tread 3-way stepladder (average distance reached was 910 mm). There were also some inter-individual differences: some subjects were able to reach further before falling because of anthropometric differences and ability to balance. There were some differences caused by a combination of product and individual differences: some subjects were able to reach further to the side when stood on higher treads than lower treads, due partly to difficulty experienced in reaching forward to touch the wall on the low treads of stepladders with five or more treads. Some subjects increased the distance that they were able to reach before falling by holding onto the wall in front of them with their other hand.

Figure 9.6 - Inducing falls by over-reaching, to assess the likelihood of mechanical failure

The floor surface appeared to influence the way the stepladders tipped. The stepladders righted themselves (remained upright) in nearly a third of the trials (22 out of 75) when on a carpeted surface but in only 1 of 75 trials on a steel surface.

9.7.2.2 Buckling of the stiles

Each stepladder was subjected to over-reaching to the point of tipping for 20 cycles or trials: ten subjects at two heights (the second and top treads) except for the 3 tread stepladder which was subjected to ten trials only because of fewer treads. After each trial the stepladders were inspected closely for damage. None of the stepladders buckled during use. Some stepladders were dented as they fell but these did not appear to affect the performance of the stepladders in subsequent trials and did not lead to buckling. As far as visible damage was concerned there were no differences between the stepladders (irrespective of Standard or Class rating).

9.7.2.3 Load distribution

The loads recorded under the back feet of the stepladders tended to be greater than those recorded under the front feet (those nearest the wall), due to the fact that the centre of mass of the subject was closer to the back feet. On higher treads on the stepladders the forces recorded tended to even out as the centre of mass was closer to the centre point between the feet. As subjects reached to one side the forces recorded under the feet on that side increased. However by placing a hand on the wall subjects were able to distribute the forces more evenly thus increasing the distance required to cause tipping.

The back feet typically recorded peak forces at around 500 N - 600 N with mean forces during use of around 400 N for the back right leg (on the side of the stepladder being leaned towards). Distortion shown in the force traces indicates that the forces developed in the stiles changed continuously, with typical variations of around 50 N - 100 N being measured between successive peaks and troughs.

A comparison was made between these recorded loads and those used in tests in Standards. BS 2037 (Class 3) uses loads of 1000 N (spread test), 1766 N (tread test) and 266 N (sideways bending test). The spread and tread tests are most easily compared with the results from this evaluation due to the direction in which they are applied (the sideways bending test is not in the same direction as the loads measured in this project). The results from this study therefore suggest that the current standard test loads are adequate to represent peak loading. However the maximum weight of subject in these trials was 89.5 kg (90th percentile British male). Also the magnitude of loads transferred through separate stiles in the Standards tests is not known (it has been shown above that the back feet usually encounter the greatest loads) and secondly the loads are static and do not subject the stepladders to variable loading as in normal use.

9.8 Discussion and conclusions

A substantial number of injuries and deaths are associated each year with falls from stepladders in the home, yet in the majority of cases the specific cause of the accident is unknown and the research reported here has not identified any one causative factor. Most accidents can be broadly described as non-specific falls caused by task factors (such as over-reaching, slipping, mis-stepping, sideways use) and/or instability of the stepladder. There are already a number of established, general rules regarding the safe use of stepladders which the British Standard BS 2037:1994 requires to be permanently labelled on stepladders. The study addressed the issue of whether or not this labelling is effective and whether the messages are pragmatic and adhered to. Two approaches were used to collect data. Interviews of consumers gave information on their recall of messages and the amount of 'misuse' of stepladders. Such 'reported' behaviour can be unreliable due to subject bias: factors such as honesty, motivation to produce the 'correct' answer, motivation and time to be involved in research and desire to appear a 'risk-taker' or a 'safety-conscious'

consumer. However consumers' reports of their own behaviour was generally supported by subsequent user trials and observed behaviour: for instance, only a third of stepladder users said they were even aware that their stepladder had any labelling and recall of messages was very poor and in user trials none of the subjects looked at the labelling on the stepladders. User trials provides more reliable data, and the data may also be more detailed, such as quantifying the height to which people will climb, the amount of grip used and the amount of over-reaching, although the effect of observation on behaviour must always be considered. Some factors remain difficult to assess, such as quantifying 'over-reaching' and rely on specific behaviour being displayed. For instance, interviews of users suggested that stepladders are often used as leaning ladders, by leaning them against a wall. None of the subjects in the user trials did this, and so observation alone would not have given complete data on all types of misuse. The study showed therefore that labels on stepladders are not read before use, the rules of stepladder safety are not recalled by users or observed as part of typical use and some rules such as over-reaching and avoiding sideways-use are impractical and demonstrated a need to increase the knowledge of these safety messages.

There had been some reports of accidents involving mechanical failure of stepladders and particularly incidents where stiles have buckled at the bottom consistent with sideways use or over-reaching. Tests in this study failed to reproduce buckling in a sample of stepladders despite twenty cycles of over-reaching to cause tipping. It is therefore suggested that mechanical failure in this way is unlikely to be a major cause of accidents. The experimental programme indicated that floor surface affects the likelihood of tipping and stepladders used on floors with a low coefficient of friction may be more likely to slip during over-reaching. The rigidity of materials used and the design affects the distribution of forces through the feet of stepladders and there is some suggestion that the deflection tests in current standards favour more rigid materials when these may not necessarily be more suited for use in stepladders.

Generally the study demonstrated that a combination of methods is often needed to provide a complete assessment of product safety.

9.9 Recommendations

There are a number of possible routes to improving stepladder safety, through more effective labelling, product information, point of sale advice, public awareness initiatives, safety standards and design.

9.9.1 Labelling

The British Ladder Manufacturers Association produce standard labels and some manufacturers include additional messages to those listed in BS 2037. It is felt that some of the messages are not adequately conveyed in the current safety labelling as many messages are in the form of pictograms only without explanation and labelling should be reviewed to ensure all messages are adequately explained and specified. Instructions for the assembly of combination ladders also need to be improved.

9.9.2 Publicity

Labelled stepladders are in most homes yet knowledge of safety messages is still minimal. It is therefore thought that any improvement in awareness may necessitate a publicity initiative. The advantage of publicity would be that rather than relying solely on a list of rules, the risks associated with stepladder use could be explained, together with ways to avoid accidents, for example, pictures of types of damage and wear to stepladders; or how to use different height stepladders for different jobs. In particular, the rules of use associated with instability need to be emphasised and fully explained: to limit over-reaching, using the stepladder facing a task and on firm, level ground. The difficult issue of over-reaching needs to be fully explained and possibly specified and/or quantified with suggestions on how to be aware of and avoid over-reaching.

9.9.3 Product Information

On-product information such as instruction manuals and/or better information on packaging may also be needed to reinforce the messages presently on labelling and to assist the selection of appropriate products. This will include information on the different standards in operation, the British Standard class ratings, the correct type of ladder or stepladder for each job. This could also include point of sale information, leaflets, permanent displays and verbal advice. Improvements in information provision will involve the co-operation of retailers, the majority of sales going through DIY multiples, mail order and small hardware retailers.

9.9.4 Standards

Standards need to be reviewed in terms of the test loads and methods used; peak loading may exceed the current static test loads and standards are lacking in performance-related, dynamic and fatigue testing. There is also concern that the European Standard which is likely to be adopted more widely in Britain has no requirements for safety labelling.

9.9.5 Design

There is need for a review of stepladder design with a view to improving instability. Over-reaching and using a stepladder side-ways are instinctive methods of use and are unlikely to be completely eradicated by public awareness initiatives. Efforts should therefore be made to produce design measures to make stepladders fit for their intended use by possibly reducing the need for over-reaching or sideways use, developing measures to produce feedback on stability during use or to make stepladders stable through a greater range of use. In addition design measures could be taken to reduce accidents through mis-stepping, slipping or wrong assembly. These could include tread size and design, top and side handrails, feet and locking mechanisms although any design changes should be reviewed for their effect on overall safety and not just falls.

9.10 Outcome

A formal report was issued to the Department of Trade and Industry as a result of this research and this was used in discussions between the government, standards bodies and the industry on ways forward. The DTI produced a booklet aimed at improving users' knowledge of stepladder safety '*The Stepladder User's Guide*' (figure 9.7 and Appendix 9.1). This was distributed by DIY retailers and DIY magazines as part of a nation-wide campaign and provoked television news coverage. The full list of safety messages included in the publicity campaign were:

- select the correct stepladder for the job (stepladders that conform to British or European Standards)
- don't use sideways on to a job - always face the work
- don't over-reach (with specification eg don't work past elbow distance or don't work with chin past stile)
- always keep a secure grip
- ensure a firm and level base
- wear flat, firm soled shoes
- check the stepladder is correctly and safely assembled and locked into position
- regularly check your stepladder and check for damage or wear - don't use if damaged or worn and don't repair or modify
- don't use to reach another level or greater heights - always have both feet on the stepladder
- don't exert sideways pressure
- don't use when folded (closed)
- always use the correct height stepladder for the job - don't use one too small for high work and don't use a tall stepladder for low work as this makes forward reach difficult and can encourage sideways use. More than one stepladder and/or ladder may be needed
- always store properly (with guidance on correct storage)
- ensure treads are clean
- ensure stepladder feet are in place and replace if worn

In addition a review of EN 131 has been instigated by British members of the CEN committee on ladders and stepladders.

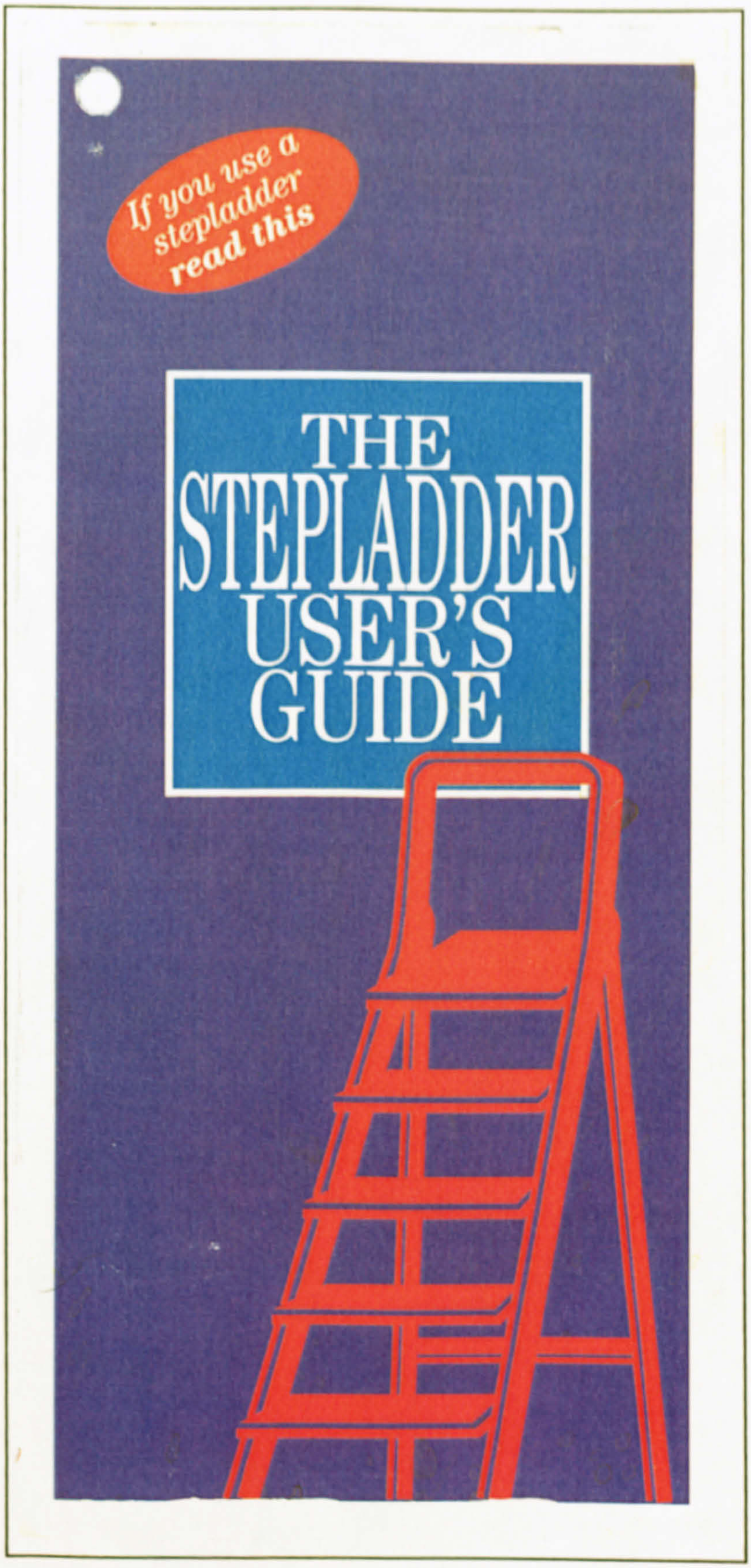


Figure 9.7 - Safety leaflet produced and disseminated by the DTI

Chapter 10 - Analysis of case studies

Chapters 6 to 9 described a series of cases studies of product safety evaluations. Each of these case studies had specific practical aims of improving the safety of each of the products. There was also an underlying aim, to assess the usefulness of the methods employed in the cases with a view to encouraging and advising designers to use these methods in the design process. This Chapter examines the general issues raised by the case studies and assesses the feasibility of using the results of the case studies to generalise to the evaluation of other products. A framework for a generic evaluation process to assist designers in the ergonomics evaluation of novel products is proposed.

10.1 Summary of case studies

The case studies were retrospective examinations of product safety; that is, the products under examination were already established in the marketplace and there was concern over the level of safety associated with their use. The following products were evaluated:

- Swimming pool covers (SPCs)
- Missiling caps from carbonated drinks bottles (bottles)
- All terrain bikes (ATBs)
- Stepladders

The products investigated were diverse - in their construction, materials, function,

operation, the environment in which they were used, their interface with the user, the hazard(s) they posed and the risk of injury perceived by the user. The process of evaluation for each product appears on first inspection to be similarly diversified, with a range both of novel and established evaluation methods, and information sources, tailored to each case. Despite this diversity it was hoped there would be some commonality in the evaluation methods that could be used to produce guidance for designers.

This Chapter will show that there were few common 'methods'. Instead it was found that there were a number of common general issues raised by the case studies; that similar activities were followed; common information sources were used; and, most importantly for this research, that there were some common generic 'stages' in each of the evaluations, which will later be developed into a generic evaluation process which could potentially be used by designers. The following sections discuss each of these common items as they were demonstrated by each of the case studies. The issues to be discussed are as follows:

i the identification of hazards and hazard scenarios
ii the selection of measurement variables
iii types of data
iv data collection techniques
v constraints on the evaluation process
vi the use of simulation in user testing
vii restrictions to the validity of the evaluations.

Following this, the generalisation of these findings into guidance for designers will be discussed.

10.2 The identification of hazards and hazard scenarios

10.2.1 Definition of hazards and hazard scenarios

In each of the product evaluations there was a common first stage, to identify the hazards of each product. Before the methods employed to do this are discussed, the definition of a hazard offered in Chapter 1 (*'the disposition, or potential, to produce harm'*) needs to be reconsidered, as it will be shown later in this Chapter and in Chapter 11 that this initial stage of identifying hazards is a core step in the evaluation process. According to the definition above, a product is a hazard if it has the potential to cause harm. This would mean that a product such as a soft toy, which would usually offer little potential for harm, would be a hazard if it were left on a staircase where it could cause an adult to fall. It is suggested however, for the purposes of this research, that there is a semantic difference in the use of the word 'hazard': a product can *be* a hazard, or it can *pose* a variety of hazards. Also it is necessary to be able to predict exactly *how* a product's potential to produce harm will materialise if we are to achieve 'design safety'. In this sense it is not enough to define a hazard as a *potential* to cause harm, but rather as *'the mechanism by which harm is incurred'*. If we consider the example of a lawnmower, its hazards would include 'electrocution' and 'laceration' (of the fingers or another body part). In order to evaluate these hazards however, it is still not enough to have identified the mechanism, we must also be able to predict the set of circumstances which might precipitate the hazard, and these circumstances could be considered as the *hazard scenarios*. To extend the example of a lawnmower, the hazard scenarios would include running over the cable, inadvertent operation or carrying out maintenance while the mower was switched on. Further examples of the hazards and hazard scenarios of some common consumer products, together with the associated injuries are suggested in table 10.1. (The table is not intended to be exhaustive but to demonstrate the differences between hazards and hazards scenarios).

Product	Hazard (or mechanism)	Hazard scenario (or circumstances)	Injury (or result)
Kettle	• spillage of hot water • leakage of hot/cold water • leakage of steam	• kettle is knocked over • kettle is unstable and falls over • kettle falls from surface • lead is pulled • spillage during pouring/filling • body of kettle leaks allowing contact between water and electric wiring • reaching across steam	burn, scald, electrocution
Knife	• misplaced blade	• knife is dropped • knife is jolted • hand or other body part is placed in the way of the blade • the blade is placed in way of the hand or other body part	cut
Lawnmower	• contact of blade with body • contact of blade with cable • impact	• inadvertent operation • mower hits obstacle • mower passes over cable • exposure of blades during operation or maintenance, movement or storage • mower is dropped	electrocution, cut
Household chemicals	• ingestion	• child gains access through closure • packaging leaks • closure not secured properly	poisoning
Child's slide	• entrapment • fall • impact • friction	• child falls from slide or steps • child slips on slide or steps • child's climbs and traps head or body part • child slides in different positions	strangulation, bruise, cut, fracture

Table 10.1 - Examples of hazards, hazard scenarios and injuries for some common consumer products

It is therefore the hazards that can result in harm, and circumstances that can precipitate these mechanisms, that we are trying to identify in the evaluation of safety.

10.2.2 Information sources used to identify hazards

A number of information sources had to be used to identify the hazards of the products in the case studies, as shown in table 10.2, and their usefulness varied across the products.

Information on:	SPCs	Bottles	ATBs	Stepladders
Accident rates	• HASS • HADD • coroners • OPCS	• HASS • legal cases	• HASS • LASS • user survey	• HASS • user survey
Accident scenarios	• coroners	• legal cases • user survey	• HASS • user survey	• HASS • user survey
Standards and regulations	• USA standard • Australian standard	• industry standard	• British Standard • Pedal cycle regulations	• British Standard • European Standard

Table 10.2 - Information sources used to identify hazards in the case studies

The main sources of data on injury *rates* were HASS and LASS, which were used for all the products. For two of the products (ATBs and stepladders) surveys of users had to be conducted. Information on fatal accidents was needed in the evaluation of SPCs (this came from HADD, OPCS and coroners' reports).

As well as the frequency of accidents, accident details were gathered in each of the evaluations. Information on SPC accidents was available on fatalities only because immersion incidents are usually either fatal or result in no medical attention and are unrecorded. Information from coroners proved scant. More useful accident descriptions were available for bottles, from legal reports. For ATBs and stepladders accident descriptions were gathered from HASS victims using postal questionnaires. These had low response rates and yielded poor results mainly due to the delay between the accident and the follow up and the victims' limited recall of their accident.

Standards and regulations were reviewed for all products, and these varied between European or national standards (SPCs, stepladders and ATBs), regulations (ATBs) and industry codes of practice (bottles). The only standards to contain relevant performance test criteria were for SPCs, and their rigour were assessed as part of the evaluation process.

The only information sources common to all of the case studies at this stage of the evaluation were the use of accident statistics from HASS and standards/regulations. The most important commonality however was that more than one information source had to be used for each product.

10.2.3 Hazards in the case studies

The hazards and associated injuries for each of the products evaluated in the case studies are shown in table 10.3 and some of the potential hazard scenarios in table 10.4. Some hazards and hazard scenarios were common between the case studies: entrapment and impacts of the product into the user were common to three of the four products; falls, pinching and other impacts were common to ATBs and stepladders. While similar hazards existed for some of the products, the hazard scenarios were however different across the products, suggesting that the evaluation procedures were likely to be different for each product.

Hazard	SPCs	Bottles	ATBs	Stepladders
Explosion		✓		
Drowning	✓			
Entrapment	✓		✓	✓
Pinching			✓	✓
Fall			✓	✓
Impact				
• user into product			✓	✓
• user into other object			✓	✓
• product into user		✓	✓	✓
• other object into user			✓	✓
Injury	asphyxiation, strangulation	cut, bruise, cut, fracture	bruise, cut, fracture	bruise, cut, fracture

Table 10.3 - Hazards and associated injuries of each product in the case studies

Hazard	SPCs	Bottles	ATBs	Stepladders
Explosion		bottle is dropped; bottle is exposed to heat		
Drowning	child gains access to pool under the cover; child falls into water collected on top of the cover			
Entrapment	child crawls under the cover; automatic cover closes while user is in the pool		rider falls between bike and other object; body part trapped between bike parts	user falls between stepladder and other object; body part trapped between stepladder parts
Pinching			body part/clothes pinched between bike and other object or between bike parts	body part/clothes pinched between stepladder and other object or between stepladder parts
Fall			over-balancing; bike on rough ground; bike hits obstacle; failure of bike parts; lack of skill	over-reaching; stepladder on unstable ground; slipping/mis-stepping; stepladder buckles; stepladder not assembled correctly
Impact of user into product			as above	as above
Impact of user into other object			as above	as above
Impact of product into user		bottle is dropped; bottle is exposed to heat; bottle is opened under unusual circumstances	as above	as above
Impact of other object into user			as above; environmental circumstances	as above; environmental circumstances

Table 10.4 - Hazard scenarios of each product in the case studies

10.3 The selection of measurement variables

Measurement variables can be considered as those aspects of the user-product interaction which are measured or tested in order to make a judgement on whether the interaction is safe. The selection of measurement variables was necessary to be able to decide which data would be collected and thus the evaluation methods and techniques to be used. The measurement variables evaluated in the case studies fell into five groups: events, time, errors, user characteristics and product attributes, as shown in table 10.5.

Variable	SPCs	Bottles	ATBs	Stepladders
User testing				
Event	passed through aperture? buckles undone? peg removed? bag move? supported by cover?	tools used? subject able to open bottle?	bike failed?	over-reached? held with both hands? both feet on same rung? read instructions?
Time	time to remove pegs; time to undo buckles			
Error		cap turned the wrong way?		ascended the back of the ladder? stood on top rail?
User characteristics	size of aperture children can pass through; maximum pulling strength	maximum opening torque		
Product testing				
	size of aperture at edges of covers; tensile strength of cover material; resistance to wear and weathering; force required to remove securing pegs; closing force of automatic cover; covers support children?	pressure inside bottles; pressure to cause missiling; pressure to cause bottle failure; torque to remove caps; tensile force to remove caps	loads set up in bike frame during off road use; loads required to cause bike failure	the size and distribution of loads in stepladder feet during over-reaching and falls

Table 10.5 - Measurement variables selected in each case study

Events, time, errors and user characteristics are all aspects of the user's performance so this process of testing can be considered as user testing. The process of measuring product attributes can be considered as product testing, the aim being to collect data which will relate the product's performance to the users' characteristics. The measurement variables were diverse across the products, however this classification into product and user testing, and the grouping of the variables into the five categories could be of use in helping focus designers' attention on the sorts of attributes that can be tested in an ergonomics evaluation.

10.4 Types of data

Within user testing, there were two principle types of data collected; direct and indirect. The types of data collected in each evaluation are shown in table 10.6.

Types of data	SPCs	Bottles	ATBs	Stepladders
Indirect				
• Subjective		• perception of difficulty in opening bottles	• attitudes to safety	• attitudes to safety
• Self-reported behaviour		• difficulty opening bottles • use of tools	• type of riding	• safe use of stepladders
• Evidence		• marks on caps to indicate the use of tools		
Direct				
• Quantitative	• pulling strength • ability to remove pegs • ability to undo buckles • ability to move bags	• opening torque • number of subjects turning caps the wrong way • number of bottles opened in user trials	• loads recorded in frames in field and laboratory tests	• number of times the stepladder was repositioned • highest step used • computed 'safety score'
• Qualitative	• technique at climbing under covers • removing pegs • moving bags	• observed difficulty opening bottles • opening technique	• damage to bikes after laboratory trials	• amount of over-reaching • reading of labelling • ease of assembly • re-positioning

Table 10.6 - Data collected in user testing

A multiplicity of data was collected for each evaluation, and each evaluation required a different combination of data. The data collected were dictated in part by practical and other constraints (see section 10.6 later). In some cases more than one type of data was collected for the same measurement variable because of limitations of data from the one source. For instance, difficulty in opening bottles was assessed using subjective data (users' perceptions of how difficult bottles are to open) and quantitative data (opening strength and the number of bottles they could open in the user trials).

10.5 Data collection techniques

Once the data to be collected had been identified, the last stage was to choose the most appropriate techniques. The techniques used for each evaluation are shown in table 10.7.

Video and questionnaire proved to be the most widely applicable data collection techniques and were used in each of the product evaluations. All testing was recorded on video as a matter of course, but proved invaluable particularly in the evaluations of SPCs, bottles and stepladders, as recording the behaviour of interest would have been impossible by human observation alone, due to the speed and/or number of the actions being assessed. Questionnaires were used to collect the subjective and self-reported data, primarily on what constituted 'normal' use of the products, and to gain information on attitudes to safety. In addition, checklists were used to record information in all of the evaluations except ATBs, primarily to record 'events' during user testing.

Data collection techniques	SPCs	Bottles	ATBs	Stepladders
Video	✓	✓	✓	✓
Checklists	✓	✓		✓
Questionnaire	✓	✓	✓	✓

Table 10.7 - Data collection techniques

10.6 Constraints on the evaluation process - safety and ethics

The methods and techniques used to carry out the product evaluations were constrained by a number of factors, not least practical and logistical requirements. Generalisation of these is difficult, but they were generally cost, time and space constraints. However, in addition to these there were two other notable issues which dictated the types of tests that could be carried out - the constraints of ethics and subject safety (table 10.8).

Constraints on the selection of testing methods	SPCs	Bottles	ATBs	Stepladders
Safety of subjects	✓	✓	✓	✓
Ethical considerations	✓	✓		

Table 10.8 - Ethical and safety constraints on product evaluation

10.6.1 Safety of subjects

Subject safety restricted the choice of evaluation methods in all cases. In the case of SPCs, field testing was impossible because children could not be exposed to swimming pools, and so simulation was necessary in the laboratory. With bottles, the observation of users opening bottles of carbonated drinks with tools, and all tests with children, had to be carried out using placebo bottles (filled with water), because subjects could not be exposed to the risk of missiling, however remote. ATB field trials were carried out at low levels of impact, and higher levels had to be simulated in the laboratory with a simulated rider, because of the risk of injury. In the evaluation of stepladders, subjects had to wear a safety harness at all times, obviously during falls but even when observing normal use, because of the risk of falls.

10.6.2 Ethics

In addition to these obvious safety considerations, there were more embedded ethical considerations that had to be taken into account. This was particularly so in the case

of SPCs, as the users at risk were children. The evaluation involved the assessment of a product with children which had not been designed with children in mind, and was intended to operate as a guard or shield to a hazardous product (swimming pool). As with any guard this has the potential to stimulate curiosity and function as a challenge to very young children. Since the product was used in conjunction with an intrinsically dangerous environment, it was considered unethical to raise the subjects' interest in the product. Also, the evaluation was to test their ability to operate the product, and a learning process was possible. The testing process then had to be designed such that children did not leave the test with an increased interest in, or skill at, operating the product with consequent increased risk if they were to subsequently to come into contact with SPCs. These issues have also been similarly addressed in the preparation of the testing procedures for the standard on child-resistant-containers (CRCs) (see Kirk, 1970).

Also, in the case of bottles, all bottles opened by children were emptied and filled with water as there was a risk, albeit very low, that missiling could occur with any carbonated drinks bottle.

This raised another potential ethical difficulty, that of informed consent. Children are potentially unable to properly understand what it means to consent to partake in experimentation which involves some residual risk, as they may not fully understand the meaning of risk. Similarly, design-induced hazards are often related to extreme use of a product, such as maximum strength exertion or misuse. Evaluation may mean one has to induce this behaviour from a subject knowing that there is risk of injury either from the hazard or from over-exertion during experimentation.

For a discussion of ethics in user testing see Moroney (1994) and Wilson and Norris (1993).

10.7 The use of simulation in user testing

A characteristic of all the evaluations was that some level of simulation was needed, either of the user, the product, the environment or the task (table 10.9). Simulation was needed because of the safety, ethical, practical and logistical constraints on the testing process outlined above.

Simulation	SPCs	Bottles	ATBs	Stepladders
User	✓	✓	✓	
Product	✓	✓		
Environment	✓		✓	✓
Task	✓	✓	✓	✓

Table 10.9 - Simulation requirements in product evaluations

In the case of SPCs, all four aspects of the product-user interaction had to be simulated: the user, the product, the task and the environment. Simulation was particularly needed in this case because of the ethical restrictions governing testing with children. The *user* was simulated in a number of ways. The degree and ease of access under the edges of covers had to be tested in-situ in the field because installation of the covers varied between sites. This could not be done in-situ with children and so two methods of simulated children climbing under the covers were devised; a cone simulating the head of a child pushing under the cover which measured the diameter of the aperture and the pushing force, and a lifting mechanism simulated a child lifting the cover and crawling under and which measured the height of the aperture and the lifting force. Two methods of simulating the user were also developed to test what happened when a child fell onto the edges of the cover: an adapted diving mannequin and 'test models' manufactured to represent only the body length, width and depth of the child. The *product* was simulated in a number of ways: the edges of the covers were removed and set up in the laboratory, the securing pegs were used to measure pulling strength, the pegs were also set up in a paving block to observe techniques of removing them, the buckles and water bags were disguised and presented to the children for exploration. In all instances the products were disguised so that children did become interested in the real product.

The *environment* was simulated in that all observations and measurements were done in the laboratory, again because the pool-side was considered dangerous and to avoid raising interest in the real product and environment. The *task* was simulated, in the assessment of the removal of the pegs, as well as comparing pulling strength to removal force, the pegs were set up realistically to see if children could understand the technique of pulling and twisting the peg at the same time.

In the evaluation of bottles, the 'user' was simulated by a systematically removing the caps with different tools to identify the combination of conditions for missiling. The product and task were simulated to measure opening torque; a replica bottle was made and was designed so that strength could be measured without restrictions on how the bottle was held and hence a more realistic measurement could be made.

In the evaluation of ATBs, the user and environment had to be simulated in the laboratory for the tests which measured the loading required to cause failure of the bike. The user was simulated by weighting the bikes and the environment was simulated using dropping and impact rigs. The task was simulated in the field trials when a sample of riding techniques were reproduced to simulate off-road riding.

In the evaluation of stepladders, the environment had to be simulated as it was not possible to carry out tests in people's homes. The observations were to be of 'natural' use as the aim was to observe the extent to which people followed the rules of safe stepladder use. It was impossible to observe people using stepladders in the home without them knowing the reason for the observation, and this would have disrupted normal behaviour. The work was therefore carried out in the laboratory, and the task had to be simulated because again subjects were not to know the reason for the observation in order to try to produce natural behaviour unaffected by observation.

The aim of any simulation is to ensure the safest, most ethical and efficient evaluation whilst maintaining enough realism, reliability and validity and thus applicability of results. The major requirement of any simulation is that all important features which

results. For instance, a finger probe used to test dimensions for access through a fire guard should also account for the force with which the finger would be pushed and the resistance of the material.

10.8 Restrictions to the validity of the evaluations

All of the restrictions mentioned above affected the validity of the evaluations, and showed that when recreating a hazard for evaluation there is always likely to be an effect on validity that must be considered in the interpretation of results. The limitations in the evaluations described in the case studies are shown in table 10.10.

Restrictions	SPCs	Bottles	ATBs	Stepladders
Simulation	✓	✓	✓	
Lack of control	✓			✓
Special users	✓	✓		
Altered behaviour	✓	✓		✓
Safety considerations	✓	✓	✓	✓

Table 10.10 - Restrictions to the validity of the results from each case study

A number of issues may have affected the validity of the evaluation of SPCs. Simulation was used to evaluate children's access under the edges of the covers and the 'edges' of the covers simulated in the laboratory may not have been at a realistic tension, making them possibly less or more difficult to pass under (although this was measured and did compare adequately to field measurements). The difficulty of carrying out user trials with children meant that maximum efforts at the tests were not guaranteed, such as the force with which children forced themselves under the edges or their pulling strength on the pegs, although given these restrictions the results were still enough to indicate an unsafe product. The lack of control over the measurements with children, such as the difficulty in enforcing controlled postures and techniques during strength measurements, also reduced the reliability of the data. Some tests did not relate directly to safety. For instance, the movement of the water-filled bags was measured only in terms of the distance they were moved and did not

Simulation was necessary in the evaluation of missiling caps and bottles had to be filled with water when opened by children or by adults with tools. This meant that the bottles weren't rigid and this potentially affected how the bottles were held.

In the laboratory tests of ATBs, the user was simulated by attaching weights to the bicycles and this would have affected the dynamic behaviour of the bike during impacts. Also the tests demonstrated only gross differences in the bikes' performance and were not sensitive to differences between bikes at less extreme impacts than those simulated.

Ethical considerations in the evaluation of stepladders that meant subjects had to wear a safety harness. This was likely to have influenced the way subjects fell during the technical evaluation of the failure of the stiles. It would also have affected the level of 'natural' behaviour observed in the user trials. Subjects were told that the reason for the trials was to collect biomechanical data (to disguise the use of the harness) and this would also have affected their behaviour by making them more aware of their movements. Any form of observation would however have negated them carrying out normal risk-taking behaviour, to some extent.

The consequences of these limitations to validity often cannot be accurately estimated. In some cases it was possible to collect more than one type of data on the same variable in order to compare results; for instance in the evaluation of stepladders, the degree of 'un-safe' use was observed in user trials, but also assessed from self-reported behaviour. Likewise, in the evaluation of bottles the use of tools was measured by both evidence of use, and self-reported behaviour. In both case studies the two sets of data supported the same conclusions. If the implications for safety of any limitations in validity cannot be measured then they should be accounted for by appropriate tolerances in final design parameters.

10.9 Generalisation of case studies into an evaluation framework

At the start of this Chapter, an aim was set to analyse the case studies and produce guidance for designers on methods to carry out ergonomics evaluations. The analysis showed that giving *methodological* advice is not easy; the diversity of activities that went into each evaluation makes it difficult to extrapolate into generic advice which can be applicable across a wide range of product groups. Instead of producing prescriptions of methods to be used, it was decided that advice would be better to concentrate on an evaluation *process* rather than the methods used. Even within this approach, there is great diversity in the components of the process. If we consider the common elements in the case studies that have been discussed in this section so far in this Chapter, and consider this to be a 'profile' of the stages or elements in each evaluation, it can be seen how different these are for each of the four products, as shown in table 10.11.

Only a limited number of items are common to each evaluation.

- the use of accident data and standards/regulations at the start of the evaluation to identify users and hazards
- user testing (with 'events' as measurement variables)
- product testing (of product attributes)
- the use of video and questionnaires as data collection techniques
- safety constraints on the selection of testing methods and the subsequent restrictions these had to the validity of the evaluations.

This 'profile' supports the idea that advice to designers must be generic, and that they must be convinced of the idea of an overall safety *evaluation process* rather than suggesting to them explicit steps of *testing*, which would be inferred by methodological guidance. Using this approach, a framework for a generic evaluation process is proposed and described in the next section.

	PRODUCT			
	SPCs	Bottles	ATBs	Stepladders
Information used to identify hazards				
• Accident rates	✓	✓	✓	✓
• Accident scenarios	✓	✓	✓	✓
• Standards and regulations	✓	✓	✓	✓
Hazards				
• Explosion		✓		
• Drowning	✓			
• Entrapment	✓		✓	✓
• Pinching			✓	✓
• Fall			✓	✓
• Impact				
• user into product			✓	✓
• user into other object			✓	✓
• product into user		✓	✓	✓
• other object into user			✓	✓
Selection of measurement variables				
User testing				
• Event	✓	✓	✓	✓
• Time	✓			
• Error		✓		✓
• User characteristics	✓	✓		
Product testing				
• Product attribute	✓	✓	✓	✓
Types of data collected				
• Indirect				
• Subjective		✓	✓	✓
• Self-reported behaviour		✓	✓	✓
• Evidence		✓	✓	
• Direct				
• Quantitative	✓	✓		✓
• Qualitative	✓	✓		✓
Data collection techniques				
• Video	✓	✓	✓	✓
• Checklists	✓	✓		✓
• Questionnaire	✓	✓	✓	✓
Constraints on the selection of testing methods				
• Safety of subjects	✓	✓	✓	✓
• Ethical considerations	✓	✓		
Use of simulation				
• User	✓	✓	✓	
• Product	✓	✓		
• Environment	✓		✓	✓
• Task	✓	✓	✓	✓
Restrictions to validity				
• Simulation	✓	✓	✓	
• Lack of control	✓			✓
• Special users	✓	✓		
• Altered behaviour	✓	✓		✓
• Safety considerations	✓	✓	✓	✓

Table 10.11 - Common elements in the evaluation process of each case study

10.10 A proposed evaluation process

The proposed evaluation process consists of three distinct stages and is shown in figure 10.1.

Stage 1: Identify all potential hazards, hazard scenarios and users
Stage 2: Set performance (safety) criteria and test questions
Stage 3: Select evaluation methods

The framework is now described as it applied to each of the case studies.

10.10.1 Stage 1 - Identify all potential hazards, hazard scenarios and users

In stage one every set of circumstances and use scenarios that can lead to injury need to be identified. Based on the case studies, it is suggested that hazards can arise due to a number of ergonomics issues:

- the design has not accounted for all possible users, for example:
    - children being able to access underneath SPCs
    - bottle closures being applied too tightly for children
- the design has not accounted for all possible uses, for example:
    - bottles being opened with tools
    - ATBs being used on rough terrain
- there is a mismatch in user and product characteristics, for example:
    - opening torque on bottles
    - the size of access under the edges of winter covers
- the design has not accounted for extended use, for example:
    - failure of ATBs, failure of stepladders.

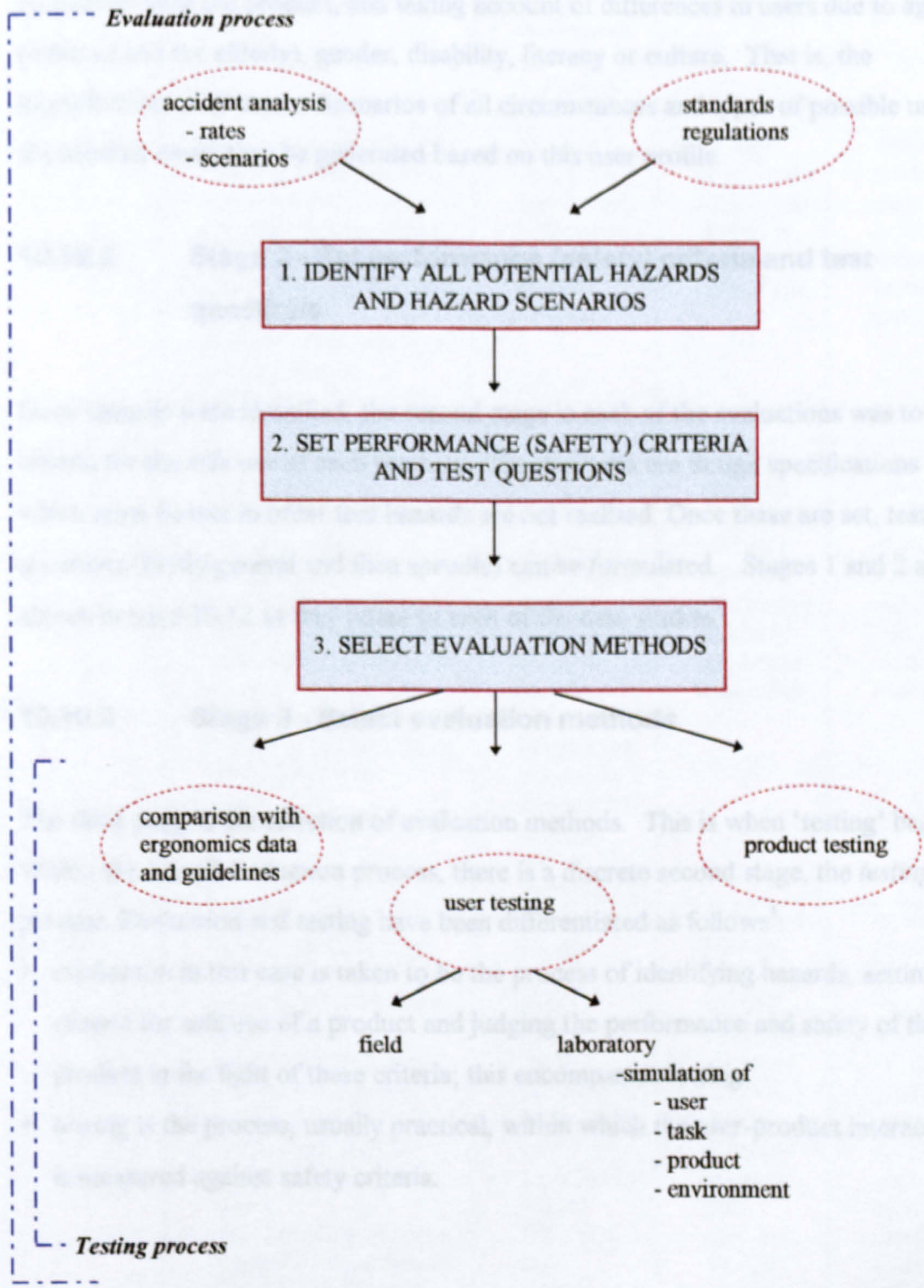


Figure 10.1 - Suggested framework for product safety evaluation based on the case studies

This suggests that the first step in identifying hazards actually needs to be the specification of all those who may come into contact with the product, either intentionally or unintentionally, and as a result of the primary or a resultant interaction with the product, and taking account of differences in users due to age (children and the elderly), gender, disability, literacy or culture. That is, the identification of all users. Scenarios of all circumstances and types of possible use of the product could then be generated based on this user profile.

10.10.2 Stage 2 - Set performance (safety) criteria and test questions

Once hazards were identified, the second stage in each of the evaluations was to set criteria for the safe use of each product. These criteria are design specifications which must be met in order that hazards are not realised. Once these are set, test questions (firstly general and then specific) can be formulated. Stages 1 and 2 are shown in table 10.12 as they relate to each of the case studies.

10.10.3 Stage 3 - Select evaluation methods

The third stage is the selection of evaluation methods. This is when 'testing' begins. Within the overall evaluation process, there is a discrete second stage, the *testing* process. Evaluation and testing have been differentiated as follows[1]:

- *evaluation* in this case is taken to be the process of identifying hazards, setting the criteria for safe use of a product and judging the performance and safety of the product in the light of these criteria; this encompasses testing
- *testing* is the process, usually practical, within which the user-product interaction is measured against safety criteria.

[1] These definitions have been adapted for use in the domain of product safety from definitions offered by Meister (1986) for use in systems ergonomics; testing is defined by him as the process of measurement and involves a judgement of adequacy, and evaluation is more than measurement in that it involves comparison to some standard. See also Roozenburg and Eekels (1995) and Cushman and Rosenberg (1991).

	SPCs	Bottles	ATBs	Stepladders
Stage 1:				
Hazard	• access to pool • entrapment in cover	• impact from cap	• impact (fall)	• impact (fall)
Users at risk	• children under 5 years	• all users • inadvertent users (eg bystanders)	• all users	• all users
Stage 2:				
Performance (safety) criteria	• no access under the cover edge for a child under 5 • the child cannot get stuck in the pool or entangled in the cover • the covers support a child on cover • collected water would not be sufficient for drowning	• all users should be able to open bottles easily and without risk of missiling	• product meet users' expectation s without increased risk of fall	• stability • product meet users' expectations without increased risk of fall
General test questions	• can children climb under edge of cover? • can children remove securing systems? • can children get out from underneath a cover • do covers support a child walking/falling/jumping on cover? • is there a risk of drowning with a child on top of the cover?	• does the torque with which caps are applied match the opening torque of the range of users? • do users practise any methods of opening that increases risk of missiling?	• what are the users' expectation s of use? • how does the product perform to meet these expectation s?	• what are the users' expectations of use? • how does the product perform to meet these expectations?
Specific test questions	• what size aperture can children climb through and what apertures can be produced at the edges of the covers? • what force can children exert on the securing pegs used for covers? • can children undo the buckles used to tighten covers? • what force is need to stop automatic covers closing • what happens when a child walks/falls/jumps on a cover? • how much water gathers on cover with child on top?	• what torque are caps applied with? • what is the opening torque of the range of users? • do users find bottles difficult to open? • do users use tools to open bottles?	• where and how are bikes ridden? • what loads are set up in the bike during different levels of use? • are these likely to lead to injury? • are there differences between products	• how are the products used in 'normal' use? • are the products likely to fail during this use? • does labelling/inst ructions affect how the product is used?

Table 10.12 - Stages 1 and 2 of the proposed evaluation process, for each case study

The testing process begins with the selection of evaluation methods. While some guidance could be given to designers on the methods that were used in the case studies, because of the diversity and adaptation of these methods that was necessary prescriptive, generalised methodological advice is difficult. The literature reviewed in Chapter 5 on ergonomics methodology and advice supports this decision. Instead, the approach taken has been to classify and distinguish between broad groups of methods, to provide designers with as wide an approach to testing as possible. Within these groups of *methods*, ideas on *techniques* would be given, but with a limit to the amount of detail given, otherwise this would make any guidance to designers akin to a methods text.

Based on the case studies, the methods available to the designer have been classified into three broad groups: comparison with ergonomics data or guidelines, product testing and user testing. This classification, as it applied in the case studies, is summarised in table 10.13. These groups are not mutually exclusive, and do not reflect the extent of the data collection and information used to assess the products. They have been classified to reflect the fact that, although the evaluations were all considered to be ergonomics evaluations, and therefore focused on the user, it was often necessary to take measurements of the product's performance and relate it to the characteristics and abilities of the users.

10.11 Discussion

The analysis of the case studies has demonstrated that a diverse range of methods and techniques are required for product safety evaluation. Prescriptive advice is seen to be difficult, because of the broad range of consumer products across which it should apply. Instead, generic issues were raised, such as the need to use simulation in user testing and the ethical and safety constraints on the methods of testing to be used, all of which put restrictions on the validity of the evaluations. Potential evaluators need to be aware of all of these issues. Also, common elements and stages in the evaluation processes were identified, and these have been used to produce a

framework for a suggested generic evaluation process. This will hopefully form the basis of guidance to designers embarking on safety evaluation.

Evaluation	SPCs	Bottles	ATBs	Stepladders
Comparison with ergonomics data	• children's pulling strength • size of aperture through which children can pass • children's ability to undo buckles • weight of objects children can move	• users' opening torque (children through to elderly)	• distribution of body weight whilst cycling	• balance during over-reaching
User testing	• propensity of children to explore covers • children's pulling strength • size of aperture children's could crawl through • children's ability to remove pegs • children's ability to undo buckles • children's ability to move water bags	• users' opening technique with hands and tools • propensity to turn caps the wrong way • users' opening behaviour • propensity to use tools	• loads set up in bike frame during off road use	analysis of stepladder use such as: • amount of over-reaching • re-positioning • use of hands • placement of feet
Product testing	• size of aperture at edges of covers • tensile strength of cover material • resistance to wear and weathering • force required to remove securing pegs • closing force of automatic cover	• pressure inside bottles • pressure to cause missiling • pressure to cause bottle failure • torque to remove caps • tensile force to remove caps	• loads required to cause bike failure	• the size and distribution of loads in stepladder feet during over-reaching and falls

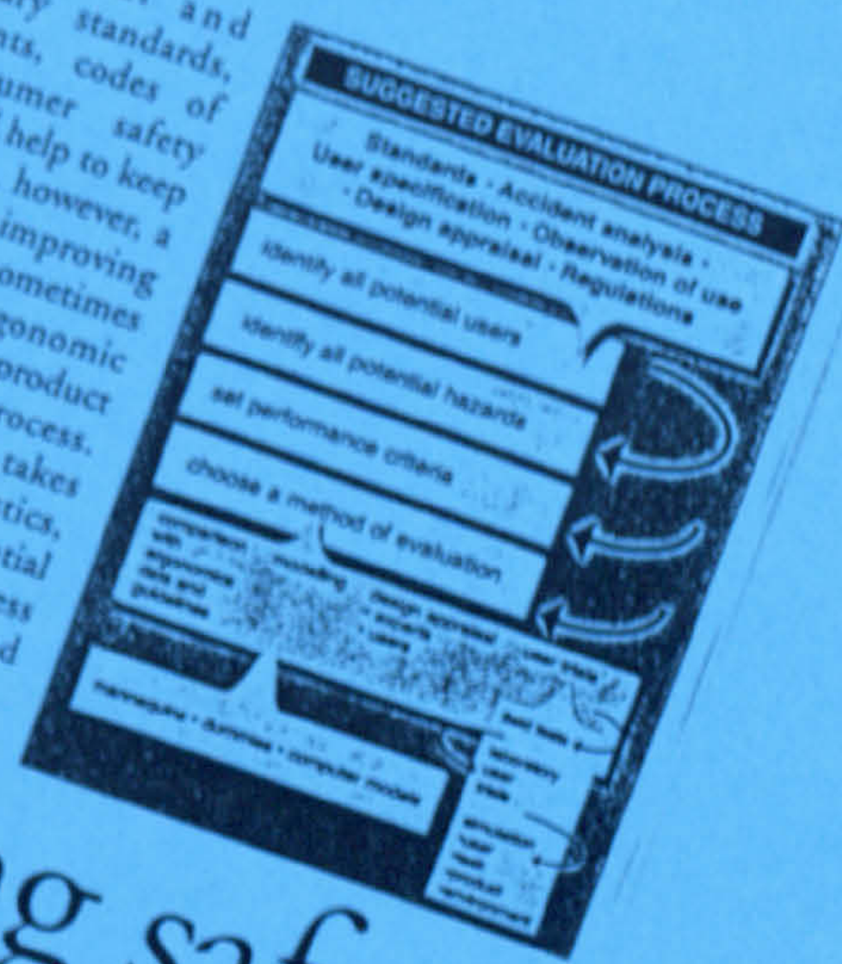
Table 10.13 - Evaluation methods used in case studies

The evaluation framework produced in this Chapter is based solely on the case studies. It is therefore of interest to know whether the choice of products and hazards evaluated in the case studies has influenced the outcome, and whether the same results would have been obtained by evaluating different products. The case studies represent a diverse range of products and the products evaluated are some of

those most frequently involved in home/leisure accidents: bikes, stairs/steps, and ladders/stepladders are cited by Rogmans (1989) as the most frequently involved products (along with carpets and pavement). The level of confidence that can be assumed from basing an evaluation process on these case studies alone could only be answered by carrying out more experimental work, but this is beyond this research. In view of this potential criticism however the next Chapter reviews the suggested evaluation process in the light of literature on methodological guidance which was reviewed in Chapter 5.

Designing safety into products

Regulation (National and European), voluntary standards, voluntary agreements, codes of practice and consumer safety awareness initiatives all help to keep products safe. There is, however, a more basic means of improving product safety which is sometimes overlooked: the ergonomic assessment of safety of the product throughout the design process. This means the designer takes into account the characteristics, abilities and limitations of potential users throughout the process of designing, producing and marketing products.



In the past, use of ergonomics data in the product design process has been limited; sometimes due to a lack of specific, applicable data, but always by a lack of practical, methodological advice. The dearth of operational guidance partly reflects the difficulty of providing such advice in a form which is sufficiently general to be appropriate to a range of products and users, yet sufficiently specific to be directly applied by those involved in design and production. A vital part of any ergonomics contribution to product development is the testing of the product-user interaction, but assessing this can be extremely complex both in the methods used and also during development.

'Designing safety into products' is a guidance document that will be published shortly. It is the culmination of research conducted by Nottingham University on behalf of The Department of Trade and Industry, with assistance from The Design Council, aimed at helping to improve the design process by 'building-in' safety.

Using ergonomics testing within product design will have a number of benefits for both the producer and the user. Greater emphasis on safety at the design stage will lead to reduced frequency and severity of accidents for users and thus, to fewer legal problems with dissatisfied customers or with the enforcement authorities. At the same time, usability and product quality will be improved: developments which will boost UK business because they increase business competitiveness world-wide and benefit the consumer. Early and continuing ergonomics testing, if applied at the right time and with the appropriate level of sophistication, can also give significant gains in the efficiency of the development process, thus accelerating the development of a new and better product.

- Safety Net, Department of Trade and Industry, London, Autumn 1997

Chapter 11 - Guidance for product designers

The framework for a suggested evaluation process produced in Chapter 10 was based on the analysis of the case studies only. This framework is now reviewed and considered alongside the published work on ergonomics evaluation methods and designers' guidance which was reviewed in Chapter 5, and a revised framework of the evaluation process is presented. This was used to form the basis of guidance to designers to encourage, promote and direct the ergonomics evaluation of safety during product development. The guidance has taken the form of publication '*Designing Safety into Products*' which together with *Childata* represents the outcome of this research. The production and content of the publication is described in this Chapter.

11.1 Introduction

The work described in this Chapter has resulted in a publication for designers, '*Designing Safety into Products*', (DSP) which is presented as an appendix to this thesis. The DSP Guide was published by the Consumer Safety Unit of the DTI in October 1997 and has been distributed free of charge to industry as a guide for designers. This Chapter describes the requirements of the publication together with the justification for its format which centres on a generic 'evaluation framework' intended to be applicable across a range of products. The final framework is developed in this Chapter, based on the evaluation process suggested in Chapter 10 and revised in the light of other published guidance on evaluation.

11.2 Requirements of guidance for designers

The Guide was conceived as a stand-alone document or 'tool' with a target audience of designers and production teams working without any ergonomics support and who would be unlikely to independently access information on ergonomics methods and techniques. Discussions were held with a representative of the Design Council and an international design consultancy (IDEO) and a product designer to identify the requirements of such a document. From these discussions the following functions of the document were identified:

- promote safety as an important design criterion to designers and producers
- promote the relationship between ergonomics, safety and good design
- encourage designers to see ergonomics as more than the use of anthropometric and basic ergonomics data
- make evaluation a feasible part of the development process
- promote a structured approach to evaluating for safety
- provide advice on evaluation methods.

In addition to these functions, in order to appeal to designers, the document should:

- be easily readable
- avoid ergonomics jargon
- offer an easily recognisable, and easy to follow, evaluation process
- avoid appearing as a textbook or academic publication
- be aesthetically appealing to design professionals.

11.3 Methodological guidance versus a generic framework for evaluation

The evidence presented in Chapter 5 suggested that ergonomics methods may be difficult to use even by ergonomists, and perhaps remain unpopular outside

the ergonomics discipline. Many ergonomics evaluation procedures can be difficult to apply, or at least require lengthy preparation and familiarisation, even for ergonomists let alone by a designer during a time- and cost-pressured development process. Stanton and Young (1998) suggested that while the plethora of methods developed by the ergonomics discipline remain documented predominantly in academic journals, there has been a rise in the number of general ergonomics 'methods texts'. They suggest that this is possibly in response to designers taking user-centred design seriously and that success has encouraged the ergonomics community to promote methods to assist in design of products and devices. However there is still no evidence of the successful transfer of these methods to the design discipline.

Because of the reported difficulty in choosing, applying and transferring ergonomics methods, the concept of giving designers a step-by-step prescription of how to evaluate any design is attractive, both to ergonomists and designers. However, there is a conflict between generic and specific guidelines, which is a characteristic of all ergonomics guidance and one which makes it difficult to produce practical, stand-alone guidance across a large range of product groups. The requirement to be generalisable can usually lead to a checklist format of advice, of 'ergonomics' factors to be considered in design (for instance see Ramsey, 1985; Meyer, 1994; Straker, 1994) but with no real guidance on how to apply techniques. On the other hand, the requirement for specificity leads to a myriad of possible evaluation techniques, so that the user needs help in selection. It has to be borne in mind that an important requirement of any design 'tool' is that it should convince designers of the feasibility of evaluation and not deter them with the prospect of having to invest time in selecting and becoming familiar with methods. There was thus a conflict between the need for completeness and rigour of any methodological guidance and for the publication to be accessible and brief.

It was therefore decided that an improved approach to encouraging ergonomics evaluation would be to produce a document which, rather than giving advice on

ergonomics methodology, concentrates on establishing the relationship between safety, ergonomics and evaluation, stresses general issues relevant to evaluation and, in terms of methodological advice, provides a generic evaluation 'framework' and ideas on how to practically incorporate evaluation into the development process.

11.4 Support for a generic evaluation framework

A framework for an evaluation process, consisting of a number of 'core' stages, was proposed in Chapter 10 based primarily on the outcome of the case studies. The published guidance reviewed in Chapter 5 was considered again for evidence of other or similar frameworks.

Four of the publications reviewed - USERfit (1996), Chapanis (1995), Rennie (1981) and Lamb (1985) - could be considered to have used an approach similar to that proposed here in that they all suggested a 'dual-level' approach to evaluation. In each publication the 'top-level' consists of discrete stages that comprise the evaluation process, with a 'lower-level' being the selection of techniques within each stage. They do however differ greatly in the techniques and elements they propose. Chapanis describes a six-stage sequential process comprising a range of activities at each stage. USERfit uses a hierarchical structure of summary tools and design tools. Rennie, Lamb and Drury all talk of preliminary steps which are used to decide which tests are carried out. Drury identifies or proposes 'preliminary steps' in his evaluation model and then formulates measures of design parameters. This process somewhat resembles the first stages of the framework proposed here, of identifying hazards and then setting performance criteria. Rennie also states that there are no rules on how to decide between evaluation techniques. There was therefore support for the idea of a framework for evaluation, rather than methodological guidance.

11.5 Revised evaluation framework

The framework produced in Chapter 10 was revised and is shown in figure 11.1, and each of the three stages is discussed in the following sections.

11.5.1 Stage 1 of the evaluation process:

The identification of users and hazards

This first stage now encompasses three separate steps: the identification of the users, those at risk and the specification of detailed hazard scenarios. The information sources suggested as potentially useful at this stage have been expanded, as it was felt there were limitations to the information sources used in the case studies. Accident data were found deficient in a number of areas: information on fatal accidents is virtually non-existent; the detection of rare or infrequent accidents with a product (those possibly attributable to misuse) depends on the sensitivity of the accident monitoring systems; lack of sensitivity can also mean products are mis-classified and accident details are often scant because of the difficulties and time-delays involved in following-up accident victims. Similarly standards and regulations are of limited use as they refer to established hazards only and do not exist for all products. The information sources and activities which are suggested as useful in this first stage, and the reasons for their inclusion, are as follows:

- *Specification of users* — This may appear an obvious step but only Dockery and Neuman (1994) and USERfit (1996) specify this in their evaluation processes. Placing it as an activity in the first stage of the proposed process emphasises its importance.

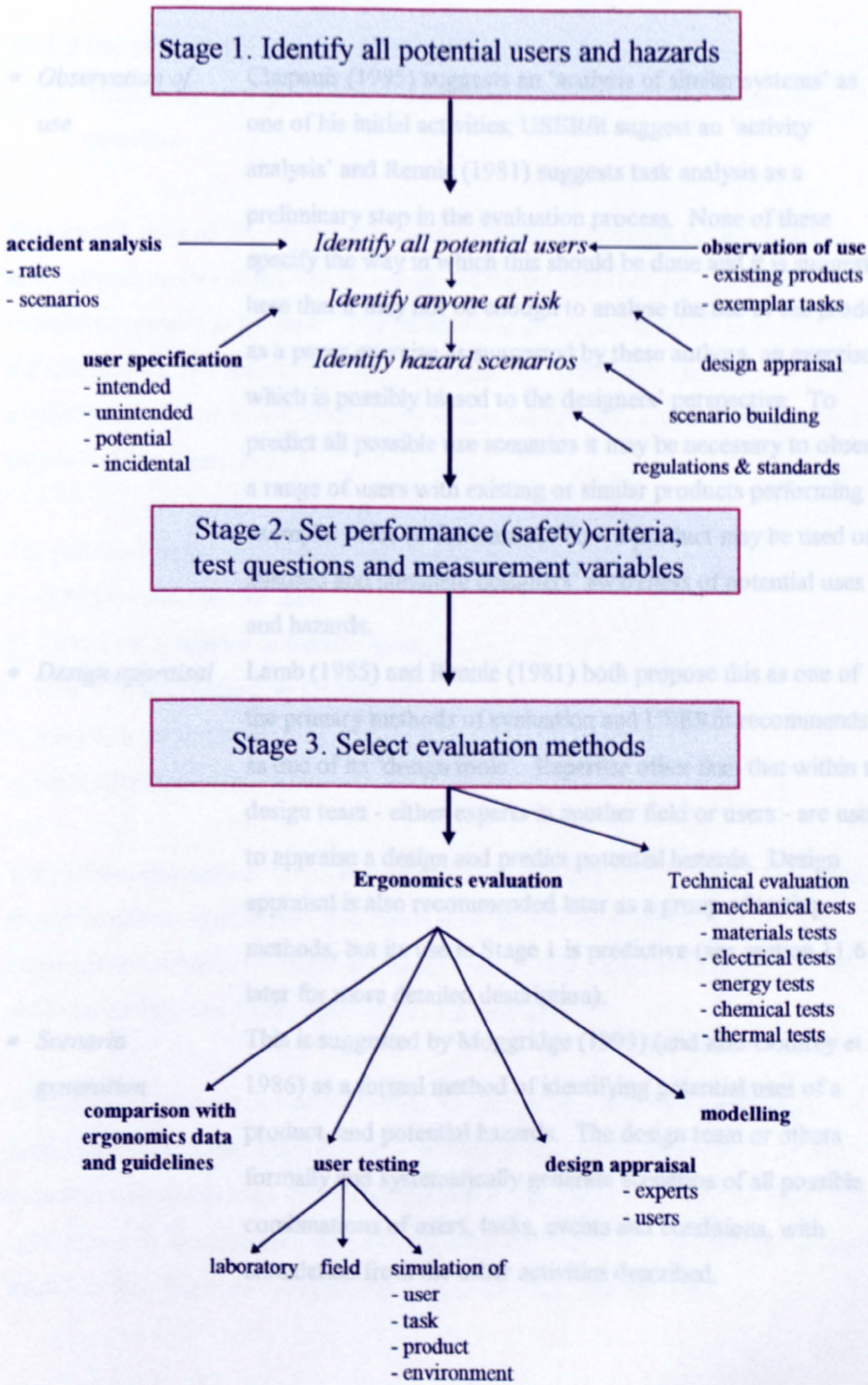


Figure 11.1 - The Product Safety Evaluation Process, revised from Chapter 10 and forming the basis of 'Designing Safety into Products'

- *Observation of use* — Chapanis (1995) suggests an 'analysis of similar systems' as one of his initial activities; USERfit suggest an 'activity analysis' and Rennie (1981) suggests task analysis as a preliminary step in the evaluation process. None of these specify the way in which this should be done and it is suggested here that it may not be enough to analyse the use of the product as a paper exercise as suggested by these authors, an exercise which is possibly biased to the designers' perspective. To predict all possible use scenarios it may be necessary to observe a range of users with existing or similar products performing exemplar tasks to demonstrate how a product may be used or misused and stimulate designers' awareness of potential uses and hazards.
- *Design appraisal* — Lamb (1985) and Rennie (1981) both propose this as one of the primary methods of evaluation and USERfit recommends it as one of its 'design tools'. Expertise other than that within the design team - either experts in another field or users - are used to appraise a design and predict potential hazards. Design appraisal is also recommended later as a group of testing methods, but its use in Stage 1 is predictive (see section 11.6.5 later for more detailed description).
- *Scenario generation* — This is suggested by Moggridge (1993) (and also Godfrey et al, 1986) as a formal method of identifying potential uses of a product, and potential hazards. The design team or others formally and systematically generate scenarios of all possible combinations of users, tasks, events and conditions, with stimulation from the other activities described.

11.5.2 Stage 2 of the evaluation process:

The setting of performance criteria, test questions and measurement variables

This second stage of the process, the setting of performance criteria, test questions and measurement variables, was described in Chapter 10 as helping to identify the evaluation methods to be used. The process was developed from the examples of the case studies. To demonstrate the generalisability of this process, this now been extrapolated to show how it would apply to another product, a stair safety gate and is shown in full in figure 11.2.

The potential hazard scenarios of this product are suggested as:

- child gets past the stair gate
- child/adult gets stuck in the stair gate
- child's limb is pinched by the stair gate
- adult falls over the stair gate
- adult injury during assembly.

The performance criteria for the first hazard would be that no child under five years should be able to operate the catch, climb over the gate or push/pull it open. The measurement variables for this first criterion would be the amount of movement the child had made in the catch within a specified time limit.

In some cases however, it may be difficult to 'design out' all hazards and this is addressed in the Guide. For instance, a performance criterion may have to be set to include an acceptable level of risk, for instance a safety gate that could be opened by 10% of two year old children would be unacceptable but a .01% chance that an adult might cut their finger on the catch might be deemed an acceptable risk.

hazard	examples of general questions	performance criteria	examples of specific questions	measurement
Child gets past the stair gate				
Child opens lock	Is lock operable by children?	No child in a specified age group should be able to open catch	Define 'operable'	Time to open, amount opened
Child climbs over gate	Can children climb over gate?	No child should be able to climb over gate or get injured trying to	What is a successful climb and how likely is a fall?	Time to climb, stability of gate and child during climb
Child pushes or pulls gate open	Can children push or pull gate open?	No child should be able to push or pull gate open	Define 'open'	Time to open, amount opened
Child gets stuck in the stairgate				
Child forces head/arm/ hand/foot through gap(s)	Can a child's head/arm/ hand/foot pass through any gap and get stuck?	Ideally no child should be able to pass their head/any part of body into gap and if they can without risk of injury	What is maximum size of gaps that prevents head/ body part of smallest child entering? What level of entrapment may cause injury?	Specify minimum head size/body part to be excluded and use data (eg CHILDATA[1]) or replicas to test gaps
Child's limb is pinched by the stair gate				
Child pinches arm/hand/ finger/leg /toe in gate or lock	Are there any moving parts where child's arm/hand/ finger/leg/toe could get caught?	No child should be able to insert their finger/leg/toe into any moving parts	Can the smallest/largest child reach moving parts? Can the smallest child insert a finger/leg/toe? What cognitive elements are involved?	Check anthropometric data (eg CHILDATA[1])to assess reach and test ability to reach or access parts
Adult gets stuck in the stair gate				
Adult forces arm/leg through gap(s)	Can an adult's arm/leg pass through any gap?	No adult should be able to insert an arm or leg in any gap	What level of entrapment is likely to cause injury? What is the maximum gap that still prevents the arm/ hand of the smallest adult entering?	Specify the minimum hand/foot size to be excluded and use data (eg ADULTDATA[1]) or replicas to test gaps
Adult falls over the stair gate				
Adult climbs over gate when in place	How easily can an adult climb over the gate?	Ideally all adults should be ableto climb over the gate with acceptable ease	What is considered a successful climb? Can those users likely to fall be identified?	Time taken to successfully climb over. Identify differences in climbing ability and techniques between adults
Adult hurts themselves assembling the stair gate				
Ease of assembly	How could injuries occur during assembly?	All adults should be able to assemble the gate with no risk of injury	Identify assembly tasks and rate of occurrence. If safe assembly is achievable by some users, identify which may have difficulty (eg elderly)	Identify differences in assembly ability between adults.

Figure 11.2 - Setting performance criteria and test questions in the evaluation of a stair gate (from 'Desiging Safety into Products')

11.5.3 Stage 3 of the evaluation process:

The selection of evaluation methods and techniques

The evaluation process suggested in Chapter 10 classified the potential evaluation methods into three groups based on those used in the case studies: comparison with ergonomics data/guidelines, user testing and product testing. The literature on ergonomics methods reviewed in Chapter 5 was used again to try to refine and reconcile this classification of methods.

Rennie (1981) divides evaluation into technical and ergonomics tests, describing technical tests as those without any reference to the user. This differentiation has been adopted here in the revision of the evaluation process, and methods have now been re-classified as either *ergonomics evaluation* or *technical evaluation methods*, with user testing and ergonomics data/guidelines being grouped under the title ergonomics evaluation. Ergonomics evaluation can be considered as the assessment of those aspects of the design that are dependent on some interaction with the user, task or environment. Technical evaluation is considered as the assessment of technical aspects of the design (such as mechanical, materials, chemical, electrical etc). This differentiation was used to identify those technical aspects which would be considered outside of the remit of the DSP Guide. The methods within ergonomics evaluation are further classified, and direction was sought on a suitable taxonomy of methods.

Many authors reviewing ergonomics methods concentrate on specific methods or techniques without fitting them into a flexible or generic evaluation process. Methods such as: walk-throughs (Meister, 1992; Haubner, 1990); expert appraisal, (Meister 1992); user trials (McClelland, 1995) and formal hazard identification methods such as fault tree analysis (Cushman and Rosenberg, 1991). Some differentiate between field and laboratory testing (eg Meister, 1986; Haubner, 1990) and between observational methods such as link charts and gantt charts (Drury, 1995). Haubner (1990) classifies the types of data that can be collected into

performance, physiological, behavioural and opinion data and Meister (1986) classifies measurement methods into observational methods, rating scales, interviews, questionnaires and objective methods. Wilson and Corlett (1995) provide a comprehensive overview of ergonomics methods, including those applicable to the evaluation of human-machine system performance and the demands on people.

However the classifications of methods with most applicability to the framework already produced from the case studies were those offered by Lamb (1985), Rennie (1981) and Meyer (1994) which were discussed in Chapter 5. Their classifications have been amalgamated here as follows:

- user trials
- expert appraisal
- performance tests
- human simulation tests.

The classification of methods produced in Chapter 10 was revised in line with this classification to include design appraisal and modelling. 'Performance tests' in the above classification have been taken to be technical testing, and human simulation tests referred to as modelling.

11.6 Format and content of 'Designing Safety into Products'

A model of the revised evaluation framework was shown in figure 11.1. This framework forms the basis of the Guide for designers: 'Designing Safety into Products' (DSP). The format and content of this publication are described in this section.

The Guide takes a pragmatic approach to 'selling' ergonomics to designers. Consultation was held with representatives of the Design Council, a design consultancy, the DTI Consumer Safety Unit and an industrial designer to try to identify the requirements of designers. It was decided that the Guide should not

appear as an academic publication, but should look like it offered practical advice that could be obtained without time-consuming study. Once the content of the Guide had been decided, technical writers and graphic designers were used to produce a document that would appeal to the target audience. Numerous drafts were reviewed by the team mentioned above as well as by other ergonomists.

The Guide introduces readers to the need for ergonomics and safety considerations in design, conveys the basic factors to be considered and then promotes ideas for evaluation methods. This format was adopted on the supposition that there are a number of basic factors to consider in *any* ergonomics evaluation and that these apply to *all* evaluations. Also that the most important issues to be conveyed, rather than detailed methodological advice, is that all evaluations must be user-centred, that all users need to be accounted for and all potential use-scenarios predicted. The selection of methods will then be dictated by performance criteria and any practical or other constraints.

The requirements of the Guide were described earlier in this Chapter in section 11.2, but chiefly its aims were to:

- persuade designers to evaluate for safety
- promote evaluation as an integral and formal part of product development
- introduce the basic principles of ergonomics and its relationship to safety
- suggest a generic evaluation process
- stimulate ideas on evaluation methods.

The contents of DSP are shown in figure 11.3 and the following sections describe how each of the above aims of the Guide are met.

1 Introduction	
About this book	*What this book contains* *Who should read it*
Design safety and ergonomics	*Approaches to ergonomics evaluation* *How evaluation can help you: competitive advantage and commercial gain* *Bringing safety into the product development process* *What should you evaluate*
2 Suggested evaluation process (*framework*)	
First steps in evaluation	*Identify all possible users* *Identify potential hazards* *Set performance criteria* *Choose a method of evaluation* *Evaluation chart*
Checking against ergonomics data and guidelines	*How and where data can help* *Limitations of using ergonomics data and guidelines*
Modelling	
Design appraisal	
User trials	*Choose your users* *Prepare the test* *Generating performance criteria and test questions* *Types of testing: real life versus laboratory* *Collect the results* *Working out statistical significance* *Applying the results*
Acting on the results	
Further information	

Figure 11.3 - Structure and contents of 'Designing Safety into Products'

11.6.1 Persuading designers to evaluate for safety

DSP tries to convince designers and producers that evaluating for safety is a viable and cost effective process which can be accommodated along with all other constraints on the product development process. To this end, 'Designing Safety into

Products' is aimed not only at designers but also at anyone with a responsibility for design or safety - design managers, directors and marketing managers. The concept of ergonomics is 'sold' before the choice of appropriate methods even becomes an issue. The benefits of an established procedure are therefore conveyed, particularly in economic terms, suggesting that it can be used to improve all facets of the product design - usability and not just safety - including expanding a product's market by accommodating a wider range of users, and importantly that evidence of a formal evaluation process is now valuable in light of strict product liability (as highlighted by Cushman and Rosenberg, 1991). The process of evaluating for safety is broken down into tangible, recognisable units, each with its own benefits (expanding on ideas by Cushman and Rosenberg):

- ensuring a product is reasonably safe for its intended use and its intended users
- extending such safety to include foreseeable misuse, including use by unintended users especially the vulnerable such as children and the elderly
- identifying those at risk
- identifying the likelihood of injury
- establishing the likely severity of any injury
- highlighting possible design improvements.

It is stressed that a reliance on standards and regulations is not a guarantee of safety as these are only *minimum* safety requirements. The need to evaluate is therefore emphasised especially where standards are lacking, changing or if they vary around the world.

11.6.2 Evaluation as an integral and formal part of product development

Ergonomics evaluation is shown to be an integral part of the whole product development process, from initial concept development right through to monitoring product performance in the market, and DSP presents the model of the development process together with its ergonomics inputs which was developed in Chapter 3 of this

thesis. The Guide stresses the need for safety evaluation not only during new product development, but in all design activities, such as:

- developing a completely new product concept (for example mobile phones, car airbags)
- designing a new product within an existing concept (a new stair gate)
- redesigning an existing product to incorporate a new:
    - function (multi-function infant carrier)
    - feature (cordless power tools)
    - control/operating procedure (remote versus hands-on)
    - display (head-up car display)
    - mechanism (child resistant lighters)
    - structure (railings on the side of a cot)
    - styling (change of colour for controls).

11.6.3 The principles of ergonomics and its relationship to safety

With evaluation established as part of the development process, the fundamental principles of the relationship between ergonomics and safety are conveyed, to try to engender a user-focused approach to the design process. The features of the product-person interaction which influence safety and which must be considered in any evaluation are described as follows (based on those proposed by in Chapter 1 of this thesis):

- product - all features of the product should be assessed, including its structure, moving parts, controls, displays, casings, fixings, power sources, information and instructions, packaging and ancillary equipment
- user - the physical and psychological characteristics of the likely user population (by 'user' we mean anyone who may come into contact with the product, either intentionally or unintentionally, and as a result of the primary or a secondary interaction with the product)

- circumstances of use - the task fro which the product will be used, associated tasks and activities
- environment - the visual, auditory, physical and social conditions under which the product will be used.

In order to stress the need to accommodate a range of users and their characteristics, some examples of the types of data that are available are given, based on the table produced in this thesis in Chapter 4 (table 4.1) and also used in CHILDATA.

Also it is stressed that evaluation must consider all stages of the product's life-cycle: manufacture, transport, packaging, assembly, installation, use by all potential users, misuse by all potential users, storage, maintenance, cleaning, dismantling, disposal, re-use (second hand life) and recycling (a message extolled by many previous authors, for instance Wilson, 1983a).

11.6.4 A suggested generic evaluation procedure

The revised framework for evaluation produced earlier in this Chapter is then presented. Each stage of the process is then described. For stage one, the information sources and activities that can be used are described. To help stimulate an awareness of potential hazards, an 'evaluation chart' provides examples of the types of hazards that might be evaluated and possible evaluation methods that could be used. This is reproduced here and shown in figure 11.4.

Evaluation chart

hazard	hazard scenario	how to evaluate the hazard
Mechanical hazards		
access to hazard (by whole body or body part)	reach through guarding, child climbing over a stair gate, finger in electrical socket	check against anthropometric data, user trials possibly with simulated users
entrapment/jamming/ pinching/shearing • between moving parts • in an aperture • between structures	 – fingers trapped in doors – head in cot sides – open stairs	check against anthropometric data, computer simulation, user trials possibly with either simulated hazards or users
impact • user into product • product into user • powered • sharp edges	 – trip into furniture – insecure fittings – slipping with a power tool – dropping/falling onto a knife	user trials, possibly with simulated users or product, or by protecting user during test
fall • between levels • on same level • unstable product	 – fall down stairs – slippery floor surface – fall from stepladder	
Ingestion hazards		
toxic substances choking	– cleaning products – small parts swallowed by children	user trials, with simulated users
Explosive hazards	batteries, pressurised containers or mobile phones in contact with fire	
Fire hazards	children's use of lighters, clothes in contact with naked flames	ergonomics guidelines, user trials, technical evaluation
Electrical hazards	not unplugging product before maintenance, handgrip too close to live component	
Thermal hazards (extremes of ambient and surface temperatures)	contact with cooker surfaces, metal surfaces in extremes of heat or cold, fires and room heaters, radiators, freezer parts	
Vibration hazards	sustained use of power tools	ergonomics guidelines, user trials with simulated users, checking against data on human exposure rates, technical evaluation
Noise hazards	prolonged exposure to alarms	
Chemical hazards	carbon monoxide poisoning, cosmetics	
Radiation hazards	checking against data on exposure rates	

Figure 11.4 - Evaluation chart from 'Designing safety into Products'

11.6.5 Ideas for evaluation methods

Four groups of evaluation methods were identified earlier and descriptions of these are given, outlining the advantages and limitations of each group of methods and giving suggestions for the techniques that may be used within each group. A brief synopsis of the descriptions from DSP is given here.

Group 1 - Ergonomics data and guidelines

Ergonomics data and guidelines are defined as describing physical, motor and cognitive capabilities of users and general design rules derived from research on human performance.

The application of ergonomics to product design often begins and ends with reference to data and guidelines, and one of the aims of the guidance in DSP is to encourage designers to see the limitations in this approach and to encourage evaluation. The main limitations are described as:

- inappropriate populations - the differences in data due to culture, occupation, social class and secular trend must be considered
- generic versus specific data - the conditions in which data have been collected have to be considered, particularly for performance or strength data.

Group 2 - Modelling

Modelling is defined as using some kind of paper-based or computer-based representation of potential users at varying levels to assess a design.

Modelling has advantages over using ergonomics data in that the evaluation can be specific to a particular product, safety tolerances can be calculated and interactions can be clearly visualised. Models are limited by the appropriateness of the (generally anthropometric) data they are based on. Also, and particularly with paper mannequins or 3-D dummies, only a limited selection of the target population is represented. Computer modelling has obvious advantages in its compatibility with

other computer design software, that models can be manipulated to some degree, re-used and adapted indefinitely, and evaluations are quick once models are established.

Group 3 - Design appraisal

Design appraisal is defined as using specialist knowledge to assess a design, using insight that could not be provided by the design team alone.

Whilst design appraisal cannot be used to quantify hazards it can prove helpful in their identification and in stimulating the search for solutions. Specialist knowledge can be drawn from users (who can be experienced in the product, task, or environment; new or naive users; or even those that may have been injured by a product) or experts such as ergonomists, safety professionals, engineers, other designers or people expert in the product (eg manufacturers, suppliers, installers, repairers, servicers), environment (eg school teachers, gardeners, residential care suppliers), task (eg parents, DIY enthusiasts) or the user groups (eg child care experts or carers).

Within this group of methods a variety of techniques are suggested such as: walk-throughs, focus groups, checklists, interviews and participative methods such as Design Decision Groups (Wilson, 1991).

Group 4 - User testing

User testing is defined as observing, measuring and assessing a sample of representative 'users' carrying out a task with a examplar or specimen product.

'User trials' are known to designers but are often considered too costly and time consuming or are carried out in only a limited form. The aim of the DSP Guide was to convince designers of the variety of techniques that could be used in user trials, including levels of simulation, to make them a feasible and valuable means of testing. The guide stresses the attention that must be paid to key factors in order to gain maximum benefit for user testing. These are summarised here:

- subjects - ensuring they are representative, how to calculate appropriate numbers, recruitment, motivation, and instructions

- using simulation - of the user, product, task or environment - to combat ethical, practical, financial or time restrictions
- choosing the location of the test and the advantages and disadvantages of laboratory versus field testing
- selecting measurement variables and test questions
- the selection of measurement techniques - directly recording users' actions (observation, direct response, automatic event recording); self-records (questionnaires, diaries, commentary, protocol analysis); recording opinion data (rating, ranking, interviews, checklists)
- interpreting results (practical versus statistical significance, calculating reliability and validity).

11.7 Discussion

This Chapter has described the production of a tool for designers, 'Designing Safety into Products'. The aim was that DSP should be used as stand-alone document by designers who otherwise have no ergonomics support and who have minimal experience of ergonomics evaluations. The Guide was based initially on the experimental work carried out for this research, but has also drawn together the knowledge on ergonomics evaluation and the relationship between ergonomics and design safety which have been reviewed in this thesis.

The document takes a generic approach to evaluation, as prescriptive advice is impossible to give across a broad range of applications such as those represented by consumer products. Also, rather than give instruction in methods, as was the intention when this work first started, the Guide promotes and provides a framework for a general evaluation process. It also conveys the principles of the relationship between ergonomics and safety and provides ideas for evaluation methods. Practical guidance needs to concentrate on fundamental issues, rather than advice on methods, for a number of reasons:

- few ergonomics methods can be applied across all product groups and across all hazards, as shown in the case studies
- as a result there are as yet no rules to guide the appropriateness of methods
- the hazard-based approach taken to design safety is akin to current developments in standards work, which take a 'horizontal' or hazard based approach
- ensuring an embedded 'ergonomics viewpoint' in the design process is more important than methodological rigour
- providing ideas and examples of techniques will hopefully broaden a designer's repertoire of evaluation methods
- there is suggestions that some ergonomics methods are still difficult to use even for the ergonomics profession.

Although there has been much written on ergonomics methods, little guidance was found in the ergonomics literature that could be used directly to produce a framework for, or classification of, methods for use in product design safety. Even less has been written on evaluating for safety, and 'Designing Safety into Products' is the only advice that has been produced aimed directly at designers and industry and not at the ergonomics profession. The fact that this guidance is now in distribution is an important first step to providing designers with tools to integrate ergonomics into the development of consumer goods, a step that ergonomists have long called for.

Chapter 12 - Review, conclusions and recommendations

12.1 Summary of work

A need was established early in the research for an improvement in the safety of consumer products. Accident investigations offer little information on accident causation, however an ergonomics approach suggests that is the interaction of four main factors that precipitates an accident: the product, the user, the task and the environment. A number of routes and contributors to consumer safety were identified as shown in figure 12.1, and in Chapter 2 design was shown to be the central and most influential factor in both of these models of consumer safety.

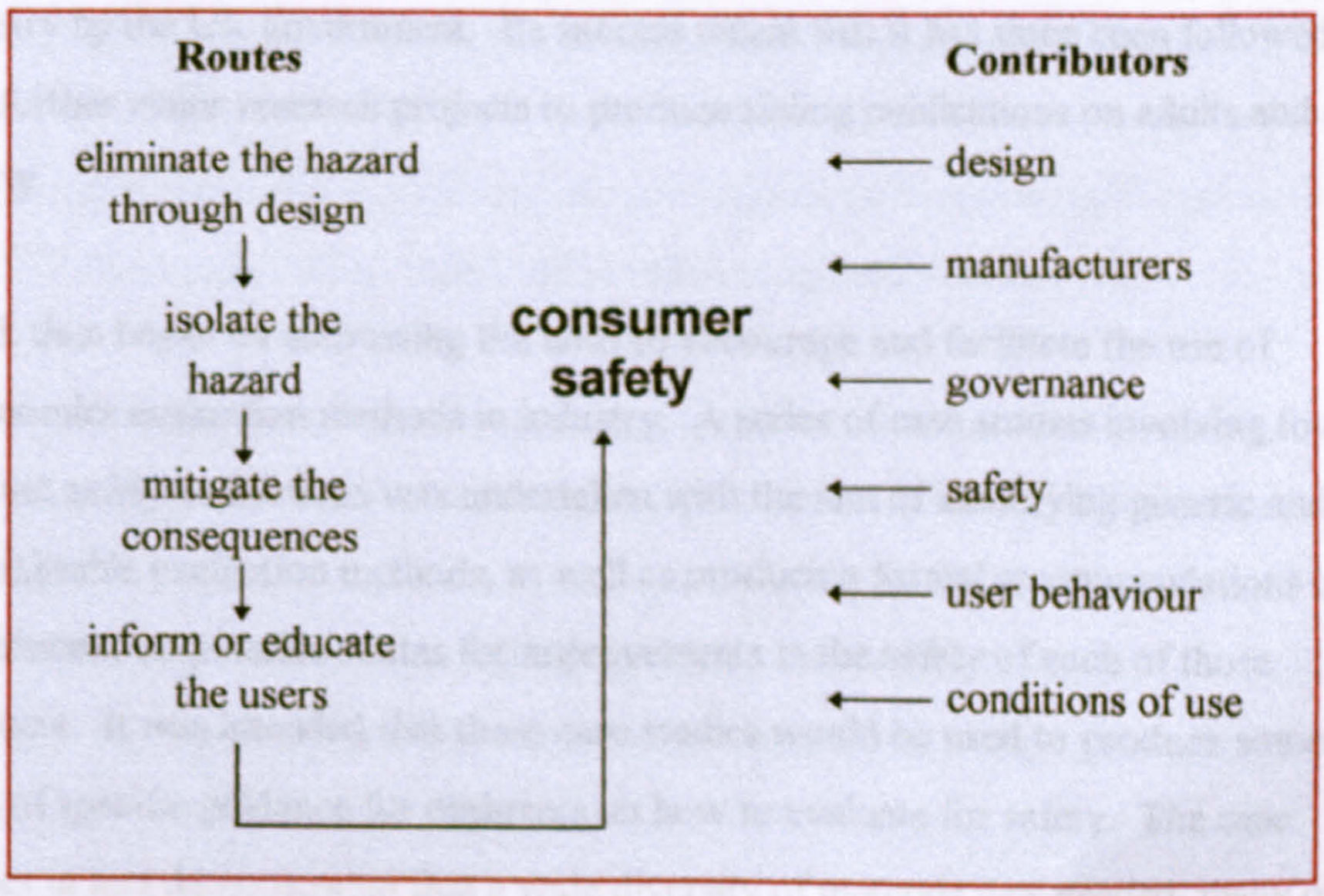


Figure 12.1 - Routes and contributors to consumer safety

With design established as a central influence on safety, this means that ergonomics has a potential to contribute to safety. The link between ergonomics and design is indisputable, yet despite more than twenty years of propositions for an improvement in the input of ergonomics to design little evidence has been found of a formal, established relationship between ergonomics and design. A need was therefore identified for an improvement in the transfer of knowledge and methods between the ergonomics and design disciplines.

Two main ergonomics contributions to product design were identified: the use of ergonomics data and guidelines and ergonomics evaluation. The aims of this research were to improve both of these contributions, and thereby improve consumer safety.

Work to improve the first input, ergonomics data, began with a review of the use of ergonomics data in design. Problems previously identified with the transfer of reliable, valid and applicable ergonomics data were shown to still exist. A series of publications assessing, structuring and promoting ergonomics data were produced to redress these problems. The first of these publications, *Childata* - a collation of data on children - is described in this thesis and has been successfully distributed to industry by the UK government. Its success meant that it has since been followed by two further major research projects to produce sibling publications on adults and the elderly.

Work then began on addressing the need to encourage and facilitate the use of ergonomics evaluation methods in industry. A series of case studies involving four product safety evaluations was undertaken with the aim of identifying generic and generalisable evaluation methods, as well as producing formal recommendations to government on possible routes for improvements in the safety of each of those products. It was intended that these case studies would be used to produce some form of specific guidance for designers on how to evaluate for safety. The case studies in fact demonstrated that a wide diversity of methods was needed, many of which were novel or were adaptations of existing methods; this led to a decision that rather than methodological advice, a framework for a generic evaluation process was

needed. This approach was supported by the literature reviewed on ergonomics methods. A framework was produced based on the case studies, then revised in light of published guidance and integrated into a publication for designers, *Designing Safety into Products* (DSP). DSP establishes and encourages a generic approach to evaluation, stresses the principles of ergonomics evaluation, its relationship to safety and the need to move past the use of ergonomics data, as well as providing some methodological guidance.

This Chapter now discusses some of the general issues surrounding the realisation of an ergonomics contribution to design, and the pressures and routes to improvements in consumer safety. This provides a context within which to evaluate the research reported in this thesis, allowing conclusions to be drawn and recommendations made about the contribution of the current research to consumer safety.

12.2 Pressures for improvements in consumer safety

Van Cott et al (1978) said (over twenty years ago) that consumers *expected* to buy goods 'that function well within human capacities'. European-wide legislative changes have supported their ideas, and consumer products must now, by law, meet consumers' expectations. Expectations of a product to 'function well' have now therefore been extended to legally enforceable *expectations of safety*.

In the past, strategies for achieving consumer safety have concentrated on risk awareness, individual motivation and instruction for users (Stoop, 1990). However, the legislative shift has been towards design as the primary route to safety, with the incorporation of developments such as designing for 'foreseeable misuse'. As well as legislative pressure to achieve product design safety, consumer pressure may also be increasingly felt. It has been suggested that novelty in a product sells, regardless perhaps of its performance, safety or ergonomics factors: 'if it does something different which was not possible before' (Butters and Tetra-Dixon, 1998). As technical performance improves and product parity increases, ergonomics and safety

could however become the main differentiating factors dictating a product's competitiveness. Design and therefore ergonomics have had their role in product safety officially sanctioned. There is a clear role for ergonomics in product safety, whether viewed from a theoretical, legislative or economic perspective, and the ergonomics discipline should be looking to respond to this opportunity for ergonomics to fulfil its potential role.

12.3 Ergonomics responding to its potential role

Priorities within the ergonomics discipline seem to have remained with occupational and technological applications, for instance, sophisticated efforts in work-related musculo-skeletal disorders, human reliability in high risk industries, human computer interaction. The continuing relative lack of interest in consumer ergonomics or consumer safety was possibly reflected in the programme at the 1997 International Ergonomics Association Congress where out of over 1500 papers just a handful touched on these subjects. Even within consumer ergonomics there persists an emphasis on usability, with little attention to safety. This is despite long-standing calls for improvements. Although little work had been published on consumer ergonomics up until the 1970s (Ivergard 1976), safety has long been established as an ergonomics criteria (Kirk, 1970). Marinnsen et al (1986) have said however that "research on safety in the 'personal sector' had been limited and designers had little more to go on than general indications and legal constraints" and made calls for "consumer safety...to be made more concrete for product designers and more applicable to the design process' (page 562).

12.4 Steps to realise ergonomics and safety in product design - criticism of the current research

The research described in this thesis has supported this call for concrete guidance for designers, and the hypothesis of the research was that formalising the input of

ergonomics into the design process would ensure that design safety would be better achieved. It is intended that the output of this current research - the provision of at least two publications aimed directly at safety and at designers - are steps towards supporting the needs of designers and ultimately the formalisation of ergonomics inputs.

The research was in two parts. The first of these, improving the accessibility of ergonomics data - the production of *Childata* and its sibling publications on adults and the elderly - is unlikely to be contentious in its aims. There are however criticisms that could be levelled at the methodology of this work:

1. The production of a hard copy data collection and its distribution and publication via the government may limit accessibility to data, and computer based/Internet dissemination should be considered[1].
2. The provisions for updating the publications are also limited, especially while maintained as a hard copy publication.
3. The work required to identify, locate and collate data suggests that the existing channels for the dissemination of ergonomics data are inadequate.
4. Co-ordination of research is needed to identify missing data, avoid unnecessary repetition of datasets and promote production of data by comparable methods and in comparable units and age groups.
5. Research is needed to identify and fill gaps in available data.
6. Detailed reviews of the publications (Childata, Adultdata and Elderlydata) are needed to allow an assessment of its format and content, the choice of data, the ability of designers to choose between data sources and the need to provide stricter design parameters.

It is recognised that each of these criticisms would, if addressed, improve the provision and ultimately the application of ergonomics data.

[1] The sibling publication Adultdata has now been produced and the hard copy version is complimented by a computer version distributed by a commercial company.

The second part of the research resulted in a potentially more contentious output, a guide for designers - '*Designing Safety into Products*' (DSP). The approach of this publication could be interpreted as 'giving ergonomics away'. It is based on the assumption that product development is most often undertaken without the involvement of an ergonomics professional and that, where possible, designers want stand-alone tools geared to their needs and not to those of academics or ergonomists.

The publication was first conceived as a guide to testing methods, giving prescriptive advice on the suitability of these methods and associated techniques to each evaluation situation. This assumes that designers have the knowledge and experience to successfully apply the different methods. The difficulty in applying ergonomics methods, even by ergonomists themselves, has been identified: 'a method which to one researcher or practitioner is an invaluable aid to all their work may to another be vague or insubstantial in concept, difficult to use and variable in its outcome' (Wilson and Corlett, 1995 page 21). Stanton and Young (1996) suggest the selection criteria an ergonomist might use when approaching a collection of methods (appropriateness, time to train to use, time to apply, the relative benefits of methods) but it is unknown if a designer or producer would ask these same questions, if she/he would have the time to consider a variety of methods, or understand the implications of different methods. Thomas et al (1990) suggest that the selection of an evaluation method or combination of methods during a design process depends on the time and resources available and the type of product, with cost often the major factor; and Meister (1992) says that it is impossible to give rules on the choice of methods, as this depends on making sure you get data you need balanced with cost, time, ease (that is likelihood of success), simplicity and that it is 'difficult to establish simple invariant rules' for test and evaluation methods.

The difficulty in choosing methods has been suggested as being due to a number of reasons: test and evaluation methodology is weak and invalidated; the ideal of a scientific method is holding back test and evaluation advancement; there is nothing approaching a database to assist test and evaluation methodology; there are lots of human factors tools and techniques but few have been validated (Meister, 1994).

The issue of validation holding back advances in methodology has been raised by other authors: Stanton and Young (1998) say that not enough is done about the rigour (reliability and validity) of published methods - that demand for methods has resulted in 'pragmatic development having priority over scientific rigour' - and suggest this as an important goal of future research. Rennie (1981) said alternatively that many ergonomists fear that their work would not stand up to 'rigorous scientific examination' and this impedes the dissemination of methods.

While these criticisms are accepted, the existence and potential contribution of ergonomics methodology needs at least to be first advertised to those outside of the ergonomics and research community. Designers and engineers may be unable to judge the appropriateness and benefits of a method without first knowing about it and practising it, but notwithstanding the difficulties of choosing methods and the possible lack of rigour, the DSP publication may be the necessary bridge between a designer's lack of understanding of ergonomics issues and their confident use of a repertoire of evaluation techniques.

Straker (1994) suggests that the complexity, volume and lack of availability of information on evaluation methods is to blame for the dearth of evaluations during product development. He suggests that designers need a simplifying structure of the evaluation process, a memory aid, and improved documentation on the advantages and disadvantages of various techniques. The *Designing Safety into Products* Guide answers each of these requirements exactly.

12.5 Organisational barriers to ergonomics inputs

As well as the barriers specific to conveying ergonomics *methods* described above, there are more general barriers to the acceptance of ergonomics as a discipline. These are of interest, as one of the aims of the current research has been to promote the use of ergonomics generally in product design. This will also provide a context for the likely success of the work undertaken in this research.

The use or non-use of ergonomics knowledge by design engineers has long been discussed; as far back as the 1960's it was being explained by reference to engineers' knowledge and skills, their attitudes to human factors and their approach to the design process (Slappendel, 1994 [referring to Meister and Farr, 1967] and Meister, 1971).

Slappendel suggested that organisational factors, such as organisational configuration and top management orientation often have most influence over the acceptance of ergonomics. This creates or perpetuates a lack of appreciation of ergonomics by designers. She recommends improved co-operation between ergonomists and designers, but sees potential areas of conflict, for instance:

- the different emphases and orientations of designers and ergonomists - ergonomics is often seen as only a part of design and that user-centred design can be approached intuitively
- ergonomists possibly seeing industrial design as encroaching on their area
- ergonomists seeing ergonomics knowledge as being created by themselves and transferred to organisations - rather than organisations being able to generate specialist knowledge internally.

She suggests that the ergonomics contribution by designers should not be underestimated and that there is a tendency for ergonomists to assume that manufacturers lack any capability in this area whatsoever. Instead it is the structure and strategy of an organisation which will limit ergonomics capability and ergonomists must know these to be able to predict the receptiveness of clients to ergonomics advice.

Fisher (1991) suggests that a key factor in ergonomics contributions being recognised is the ability to communicate ergonomics' role and contributions in clear and concise terms. Obstacles include the poor visibility of the role of ergonomics, poor placement in the organisation, overlap with engineers and industrial designers, a lack of recognition for longer lead times needed for resolving ergonomics issues and that ergonomics has to have an input in all stages of the design process.

Both of these viewpoints lend support to the approach of 'giving ergonomics away' to designers or developers, and providing them with tools to help build on their abilities. This is rather than ergonomists assuming they have to be directly involved in each product's development. Efforts need to be made to raise the profile of ergonomics and especially to providing industrial designers with tools to assist their ergonomic input, the approach taken by this current research.

12.6 Ways forward

Raising the profile of ergonomics through marketing has been examined by a number of authors, looking for routes to improve the role of ergonomics in product design. Harris (1990) says that ergonomics is difficult to promote because the long term benefits associated with improved design are typically ignored or undervalued, because of pressure to get products 'on-stream'. Time and cost pressures mean ergonomics advice is rarely sought early in the design process and only when problems are evident. Pikaar et al (1990) said that there are two conditions to ergonomics input being accepted: that the benefits of an investment have to be shown beforehand and the contribution must fit the established project procedures. Cushman and Rosenberg (1991) suggest that ergonomics can be promoted to a design team as a 'vehicle for conflict resolution', and with regards to ergonomics testing, that it can be promoted as a way of proving the usability claims made by marketing. Harris suggests that the key to a successful product is designing for the target market, for which an ergonomist's knowledge is vital. Thomas et al (1990) also propose marketing ergonomics in this way, as a means of ensuring that the product is meeting the needs of its intended users - selling ergonomics by the 'increase sales potential' route - and as a means by which manufacturers can gain confidence that they have fulfilled their legal obligations.

12.7 Conclusions

Ergonomics - 'the concept' - should not be the sole possession of ergonomists. Indeed, if it is to be effective it is suggested that ergonomists should be providing designers with tools and techniques to easily accommodate ergonomics (and within the emphasis of this research, to promote safety) within their design process. The need for a safety input to design has been discussed, as well as the practical and organisational barriers to its realisation. There have been recommendations of organisational measures to improve designer-ergonomist interfaces where ergonomics support exists within an organisation, but not all designers work within structured design and development departments and there are many designers who work alone or without the support of a product development organisation. In both of these environments however designers need *practical* assistance to make ergonomics concepts integral to their work, rather than an ergonomics consultation being an 'add-on' when time or cost allows, or worse, once problems have been identified.

It is suggested that there are three main barriers to ergonomics in design:

- conflict (between ergonomics and other criteria)
- availability of information
- lack of formality, structure and accountability for ergonomics.

Conflict will always exist between any number of design criteria, with pressures such as marketing, engineering, time or cost often negating ergonomics. This can only ever be overcome by raising the profile of ergonomics. The design-support publications which are the output of this research are intended as practical tools for empowering designers, by increasing the accessibility of basic ergonomics information. The publications should, however, also contribute to raising the profile of ergonomics, as well as formalising and structuring ergonomics and safety into design. This work therefore addresses all three of the potential barriers to ergonomics listed above. It can therefore be concluded that the hypothesis of the research has been accepted, and these tools should help realise improvements in the

input of ergonomics in design. The contribution of the tools to the realisation of consumer safety will however, as with any intervention, require long term evaluation.

The conclusions to be drawn from this research can be summarised as follows:

1. Consumer products and safety have not been a priority within ergonomics research.
2. There are still inadequacies in the production and dissemination of ergonomics data:
    - research to produce data for use in design is not efficient, in that there is overlap and duplication in much research, and data that could have design applications are not recognised
    - there are still gaps in available data, much of the missing data are product-related, performance or safety related data
    - data are still not systematically disseminated outside the profession and specifically to designers
    - it remains incumbent on designers to seek out information and data
    - there are inadequate links between the users of the data (the design profession) and the producers of the data (the ergonomics research and academic communities).
3. Ergonomics has not yet made its methods usable to those outside the discipline:
    - it is not possible to produce a 'laundry list' of factors for safe design
    - it is not possible to give prescriptive guidance on how to evaluate for safety, which could be applied across a broad range of products or hazards
    - the experimental work carried out in this research, in the form of case studies, was not sufficient to produce a framework for a generic evaluation process, and had to be supplemented with ideas from literature and fundamental investigations by the author.
4. This research has focused on the *practical* needs of designers and met the need for improved dissemination of ergonomics knowledge through the distribution of free publications to manufacturers and designers.

5. The design-support publications not only fulfil the practical needs of conveying data and guidance but also represent pro-active steps towards product design safety, in that they will advertise a formal input of ergonomics, raise its profile and convey the basic principles of ergonomic design.
6. Ergonomics - its concepts, knowledge, methods and benefits - needs to be marketed to those responsible for producing safe products, to overcome professional and organisational barriers:
    - ergonomics needs to promoted as a culture, within organisations and to individuals
    - ergonomics input to design must be seen to be much more than just the use of ergonomics data
    - ergonomists must improve their contribution through a better understanding of designers and the product development process.

12.8 Recommendations and further work

1. The output from this research needs to be evaluated:
    - the format and content of *Childata*. Evaluation was undertaken by the DTI and positive feedback meant that the sibling publications on adults and the elderly have followed the same structure. However, a detailed study of how anthropometric data are interpreted and applied by designers would allow further improvements in the provision of data generally
    - the usability and value of *Designing Safety into Products* need to be assessed in terms of its appeal to designers, its ability to convey ergonomics concepts, the applicability of the evaluation framework and the likelihood of the use of any of the evaluation methods described
    - the success of the dissemination routes of both publications needs to be reviewed to determine whether they are reaching their target audience of product developers.

2. Links between ergonomics and design (as well as manufacturing, engineering and marketing) need to be improved and formalised. This could be achieved in a number of ways:
    - standardised teaching of ergonomics to all related disciplines, not just in further education but also in professional and continued training, with some emphasis placed on general ergonomics concepts and evaluation methodology rather than just physical ergonomics and anthropometry
    - the development of professional links between ergonomists and related disciplines to advertise the potential contribution of ergonomics, improve access to information, and foster better understanding of relevant disciplines
    - the development of more 'stand alone' tools to aid the application of ergonomics, such as directories of ergonomics guidelines and checklists of ergonomics factors to be considered.
3. A co-ordination of research effort is needed to ensure gaps in knowledge are identified and filled.
4. More research is needed to look at the feasibility of producing guidance on prescriptive, validated ergonomics methods.
5. An impetus for improvements in consumer safety needs to be found, whether from commercial pressure on industry, legislation or consumer demands, to match the improvements in safety and the use of ergonomics seen in other industries, such as vehicle design or information technology.

References

ACT, 1994, *Personal* communication, The Association of Cycle Traders, 31a High Street, Tunbridge Wells, Kent, 15th March, 1994.

Abbot H and Tyler M, 1997, Safer by design: *A guide to management and law of designing for product safety*. Second Edition. Gower Publishing and The Design Council, London.

Abedini K, 1989, An assessment of industrial designers use of human factors criteria in product design evaluation. In: *Proceedings of the Human Factors Society 32nd Annual Meeting,* Human Factors Society, Santa Monica, California.

Akerboom SP, 1993, The effect of pictogram and consumers' attributes on noticing, comprehension of and compliance with the pictogram. In: *Proceedings of the 2nd International Conference on Product Safety Research*. European Consumer Safety Association, Amsterdam, November 1993.

Ashby K, Routley V and Stathakis V, 1998, Enforcing legislative and regulatory strategies to prevent product related injury. In: *Proceedings of the 6th International conference on product safety research,* Amsterdam, 15-16th May 1998, European Consumer Safety Association, Amsterdam, The Netherlands.

Axelsson P & Carter N, 1995, Measures to prevent portable ladder accidents in the construction industry. *Ergonomics,* **38(2)**, 250-259.

Ayres TJ, Gross MM, Wood CT, Horst DP, Beyer RR & Robinson JN, 1989, What is a warning and when will it work? In: *Proceedings of Human Factors Society 33rd Annual Meeting,* Human Factors Society, Santa Monica, California, pp426-430.

BDRC, 1993, *Personal communication* Brunel Design Research Centre, Brunel University, Surrey.

BMRB, 1990, *Target Group Index Survey*,. British Market Research Bureau, London.

BPA, 1997, *Personal communication,* Baby Products Association, London, August 1997.

BSDA, 1993, *Personal communication.* British Soft Drinks Association.

BSI, 1990, *BS 7231: Part 1: Body measurements of boys and girls from birth up to 16.9 years.* British Standards Institute, London.

Baber C, 1996, Repertory grid theory and its application to product evaluation. In: *Usability evaluation in industry,* Edited by PW Jordan, B Thomas, BA Weerdmeester and IL McClelland, Taylor and Francis, London, pp157-165.

Baber C and Mirza MG, 1996, Ergonomics and the evaluation of consumer products: surveys of evaluation practices. In: *Human Factors in Consumer Product Design,* Edited by NA Stanton, Taylor and Francis, London.

Barkla D, 1961, The estimation of body measurements of British population in relation to seat design. *Ergonomics,* 4, 123-132.

Benedyk R and Minister S, 1998, Applying the BeSafe method to product safety evaluation. *Applied Ergonomics,* 29(1), 5-14.

Berns T, 1981, The handling of consumer packaging. *Applied Ergonomics,* 12(3), 13-161.

Bicycle Association of Great Britain, 1994, *Personal communication.* The Bicycle Association, Starley House, Eaton Road, Coventry. May 20th 1994.

Bjornstig U and Johnsson J, 1984, Ladder injuries: mechanisms, injuries and consequences. *Journal of Safety Research,* 23, 9-18.

Bowles R, 1976, *The variation of pressure with temperature of carbonated water in sealed containers; Part 1 – the CO2/H2O system.* Research report number 52. HP Bulmer Limited, Hereford.

Brockoff HST, Oudesluys C & Bastiaanse JC, 1976, *Dimensions of children as related to the construction of child restraint systems.* Report no. 713003-B, AB Volvo, S-405 08 Goteborg, Sweden.

Bullock MI, 1994, Ergonomics: a solution to product mis-match. In: *Proceedings of the Australian Ergonomics Society Conference,* Sydney, Australia, 4-7 December Australian Ergonomics Society Conference, Sydney, Australia.

Butters LM and Tetra-Dixon R, 1998, Ergonomics in consumer product evaluation: an evolving process. *Applied Ergonomics,* 29(1), 55-58.

CAPFA, 1991, *Presentation by the Child Accident Prevention Foundation of Australia.* Child Accident Prevention Trust Annual Meeting, London, October 1991.

Cairney P & Sless D, 1982, Communication effectiveness of symbolic safety signs with different user groups. *Applied Ergonomics,* 13(2), 91-97.

Carroll JM and Rosson, MB, 1985, Usability specification as a tool in iterative development. In: *Advances in Human Computer Interaction, Volume 1,* Edited by HR Hartson, Ablex Publishing Corporation, Norwood, New Jersey.

Chapanis A, 1970, Relevance of physiological and psychological criteria to man-machine systems: the present state of the art. *Ergonomics,* 13, 337-346.

Chapanis A, 1995, Ergonomics in product development: a personal view. *Ergonomics,* 38(8), 1625-1638.

Chinn S, Rona RJ & Price CE, 1989, The secular trend in height of primary school children in England and Scotland 1972-79 and 1979-86. *Annals of Human Biology,* 16(5), 387-395.

Chinn S & Rona RJ, 1994, Trends in weight-for-height and triceps skinfold thickness for English and Scottish children, 1972-1982 and 1982-1990. *Paediatric and Perinatal Epidemiology,* 8, 90-106.

Christensen JM, 1980, Human factors in hazard/risk evaluation. In: *Proceedings of the symposium on human factors and industrial design in consumer products.* Human Factors Society, Santa Monica, California, pp422-477.

Cohen H and Li L, 1991, A scenario analysis of ladder fall accidents. *Journal of Safety Research,* 22, 31-39.

Collins, 1990, *Collins English Dictionary,* Collins, London.

Corlett EN and Clarke TS 1995, *The ergonomics of workspaces and machines - A design manual.* Taylor and Francis, London.

Cross N, Christiaans H and Dorst K, 1996, *Analysing design activity.* Wiley, New York.

Cummings S and Nevitt M, 1994, Falls. *The New England Journal of Medicine,* 331(13), 872.

Cushman WH and Rosenberg DJ, 1991, *Human factors in product design.* Elsevier Science Publications, Amsterdam.

DIN, 1980, *Kopermasse des Menschen: werte (Body dimensions of people: values).* Deutsches Institut fur Normung (German Standards Institute).

DoT, 1993, *Transport Statistics,* Department of Transport, London.

DTI, 1992, *Home Accident Surveillance System - Report on 1990 Accident Data and Safety Research,* Department of Trade and Industry, London. October 1992.

DTI, 1995, *Home Accident Surveillance System - Report on 1993 Accident Data and Safety Research,* Department of Trade and Industry, London. May 1995

Davies S, Haines H, Norris B and Wilson JR, 1998, Safety pictograms: are they getting the message across? *Applied Ergonomics*, 29(1), 15-24.

DeJoy DM, 1987, Judgemental heuristics in consumer products safety. In: *Interface 87 Proceedings - Human implications of product design.* Human Factors Society, Santa Monica, California, pp265-272.

DeJoy DM, 1989, Consumer Product Warnings: Review and analysis of effectiveness research. In: *Proceedings of Human Factors Society 33rd Annual Meeting*, Human Factors Society, Santa Monica, California, pp936-940.

Diaper D, 1989, *Task analysis in human computer interaction.* Ellis Horwood, Chichester.

Diffrient N, Tilley R and Bardargjy J, 1974, *Humanscale 1/2/.* MIT Press, Cambridge, Massachusetts.

Dockery CA and Newman T, 1994, Developing a better design process: redesigning the organisation to produce more ergonomic designs. In: *Proceedings of Human Factors Society 38th Annual Meeting*, Human Factors Society, Santa Monica, California, pp759-763.

Dreyfuss H, 1971, *The Measure of Man.* Whitney, New York.

Drury, CG, 1989, Model guided evaluation of consumer products, *Applied Ergonomics*, 20(4), 261-266.

Drury C and Brill M, 1983, Human factors in consumer product investigations. *Human Factors*, 25(3), 329-342.

Dunn JP, Berger ST, Mondino BJ and Godwin LT, 1990, Ocular trauma caused by exploding glass bottles containing dry ice and water. *Ophthalmic Surgery*, 21 (9), 628-631.

Eason KD, 1984, Towards the experimental study of usability, *Behaviour and Information Technology*, 3(2), 133-145.

Easterby RS & Hakiel SR, 1981, Field testing of consumer safety signs: The comprehension of pictorially presented messages. *Applied Ergonomics*, 12(3), 143-152

Ermon N, 1986, Ergonomic design of ladders. *Accident Analysis and Prevention*, 18(5), 442.

Euromoniter, 1991, *Euromoniter Special Reports: Bicycles.* Euromoniter Publications, London.

Evboumwan NFO, Sivaloganathan S and Jebb A, 1996, A survey of design philosophies, models, methods and systems. In : *Proceedings of the Institution of Mechanical Engineers Part b - Journal of Engineering Manufacture*, 210(4), pp.301-320.

Falke, J, 1989, Elements of a horizontal product safety policy for the European Community. *Journal of Consumer Policy*, 12(2) 220-228.

Feilden GBR, 1963, *Engineering Design – 'The Fielden Report'*, HMSO, London.

Fisher W, 1991, Increasing human factors effectiveness in product design. In: *Proceedings of the Human Factors Society 35th Annual Meeting*, Human Factors Society, Santa Monica, California, pp471-475.

Fraquelli R, 1996, *Personal communication*, IDEO Design, London. October 1996.

Freeman JV, Cole TJ, Chinn S, Jones PRM, White EM and Preece MA, 1995, Cross sectional stature and weight reference curves for the UK, 1990. *Archives of Diseases in Childhood*, 73, 17-24.

Friedmann K, 1988, The effect of adding symbols to written warning labels on user behaviour and recall. *Human Factors*, 30(4), 507-515.

Fulton EJ and Feeney RJ, 1983, Powered domestic lawnmowers: Design for safety. *Applied Ergonomics*, 14(2), 91-95.

GHS, 1990, *The General Household Survey - An interdepartmental survey co-ordinated by the Central Statistical Office*. HMSO Publications, London.

Galer IAR and Page M, 1996, Combining physical, physiological and subjective data in the evaluation of product usability. In: *Usability evaluation in industry*, Edited by PW Jordan, B Thomas, BA Weerdmeester and IL McClelland. Taylor and Francis, London, pp 29-36.

Godfrey SS, Fontenelle GA, Brems DJ, Brelsford JW Jr and Laughery KR, 1986, Scenario analysis of children's ingestion accidents. In: *Proceedings of the Human Factors Society 30th Annual Meeting. Human Factors Society, Santa Monica, California*, pp566-569.

Goldsmith, R, 1985a, So what is ergonomics? *Ergonomics*, 28(10), 1407-1408.

Goldsmith A, 1985b, The role of good design and manufacturing in preventing ladder accidents. *Journal of Product Liability*, 8, 127-140.

Grandjean E, 1984, Foreword - Ergodesign '84. *Behaviour and information technology*, 3, 261-262.

HASS, 1993, *Data from the Home Accident Surveillance System*. Department of Trade and Industry, London.

HADD, 1995, *Data from the Home Accident Deaths Database.* Department of Trade and Industry, London.

Haddon, W, 1973, Energy damage and the ten counter measure strategies. *Journal of Trauma,* 13(4), 321-331.

Hale, AR, 1985, *The human paradox in technology and safety.* Inaugural lecture, Delft University of Technology, The Netherlands.

Hale AR and Glendon I, 1987, Individual behaviour in the control of danger. *Industrial Safety Series,* Volume 2, Elsevier, Amsterdam.

Halfords, 1994, *Personal communication.* Halfords Ltd, Coventry.

Harris, C M-T, 1990, A study in the marketing of ergonomic expertise in the industrial setting. *Ergonomics,* 33(5), 547-552.

Haubner PJ, 1990, Ergonomics in industrial product design. *Ergonomics,* 33(4), 477-485.

Hayward, G, 1988, Fatal home accidents - a product database. *Accident Analysis and Prevention,* 20(5) 399-410.

Heinrich HW, 1959, *Industrial accident prevention. A scientific approach.* McGraw-Hill, New York.

Hoefnagels R and Schoone-Harmsen M, 1992, Test methods in safety standards. In: *Proceedings of the Human Factors Society 30th Annual Meeting.* Human Factors Society, Santa Monica California, pp1034-1038.

IEA, 1997, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association,* Tampere, Finland, June 29th -July 4th, 1997. Finnish Institute of Occupational Health, Helsinki. ISBN 951-802-188-0.

Imrhan SN and Loo C, 1986, Torque capabilities of the elderly in opening screw top containers. In: *Proceedings of the Human Factors Society 30th Annual Meeting.* Human Factors Society, Santa Monica, California.

Ivergard TBK, 1976, Ergonomics and the consumer. *Ergonomics,* 19(3), 321-329.

Jacobs RJ, Johnston AW & Cole BL, 1975, The visibility of alphabetic and symbolic traffic signs. *Australian Road Research,* 5 (7), 68-86.

Jaynes LS & Boles DB, 1990, The effect of symbols on warning compliance. In: *Proceedings of Human Factors Society 34th Annual Meeting,* Human Factors Society, Santa Monica, California. pp984-987.

Jenkins DW and Davies BT, 1989, Product safety in Great Britain and the Consumer Protection Act 1987. *Applied Ergonomics*, 20(3), 213-217.

Jordan PW, 1998, Human factors for pleasure in product use. *Applied Ergonomics*, 29(1), 25-34.

Jordan PW, Thomas B, Weerdmeester BA and McClelland IL, 1996a, (Eds), *Usability evaluation in industry*. Taylor and Francis, London.

Jordan PW, Thomas B and McClelland IL, 1996b, Issues for usability evaluation in industry. In: *Usability evaluation in industry*, Edited by PW Jordan, B Thomas, BA Weerdmeester and IL McClelland, Taylor and Francis, London.

Juptner H, 1976, Safety on ladders: an ergonomic design approach. *Applied Ergonomics*, 7(4), 221-223.

Kanis H, 1987, Ergonomics for designing products. In: *Contemporary Ergonomics*, Proceedings of the Ergonomics Society 1987 Annual Conference, Swansea, Wales, 6-10 April 1987. pp156-161.

Kanis H and Weegels MF, 1990, Research into accidents as a design tool. *Ergonomics*, 33(4), 439-445.

Kelly, C & Crane, N, 1989, *Richard's Mountain Bike Book*. Pan, London.

Kemp A and Sibert JR, 1991, Outcome in children who nearly drown: a British Isles study. *British Medical Journal*, 302, 931-933.

Kemp A and Sibert JR, 1992, Drowning and near drowning in children in the United Kingdom: lessons for prevention. *British Medical Journal*, 304, 1143-1146.

Keynote, 1992, *Keynote Report: Bicycles - A Market Sector Overview*. Keynote Publications, London.

Kirk NS and Ridgeway, 1970, Ergonomics testing of consumer products. 1 - General considerations, *Applied Ergonomics*, 1, 295-300.

Kirwan B and Ainsworth L, 1992, *A guide to task analysis*. Taylor and Francis, London.

Konz S and Ravishankar H, 1989, Knurls on pop bottle lids. In: *Proceedings of the Human Factors Society 33rd Annual Meeting*, Human Factors Society Santa Monica California.

Kusukami K and Ikeda T, 1989, Identification of an accident pattern to focus on from presumed accidents. In: *Proceedings of the Human Factors Society 33rd Annual Meeting*, Human Factors Society Santa Monica California, pp1034-1037.

Laerdal, 1991, *Personal communication*, Dr Maroley, Technical Department, July 1991.

Lamb MD, 1985, *Ergonomics evaluations of consumer products*, TUV Rheinland, Institute fur Unfallforschung and Ergonomie, Cologne, Germany.

Lehto MR, 1992, Designing warning signs and warning labels: Part II - Scientific basis for initial guidelines. *International Journal of Industrial Ergonomics*, 10, 115 -138.

Lehto MR & Miller JM, 1986, *Warnings: Volume I - Fundamentals, design and evaluation methodologies*. Fuller Technical Publications, Ann Arbour, Michigan.

Leplat J, 1984, Occupational accident research and systems approach. *Journal of Occupational Accidents*, 6, 77-89.

Levene S, 1991, Coroners' records of accidental deaths. *Archives of Diseases in Childhood*, 66, 1239-1241.

Marinissen AH, Molenbroek JFM & Schoone-Harmsen M, 1986, A secure way to safer products. In: *Proceedings of the Human Factors Society 30th Annual Meeting*, Human Factors Society Santa Monica California, pp561-565.

Mayer DL and Laux LF, 1989, Recognizability and effectiveness of warning symbols and pictorials. In: *Proceedings of the Human Factors Society 33rd Annual Meeting*, Human Factors Society Santa Monica California, pp984-988.

McCarthy RL, Ayres TJ, Wood & Robinson JN, 1995, Risk and effectiveness criteria for using on-product warnings. *Ergonomics*, 38(11), 2164-2175.

McClelland I, 1987, Consumer product design and the incorporation of ergonomics. In: *Interface 87 Proceedings - Human implications of product design*. Human Factors Society, Santa Monica, California, pp13-17.

McClelland I, 1990, Marketing ergonomics to industrial designers. *Applied Ergonomics*, 33(4), 391- 398.

McClelland I, 1995, Product assessment and user trials. In: *Evaluation of human work*. Second Edition. Edited JR Wilson and EN Corlett, Taylor and Francis, London. pp249-285.

McClelland IL and Thompson D, 1976, *Ergonomic data for evaluation and specification of operating devices on components for use by school children*. Report no. 75/2/21. Institute for consumer ergonomics, Loughborough, Leicestershire, June 1976.

McIntyre D, 1979, *The effects of rung spacing on the mechanics of ladder ascent.* PhD Thesis, University of Oregon, USA.

Meister D, 1971, *Human Factors: Theory and Practice.* Wiley Interscience, New York.

Meister D, 1985, *Behavioural analysis and measurement methods.* Wiley, New York.

Meister D, 1986, *Human factors testing and evaluation.* Elsevier, Amsterdam.

Meister D, 1992, Fundamental problems in behavioural test and evaluation. In: *Advances in Industrial Ergonomics and Safety IV,* Edited by S Kumar, Taylor and Francis, London.

Meister D, 1994, T & E - Where are we now and where are we going? In: *Proceedings of the Human Factors Society 38th Annual Meeting*, Human Factors Society, Santa Monica California.

Meister D & Farr DE, 1967, The utilisation of human factors information by designers. *Human Factors,* 9, 71-87.

Mertens, A, 1986, Heim- und Freizeitunfalle: Aufkalarung intensivieren. *Bundesarbeitblatt.* No 5, 32-35.

Meyer R, 1979, Who is a consumer and what is a consumer product? *CP News,* 4, 3.

Meyer, P, 1994, A product ergonomics evaluation checklist. In: *Proceedings of the Australian Ergonomics Society Conference*, Sydney, Australia, 4-7 December Australian Ergonomics Society Conference, Sydney, Australia, 83-87.

Mintel, 1991, *Market Intelligence: Bicycles.* Mintel Publications, London.

Moggridge W, 1993, Design by story-telling. *Applied Ergonomics,* 24(1), 15-18.

Moll RA, Panitch G & Moll P, 1985, Product safety/liability considerations in the design of consumer products. In: *Interface 85 - 4th Symposium on Human Factors and Industrial Design in Consumer Products.* St Paul, Minnesota, 20-22 May 1985. 125-133. Human Factors Society, Santa Monica, California.

Moroney, WF, 1994, Ethical issues related to the use of humans in human factors and ergonomics. In: *Proceedings of the Human Factors Society 32nd Annual Meeting*, Human Factors Society Santa Monica California, pp404-108.

Muir L and Kanwar S, 1993, Ladder injuries. *Injury,* 24(7), 485-487.

Mulder, S and Rogmans WHJ, 1991, The evaluation of the European Home and Leisure Accident Surveillance System. *Journal of Safety Research,* 22, 201-210.

NRC, 1989, *Improving risk communication.* National Research Council, Committee on Risk Perception and Communication, National Academy Press, Washington, USA.

Nagashima K and Konz S, 1986, Jar lids: Effect of diameter, gripping materials and knurling, In: *Proceedings of the Human Factors Society 30th Annual Meeting*, Human Factors Society Santa Monica California.

Nixon JW, Pearn, JH and Petrie GM, 1979, Childproof safety barriers. *Australian Paediatric Journal* 15, 260-262.

Norris BJ, Davies S, Haines H and Wilson JR, 1997, *The role of pictogram in the conveying of consumer safety information: Policy report to the Department of Trade and Industry, Consumer Safety Unit.* Product Testing and Safety Group, University of Nottingham, June 1997.

Norris BJ and Wilson JR, 1988, Child safety: where are the data the designers need? In: *Contemporary Ergonomics, Proceedings of the Ergonomics Society 1988 Annual Conference*, Manchester, 11-15 April 1988, pp202-207.

OPCS, 1992, *Mortality Statistics*. Office of Population and Census Surveys, London.

OPCS, 1993, *Fatal accidents occurring during sporting and leisure activities, 1992 registrations*. Report No. DH4 93/3, 23 September 1993. Office of Population & Census Surveys, London.

Parker JF and West VR, 1973, *Bioastraonautics Data Book.* NASA Scientific and Technical Information Office, Washington DC, USA.

Pearn J and Nixon J, 1977, Prevention of childhood drowning accidents. *Medical Journal of Australia,* 1, 616-618.

Peebles L & Norris BJ, 1998, *Adultdata: The handbook of Adult Anthropometric and Strength Measurements - Data for Design Safety*. Department of Trade and Industry, London. ISBN 0-9522571-2-3. May 1998.

Pheasant ST, 1982, A technique for estimating anthropometric data from the parameters of the distribution of stature. *Ergonomics,* 25(11), 981-992.

Pheasant ST, 1986, *Bodyspace: Anthropometry, ergonomics and design.* Taylor and Francis, London.

Pheasant S, 1996, *Bodyspace: Anthropometry, ergonomics and the design of work.* Second Edition. Taylor and Francis, London.

Pheasant S and ONeill D, 1975, Performance in gripping and turning - a study in hand/handle effectiveness. *Applied Ergonomics*, 6(4), 205-208.

Pikaar RN, Lenior TMJ, & Runsdorp JE, 1990, Implementation of ergonomics in design practice: outline of an approach and some discussion points. *Ergonomics*, 33(5), 583-587.

Pimble J and O'Toole S, 1982, Analysis of accident reports. *Ergonomics* 25(11) 967-979.

Pitt WR and Balanda KP, 1991, Childhood drowning and near-drowning in Brisbane: the contribution of domestic pools. *The Medical Journal of Australia*, 154, 661-665.

RoSPA 1987, *Personal communication*. Design for safety: Royal Society for the Prevention of Accidents National Home Safety Seminars, Blackpool, November 1987.

RoSPA, 1990, *Drowning statistics*. Royal Society for the Prevention of Accidents Water Safety Division, Birmingham.

Ramsey JD, 1985, Ergonomic factors in task analysis for consumer product safety. *Journal of Occupational Accidents*, 7, 113-123.

Reason J, 1995, A systems approach to organisational error. *Ergonomics*, 38(8), 1708-1721.

Rennie AM, 1981, The application of ergonomics to consumer product evaluation. *Applied Ergonomics*, 12(3), 163-168.

Rogmans, WHJ, 1989, Consumer interest in safety-related standards for European consumer products. *Journal of Consumer Policy*. 12 193-205.

Rohles FH, Moldrup KL and Laviana JE, 1983, *Opening jars: an anthropometric study of the wrist twisting strength of children and the elderly*. Institute for Environmental Research, Kansas State University, Manhatten, Kansas.

Ronco PG, 1963, A bibliography and overview of human factors reference works. *Human Factors*, 5, p551.

Roozenburg NFM and Eekels J, 1995, *Product design: Fundamentals and methods*. Wiley, New York.

Rosen, P, 1994, The social construction of mountain bikes: technology and post-modernity in the cycle industry. *Social Studies of Science*, 23, 479 - 513.

Ryan JP, 1983, Human factors design criteria for safe use of consumer products. In: *Proceedings of the Human Factors Society 27th Annual Meeting*, Human Factors Society Santa Monica California, pp811-815.

Ryan, J, 1985, Do safety standards make safer products? In: *Interface 1985, Proceedings of Human implications of product design.* Human Factors Society Santa Monica California, pp119-124.

SPATA, 1993, *Safety advice for home pool owners.* Swimming Pool and Associated Trades Association/ Royal Society for the Prevention of Accidents.

Schoone-Harmsen M, 1990, A design method for product safety. *Ergonomics,* 33(4), 431-437.

Schneider LW, Lehman RJ, Pflug MA and Owings CL, 1986, Size and shape of the head and neck from birth to four years. , Report No UMTRI-86-2, *Consumer Product Safety Commission*, Washington, USA.

Shackel B, 1986, Ergonomics in design for usability, In: *People and Computers IV,* Edited by: MD Harrison and A Monk, Cambridge University Press, Cambridge.

Shooman ML, 1968, *Probabilistic reliability: an engineering approach.* McGraw Hill, New York.

Sibert JR, Webb E and Cooper S, 1988, Drowning and near drowning in children. *The Practitioner*, 232, 439-440.

Slappendal C, 1994, Ergonomics capability in product design and development: an organisational analysis. *Applied Ergonomics,* 25(5), 266-274.

Snyder RG, Spencer ML, Owings CL and Schneider LW, 1975, *Physical characteristics of children as related to death and injury for consumer product design.* Report no. UM-HSRI-BI-75-5, Consumer Product Safety Commission, Bethesda, MD.

Snyder RG, Schneider LW, Owings CL, Reynolds HM, Golomb DH & Schork MA, 1977, *Anthropometry of infants, children and youths to age 18 for product safety design.* Report no. UM-HSRI-77-17, Consumer Product Safety Commission, Bethesda, MD.

Somers RL, 1994, *Product caused injuries.* In: *Proceedings of the Australian Ergonomics Society Conference*, Sydney, Australia, 4-7 December Australian Ergonomics Society Conference, Sydney, Australia, pp19-21.

Stanton NA and Baber C, 1996, Factors affecting the selection of methods and techniques prior to conducting a usability evaluation. In: *Usability evaluation in industry.* Edited by PW Jordan, B Thomas, BA Weerdmeester and IL McClelland, Taylor and Francis, London, pp39-48.

Stanton NA and Young M, 1995, *Development of a methodology for improving safety in the operation of in-car devices.* ESPRC/DOT LINK Report 1. University of Southampton, Southampton.

Stanton N and Young M, 1998, Is utility in the mind of the beholder? A study of ergonomics methods. *Applied Ergonomics*, 29(1), 41-54.

Steenbekkers LPA, 1993, *Child development, design implications and accident prevention.* Delft University Press, Delft, Netherlands.

Stoop J, 1990a, Scenarios in the design process. *Applied Ergonomics*, 21(4), 304-310.

Stoop J, 1990b, *Safety and the design process.* Delft University of Technology, Delft, The Netherlands, ISBN 90-9003301-7.

Straker LM, 1994, An aid for designing consumer product evaluations. In: *Proceedings of the Australian Ergonomics Society Conference*, Sydney, Australia, 4-7 December Australian Ergonomics Society Conference, Sydney, Australia. pp95-99.

Sulke, SB, 1990, Solar pool blankets: another water hazard. *Paediatrics, 85(6)*, 1114-1117.

Surry J, 1974, *Industrial accident research. A human engineering appraisal.* Labour Safety Council, Ontario Ministry of Labour, Toronto.

TIDE, 1993, *TIDE information package.* Technology Initiative for the Disabled and Elderly Programme, European Commission, DGXIII, April 1993.

TRRL, 1989, *Pedal cycle accidents - a hospital based study.* Transport and Road Research Laboratory, Crowthorne, Berkshire, RG11 6AU.

Today, 1993, Hidden dangers. *Today Newspaper.* 21st June 1993.

Thomas DB, Dziambor G and Bohr-Bruckmayr E, 1990, Ergonomics in product testing. *Ergonomics*, 33(4), 453-458.

Trommelen M, 1994, Perceived hazardousness of child-care products and the effectiveness of safety information. *International Journal for Consumer Safety*, 1(2), 81-91.

USERfit, 1996, *USERfit - A practical handbook on user-centred design for Assistive Technology*, TIDE 1062 USER project, Commission of the European Communities, Report Number ECSC-EC-EAEC, Brussels-Luxembourg.

United Leisure Magazines, 1994, *Bicycle Buyers Guide 1994*, ULM, London.

Van Cott HP, Kramer JJ, Pezoldt VJ, Porter LG, Fired C, Fechter JV and Persenky JJ, 1978, *A Standard Ergonomics Reference System: The concept and its assessment.* Report no. BBSIR 77-1403, Institute for Applied Technology, National Bureau of Standards, Washington DC, USA.

Van Weperen, W, 1993, Guidelines for the development of safety-related standards for consumer products. *Accident Analysis and Prevention*, 25(1) 11-17.

Vaubel KP & Young SL, 1992, Components of perceived risk for consumer products. In: *Proceedings of Human Factors Society 36th Annual Meeting*, Human Factors Society, Santa Monica, California, pp494-498.

Von Wolf M, Plasch G & Plasch J, 1989, Die Absturnzunfalle an 266 fallen zu unfallursachen - folgen und - verhutung zentralbl. *Chir*, 114:238.

Wagenaar WA, 1983, Menselijk falen. *Nederlands Tijdschrifts voor Psychologie*, 38, 209-222.

Ward S, 1994, The designer as ergonomist. In: *Proceedings of the Australian Ergonomics Society Conference*, Sydney, Australia, 4-7 December Australian Ergonomics Society Conference, Sydney, Australia, pp101-106.

Warne CA, 1982, Designing out accidents – first understand the problem. *Applied Ergonomics*, 13(1), 2-6.

Watchdog, 1993, *Watchdog*. BBC TV, London. 12th June 1993.

Weegels MF, 1992, Accidents with consumer products. In: *Proceedings of Human Factors Society 36th Annual Meeting*, Human Factors Society, Santa Monica, California, pp1024-1028.

Weegels MF, 1996, *Accidents involving consumer products*. Delft University of Technology, Delft, The Netherlands, ISBN 90-9009224-2.

Wilde GJS, 1984 , Evidence refuting the theory of risk homeostasis? A rejoinder to Frank P. McKenna. *Ergonomics*, 27, 297-304.

Willhoft E, 1986, Exploding carbonated beverage bottles. *Law Society Gazette*, 25th June 1986.

Willhoft E, 1992, Is the 1987 Consumer Protection Act doing its job to counter corporate interests and protect the public? *British Food Journal*, 94(6), 29-35.

Wilson JR, 1983a, Pressures and procedures for the design of safer consumer products. *Applied Ergonomics*, 14(2), 109-116.

Wilson JR, 1983b, *Pressures and procedures for the design of safer consumer products*. PhD thesis, Department of Production Engineering, University of Birmingham.

Wilson JR, 1984, Standards for product safety design: A framework for their production. *Applied Ergonomics*, 15, 203-210.

Wilson JR, 1991, Design Decision Groups - a participative process for developing.... In: *Participatory Ergonomics*, edited by K Noro and AS Imada. Talyor and Francis, London.

Wilson JR and Corlett EN, 1995, *Evaluation of human work*. Second Edition. Taylor and Francis, London.

Wilson JR and Norris BJ, 1992, Knowledge transfer: scattered sources to sceptical users. *Ergonomics*. 36(6), 677-686.

Wilson JR and Norris BJ, 1993, Ethical considerations in ergonomics product safety testing for children. In: *Proceedings of the International Conference on Product Safety Research*, 22-23rd November 1993, Amsterdam, The Netherlands. European Consumer Safety Organisation.

Wilson JR and Whittington C, 1982, An overview of consumer ergonomics in the United Kingdom. *Applied Ergonomics*, 13(1), 25-30.

Wilson M and Breeze R, 1990, *Ergonomics evaluation of plastic carbonated drinks bottles*. Report prepared by ICE Ergonomics, Loughborough, Leicestershire. December 1990.

Wintemute GJ, and Wright MA, 1990, Swimming pool owners opinions' of strategies for prevention of drowning. *Paediatrics*, 85(1), 63-69.

Wogalter MS, Desaulniers DR & Brelsford JW, 1986, Perceptions of consumer products: Hazardousness and warning expectations. In: *Proceedings of the Human Factors Society 30th annual meeting*, Human Factors Society, Santa Monica, California, pp1197-1201.

Woodcock Webb K, 1988, Pitfalls in the use of accident data to focus ergonomic attention. In: *Trends in Ergonomics/Human Factors V*, Aghazadeh F (Ed), Elsevier/North Holland.

Zurwelle DW, 1993, The user as partner in the product development process. In: *Proceedings of the Human Factors Society 37th Annual Meeting*, Human Factors Society, Santa Monica, California, pp435-437.

Appendices

Appendix 4.1

Questionnaire sent to designers on their use of ergonomics data

QUESTIONNAIRE

Ergonomics Databank for Designing for Children

1. Please state your job title.....

2. Please list the product(s) or product area(s) in which your company is involved.....
.....
.....
and for which you have specific design responsibility (if applicable).....
.....
.....

3. Do you or your design team presently use any sources of ergonomics data on children in your design process (eg anthropometric tables, strength measurements) and if so, please state the title, authors, date, publishers and country of origin of the sources.....
.....
.....
.....
.....

4. Where did you find this information and did you have any difficulties in accessing the information you required?.....
.....
.....

5. Have you had any difficulties in using or interpreting the information?.....
.....
.....
.....

6. Are there any data on children which you have needed but have been unable to access eg. data on special populations such as the very young children or the disabled or data related to specific products?.....
.....
.....
.....
.....
.....

7. If you would like more information about the project please state your name and address (obligatory).....
.....
.....
.....

Please return to:
Beverley Norris, Institute for Occupational Ergonomics, FREEPOST, University of Nottingham, University Park, Nottingham, NG7 1BR. Tel: (0602) 484848 extension 3807/3557. Fax (0602) 583015.

All responses will be treated in the strictest confidence.
Thank you in advance for your cooperation.

Appendix 4.2

Introduction and background information to *Childata*

CONSUMER SAFETY UNIT

CHILDATA

The Handbook of Child Measurements and Capabilities

- Data for Design Safety

dti

Department of Trade and Industry

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This handbook is intended for use in conjunction with existing safety standards. Many products are subject to legal safety requirements and the handbook in no way replaces such requirements. If in doubt, you should contact the Department of Trade and Industry's Consumer Safety Unit (see Section 9 for further contacts).

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Budavári & Eiben (1982)

Clymer & Silva (1968)

Cureton & Barry (1964)

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Govatos (1966)

Hardin & Ramirez (1972)

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⇨ *Read these sections before using any of the data in the handbook*

1 Introduction

The CHILDATA Handbook - a Databank of children's measurements and capabilities - has been produced to meet the needs of manufacturers, designers, standards bodies and research organisations for the ergonomics and performance data which are fundamental to the design of products and environments suitable for children. Without such data, design might be left to informed guesswork or will at least require an excessive process of expensive and time consuming testing, evaluation and redesign. However, the data have until now remained either inaccessible or difficult to select and apply. It is intended that CHILDATA will be usable in conjunction with existing safety standards by those concerned with the design or provision of products with which children may come into contact. These may be products intended for use: *by* children, such as toys, nursery products and playgrounds; *with* children, such as safety guards, pushchairs, cots and beds; or *around* children, such as playpens, architectural features (eg door and window handles, railings) and household consumer products (eg electrical goods).

The aim of the Handbook is to bring together all appropriate, available ergonomics data on children into one easy to use design resource. To ensure that CHILDATA is easy and quick to use, only the most useful measurements and reliable sources have been included. Some data have been excluded, usually those with limited applicability or very specialised data, for example, facial measurements. Sources of additional data not included are given in the bibliography at the end of the Handbook.

CHILDATA is a collection of the most up to date and reliable ergonomics and performance information on children. There are data on 187 measurements of children's characteristics and abilities for children from birth to 18 years old from the UK, USA, The Netherlands, Germany, Australia and many other countries. Included is information on children's body sizes (referred to as anthropometric data), children's strength, motor abilities (such as running and jumping), skills related to specific products (such as the height of barriers they can climb) and some psychological abilities (such as their understanding of safety symbols). These data can be applied to any product or environment with which a child may interact to ensure that the interaction is as safe, comfortable and effective as possible. They can be used in a classical ergonomics fashion, so that products 'fit' children and are usable and safe. Equally important, data may be used to help ensure that children are excluded or protected from a hazard. For example, data on hand and finger size can be used to prevent hands or fingers reaching around or through guards or to stop fingers becoming trapped in openings; hand strength data can be used to ensure the controls on electrical goods cannot be operated and door handles cannot be opened.

The CHILDATA Handbook consists mainly of tables organised according to the type of measurement (eg anthropometry, strength etc) and each table lists data according to age and sex. Some background information is also listed, such as the country of origin, date of publication and the number of subjects measured and this information should be taken into account when using the data. For some measurements, more than one source is presented, usually because they relate to different age groups or, particularly in the case of the anthropometric data, different countries of origin are included for comparison.

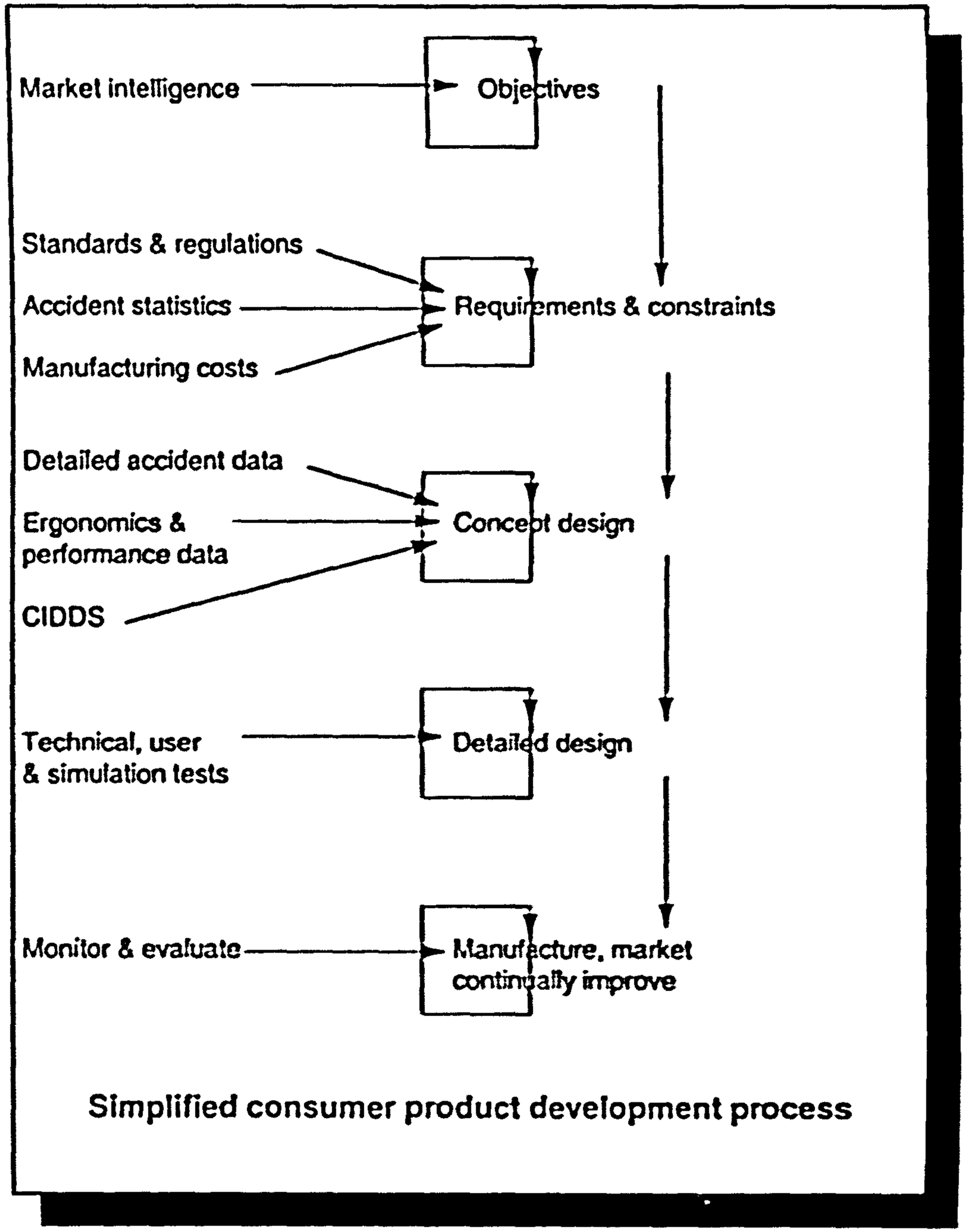
Sections 2, 3 and 4 describe how to use and select the data and should be read before using any of the databank. They give an introduction to using ergonomics data in general (section 2), the special considerations that should be given to designing for children (section 3), and information specific to the sources used in CHILDATA, such as how to choose between them (section 4). Section 5 is a guide to the tables, including an hierarchical index of all measurements and illustrations of the anthropometric measurements. The data tables are followed by a list of references, a list of other sources of useful data that could not be included, a list of useful contacts and finally an alphabetical index to the measurements.

2 Using ergonomics data in design

Ergonomics involves the study of how people interact with their surroundings, the products and tools they use, the buildings they work and live in, the information they receive, and of how all of these activities are organised. The aim of ergonomics is to improve every level of this interaction, to enhance people's comfort, satisfaction and safety and the usability and effectiveness of their tools and products. Ergonomics begins with measurements of people and with studies of how people perform and interact with their environment; these studies produce information about human characteristics and abilities. Without this basic information, we cannot expect the products we produce to 'fit' their users. The ergonomics and performance data contained in this databank are the results of such measurements and studies and should be the starting point for developing products designed for use by or around children.

Use of the information in the CHILDATA Handbook is not an alternative to testing and evaluation, but should increase test efficiency and reduce the amount of testing. It will also shorten product development times and reduce the chance of marketing an unsafe, unsuitable or unusable product. This becomes clear when we look at a simplified description of the consumer product development process, especially when designing products to be used by, or to be safe for, children:
Once design objectives have been set, accident data such as that produced by the DTI's Consumer Safety Unit Home Accident Surveillance System [1] may be used to establish likely risks; in addition, standards and regulations will produce requirements and constraints on the design just as much as will market intelligence and manufacturing cost information. From an outline or concept design, ergonomics and performance data can be applied to enhance product usability, safety and design quality, and to help accelerate the iterative design process into a detailed design. Although a programme of testing and evaluation - involving technical, user and simulation tests - is always necessary, this can be a far more effective and speedy process if ergonomics and performance data have been applied from early in the development.

Use of information from CHILDATA, in conjunction with safety standards, will assist product design in terms of both safety and the effectiveness of the design process and will therefore improve product competitiveness. However, the data are by themselves not a guarantee of user or child safety; care must be taken in their interpretation and application. Testing, whilst it may be made more economical and effective by prior use of this handbook, will usually still be necessary for new designs or substantial redesigns.



Simplified consumer product development process

2 Using ergonomics data in design

2.1 Types of data

CHILDATA contains data on all aspects of children's behaviour and these can be classified into three broad categories: anthropometry, physical abilities and psychological abilities.

2.1.1 Anthropometry

Anthropometry is the measurement of body dimensions:

Static anthropometry

Static anthropometry is the measurement of body dimensions with the body held in standardised, static postures. Measures include stature, weight, centre of gravity, body breadths, depths, circumferences, the height of body landmarks from the floor, seating dimensions, face, hand and foot dimensions. Static anthropometric data account for over half of the measurements in the Handbook and are the main type of data used to ensure the 'physical fit' of items to be used by or with children.

Functional anthropometry

Functional anthropometry, in contrast, is the measurement of the limits of movement of the human body such as the distance that can be reached overhead, in front of or to the side of the body and the maximum step height. Functional anthropometric data will often be used to ensure that equipment is made inoperable or inaccessible by children.

2.1.2 Physical abilities

Physical abilities data include measurements of any physical activity. Three main types of data are included in the Handbook:

Strength

Strength can be measured in a number of ways. It can be the isolated strength around a joint (eg the force exerted when bending the elbow and keeping the rest of the body still), the force exerted in a specific action (eg pushing) or when applied to a specific object (eg opening bottle caps). The last two may be measured in standardised postures or by allowing posture to be varied to produce maximum force. Data are included on the strength of the arms, hands, fingers, legs and mouth and include pushing and pulling, lifting, twisting, pinching and biting forces.

Movement

These measurements refer to general movement skills and include data on running speeds and distances, jumping distances, swimming, walking across beams and ladders, and balance.

Specific performance

These are measurements of physical abilities related to specific activities or products, such as climbing fences, opening windows, throwing objects and swallowing.

2.1.3 Psychological abilities

Measurements of psychological abilities can include information on how we perceive the world and process information. Much of the information is often difficult to apply to design or may be too specific to include in a collection of data for general design use such as this. Although some psychological data have been included in CHILDATA, designers should also be aware of the more general guidance that is available regarding children's psychological development (Section 3) and the reader is referred to general texts on child development for more information. Psychological data included in CHILDATA fall into two categories:

Perceptual abilities

Perceptual abilities include measurements of children's visual and auditory perception, presented as reaction times to visual and auditory stimuli.

Cognitive abilities

Cognitive abilities include children's understanding of warning symbols, understanding and preference for colour and attention span.

2 Using ergonomics data in design

2.2 Types of interaction

Children interact with their environment in a number of ways and ergonomics data can be used for each type of interaction. Table 1 gives examples of the five types of interaction and how ergonomics data can be used ▶ and some of these are shown in figure 1.

2.3 How people vary

Ergonomics data are used to ensure that products and environments are designed to fit and suit as many people as possible. It is apparent that people vary in size, shape, strength, physical and psychological abilities and in personal preferences but it is important to determine exactly how people vary and how many people will be accommodated, or excluded, with a certain set of design parameters. It is therefore important to understand the reasons for, and to specify the extent of, human variability.

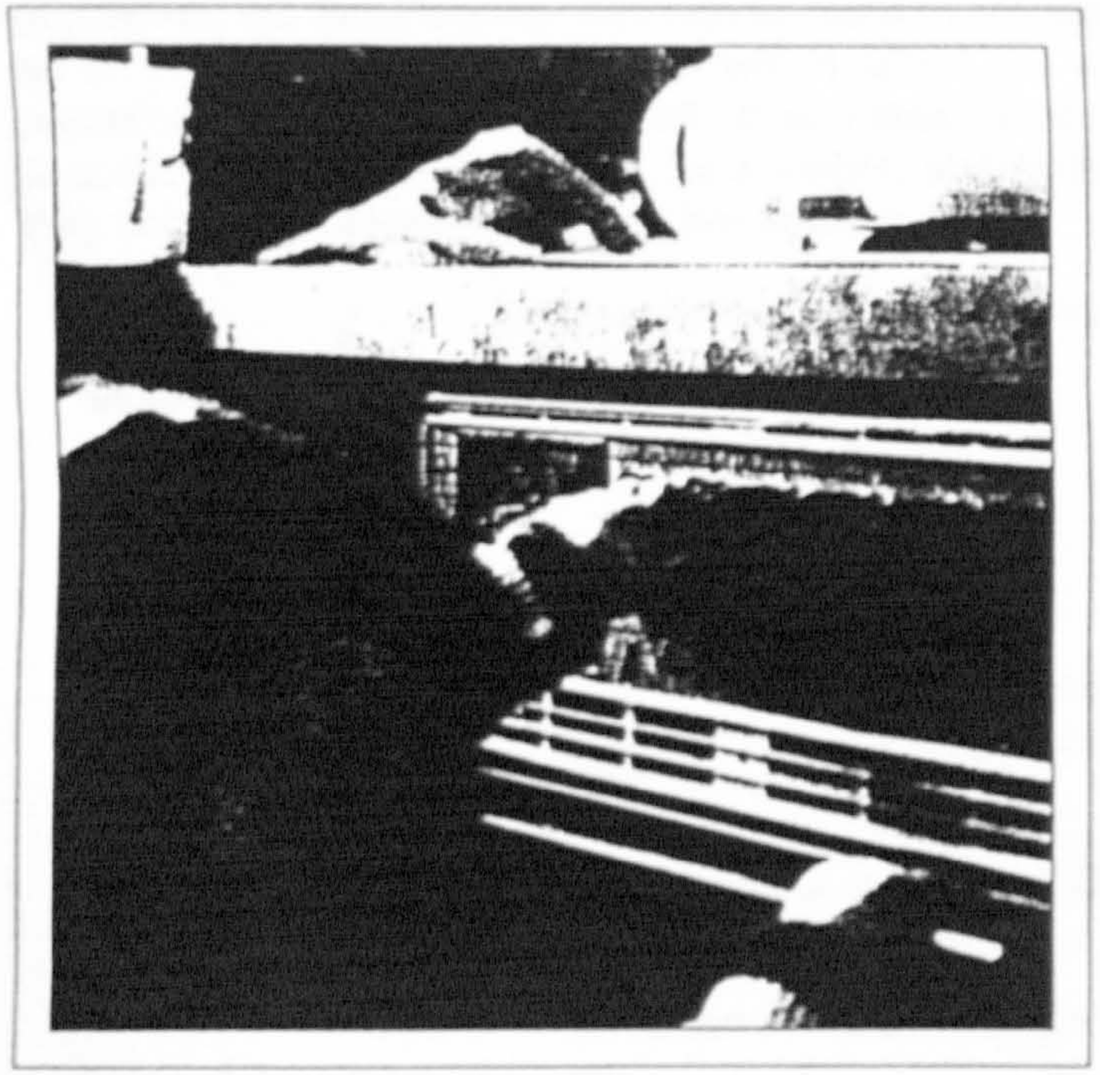
2.3.1 Calculating the limits of human variation

Providing information for designers means that we should be able to put limits on the range of peoples's physical and psychological functions. It is impossible to measure everyone, so the range of variability of an attribute is predicted by measuring a random selection of people representative of the group we intend to design for (the target population). Depending on the size of the sample and the size of the target population, the accuracy of the predictions can be specified. Most surveys of anthropometric measurements, including those presented in the CHILDATA Handbook, use sample sizes large enough to predict the variability of body dimensions with acceptable precision. Other measurements, such as strength, children's performance and psychological abilities, are often collected as part of smaller scale or ad hoc research, and sometimes use small sample sizes. While the non-anthropometric data in the Handbook represent the most reliable and applicable data available, the information provided on sample sizes should be used to give some indication of the reliability of the data. Methods to calculate confidence limits based on sample size are presented elsewhere [2].

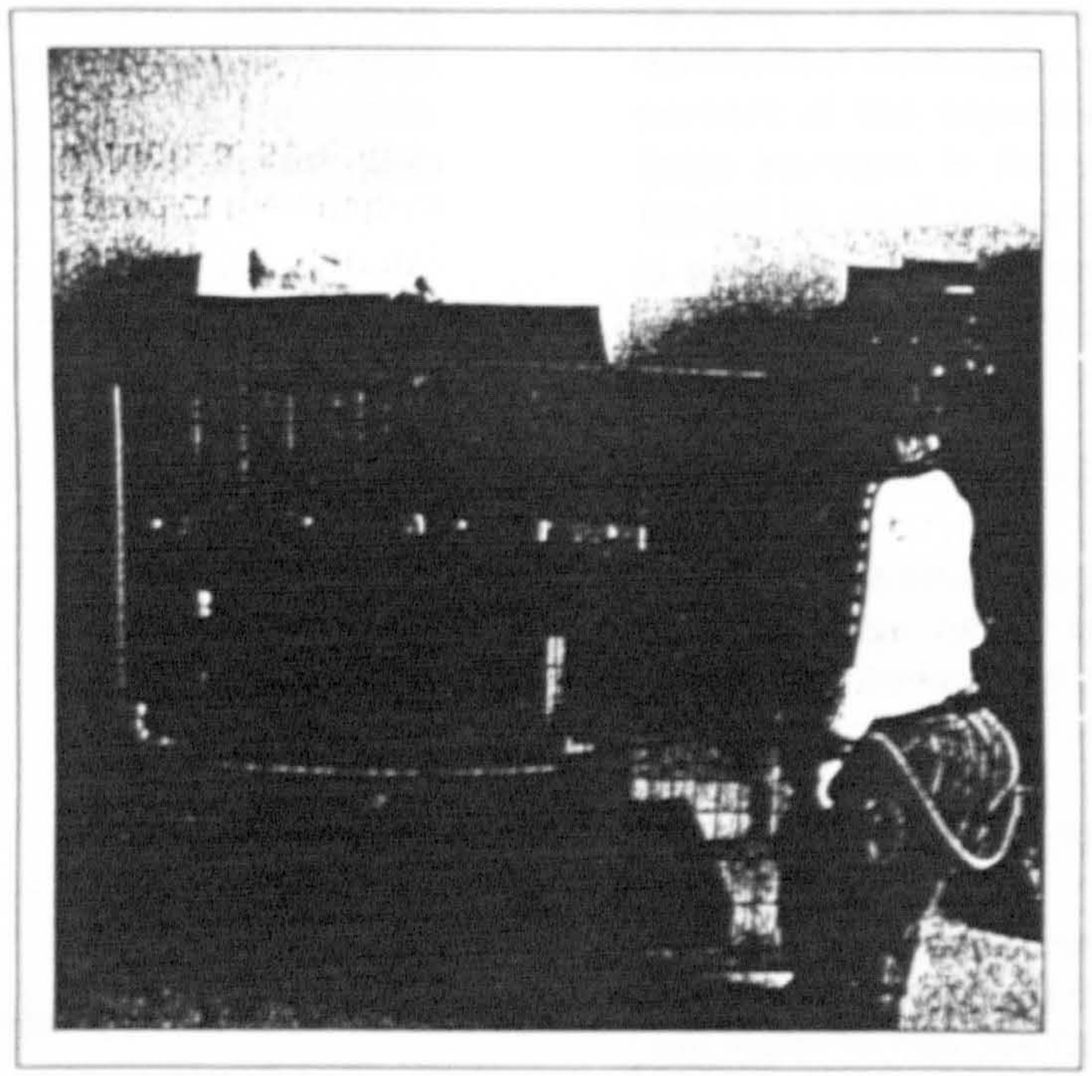
Table 1: Types of interaction and uses of ergonomics data

Child interacts with:	Examples of products or environments	Possible applications of ergonomics data	Data to be used include:
Product	medicines and their packaging	make child resistant - inoperable or unattractive	hand size, opening strength, attractiveness of colour, understanding of symbols
	dummy or pacifier	prevent swallowing	mouth size
	bicycle	reach to pedals and handlebars, size of handlebars	arm length, leg length, sitting height, hand size
	cooker controls	prevent operation	overhead reach height, wrist turning strength, hand size
Personal space	infant carriers	support and retention	body length, shoulder breadth, hip breadth, chest depth
	stair guards	prevent access over or through stair guard, prevent operation of locking device, stability	step height, ability to climb barriers, reach height, wrist turning strength, lifting strength, pushing strength, pulling strength
	fireguard	prevent access or entrapment, operation of locking device, stability	finger breadth, finger length, hand, strength, pushing strength pulling strength
Physical environment	window and door handles	prevent operation	overhead reach height, height at which window handles can be operated
	railings and bannisters	prevent access over or through, prevent entrapment	step height, ability to climb fences, shoulder breadth, chest depth, head breadth, head length
Social environment	child resistant containers	operable by elderly and disabled but not by children	comparison of children's and adults cognitive and fine motor skills
Information	safety signs	recognition and comprehension by children	children's understanding of colour codes, understanding of symbols
	warning alarms	recognition and comprehension by children	auditory perception

Figure 1: examples of ergonomics data used in design



Information and data on children's overhead reach, handsize, pulling strength and wrist twisting strength should be used to prevent children reaching to, and operating, the controls or doors on domestic products such as cookers.



Products used around children should also account for their inadvertant use; information on children's finger sizes should be used to prevent access through fire-guards and the security and stability of such items should account for children's pushing and pulling strength.

To be effective, the design of barriers, railings and fences should be based on children's abilities to climb over such barriers; maximum step height and foot size should be used to prevent a child making a foothold on horizontal bars and spacing between bars should be based on head size to prevent the risk of head entrapement.

2 Using ergonomics data in design

Provided that the sample of people measured is a true representation of the target population, the results generated can be used to calculate the range of variability of an attribute and limits can be set within which we would expect any particular percentage of the population to fall. If we measured every member of a population to collect information on stature, for example, and plotted the frequency with which they occur, the results would look like figure 2.

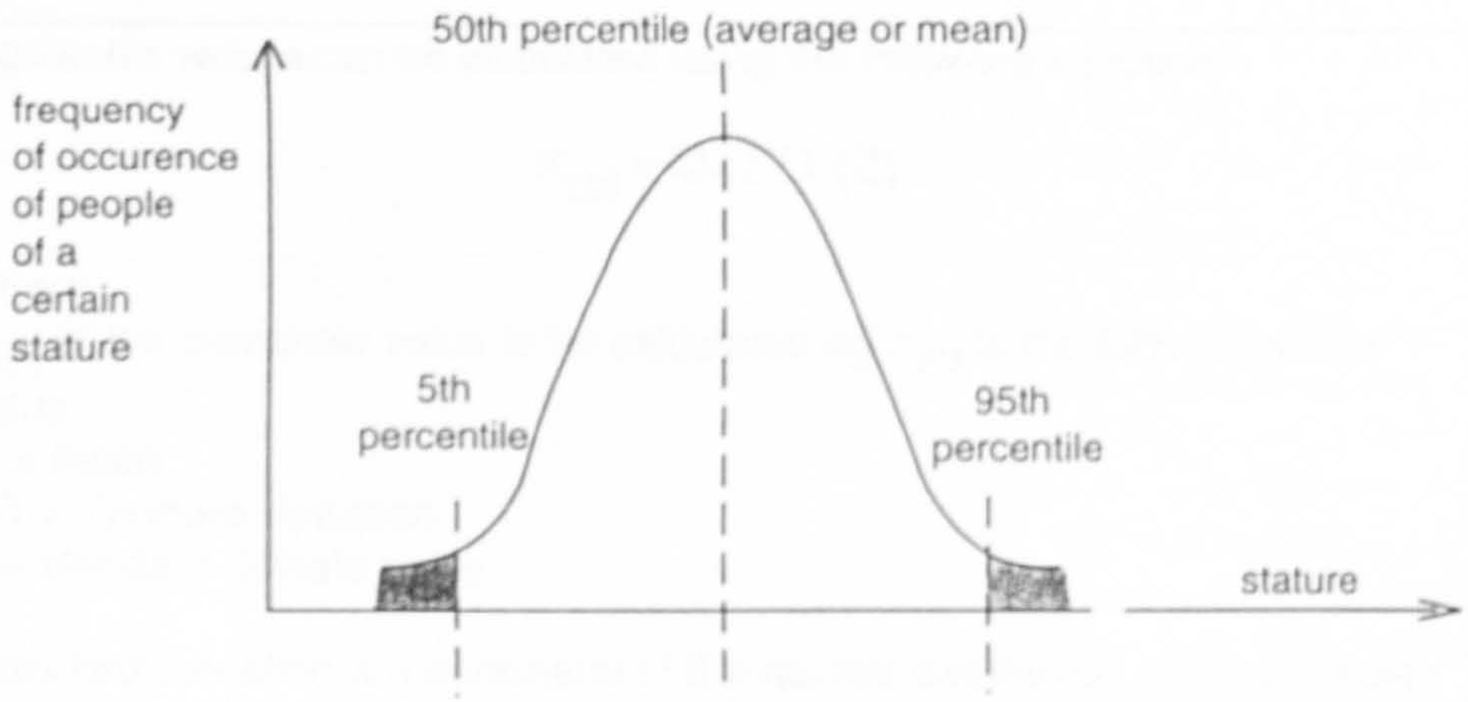


Figure 2: Distribution of stature (normal distribution)

The area under the graph represents the total population. The majority of people fall within the middle range with a low incidence of very tall or very short people. The graph is symmetrical around the midpoint and this point divides the area under the graph in half, such that 50% of the population is shorter than this value and 50% is taller. This is called the 50th percentile value. In the case of stature, the 50th percentile is also equivalent to the average or mean. When this is so, the graph is called a Normal or Gaussian distribution and stature is said to be normally distributed. When a variable is normally distributed, it is easy to predict the limits of the range of that variable, or to calculate a range within which a specified percentage of people will occur.

In design it is often difficult to accommodate every individual in a population, and a common design compromise is to design to accommodate the middle 90% (or 95%); that is, to exclude the smallest 5% (or 2.5%) and the largest 5% (or 2.5%) of the population. The majority of sources of anthropometric data present the fifth and ninetyfifth percentile values and these are used as an acceptable range of the variable. These figures are used because, as figure 2 shows, the slope of the distribution decreases sharply towards the tails and accommodating an extra one percent of the population at each extreme of the distribution requires a relatively large increase in the value of the variable. However, more extreme percentiles should be used where critical design scenarios occur, and in situations where there is a known risk a safety margin might also be applied (this is discussed further in Section 2.4). Examples of designing to accomodate different ranges of the population are shown below:

Designing for an acceptable range of the population:

positioning and design of straps in an infant car seat
5th percentile female to 95th percentile male torso dimensions are required to specify the limits of adjustment of straps so that a specified group of infants can be accomodated

Designing for extremes of the population:

maximum space between vertical bars on a stair gate
minimum female foot breadth of children once crawling should be used to set maximum space between bars to prevent feet passing through the bars, to avoid entrapment and the use of the bottom crossbar as a foothold to climb over the gate

minimum operating torque of handle turned to open stair gate
maximum male wrist twisting strength of children once they are crawling and standing should be used to specify operating torques and reduce the risk of inadvertent operation of the handle by the child

2 Using ergonomics data in design

Percentile values of a variable can be easily calculated, provided the variable is normally distributed. The majority of anthropometric data are normally distributed, although weight is a notable exception. (Weight is usually 'positively skewed', indicating a disproportionate number of people who are heavier than would be expected).

Percentile values can be calculated using the following equation:

$$X_{(p)} = M + SD\ (Z)$$

where
$X_{(p)}$ is the percentile value to be calculated eg X_{99} is the 99th percentile value
M = mean
SD = standard deviation
Z = standard deviate score

Standard deviation is a parameter of the normal distribution used to indicate the amount of variance in an attribute. Approximately 68% of a population will lie within one standard deviation either side of the mean (±1 x SD) and approximately 95% lie within two standard deviations either side of the mean (± 2 x SD). The standard deviation is calculated using the following equation:

$$SD = \left(\frac{\Sigma(X-M)}{n-1}\right)^{1/2}$$

where X = each measured value
M = mean
n = number in sample

Standard deviate scores (or Z scores) can be found in the table in Appendix 1, giving Z scores for percentile values from 0.001% to 99.999 percentile.

Nearly all data tables present mean and standard deviation values so if the percentile values required are not presented they can be calculated using the above equation.

2.3.2 Reasons for human variability

As stated above, the accuracy of our predictions of human variability depends not only on the size of the size of the sample we test but how well they represent the target population. It is therefore important to understand the reasons for human variability and how the group of children for whom we have data may differ from those we are trying to accommodate in our designs. The major sources of variability are as follows:

Gender

Body proportions can vary between the sexes during childhood. Therefore, when designing to accommodate the range of a mixed population, data should be examined carefully before automatically using the 5th percentile female value and 95th percentile male value to set design limits, as is often the accepted practice when designing for adults. There may be instances when these will not accommodate the range of children at a particular age, especially during adolescence. Step by step guidance on combining datasets (eg male and female) can be found elsewhere [2].

The majority of the data in the Handbook are presented separately for males and females. Data on infants however, usually up to two years of age, are presented by the sources as a combined population, as the differences between the sexes at this age are considered minimal.

Age groups

Children do not develop at a steady rate throughout childhood. It should not be assumed therefore that trends in data in one age group will apply to another; that is, that the proportional change in a particular body dimension over one age range will be the same over another range. The age groups of the data used should match the target age group exactly. This is particularly important with regard to infants and adolescents, when anthropometric measurements can change rapidly. Data on infants are sometimes presented in six monthly age bands, and mean data for that group should be used with caution. Also, the specification of ages of children used to collect data can vary between sources. Unless otherwise stated, the ages of children in the databank refer to birthday years, that is, age three includes all children aged from their third and up to their fourth birthdays; data are sometimes classified according to the six months prior to and after a birthday, that is, age three including children from age 2.5 to 3.5 years, but where this occurs it is clearly stated.

Disability

Anthropometric and performance measurements are nearly always carried out on children without any form of physical or psychological impairments or difficulties. This is because the majority of behavioural research is carried out for medical applications and not for design, and the data are only intended to represent children without any sort of impairment. The data presented here will not therefore necessarily accommodate children with any sort of disability and designers must be aware of this. This is a serious inadequacy of much of ergonomics data and needs to be addressed. Very limited amounts of design data on children with specific disabilities have been published and may be accessed through specific searches.

Cultural differences

It is widely recognised that people around the world differ in size and shape; for instance, some racial or ethnic groups are taller than others. Worldwide variation in stature has been suggested as being nearly 40 centimetres, between the mean height of the tallest and shortest adults in the world [2]. It is therefore to be expected that these differences also exist in childhood, and the databank contains data from a number of countries in order to help assess these differences. Within multiracial/ethnic communities such as the UK there are also observed anthropometric differences between children of different ethnic groups[3]. Anthropometric differences are due not only to genetic differences, but to differences in socio-economic conditions even within the same country. This is particularly so in developing countries but even within the UK, small differences in the rate of growth have been observed recently between children in Scotland and England [4,5]. In order for any anthropometric data to be truly representative of a population they should account for all racial/ethnic, demographic and socio-economic variables within that population. Not all of the sources of data in this Handbook account for these factors and the sampling procedure of any data source should be studied. The samples of the major anthropometric sources are described in detail in Section 4. The sample details of the sources of all other data, where available, are summarised within the data tables.

Secular trend

Over varying time periods, indeed centuries, there has been a documented increase in stature [6]. Changes in body size over time are referred to as a secular trend and have been attributed to improvements in living conditions [7]. The overall increase in adult-attained stature has been linked to an earlier onset of the adolescent growth spurt [8] and this suggests that any secular increase in body dimensions may be more accentuated in children and perhaps less predictable that those observed in adults. It is unlikely that one figure representing secular trend in stature will be valid across all ages of children; for instance, the stature of 13 year old Japanese children increased by approximately 80mm from 1948 to 1978 but by less than 70mm in six year olds over the same period [9].

There is much debate as to whether or not the secular increase in stature has halted in developed countries such as the UK. From 1979 to 1986 there was no increase in the stature of 5 to 12 year old children in England and Scotland [10] but some increase has since been recorded from 1986 to 1990 [5]. A recent increase has also been recorded in Dutch children aged 6 to 18 years living in the north of the country [11]. Meanwhile data collected on children in the USA in the 1960s and 1970s are considered by some as still valid for use there in the 1990s [12]. It is therefore important to consider when anthropometric data were collected, whether there has been any secular trend in stature since then and, if so, how a secular trend in stature relates to other anthropometric measurements.

2.4 Applying the data

The caution concerning human data outlined above, such as changes in human characteristics over time, can be overcome, provided that the designer is aware of them and accommodates any uncertainty with appropriate tolerances. These tolerances depend upon how the data are being used and how critical the design scenario is.

2.4.1 Design scenarios

There are five main scenarios which can be used to describe the ways in which data may be applied to design. These are presented in table 2.

design scenario	aim	examples	design should accommodate	critical design scenarios:
fit	design to ensure user-product match and appropriate and effective use	cots, pushchairs, bicycles, cycle helmets, car restraints	maximum range of the population *eg 5th to 95th %ile*	use both maximum and minimum expected values
reach	placement to ensure access and appropriate and effective use	position of handrails, step height	smallest of population *eg 5th %ile*	use minimum expected value
clearance	placement to avoid undesirable or unintentional contact	access hatches,desk-seat gap	largest of population *eg 95th %ile*	use maximum expected value
entrapment	avoid unintentional retention of the whole body or body parts	wholebody: railings, washing machines head: cot sides, ladders, bannisters hand/finger: doors, cupboards, folding pushchairs, fire guards	largest of population *eg 95th %ile*	use maximum expected value
exclusion	ensure inaccessibility and inoperability	barriers, railings, guards, inoperable controls, packaging	maximum range of the population *eg 5th to 95th %ile*	use maximum and minimum expected values

Table 2: Design scenarios and how ergonomics data should be applied

There are situations when it is unacceptable to design to accommodate only the majority of the population and exclude the extremes. These are critical situations in which there is a risk of injury. Here, safety margins should be used to ensure the entire population is accounted for. For example, if a fire guard is to be effective and safe there must be no design-related risk of any child being able to pass their fingers through or around the guard to reach the fire. By a combination of minimising gaps in the guard and increasing the distance between the guard and the fire, the risk of injury even for children with the smallest diameter fingers, hand and wrists and with the longest arms can be considerably reduced.

One method that has been suggested to derive acceptable safety margins is to calculate maximum or minimum values of anthropometric variables rather than use 5th and 95th percentiles [13]. These can be calculated using the equations in the box below.

Maximum value of variable = $X_{95} + 0.7(SD)$

Minimum value of variable = $X_5 - 0.7(SD)$

where
X_5 = fifth percentile value
X_{95} = ninetyfifth percentile value
SD = standard deviation

Whenever design situations involve a real risk of injury, additional safety tolerances should always be added to the design limits already indicated by anthropometric data or human performance data.

2.4.2 Other considerations

The following issues should also be considered when applying ergonomics data.

Clothing All anthropometric data in the Handbook are measured with children barefoot and in underwear. Infants are measured naked and without nappies. If applying data such as stature and reach heights to situations where children may be clothed, an allowance for shoes should be made which may vary depending on current fashions. A correction of 25mm for children up to 12 years and boys over 12 years, and 45mm for girls and women over 12 years has been recommended [2]. Corrections for other clothing are likely to be negligible with the exceptions of outdoor wear, protective clothing (eg cycle helmets), gloves and babies' nappies.

Strength Strength measurements depend on the posture adopted to perform the task and the motivation of the subjects, especially children, during measurements. If strength is measured in a standardised posture the results may be lower than can be achieved in realistic settings. For instance, pushing strength measured with one arm with static posture will be far less than if two arms and body weight can be used. Also, it may be difficult to guarantee maximum effort in experiments from young children who may be unnerved by experimental conditions.

Posture Functional anthropometric measurements such as reach are usually taken in standardised postures and do not account for stretching or twisting to maximise the reach.

3 Designing for children of different ages

Childhood is a period of continual and sometimes rapid change in physical and psychological abilities. Also, there can be huge variations between children of the same age, particularly around adolescence. Designing for children can be more difficult than designing for adults because of this continual change and the wider variation within age groups. This section describes some key stages in child development and identifies how certain important developmental factors should be taken into account when designing for children.

3.1 Anthropometric measurements

The rate of growth varies during childhood; growth is rapid during the first few years of life then decreases after infancy until the 'adolescent growth spurt' when it increases again. The timing of the growth spurt varies between individuals and is different in boys and girls. A general guide would be anywhere between age 9 and 14 years for girls and 11 and 16 years for boys although there is some evidence that, along with a secular increase in stature, the adolescent growth spurt is also starting earlier [6].

While there is a general increase in body dimensions with age, the amount of variation within each age group also increases, demonstrated by an increase in the standard deviation of anthropometric measurements with age. Wide variation within age groups can lead to an overlap across age groups; for instance, a tall 7 year old boy may be taller than a short 10 year old (1320mm and 1290mm respectively [2]). This variation within age groups sometimes makes it more appropriate to design according to variables other than age; weight for instance is sometimes used to specify the suitability of baby carriers and nappies. Some anthropometric data (although none in this Handbook) are in fact classified according to weight rather than stature.

Anthropometric differences between the sexes start to appear slowly after birth and increase with age. Differences in the timing of the adolescent growth spurt mean that girls can overtake boys around adolescence. After about age 13 the anthropometric differences between the sexes become more pronounced; dimensions such as shoulder breadth in boys and hip breadth in girls increase and start to resemble adult proportions.

Body proportions are also changing throughout childhood. At birth, the ratios of head length and leg length to stature are greater than in older children or adults. Head length is around 25% of stature at birth but decreases to around 10% in adults.

3.2 Physical abilities

Motor abilities develop in the same sequence in all children but at different rates. Motor development starts with simple reflexes like grip, then postural movements such as moving the head, followed by locomotor skills such as sitting, crawling, standing and on to fine manipulative skills such as holding a pen. Motor control develops first in the head and works down the body to reach the feet last, and starts with the control of the middle of the body and works out to the extremities.

A general scheme of motor development in infants:

birth	grasp reflex.
1 month	holds head erect and steady for 15 seconds
2 months	sits with support
3 months	fingers oppose palm, thumb not used
5 months	sits alone momentarily
6 months	uses thumb in opposition
7 months	early stepping movements, poor pincer grip
9 months	walks with help
11 months	walks alone
14 months	walks up stairs with help

(Bayley Scales of Infant Development [14])

A general sequence of locomotor development:

sit
crawl
creep
stand
walk
run
climb
balance
catch
throw

3 Designing for children of different ages

Again, there can be immense differences within age groups, and development in one variable does not necessarily mean equivalent development in all. For instance, a child with 95th percentile stature may have 5th percentile hand strength. Some differences in motor performance between the sexes can start in early childhood; girls are considered to perform better at tests of balance, hopping and flexibility while boys perform better at running and throwing. Male/female differences in strength and endurance become more measurable after adolescence. Performance in all such motor skills improves up to adolescence, when skills level off without further specific training.

3.3 Psychological abilities

The development of perceptual and cognitive abilities in children is particularly relevant to design, in terms of when and how children are able to understand and interact with their surroundings. However much of the information available concentrates on the first measurable emergence of perceptual abilities such as the ability to perceive depth or colour. The conditions of such experiments are often too specific and controlled to allow the results to be generalised for the purposes of design. For guidance on the general developmental milestones the reader is referred to development texts (see Section 8, Bibliography). However, the most important psychological design issues, such as whether a child will be able to understand written instructions, recognise and act upon a warning sign or work out how to operate a lock, are very dependent on factors such as motivation, previous exposure, peer support and curiosity rather than strict measures of reading skills, visual perception or reaction times. If designing for children involves such issues it may be necessary to carry out user evaluation and testing rather than relying on general developmental guidelines.

3.4 Stages of development related to safety

The following is a list of stages of child development with examples of how particular stages may relate to design, and particularly to design safety, adapted from the Child Accident Prevention Trust (with permission). The list is by no means intended to be exhaustive but highlights a selection of possible risks.

Age	Skills	Risks
3 months	wriggles, kicks	instability in baby bouncers
5 months	rolls over, reaches for objects, grasps, puts objects in mouth	rolling off surfaces, reaching for dangerous items, choking
8 months	crawls, sits alone	falling down steps or stairs, pulling hot items onto themselves
9 months	pincer grip, pulls to stand,	opening cupboards
10 months	walks holding furniture	climbing and falling
11 months	knows things when they are out of sight	looking for items placed out of sight, ingesting household products
13 months	walks unaided, crawls upstairs operates knobs & switches	opening windows, containers, falling from stairs
18 months	explores, imitates	playing with knives, operating controls on household products
2 years	screws beyond one turn, interested in smell/ taste/texture	operating locks & catches on safety gates, using lighters & matches
3 years	stops putting objects in mouth	operating child resistant containers, playground accidents
pre-school	climbs trees, operates bolts, competent on stairs	falling from bicycles & trees, operating electrical products

4 How to select data

4.1 Anthropometric data

4.1.1 Sources of anthropometric data

In order to provide some international comparison of anthropometric data, stature and weight data have been included from a number of countries. There may be differences between the sources in terms of sample sizes, sampling techniques, representativeness of the population, classification of age groups, measurement techniques or year of measurement. These should be noted when using the data to make international comparisons.

Country	Age range (years)	Source
UK	0-18 (weight from age 3 only)	Pheasant 1988
Ireland	newborn	Hayes 1983
Netherlands	0-12	Steenbekkers 1993
Spain	0-2	Ferrandez 1986
Belgium	12-18 (males only)	Ostyn 1980
Germany	3-17	DIN 1981
Norway	3-16	Waaler 1983
USA	newborn	Copper 1993
USA	0-19	Snyder 1977
Turkey	6-15	Dindar 1989
Saudi Arabia	newborn	Rasheed 1991
Saudi Arabia	6-16	Magbool 1993
India	6-12	Singh 1987
Japan	7-15	Ashizawa 1987
China	0-7	Zhang 1988
China	7-17	Yi-Ling 1982
New Zealand	0-9	Clymer 1988
Stature only:		
France	0-16	Joubert 1982
Hungary	6-14	Budavari 1982

(Note that stature in infants less than two years old is measured as crown to sole length.)

The remainder of the anthropometric measurements (over 140) are taken from a smaller selection of sources. These primary sources are listed and decribed below:

Country	Age range (years)	Source
UK	0-18	Pheasant 1986
UK	0-16	BSI 1990
Netherlands	0-12	Steenbekkers 1993
Netherlands	0-5.5	Steenbekkers 1989
Germany	3-17	DIN 1981
USA	0-19	Snyder 1977
USA	0-13	Snyder 1975
USA	2-10	Owings 1977
USA	0-4	Schneider 1986

Pheasant 1986 (UK)
The data were produced using a method of estimating anthropometric measurements from stature. Stature was measured in 1970/1971 [15] in a nationwide sample of 15,000 children representative of the UK school population aged three to eighteen years. The stature data were considered to be still valid in 1985 when the data were re-published [16]. The anthropometric measurements were calculated using body part/stature ratios from North American sources [17,18]. All data are calculated to the nearest 5mm. The majority of UK anthropometric data in the Handbook are taken from this source.

BSI 1990 (UK)
While this is the most recent large scale anthropometric survey of children in Britain, the data were collected for the clothing industry and many of the measurements have limited application to design, for instance bent arm length. Some of the measurements have been used in order to supplement the data from Pheasant, and these are mainly circumferential measurements. Data on 2000 infants (0-5 years) were collected in 1987; 4770 girls (5-16) were measured in 1986 and 3428 boys (5-16) were measured in 1978. The subjects were nationally representative (excluding Northern Ireland), from mainly urban areas and socio-economic factors were disregarded. Most importantly, the results represent Caucasian subjects only.

Steenbekkers 1993 (The Netherlands)
This is the primary source of Dutch data. A sample of 2245 children aged 2 to 12 years were measured between February 1990 and February 1991. These are the most recent anthropometric data on European children available. The sample was geographically representative of the Netherlands and included children born both in the Netherlands and abroad and those born to non-Dutch parents; the sample was not considered sufficiently representative of socio-economic factors. A sample of 87 infants aged 0 to 14 months were also measured in one geographical area of the Netherlands a few years earlier. Monthly age groups in infants were classified as thirty days.

Steenbekkers 1989 (The Netherlands)
A few measurements are taken from this study that were not recorded in the subsequent 1993 study by Steenbekkers. A sample of 633 children aged 0 to 5.5 years were measured in one region of the Netherlands between 1987 and 1989.

DIN 1980 (Germany)
Deutsches Institut fur Normung (DIN) is the German Standards organisation and the data are taken from the German Standard for body measurements of children. The data were collected between 1968 and 1977. It should be noted that at that time the data are stated as representative of 'the regional and social variation' of children from the Federal Republic of Germany.

Snyder 1977 (USA)
This is the most comprehensive collection of design-related child anthropometric data available. The data were collected between 1975 and 1977 on a sample of 4127 children aged between birth and 19 years and were nationally representative of ethnic, demographic and socio-economic variables.

Snyder 1975 (USA)
This is a prior report from the same US authors providing some additional measurements, recorded on a sample of 4027 children aged between birth and 13 years, again nationally representative and measured between 1972 and 1975. Monthly age groups in infants were rounded to the nearest month.

Owings 1977, Schneider 1986 (USA)
Owings provides dimensions on the hands of children aged 2 to 10 years (sample 350) collected as part of the Snyder survey. Some facial measurements are taken from Schneider, a nationally representative study of 300 children aged from birth to four years measured in the early to mid 1980's.

4.1.2 Validity of anthropometric data

The validity of the large data sources (Pheasant, BSI, Steenbekkers 1993, DIN 1980 and Snyder 1977) have been assessed for the purposes of the CHILDATA Handbook. This involves their validity as sources of nationally representative data (given any secular trend) and also for use with a target population of UK children, given that UK or even European data are not available for all of the measurements.

Stature and weight from each source were compared to the most recent UK data [19] in order to assess UK secular trend and international differences. The results are presented in terms of an adjustment figure for each source, where this has been considered necessary. The method of comparison and the current UK stature and weight data are described in Appendix 2.
Table 3 indicates the discrepancies in stature and weight between the sources and current UK data. The figures are the percentage adjustments required for each source (ie increase or decrease source data by the figure shown).

			% difference from current UK data:			
Country	Source	Age (years)	Stature male	Stature female	Weight male	Weight female
Britain	Pheasant 1986	2-18	-1.40%	-1.27	0.99	-0.31
	BSI 1990	5-16	-0.97	-0.37	-1.14	-2.49
USA	Snyder 1977	4-19	-0.31	-0.31	4.42	1.02
Germany	DIN 1980	3-17	1.44	1.79	n/a	n/a
NL	Steenbekkers 1993	2-12	3.17	3.16	8.07	7.1

-ve value indicates source data are lower than current UK data
+ve value indicates source data are greater than current UK data

Table 3: Comparison of mean percentage stature and weight data between major CHILDATA sources and current UK data (Freeman et al, 1995)

4 How to select data

Pheasant 1986 (UK)
Table 3 indicates that, according to Pheasant, UK children are approximately 1% to 1.5% shorter than current estimates for the same age group; males are around 1% heavier while females are around 0.3% lighter. Using differences in stature only and assuming that differences in stature are reflected proportionately throughout the body (see discussion in Appendix 2), this suggests that all data from Pheasant should be increased by the appropriate adjustment figure. Increasing male data by 1.5% would mean an increase of between 0.8mm and 1.3mm for hand breadth (50th percentile 2 and 18 year old boys respectively) and between 11mm and 21.7mm for shoulder height (same subjects). The decision as to whether these adjustments are warranted in any particular situation must be left to the user. The absolute adjustments might be considered negligible for small body dimensions such as hand measurements, given the confidence limits within which all anthropometric data are reported; for example, stature data is often only measured to within the nearest 5mm [12,22] and all of Pheasant's data are rounded to the nearest 5mm. For larger body dimensions such as shoulder height, the adjustment is still small compared to the amount of variation that is found within each age group (shoulder height varies by 180mm between 5th and 95th percentile 18 year old boys). The adjustment figures are provided to give some indication of possible changes in the population; adjustment factors based on stature are provided for use at the designer's discretion but should be considered in any design situation where there is concern over safety.

BSI (UK)
BSI data also indicate shorter stature than current estimates although the differences between BSI and current data are less than for Pheasant, which is to be expected since BSI data are more recent. Male stature from BSI (collected in 1978) is approximately 1% lower than current stature, and female stature (collected in 1986) is around 0.4% less; there is however a difference of 2.5% in female weight data. Possible adjustment of data should again be considered where there is any concern over design safety.

USA data
Data from Snyder (1977) were collected during the 1970's and it has been suggested that data collected then are still valid for US children (this was recently demonstrated for school age children in one area of the USA [12]). The difference between stature data from Snyder and the current UK estimates is very small, with Snyder's data around 0.3% lower than current UK childhood stature. It would therefore appear that Snyder's data from the United States, including that from other sources (such as Owings and Schneider) are the most appropriate of the non-UK sources in the Handbook for use with a UK population. Possible adjustment of data should again be considered where there is any concern over design safety, especially given the greater differences in weight between US and UK data, particularly for males.

German data
The DIN standard has not been updated since the late 1970's. Also, data were collected on children in the Federal Republic only which means the appropriateness of these data for the current German childhood population should be assessed given the political changes in the country. German stature data are approximately 1.5% higher than current UK childhood stature and possible adjustment of data should again be considered where there is any concern over design safety.

Dutch data
Data from Steenbekkers are the most recent data available for Dutch children and as such are the most valid source available for that population. They are also the most recent source of data on any European childhood population. Dutch children are taller and heavier than current UK children, stature is approximately 3% greater than current UK childhood stature and there is approximately 8% difference in weight. This difference should be considered if using data from Steenbekkers for a UK target population and possible adjustment of data should again be considered where there is any concern over design safety.

If there are no UK data available for a particular measurement it is recommended that the most appropriate data to use, based on a comparison of stature only are, in descending order:

1 USA (Snyder, Schneider and Owings)
2 Germany (DIN)
3 Netherlands (Steenbekkers)

It should be remembered that the assessment of validity has been based on differences in stature and weight only and these differences may not be reflected proportionately in other anthropometric measurements. No assessment has been made of data on infants (see table 3 and Appendix 2).

Guidance regarding the application of all anthropometric data to design is given in section 3.

4.2 Non-anthropometric data

A number of sources of data are sometimes presented for measurements other than anthropometry, eg for strength. This is often because the sources give data on different age groups, the data are from different countries or because they use different methods to collect data. For instance, grip strength may be measured with either one or two hands and this will obviously affect the results.

If more than one source is presented for any measurement, the details of how the data were collected should be used to decide which is most appropriate for the design application. The background information provided for each source such as the year of publication, the country of origin and the sample size and details should also be used to assess the validity of the data.

5 How to find the data you need

The datatables are organised into five sections, each section containing data on different types of measurements:

1 Static anthropometry
2 Functional anthropometry
3 Physical abilities
4 Psychological abilities
5 Cognitive abilities

Figure 3 shows how the data are organised and this is followed by a full list and classification of measurements. This is a hierarchical classification of measurements according to measurement type (eg static anthropometry, strength) and body part (eg head, torso). The classification is followed by a full set of anatomical diagrams showing all of the anthropometric measurements contained in the Handbook. The datatables for each measurement are then presented in numerical order.

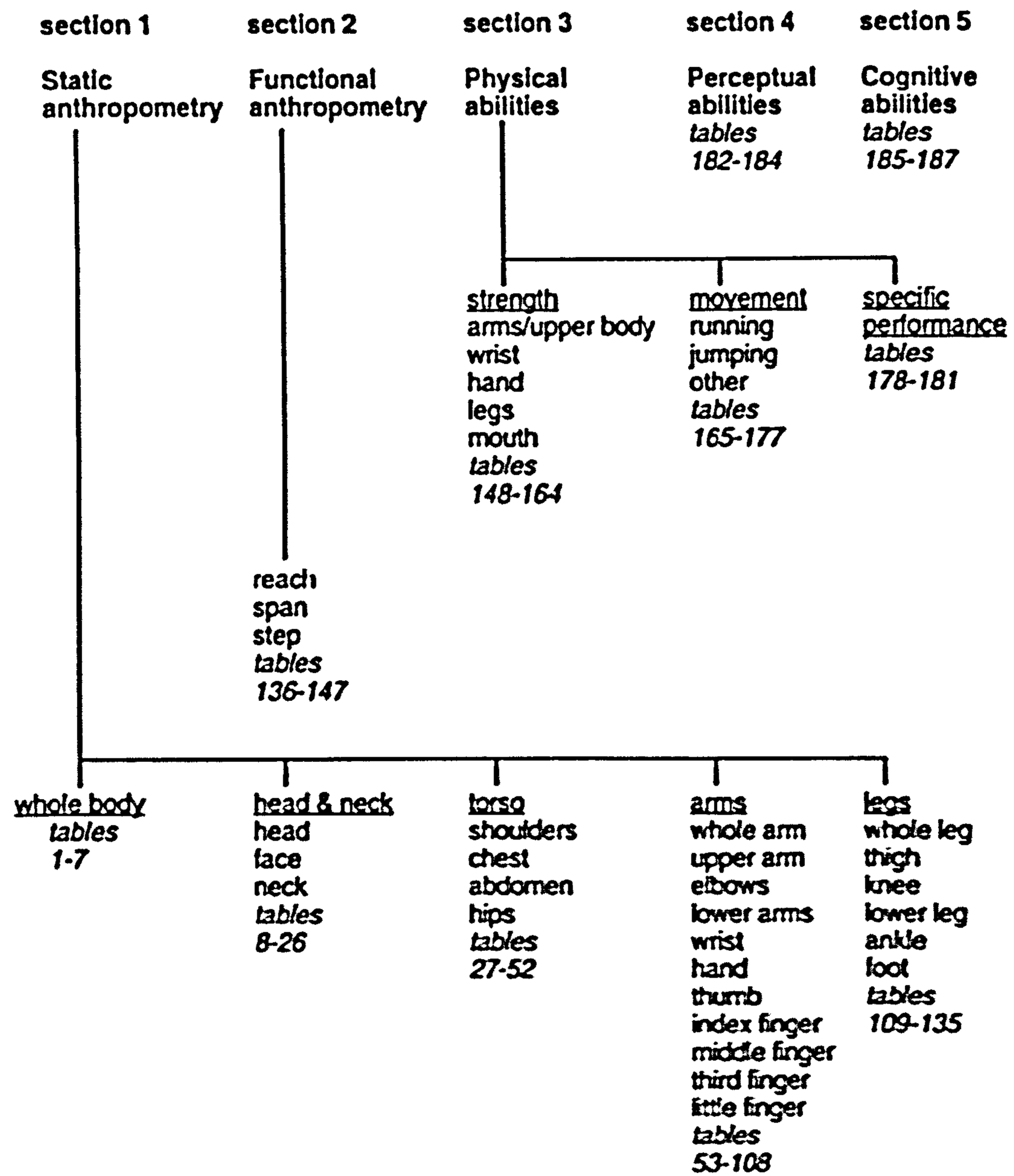


Figure 3: Classification of measurements

5.1 Classification

Section 1 Static Anthropometry

1.1 Whole body

1 Weight
2 Stature
3 Body length, crown to sole (supine)
4 Sitting height
5 Sitting height, crown to rump (supine)
6 Centre of gravity (standing)
7 Centre of gravity (seated)

1.2 Head and neck

Head
8 Head breadth
9 Head length
10 Head circumference
11 Head height
12 Maximum head diameter (chin to back of head)
13 Ear to ear (bitragion) breadth

Face
14 Face breadth(bizygomatic or cheekbones)
15 Face breadth (brow ridges)
16 Jaw breadth
17 Face height
18 Face height (bridge of nose - chin)
19 Eye height (from floor)
20 Eye height (seated)
21 Eye separation (interpupillar distance)
22 Mouth breadth
23 Mouth opening (between incisors)
24 Nose length

Neck
25 Neck breadth
26 Neck circumference

1.3 Torso

Shoulders
27 Shoulder height (from floor)
28 Shoulder height (supine)
29 Shoulder height (seated)
30 Shoulder breadth (bideltoid)
31 Shoulder breadth (biacromial)

Chest
32 Chest height at armpit
33 Chest breadth at armpit
34 Chest breadth at nipples
35 Chest depth
36 Chest circumference at armpit
37 Chest circumference at nipples

Abdomen
38 Waist height at navel
39 Waist breadth (in infants)
40 Waist breadth at navel
41 Abdominal depth
42 Waist circumference (maximum in infants)
43 Waist circumference (natural)
44 Waist circumference at navel

Hips
45 Hip height at trochanter
46 Hip breadth (maximum in infants)
47 Hip breadth at trochanter
48 Hip breadth (maximum when seated)
49 Hip depth
50 Hip circumference
51 Buttock height at maximum depth
52 Buttock height at gluteal furrow

1.4 Arms

53 Arm length to fingertip
54 Arm length to grip

Upper arms
55 Upper arm length (shoulder to elbow)
56 Upper arm depth
57 Upper arm circumference
58 Upper arm circumference at armpit

Elbows
59 Elbow height (from floor)
60 Elbow height (supine)
61 Elbow height (seated)
62 Elbow breadth

Lower arms
63 Lower arm length (elbow to fingertip)
64 Lower arm length (elbow to grip)
65 Lower arm breadth
66 Lower arm circumference

Wrist
67 Wrist breadth
68 Wrist depth
69 Wrist circumference

Hand
70 Knuckle height (from floor)
71 Hand length (to wrist)
72 Hand length (to thumb crotch)
73 Palm length
74 Hand breadth at palm
75 Hand breadth at thumb
76 Hand depth
77 Hand circumference at palm
78 Hand clearance (minimum aperture)
79 Maximum grip diameter (between thumb and index finger)
80 Maximum grip diameter (between thumb and middle finger)
81 Grip length (middle finger to thumb)
82 Fist breadth
83 Fist depth
84 Fist circumference

Thumb
85 Thumb length
86 Thumb breadth at distal joint
87 Thumb diameter (minimum aperture)

Index finger
88 Index finger length
89 Index finger breadth at distal joint
90 Index finger breadth at middle joint
91 Index finger diameter (minimum aperture)

5.1 Classification

Middle finger
92 Middle fingertip height (from floor)
93 Middle finger length
94 Middle finger length (distal joint to tip)
95 Middle finger length (middle joint to distal joint)
96 Middle finger length (knuckle to middle joint, hand clenched)
97 Middle finger breadth at distal joint
98 Middle finger breadth at middle joint
99 Middle finger depth at distal joint
100 Middle finger depth at middle joint
101 Middle finger diameter (minimum aperture)

Third finger
102 Third finger length
103 Third finger breadth at distal joint
104 Third finger breadth at middle joint

Little finger
105 Little finger length
106 Little finger breadth (at distal joint)
107 Little finger breadth (at middle joint)
108 Little finger diameter (minimum aperture)

1.5 Legs
109 Leg length, buttock to sole (seated)
110 Leg length, buttock to sole (supine)

Thigh
111 Upper leg length, buttock to knee (seated)
112 Upper leg length, buttock to popliteal (seated)
113 Upper leg length, buttock to popliteal (supine)
114 Thigh breadth (maximum when seated)
115 Thigh depth (clearance when seated)
116 Upper thigh depth
117 Mid thigh depth (supine in infants)
118 Upper thigh circumference
119 Mid thigh circumference (supine in infants)

Knee
120 Knee height (seated)
121 Popliteal height (seated)
122 Knee breadth (seated)
123 Knee circumference

Lower leg
124 Lower leg length, knee to sole (supine)
125 Lower leg length, popliteal to sole (supine)
126 Calf height (at maximum circumference)
127 Calf depth
128 Calf circumference

Ankle
129 Ankle height
130 Ankle breadth
131 Ankle circumference

Foot
132 Foot height
133 Foot length
134 Foot breadth
135 Heel breadth

Section 2 Functional Anthropometry

2.1 Reach

136 Overhead reach to grip (standing)
137 Overhead reach to grip (seated)
138 Overhead reach to fingertip (on tiptoes)
139 Overhead reach to fingertip (jumping)
140 Forward reach to grip (standing)
141 Forward reach to grip (seated)
142 Forward reach to grip (stretching and seated)
143 Forward reach to fingertip (stretching and seated, legs outstretched)
144 Sideways reach to grip (standing)

2.2 Span

145 Span
146 Elbow span

2.3 Legs

147 Step height

5.1 Classification

Section 3 Physical Abilities

3.1 Strength

Arms/upper body
148 Pushing forwards
149 Pushing downwards
110 Pushing sidewards
151 Pulling
152 Lifting
153 Hanging by the arms
154 Hitting force

Wrist
155 Twisting
156 Opening

Hand
157 Grip/squeeze
158 Pinch (pads of fingers)
159 Pinch (tips of fingers)
160 Pinch (lateral)
161 Shear

Legs
162 Pushing forwards

Mouth
163 Bite
164 Lips

3.2 Movement

Running
165 Endurance
166 Distance
167 Speed

Jumping
168 Forwards
169 Sideways
170 Upwards
171 Over a barrier

Other
172 Swimming
173 Walking across a ladder
174 Walking sideways
175 Hopping
176 Static balance
177 Dynamic balance

3.3 Specific performance

178 Height at which windows can be opened
179 Climbing fences
180 Throwing
181 Volume of a swallow

Section 4 Perceptual abilities

182 Reaction times to visual stimuli
183 Reaction times to auditory stimuli
184 Reaction times to visual and auditory stimuli

Section 5 Cognitive abilities

185 Understanding colour
186 Understanding safety symbols
187 Attention span

Appendix1

p and z values of the normal distribution

p	z	p	z	p	z	p	z
1	-2.33	26	-0.64	51	0.03	76	0.71
2	-2.05	27	-0.61	52	0.05	77	0.74
3	-1.88	28	-0.58	53	0.08	78	0.77
4	-1.75	28	-0.55	54	0.10	79	0.81
5	-1.64	30	-0.52	55	0.13	80	0.84
6	-1.55	31	-0.50	56	0.15	81	0.88
7	-1.48	32	-0.47	57	0.18	82	0.92
8	-1.41	33	-0.44	58	0.20	83	0.95
9	-1.34	34	-0.41	59	0.23	84	0.99
10	-1.28	35	-0.39	60	0.25	85	1.04
11	-1.23	36	-0.36	61	0.28	86	1.08
12	-1.18	37	-0.33	62	0.31	87	1.13
13	-1.13	38	-0.31	63	0.33	88	1.18
14	-1.08	39	-0.28	64	0.36	89	1.23
15	-1.04	40	-0.25	65	0.39	90	1.28
16	-0.99	41	-0.23	66	0.41	91	1.34
17	-0.95	42	-0.20	67	0.44	92	1.41
18	-0.92	43	-0.18	68	0.47	93	1.48
19	-0.88	44	-0.15	69	0.50	94	1.55
20	-0.84	45	-0.13	70	0.52	95	1.64
21	-0.81	46	-0.10	71	0.55	96	1.75
22	-0.77	47	-0.08	72	0.58	97	1.88
23	-0.74	48	-0.05	73	0.61	98	2.05
24	-0.71	49	-0.03	74	0.64	99	2.33
25	-0.67	50	0	75	0.67		2.5

p	z	p	z
0.5	-2.58	99.5	2.58
0.1	-3.09	99.9	3.09
0.01	-3.72	99.99	3.72
0.001	-4.26	99.999	4.26
-1.96	97.5	1.96	

z = standard deviate or z score
p = percentile

Appendix 2

Assessment of validity of anthropometric sources - international differences and secular trend

1 Current UK stature and weight data

The current UK stature and weight data used for the assessment of validity were estimates used to construct the new Growth Reference Curves for stature and weight produced by Freeman et al [19]. These replace the growth curves in use since the 1960s [20]. The new curves are based primarily on the latest available data from the annual National Study of Health and Growth, a survey of 10,992 children aged 5 to 12 measured in England during 1990 and in Scotland in 1989-1990 [21]. These were combined with other sources (including the BSI data) to extend the age ranges from birth to 18 and to construct the reference curves. The GRC data represent Caucasian children only.

2 Use of stature to estimate international anthropometric differences

Differences in anthropometric measurements between countries are usually only reported in terms of height, weight, Body Mass Index (BMI) or skinfold measurements, as these are considered the most useful indicators of children's growth. For the designer however, comparison of other key measurements such as head breadth, finger diameter and overhead reach would be more useful. One such study comparing head circumference found a difference between UK and Japanese children (UK children's head circumference being greater than that of Japanese children), and suggested that this primarily reflected the differences in stature; the ratio of head circumference to stature was almost identical in UK, North American and Japanese children) [23]. It has been suggested that differences in stature can be used to estimate differences between populations in other body parts, by calculating the ratio of the body part to stature. This assumes that body proportions are similar in both populations and has been demonstrated to be an acceptable method of estimation for body lengths, but less so for those measurements subject to bodyfat deposits such as body breadths and circumferential measurements [24].

3 Use of stature to estimate secular trend in other anthropometric data

There is very little guidance on how a secular increase in stature affects other anthropometric measurements. It has been has suggested that in some countries a secular increase in stature has been produced almost wholly by an increase in leg length only [6,11]. However, more precise information than this is needed, using comparable data over long periods of time on a complete range of body dimensions and from a larger sample of countries. This is as yet unavailable and so any practical interpretation of secular trend has had to be based on the stature and weight data only.

4 Method of comparison of stature and weight data

Current UK childhood stature and weight data were taken from the new Growth Reference Curves produced by Freeman et al (1994). The data are grouped in monthly age groups from birth to 18 years. Data from the sources in the Handbook however are grouped into yearly age groups. Source data for each yearly age group were therefore compared to the mid-year month data from GRC (ie 4 year old data from the Databank were compared to data for children aged 4 years and 5 - 5.9 months from GRC). Curve fitting was attempted, but it was decided that the level of accuracy offered by direct comparison of the datapoints was sufficient. This method assumes that sample sizes in the sources are large enough to ensure that yearly data adequately represent children of all ages spread equally across the twelve months of the year.

5 Comparison of mean data only

For most sources comparison was made of mean data only. However a comparison of mean, fifth and ninetyfifth percentile values was made for Pheasant's data in order to investigate any differences throughout the population. The increase in mean stature was around 1.3%; the increase in fifth percentile stature was slightly higher (around 2%) while the increase in ninetyfifth percentile stature was slightly lower, around 0.7%. While these results suggest that further investigation may be necessary, the magnitude of the differences between the percentiles suggests that the data are valid for use with the current UK population.

Appendix 2

6 Comparison of infant data

Infant data could not be compared in this way because of differences in data groupings. First of all, age groups were different; GRC data were grouped in monthly age groups while all the infant data in the Handbook were grouped in either three or six monthly age groups. The amount of variation in anthropometric measurements in infants from birth to around two years is too great to compare across these age groups. Secondly, the GRC data were presented separately for males and females while the sources present data combined for males and females. Comparison of data from each source was therefore started from the first age group where age and sex groups were comparable.

Appendix 4.3

Questionnaire sent to *Childata* users

CHILDATA QUESTIONNAIRE

1. How did you find out about CHILDATA?

☐ colleagues ☐ associates ☐ other, please state

_____

2. Does CHILDATA provide all the data you require?

yes ☐ No ☐

3. If no, what other data do you require?

_____

_____

4. How easy is it to find the data you need?

very easy			very difficult
☐	☐	☐	☐

5. How could finding the data be improved?

_____

_____

6. How understandable are the tables?

very easy			very difficult
☐	☐	☐	☐

7. How could the tables be improved?

_____

_____

8. Have you any other suggestions for improving CHILDATA?

_____

_____

Appendix 4.4

Results of survey of *Childata* users

To: Mr Dessent CACP
Ms Norris Nottingham University

From: Paul Hale
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4.H.6
1 Victoria St
London
SW1H OET

Tel: 0171 215 0380
Fax: 0171 215 0357

22 July 1997

CHILDATA

You will find the following analysis of the CHILDATA questionnaires of interest.

Of the completed questionnaires:

- 83% stated that CHILDATA met their needs,
- 90% stated that CHILDATA was easy or very easy to use, and
- 89% stated that CHILDATA was easy or very easy to understand.

This is an overwhelming endorsement for the format and data contained within CHILDATA. I would suggest a similar approach is used for ADULT and ELDERLY DATA.

Other details were requested and numerous answers were received as follows:

- what extra data is needed?

  - Centre of gravity, greater variety of force measures, mental abilities of different ages, compatible data across ages e.g. all 18 months not some at 1yr/2yrs/18 months.
  - Strength Limits for applying twist to a small object such as a butterfly nut or hot water bottle top.
  - Height of barriers/handrails - could not find length 23 on page 24.
  - Provision of equivalent/advised European figures.

- Can anticipate some ages not covered for some dimensions and 5H/95H % i.e. not always available.

- Additional data/surveys on existing measurements would be useful - some surveys with small sample sizes.

- More info on perceptual abilities would make handbook complete.

- Limits of joint movement (angles).

- Shoulder height seated for 0-27 months (needed for strangulation hazards on large toys, beds, cots etc.).

- There seems to be measurements that are not included.

- More relevant UK or local data would be useful.

- Some times data for younger children are missing.

- Data for density of children.

- More data about exerted strength.

⇨ How could CHILDATA be improved?

- It could be improved by giving a more specific index, and the pages need to easy to turn over as they tended to come off the spine or get caught.

- Alphabetic index, Dividers between sections.

- Page tabs.

- Putting the data into sections which are arranged in alphabetical order.

- More clearly presented esp re UK vs other nations.

- A Better list of contents - Index.

- The more you use the data tables the easier it is to find the data needed.

- Difficulties in comparison between Jersey and UK data.

- Dynamic Measurements - e.g. Sat Riding a Bike.

- Ethnic group data.

- guidelines for associated measures e.g. clothing sizes, shoe sizes etc.

- Index.
- Put on CD-ROM.
- Use of slightly larger spine and softer cover would improve travelling of the document.
- Should be made more available to libraries for general public.
- Split into 2 Age Ranges: 0-3 years and 3-14 years.
- Always give the sample sizes.
- Indicate which samples are statistically reliable and which are more a guidance or trend.

⇨ How could the tables be improved?

- They could be improved by making it a bit more clearer or more explanation about the tables.
- It is easy to confuse units (metric/imperial) and population/age differences - illuminating these differences would reduce error.
- Should all twist forces not be in Nm?
- Consistent use of units and breakdown intervals.
- Clearer labels.
- One table caused problems, it was only in months up to 36 months in total. Suggest years in bold type face months in normal.
- direct male/female comparison.
- By using more understandable words, and with a comment alongside the table.
- "How to use" to lay people could be simpler to understand.
- Repeat the drawing on the first page of the section in ICON-size next to the source-header.
- More detailed description about what is measured.
- Better relations between numbers.

- Unsolicited comments:

  - Unfortunately, it is not what I expected. However, it has given me insight into product design and I can see how it would be useful in this context.

  - The CHILDATA was not applicable for our use, but I feel it is a useful book of information and easy to access.
  -
  - Not relevant to our work as Health Visitors (HV).

  - Excellent reference which will be further improved by updates etc./more data.

  - Useful/helpful document - appreciate its existence.

  - An excellent publication.

  - Very user friendly.

  - Time Saving and all information easily digestible.

Obviously this has been a good response with numerous ideas put forward for improving CHILDATA. We must now consider how these suggestions could be included in CHILDATA and whether we need to consider them for ADULT and ELDERLY DATA now?

Paul Hale

Appendix 5.1

Descriptions of common evaluation methods (listed in Table 5-2, Chapter 5).

Methods 1-7 are described in Jordan et al (1996) and methods 8-14 in Stanton and Young (1998) - see references.

1 DIY - Do-It-Yourself Usability Evaluation (Botman, 1996)

Intended to help software developers to increase their 'end-user consciousness'. It consists of six steps (not all of which need to be taken):

- orientation on the users and their environment
- expert view
- user's view
- user testing
- evaluation report
- recommendations for improvement.

2 TAFEI - Task Analysis for Error Identification (Stanton and Baber, 1996)

A Human Error Identification (HEI) technique which maps human activity onto machine states to identify potential errors in use. It consists of 3 components:

- hierarchical task analysis (HTA) - provides a description of human activity
- state-space diagrams (SSDs) - provides a description of machine activity
- transition matrices (TM) - a mechanism for determining potential erroneous activity through the interaction of the human and the device.

It can be used at all stages of the design cycle, from conceptual stages to existing products.

3 FACE - Fast Audit based on Cognitive Ergonomics (Hulzebosch & Jameson, 1996)

A computer-based evaluation tool, implemented in HyperCard, for the evaluation of interface design, which produces supplementary documentation during the evaluation.

4 SUS - System Usability Scale (Brooke, 1996)

A five-point Likert scale (strongly disagree - stingily agree) of 10 statements referring to system usability issues, developed at Digital Equipment Corporation.

1. I think that I would like to use this system frequently
2. I found the system unnecessarily complex
3. I thought the system was easy to use
4. I think that I would need the support of a technical person to be able to use this system
5. I found the various functions in the system were well integrated
6. I thought there was too much inconsistency in this system
7. I would imagine that most people would learn to use this system very quickly
8. I found the system very cumbersome to use
9. I felt very confident using the system
10. I needed to learn a lot of things before I could get going with this system.

5 SUMI - Software Usability Measurement Inventory, (Kirakowski, 1996)
An attitude scale to measure users' attitudes to specific software systems, consisting of 50 attitude statements with a 3-point response format (agree, don't know, disagree).

6 Co-Discovery (Kemp and Van Gelderen, 1996)
Used to provide an insight into a user's first impressions of a product, as well as the usability flaws and merits. Subjects review a product in pairs, subjects who already know each other. This concentrates attention on the product rather than on each other. Questions and tasks are given to focus the review.

7 Private Cameras (De Vries et al, 1996)
Users are asked to discuss their perceptions and attitudes to a product in a private room, into a video camera. The sense of privacy is intended to induce honesty in the respondents.

8 HTA - Hierarchical Task Analysis (Annett et al 1971; Stammers and Shepherd, 1995)
Hierarchical Task Analysis breaks tasks down into goals, plans into a hierarchical structure to highlight potential areas for interventions and improvements. It has been in use for 20 years and is simple to use but needs practice.

9 PHEA - Predictive Human Error Analysis (Embrey, 1995)
Based on HTA and an error taxonomy, a semi-structured human error identification technique. Each task is taken in turn and error modes associated with that activity are identified and the consequences determined, giving a prediction of performance.

10 KLM - Keystroke Level Mode (Card, Moran and Newell, 1983)
Predicts the task performance time for the error-free operation of a device. Tasks are broken down into component activities (mental operations, motor operations, device operations) and the operation time calculated, to estimate performance time for the whole task.

11 Heuristics (Nielsen, 1992)
An analyst uses their judgement, intuition and experience to evaluate products. It is easy and quick to use, but can be subjective and variable. Several other techniques incorporate the heuristic approach, such as checklists, guidelines and PHEA.

12 Link Analysis (Stammers et al 1990; Kirwan and Ainsworth, 1992)
A link analysis represents the sequence in which device elements are used in a given task, to provide links between elements and assess if relationships are adequate in terms of task sequence. It can be used to assess alternative arrangements. Attentional gaze can also be record to assess the layout of display elements.

13 Layout Analysis (Eaterby, 1984)
This builds on link analysis to consider functional groupings of device elements, using the criteria of frequency and sequence of use, and importance to sort elements.

14 Repertory Grids (Kelly, 1955; Baber, 1996)
This gives an insight into consumer perception of devices but is not predictive. Elements (forms of a product) and constructs (aspects important to its operation) are identified by an analyst and different versions of product are rated against each construct.

15 User Trials
Any evaluation where the use of a product by a user is observed and assessed. Can involve some levels of simulation, either of the user, product, task or environment. (Also Observation).

16 User Panels: Lay, Specialist Or Trained
A panel or group of users, either with experience of a product or not, are asked to give their opinions on a product.

17 Expert Appraisals
A panel or group of experts are asked to give their opinions on a product. 'Experts' can consist of professionals experienced in either the product, the user(s), the task, the environment, safety, design, engineering, ergonomics, or any profession which could give an insight into the use of the product, other than the design team.

18 Discussion Groups
Groups of users or experts are asked to discuss a product. The groups may be given activities to focus their attention on certain aspects of the design, and consensus may be sought between the group.

19 Convenience Diaries
The use of a product is recorded and assessed by a user in realistic environment, such as the home, away from other observers. Records are made at regular intervals to obtain a longitudinal assessment.

20 Checklists

A pre-determined list of elements, or 'aide-memoire', which are observed or accounted for during the assessment of a product. The list may be produced as a result of expert consolation or previous product assessments.

21 Interviews

The perceptions of users are acquired through questioning. Interviews can be face-to-face or telephone, and can be structured, semi-structured or unstructured. A high degree of ecological validity.

22 Questionnaires

A structured list of questions that can be administered face-to-face, over the telephone or postal. A flexible way of obtaining access to a large number of people.

Appendix 6.1

Standards for Swimming Pool Covers

The Australian Standard 2020 "Safety covers for private swimming pools and wading pools (For the protection of children 5 years of age and under)" was introduced in 1977. A voluntary standard, it contains guidelines for *safety* covers which will protect children of five years and under against drowning in domestic swimming pools. The main provision of the standard is that the cover should not allow a child's face to be submerged in water, either by falling between the edge of the cover and the pool or in water on the surface of the cover. Specifications to fulfil this requirement include:

i) the cover must support 50 kg (the weight of two children under five) without any water flowing onto the cover.
ii) maximum rainfall must drain from the cover in 30 minutes.
iii) when one child is on top of the cover no openings should appear through which another child can pass.
iv) no openings should allow through the head of a child approximately one year old.
v) the cover should be easy to use and have adequate labelling.

These are tested as follows:

i) At various points around the cover 50 kg must be supported for five minutes without any water flowing onto its surface from the pool.
ii) Based on a maximum rainfall likely to occur once in every five years, 1 litre/mm^2 per minute of water can be sprayed onto the cover for 30 minutes without any pooling or retention of water.
iii) When a bag of sand (25 kg, 250 mm diameter) is dropped onto the cover no openings should appear through which the same bag can pass.
iv) No openings in the cover should let through a cylinder of 105 mm diameter when pushed with 15 kg force.
v) The cover should be installed or removed by one adult in five minutes or less.
vi) Labelling should be permanent and include date of manufacture and life expectancy. Written instructions on installation should be given.

The USA standard (ASTM: ES 13-89) "Emergency Standard performance specification for safety covers and labelling requirements for all covers for swimming pools, spas and hot tubs", includes *all* covers as its remit. Those covers which can not meet its requirements must have permanent labelling listing the safety features they cannot fulfil. Requirements for safety covers include:

i) the cover must support two adults and one child, as in a rescue situation
ii) one child on top of the cover should not produce any openings through which another can pass

iii) any residual water on top of the cover should not be hazardous to a child of three

iv) no openings should allow through the head of a fifth percentile 7 month old child

v) all ties and anchors for the covers should inhibit children under five years from operating or removing the cover

These criteria are tested as follows:

i) The cover should support 220 kg.

ii) An object 90 mm x 140 mm and 16 kg should not be able to pass through any openings caused by 22.7 kg being placed on the cover 1.2 metres from the edge.

iii) A 16 kg resuscitation mannequin representing a three year old child should be placed on the cover 600 mm from the edge. After three minutes there should not be an unsafe amount of water on the surface of the cover, defined as that which completely covers the torso of the mannequin.

iv) No openings around the cover should let through a cylinder of 114.3 mm diameter when pushed with 18 kg force.

v) Guidance on labelling includes specifications for colour, size of lettering and placement.

Appendix 6.2

Swimming pool covers: Pool owner questionnaire

No. ☐☐☐

October 1991

INSTITUTE FOR OCCUPATIONAL ERGONOMICS

Questionnaire

The Safety and Design of Swimming Pool Covers

On behalf of the Department of Trade and Industry, Nottingham University are investigating the use of swimming pool covers and pool safety in general. As a pool owner your participation in this survey will be invaluable. We are very interested in your views on swimming pool safety and the information you provide will help us make recommendations towards improving safety. All information will be treated with the strictest confidence and we do not ask for information on trade names or products. Your name will be removed from the questionnaire for final analysis.

We hope you can find time to answer this simple questionnaire and return it to us in the pre-paid envelope. Thank you very much for your cooperation in helping to make domestic swimming pools safer.

Beverley Norris
Institute for Occupational Ergonomics
Department of Manufacturing Engineering
and Operations Management
University of Nottingham
Nottingham, NG7 2RD

Name .....

Address .....

.....

..... Postcode .....

Section 1: ABOUT YOUR SWIMMING POOL

1. How many years in total have you had a swimming pool? .....

2. Why did you want a swimming pool? .....

   .....

   .....

3. If you moved to another property how important would it be for you to have another pool?

extremely important	☐	very important	☐
moderately important	☐	slightly important	☐
not at all important	☐	don't know	☐

4. Please write down the dimensions of your swimming pool (please state units e.g. feet, metres)

   length .....

   width .....

   depth at deepest end .....

   depth at shallow end .....

5. Please indicate any design features of your pool (tick more than one if necessary)

roman end	☐	stepped entry	☐
deck level pool	☐	slide	☐
removable ladders	☐	non-removable ladders	☐
hinged ladders	☐	diving board	☐
*other	☐		

*if other please specify .....

6. Please describe or draw the shape of your pool .....

7. How many months per year is your pool in regular use? .....

.....

8. If the pool is not in regular use all year round, please indicate how the pool is left when not in use (tick more than one if necessary.

emptied	☐
covered with a secured cover	☐
covered with a loose cover	☐
uncovered	☐
*other	☐

*if other, please specify .....

9. Is your pool (tick one only)

Indoor	☐	go to question 10
outdoor (open air)	☐	go to question 11
outdoor (with a semi permanent enclosure)	☐	go to question 12

<u>Indoor pools</u>

10. Is the pool building (tick one only)

attached to the main body of the house ☐

<u>OR</u>

in a separate, stand alone building ☐

(a) How many doors are there to the garden or connecting to the house, and if so to what rooms do they connect?

number of doors to the garden ☐

number of doors connecting to the house ☐ and to which rooms do they connect? .....

.....

(b) Are these doors kept locked?

always	☐	often	☐
sometimes	☐	rarely	☐
never	☐	don't know	☐

(NOW GO TO SECTION 2 - page 7)

Open air pools

11. Is the pool above ground ☐

in ground ☐

(a) Is there any construction around the pool which is designed to prevent access to the pool?

yes ☐

no ☐ GO TO SECTION 2 - page 7

don't know ☐ GO TO SECTION 2 - page 7

(b) If yes, please indicate what type of construction and its approximate height:

fence ☐ height .....

hedge/trees ☐ height .....

wall ☐ height .....

a combination of these ☐ height .....

*other ☐ height .....

*please specify .....

(c) Does the construction have a lockable gate. If YES, how frequently is it locked?

yes ☐ → always locked ☐

no ☐ often locked ☐

don't know ☐ sometimes locked ☐

never locked ☐

don't know ☐

(d) Did you have it installed yourselves?

- yes, at the same time as pool ☐
- yes, but later than the pool ☐
- no ☐
- don't know ☐

(NOW GO TO SECTION 2) - page 7

<u>Outdoor Pools with a semi-permanent enclosure</u>

12. Is the enclosure
- transparent ☐
- opaque ☐
- don't know ☐

(a) How many doors does the enclosure have? .....

(b) How often are they kept locked?
- always ☐
- often ☐
- sometimes ☐
- rarely ☐
- never ☐
- don't know ☐

(c) Did you have it installed yourselves?

- yes, at the same time as pool ☐
- yes, but later than the pool ☐
- no ☐
- don't know ☐

Section 2: ABOUT SAFETY

13. Are there any permanent warning signs or labelling around the pool area?

yes ☐

no ☐

don't know ☐

If yes, what do they say? .....

14. Is the "pool depth" and "deep end/shallow end" clearly marked around the pool?

yes ☐

no ☐

don't know ☐

15. Are there any lifebelts around the pool?

yes ☐

no ☐

don't know ☐

16. Is the pool or the pool area alarmed to detect entry to the pool or pool area?

yes ☐

no ☐

don't know ☐

17. When you first had a swimming pool, did you feel it was a safety hazard?

yes ☐

no ☐

don't know ☐

18. Have you taken any steps to improve the safety of your pool?

yes ☐ no ☐

If yes, please describe the safety precautions you took .....

.....

19. When you first had a swimming pool, were there any children in the household under 5 years of age?

yes ☐ no ☐

20. If yes, were any of these children UNABLE to swim when you first had the swimming pool?

yes ☐

no ☐

don't know ☐

21. Is anybody in the household trained in cardio-pulmonary resuscitation (mouth to mouth resuscitation).

yes ☐

no ☐

don't know ☐

22. Do you feel your pool is safe .....

	yes	no	don't know
... for those in your household?	☐	☐	☐
... for visitors to your house?	☐	☐	☐
... for children in the neighbourhood?	☐	☐	☐

Why do you feel this? .....

.....

Section 3: ABOUT YOUR POOL COVER

23. Do you use pool cover(s)?

yes, currently ☐

•yes, in the past ☐

•no ☐

•Why have you stopped using a cover or why have you never used one? ....

.....

.....

IF YOU ANSWERED 'YES' TO QUESTION 23, ANSWER ALL THE QUESTIONS BELOW. IF YOU ANSWERED 'NO' OR 'DON'T KNOW', GO TO SECTION 4 - page 12.

24. Please indicate the type(s) of cover(s) you use and number them "Cover 1, 2, 3 etc." if more than one:

bubble cover	☐	foam cover	☐
winter mesh cover	☐	automatic vinyl cover	☐
automatic slatted cover	☐	•other	☐

•please indicate .....

(If you use different covers in summer and winter please answer questions for both or all three).

	Cover 1	Cover 2	Cover 3
25. Approximately how old is the cover?	.....	.....	.....

26. Why do you use the cover? e.g. heat retention, cleanliness, safety etc. .....

Cover 1 .....

Cover 2 .....

Cover 3 .....

27. How effective do you consider the cover to be?

	Cover 1	Cover 2	Cover 3
extremely effective	☐	☐	☐
very effective	☐	☐	☐
moderately effective	☐	☐	☐
slightly effective	☐	☐	☐
not at all effective	☐	☐	☐
don't know	☐	☐	☐

28. Does the cover have any permanent safety labelling?

	Cover 1	Cover 2	Cover 3
yes	☐	☐	☐
no	☐	☐	☐
don't know	☐	☐	☐

29. How do you consider that the use of this cover effects the safety of your pool compared to if there was no cover at all. Does the cover make your pool .....

	Cover 1	Cover 2	Cover 3
much safer	☐	☐	☐
slightly safer	☐	☐	☐
makes no difference to safety	☐	☐	☐
slightly more dangerous	☐	☐	☐
much more dangerous	☐	☐	☐
don't know	☐	☐	☐

30. Did you purchase your cover(s) yourself?

yes ☐ (PLEASE GO TO QUESTION 31

no ☐ (PLEASE GO TO SECTION 4 - page 12)

31. When you bought the cover(s) do you think you were given adequate information about the different types of cover available?

yes ☐

no ☐

don't know ☐

32. Was/were the cover(s) supplied by your swimming pool installer?

yes ☐

no ☐

don't know ☐

33. Were you given information on the installation, use and maintenance of your cover(s)?

	Cover 1	Cover 2	Cover 3
yes, verbal information	☐	☐	☐
yes, written information	☐	☐	☐
yes, verbal and written information	☐	☐	☐
no	☐	☐	☐
don't know	☐	☐	☐

34. How do you feel about the information you were given? Was it:

	Cover 1	Cover 2	Cover 3
very useful	☐	☐	☐
useful	☐	☐	☐
adequate	☐	☐	☐
inadequate	☐	☐	☐
useless	☐	☐	☐
don't know	☐	☐	☐

35. Was any reference made in this information to the safety implications of your cover(s)?

	Cover 1	Cover 2	Cover 3
yes	☐	☐	☐
no	☐	☐	☐
don't know	☐	☐	☐

Section 4: GENERAL QUESTIONS

36. Are you aware that there are "safety" swimming pool covers available?

yes	☐
no	☐
not sure	☐

37. Have there ever been any potentially or actual dangerous incidents around your pool?

yes ☐

no ☐

don't know ☐

If yes, please describe .....

.....

.....

38. Do you have any comments on the safety aspects of swimming pool covers?

.....

.....

.....

39. Do you have any comments on if or how pool safety in general could be improved?

.....

.....

.....

40. Some countries have introduced legislation which requires all domestic swimming pools to be fenced or guarded to a specified standard. Do you have any comments on how effective you think this would be towards increasing pool safety and how you would react to similar legislation in the UK?

.....

.....

.....

41. Is there any other information you feel may be of interest to this study or comments you would like to make

.....

.....

.....

Section 5: ABOUT YOUR FAMILY

42. Please give the age and sex of all those who normally live at this address:

Please fill in boxes below		
Sex M/F	Age at last birthday	Can they swim? How well?

43. If there are any children (under 16) who do not normally live at this address but who regularly visit your home please give their age, their relationship to you and how often they visit:

Please fill in boxes below			
Age	What is their relationship with you?	How often do they visit?	Can they swim?

44. Are the child(ren) who visit accompanied by a parent or guardian?

always ☐ usually ☐

sometimes ☐ often ☐

never ☐ don't know ☐

45. Do your immediate/next door neighbours have children younger than 5 years old?

yes ☐

no ☐

don't know ☐

THANK YOU VERY MUCH FOR YOUR HELP. PLEASE NOW RETURN THE QUESTIONNAIRE IN THE ENVELOPE PROVIDED.

Appendix 6.3

Swimming pool covers: Pool owner survey results

Appendix 2: RESULTS OF THE SURVEY OF 179 DOMESTIC SWIMMING POOL OWNERS

	N	Min	Max	Mean	Std.Err.	Std.Dev.	Skewness	Kurtosis
years	176	1.000000	40.00000	10.78409	.5596061	7.424013	1.157688	1.835452

TABLE 18: QUESTION 1; HOW MANY YEARS HAVE YOU HAD A SWIMMING POOL?

REASON	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
1 NO ANSWER	8	4.47	8	4.47
2 RECREATION	9	5.03	17	9.50
3 EXERCISE	5	2.79	22	12.29
4 SWIMMING	21	11.73	43	24.02
5 FOR FAMILY/CHILDREN	19	10.61	62	34.64
6 PLEASURE	8	4.47	70	39.11
7 POOL CAME WITH THE HOUSE	45	25.14	115	64.25
8 FOR KIDS TO LEARN TO SWIM	6	3.35	121	67.60
9 SEA TOO POLLUTED	1	.56	122	68.16
10 HEALTH/THERAPY	3	1.68	125	69.83
2 AND 3	7	3.91	132	73.74
2 AND 4	2	1.12	134	74.86
2 AND 5	2	1.12	136	75.98
2 AND 8	3	1.68	139	77.65
3 AND 4	3	1.68	142	79.33
3 AND 5	5	2.79	147	82.12
3 AND 6	10	5.59	157	87.71
4 AND 5	3	1.68	160	89.39
4 AND 6	1	.56	161	89.94
4 AND 7	2	1.12	163	91.06
4 AND 8	1	.56	164	91.62
4 AND TO ADD VALUE TO HOME	1	.56	165	92.18
5 AND 6	1	.56	166	92.74
5 AND 7	1	.56	167	93.30
6 AND 8	1	.56	168	93.85
7 AND 8	1	.56	169	94.41
2, 3 AND 5	3	1.68	172	96.09
2, 3 AND 8	2	1.12	174	97.21
2, 5 AND 6	1	.56	175	97.77
3, 5 AND 6	1	.56	176	98.32
3, 6 AND 8	2	1.12	178	99.44
5 AND 8	1	.56	179	100.00

TABLE 19: QUESTION 2; WHY DID YOU WANT A SWIMMING POOL?

IMPORTANCE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	2	1.12	2	1.12
EXTREMELY	14	7.82	16	8.94
VERY	24	13.41	40	22.35
MODERTLY	52	29.05	92	51.40
SLIGHTLY	24	13.41	116	64.80
NOTATALL	59	32.96	175	97.77
DONTKNOW	4	2.23	179	100.00

TABLE 20: QUESTION 3; IF YOU MOVED TO ANOTHER PROPERTY HOW IMPORTANT WOULD IT BE FOR YOU TO HAVE ANOTHER POOL?

POOL DIMENSIONS	N	Min	Max	Mean	Std.Err.	Std.Dev.	Skewness	Kurtosis
length of pool	172	3.600000	21.90000	8.872965	.1759875	2.308054	.9523870	5.193859
width of pool	173	1.800000	12.00000	4.459826	.0879375	1.156637	2.415625	12.80806
depth at deep end	174	.8000000	3.000000	1.844828	.0357003	.4709193	-.041075	-.394067
depth at shallow end	173	.3000000	3.000000	.9827746	.0201737	.2653439	2.543330	19.24136

TABLE 21: DIMENSIONS OF THE POOLS (METRES)

1st DESIGN FEATURE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	10	5.59	10	5.59
ROMAN END	35	19.55	45	25.14
DECK LEVEL POOL	21	11.73	66	36.87
REMOVABLE LADDERS	71	39.66	137	76.54
HINGED LADDERS	2	1.12	139	77.65
STEPPED ENTRY	28	15.64	167	93.30
FIXED LADDERS	11	6.15	178	99.44
DIVING BOARD	1	.56	179	100.00

2nd DESIGN FEATURE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	87	48.60	87	48.60
DECK LEVEL POOL	2	1.12	89	49.72
REMOVABLE LADDERS	30	16.76	119	66.48
HINGED LADDERS	3	1.68	122	68.16
STEPPED ENTRY	24	13.41	146	81.56
SLIDE	3	1.68	149	83.24
FIXED LADDERS	11	6.15	160	89.39
DIVING BOARD	18	10.06	178	99.44
OTHER	1	.56	179	100.00

3rd DESIGN FEATURE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	151	84.36	151	84.36
DECK LEVEL POOL	1	.56	152	84.92
REMOVABLE LADDERS	1	.56	153	85.47
STEPPED ENTRY	8	4.47	161	89.94
SLIDE	2	1.12	163	91.06
FIXED LADDERS	2	1.12	165	92.18
DIVING BOARD	13	7.26	178	99.44
OTHER	1	.56	179	100.00

TABLE 22: 1ST, 2ND AND 3RD DESIGN FEATURES USED ON POOLS

SHAPE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	2	1.12	2	1.12
RECTANGULAR	101	56.42	103	57.54
RECTANGULAR+ROMAN END	29	16.20	132	73.74
KIDNEY	8	4.47	140	78.21
CIRCULAR	15	8.38	155	86.59
IRREGULAR	8	4.47	163	91.06
RECT + ENTRY	11	6.15	174	97.21
OVAL	5	2.79	179	100.00

TABLE 23: SHAPE OF POOL

	N	Min	Max	Mean	Std.Err.	Std.Dev.	Skewness	Kurtosis
months	174	1.500000	12.00000	4.715517	.1675614	2.210286	2.097514	4.771413

Months	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
1.000000 <= - < 1.990000	1	.57	1	.57
2.000000 <= - < 2.990000	12	6.90	13	7.47
3.000000 <= - < 3.990000	29	16.67	42	24.14
4.000000 <= - < 4.990000	54	31.03	96	55.17
5.000000 <= - < 5.990000	49	28.16	145	83.33
6.000000 <= - < 6.990000	15	8.62	160	91.95
7.000000 <= - < 7.990000	1	.57	161	92.53
8.000000 <= - < 8.990000	2	1.15	163	93.68
9.000000 <= - < 9.990000	0	.00	163	93.68
10.00000 <= - < 10.99000	0	.00	163	93.68
11.00000 <= - < 11.99000	0	.00	163	93.68
12.00000 <= - < 12.99000	11	6.32	174	100.00

TABLE 24: THE NUMBER OF MONTHS PER YEAR THAT POOLS ARE IN REGULAR USE

	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	13	7.26	13	7.26
EMPTY	1	.56	14	7.82
SECURED COVER	79	44.13	93	51.96
LOOSE COVER	33	18.44	126	70.39
UNCOVERED	47	26.26	173	96.65
OTHER	6	3.35	179	100.00

TABLE 25: QUESTION 8; IF THE POOL IS NOT IN REGULAR USE ALL YEAR ROUND PLEASE INDICATE HOW THE POOL IS LEFT WHEN NOT IN USE

	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	3	1.68	3	1.68
INDOOR	20	11.17	23	12.85
OPEN AIR	142	79.33	165	92.18
SEMI-PERM ENCLOSURE	14	7.82	179	100.00

TABLE 26: THE NUMBER OF POOLS THAT ARE INDOOR, OUTDOOR OR OUTDOOR WITH A SEMI-PERMANENT ENCLOSURE

NUMBER OF DOORS TO THE GARDEN	INDOOR POOLS: TYPE OF BUILDING ATTACHED	SEPERATE	Row Total
NONE	1 5.00%	0 .00%	1 5.00%
ONE	2 10.00%	1 5.00%	3 15.00%
TWO	4 20.00%	6 30.00%	10 50.00%
THREE	3 15.00%	0 .00%	3 15.00%
FOUR	1 5.00%	2 10.00%	3 15.00%
Col.Tot.	11 55.00%	9 45.00%	20 100.00%

TABLE 27: THE NUMBER OF INDOOR POOLS IN SEPERATE STAND-ALONE BUILDINGS OR BUILDINGS ATTACHED TO THE HOUSE AND THE NUMBER OF DOORS FROM THOSE BUILDINGS THAT LEAD TO THE GARDEN

ROOMS TO WHICH THEY CONNECT	NUMBER OF DOORS TO THE HOUSE			
	NONE	ONE	TWO	Row Total
STUDY	0 .00%	1 9.09%	0 .00%	1 9.09%
LAUNDRY	0 .00%	1 9.09%	0 .00%	1 9.09%
HALL	0 .00%	1 9.09%	0 .00%	1 9.09%
LOUNGE	0 .00%	2 18.18%	0 .00%	2 18.18%
CONSERVATORY	0 .00%	1 9.09%	1 9.09%	2 18.18%
GAMES ROOM	0 .00%	1 9.09%	0 .00%	1 9.09%
MORNING ROOM	0 .00%	1 9.09%	0 .00%	1 9.09%
LAUNDRY + STAFF FLAT	0 .00%	0 .00%	1 9.09%	1 9.09%
GAMES ROOM + SHOWER	0 .00%	0 .00%	1 9.09%	1 9.09%
Col.Tot.	0 .00%	8 72.73%	3 27.27%	11 100.00%

TABLE 28: INDOOR POOLS IN BUILDINGS ATTACHED TO THE HOUSE; THE NUMBER OF DOORS TO THE HOUSE AND THE ROOMS TO WHICH THEY CONNECT

ARE THE DOORS KEPT LOCKED?	TYPE OF INDOOR POOL BUILDING		
	ATTACHED	SEPERATE	Row Total
ALWAYS	8 40.00%	3 15.00%	11 55.00%
OFTEN	0 .00%	3 15.00%	3 15.00%
SOMETIMES	1 5.00%	0 .00%	1 5.00%
RARELY	0 .00%	1 5.00%	1 5.00%
NEVER	2 10.00%	2 10.00%	4 20.00%
Col.Tot.	11 55.00%	9 45.00%	20 100.00%

TABLE 29: INDOOR POOLS; HOW OFTEN THE DOORS ARE KEPT LOCKED ACCORDING TO THE TYPE OF BUILDING (ATTACHED TO THE HOUSE OR SEPERATE/STAND ALONE)

	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
ABOVE-GROUND	16	8.94	16	8.94
IN GROUND	163	91.06	179	100.00

TABLE 30:THE NUMBER OF POOLS THAT ARE ABOVE-GROUND OR INGROUND

CONSTRUCTION TO DENY ACCESS	OPEN AIR POOLS
DONT KNOW	1 .70%
YES	56 39.44%
NO	85 59.86%
Col.Tot.	142 100.00%

TABLE 31: OPEN AIR POOLS QUESTION 11a); IS THERE ANY CONSTRUCTION AROUND THE POOL WHICH IS DESIGNED TO PREVENT ACCESS TO THE POOL?

TYPE OF CONSTRUCTION	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
FENCE	15	24.59	15	24.59
HEDGE/TREE	1	1.64	16	26.23
WALL	13	21.31	29	47.54
ANY COMBINATION	9	14.75	38	62.30
HEDGE/TREE AND FENCE	9	14.75	47	77.05
WALL AND FENCE	7	11.48	54	88.52
HEDGE/TREE AND WALL	3	4.92	57	93.44
HEDGE/TREE,FENCE AND WALL	4	6.56	61	100.00

TABLE 32: TYPE OF CONSTRUCTION USED PLACED AROUND OUTDOOR POOLS TO PREVENT ACCESS

HEIGHT (METRES)	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
.6000000 <= - < .7900000	4	9.30	4	9.30
.8000000 <= - < .9900000	7	16.28	11	25.58
1.000000 <= - < 1.190000	0	.00	11	25.58
1.200000 <= - < 1.390000	12	27.91	23	53.49
1.400000 <= - < 1.590000	8	18.60	31	72.09
1.600000 <= - < 1.790000	2	4.65	33	76.74
1.800000 <= - < 1.990000	2	4.65	35	81.40
2.000000 <= - < 2.190000	4	9.30	39	90.70
2.200000 <= - < 2.390000	0	.00	39	90.70
2.400000 <= - < 2.590000	3	6.98	42	97.67
2.600000 <= - < 2.790000	0	.00	42	97.67
2.800000 <= - < 2.990000	0	.00	42	97.67
3.000000 <= - < 3.190000	0	.00	42	97.67
3.200000 <= - < 3.390000	0	.00	42	97.67
3.400000 <= - < 3.590000	0	.00	42	97.67
3.600000 <= - < 3.790000	1	2.33	43	100.00

TABLE 33: THE HEIGHT OF CONSTRUCTIONS PLACED AROUND OUTDOOR POOLS TO PREVENT ACCESS

LOCKABLE GATE?	CONSTRUCTIONS AROUND OUTDOOR POOLS
YES	34 55.74%
NO	27 44.26%
Col.Tot.	61 100.00%

TABLE 34: OPEN AIR POOLS WITH A CONSTRUCTION TO PREVENT ACCESS; DOES IT HAVE A LOCKABLE GATE?

KEPT LOCKED?	CONSTRUCTIONS WITH A LOCKABLE GATE
ALWAYS	21 61.76%
OFTEN	1 2.94%
SOMETMS	6 17.65%
NEVER	6 17.65%
Col.Tot.	34 100.00%

TABLE 35: CONSTRUCTIONS WITH A LOCKABLE GATE; ARE THEY KEPT LOCKED?

DID YOU PUT IT IN YOURSELVES?	POOLS WITH A CONSTRUCTION TO DENY ACCESS
YES, THE SAME TIME AS THE POOL	24 39.34%
YES, BUT LATER THAN THE POOL	13 21.31%
NO	16 26.23%
DONTKNOW	8 13.11%
Col.Tot.	61 100.00%

TABLE 36: POOLS WITH A CONSTRUCTION TO PREVENT ACCESS; DID YOU PUT IT IN YOURSELVES AND IF SO, WHEN?

	POOLS WITH A SEMI PERMANENT ENCLOSURE
TRANSPARENT	8 53.33%
OPAQUE	6 40.00%
DONTKNOW	1 6.67%
Col.Tot.	15 100.00%

TABLE 37: OUTDOOR POOLS WITHA SEMI-PERMANENT ENCLOSURE; IS THE ENCLOSURE TRANSPARENT OR OPAQUE?

ARE THEY KEPT LOCKED?	NUMBER OF DOORS				
	ONE	TWO	THREE	DONTKNOW	Row Total
ALWAYS	2 13.33%	1 6.67%	0 .00%	0 .00%	3 20.00%
SOMETMS	0 .00%	1 6.67%	0 .00%	0 .00%	1 6.67%
NEVER	5 33.33%	2 13.33%	2 13.33%	0 .00%	9 60.00%
DONTKNOW	1 6.67%	0 .00%	0 .00%	1 6.67%	2 13.33%
Col.Tot.	8 53.33%	4 26.67%	2 13.33%	1 6.67%	15 100.00%

TABLE 38: OUTDOOR POOLS WITH A SEMI-PERMANENT ENCLOSURE; HOW MANY DOORS DOES IT HAVE AND ARE THEY KEPT LOCKED?

DID YOU PUT IT IN YOURSELVES?	POOLS WITH A SEMI PERMANENT ENCLOSURE
DONT KNOW	1 6.67%
YES, THE SAME TIME AS THE POOL	5 33.33%
YES, BUT LATER THAN THE POOL	9 60.00%
Col.Tot.	15 100.00%

TABLE 39: OUTDOOR POOLS WITH A SEMI-PERMANENT ENCLOSURE; DID YOU PUT IT IN YOURSELVES AND IF SO, WHEN?

WARNING SIGNS?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	15	8.38	15	8.38
NO	164	91.62	179	100.00

TABLE 40: QUESTION 13; ARE THERE ANY PERMANENT WARNING SIGNS OR LABELLING AROUND THE POOL AREA?

DEPTH MARKED?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	12	6.70	12	6.70
NO	167	93.30	179	100.00

TABLE 41: QUESTION 14; IS THE "POOL DEPTH" AND "DEEP END/SHALLOW END" CLEARLY MARKED AROUND THE POOL?

LIFEBELTS?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	30	16.76	30	16.76
NO	149	83.24	179	100.00

TABLE 42: QUESTION 15; ARE THERE ANY LIFEBELTS AROUND THE POOL?

POOL AREA ALARMED?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	6	3.35	6	3.35
NO	173	96.65	179	100.00

TABLE 43: QUESTION 16; IS THE POOL OR THE POOL AREA ALARMED TO DETECT ENTRY TO THE POOL OR POOL AREA?

POOL A HAZARD?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	73	40.78	73	40.78
NO	101	56.42	174	97.21
DONTKNOW	5	2.79	179	100.00

TABLE 44: QUESTION 17; WHEN YOU FIRST HAD A SWIMMING POOL, DID YOU FEEL IT WAS A SAFETY HAZARD?

ANY STEPS TO IMPROVE	THOSE WHO FELT THEIR POOL WAS A HAZARD
YES	45 61.64%
NO	28 38.36%
Col.Tot.	73 100.00%

TABLE 45: OF THOSE WHO AT FIRST CONSIDERED THEIR POOL A SAFETY HAZARD, HOW MANY TOOK STEPS TO IMPROVE THE SAFETY OF THEIR POOL?

STEPS TAKEN TO IMPROVE POOL SAFETY	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
REMOVED/REMOVABLE LADDERS	2	2.50	2	2.50
1 = NO UNSUPERVISED SWIMMING	15	18.75	17	21.25
2 = NONSLIP SURROUND	1	1.25	18	22.50
3 = MADE POOL INACCESSIBLE	28	35.00	46	57.50
SAFETY COVER WHEN OWN CHILDREN NONSWIMMERS	1	1.25	47	58.75
USE A WINTER MESH COVER	5	6.25	52	65.00
USE A DOME/ENCLOSURE	3	3.75	55	68.75
4 = USE A COVER	3	3.75	58	72.50
DOORS/GATES ALWAYS LOCKED	1	1.25	59	73.75
TOLD NEIGHBOURS ABOUT POOL	1	1.25	60	75.00
RAISED THE POOL	1	1.25	61	76.25
1 AND 2	1	1.25	62	77.50
1 AND 3	2	2.50	64	80.00
1 AND LIGHTING	1	1.25	65	81.25
POOL FENCED WHEN OWN CHILDREN YOUNG	2	2.50	67	83.75
OPEN POOL (ENCLOSED POOL SEEN AS DANGEROUS)	1	1.25	68	85.00
2 AND STEPPED ENTRY	1	1.25	69	86.25
ENCLOSED GARDEN	5	6.25	74	92.50
TAUGHT OWN CHILDREN TO SWIM	1	1.25	75	93.75
REMOVED DIVING BOARD	1	1.25	76	95.00
LEVELLED THE SURROUND	1	1.25	77	96.25
3 AND 4	2	2.50	79	98.75
1 AND REMOVED DIVING BOARD	1	1.25	80	100.00

TABLE 46: STEPS TAKEN BY OWNERS TO IMPROVE THE SAFETY OF THEIR POOLS

UNDER FIVES?	THOSE WHO FELT THEIR POOL WAS A HAZARD
YES	36 49.32%
NO	37 50.68%
Col.Tot.	73 100.00%

TABLE 47: OF THOSE WHO AT FIRST CONSIDERED THEIR POOL A SAFETY HAZARD, HOW MANY HAD CHILDREN UNDER FIVE YEARS OF AGE IN THE HOUSEHOLD AT THE TIME?

UNABLE TO SWIM?	HOUSEHOLDS WITH CHILDREN UNDER FIVE
YES	61 92.42%
NO	5 7.58%
Col.Tot.	66 100.00%

TABLE 48: HOUSEHOLDS WITH CHILDREN UNDER FIVE WHEN THE POOL WAS FIRST INSTALLED; WERE ANY OF THEM UNABLE TO SWIM?

CPR TRAINED?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	89	49.72	89	49.72
NO	86	48.04	175	97.77
DONTKNOW	4	2.23	179	100.00

TABLE 49: QUESTION 21; IS ANYBODY IN THE HOUSEHOLD TRAINED IN CARDIO-PULMONARY RESUSCITATION (MOUTH TO MOUTH RESUSCITATION?

a) SAFE FOR HOUSEHOLD?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	178	99.44	178	99.44
NO	1	.56	179	100.00
b) SAFE FOR VISITORS?				
YES	170	94.97	170	94.97
NO	6	3.35	176	98.32
DONTKNOW	3	1.68	179	100.00
c) SAFE FOR CHILDREN IN THE NEIGHBOURHOOD?				
NO ANSWER	15	8.38	15	8.38
YES	131	73.18	146	81.56
NO	24	13.41	170	94.97
DONTKNOW	9	5.03	179	100.00

TABLE 50: QUESTION 22; DO YOU FEEL YOUR POOL IS SAFE
a) FOR THOSE IN YOUR HOUSEHOLD?
b) FOR VISITORS TO YOUR HOUSE?
c) FOR CHILDREN IN THE NEIGHBOURHOOD?

REASONS WHY POOL IS CONSIDERED SAFE OR UNSAFE(*)	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
1 CHILDREN/VISITORS ALWAYS SUPERVISED	62	37.35	62	37.35
2 POOL IS VISIBLE FROM THE HOUSE	2	1.20	64	38.55
3 INVITED GUESTS ONLY	5	3.01	69	41.57
4 EXPERIENCE OF BEING A POOL OWNER	1	.60	70	42.17
5 ACCESS TO POOL IS LIMITED	33	19.88	103	62.05
6 ACCESS TO POOL IS POSSIBLE (*)	8	4.82	111	66.87
7 UNSAFE IF CHILDREN ENTER UNKNOWN (*)	3	1.81	114	68.67
8 COVER USED ON POOL	4	2.41	118	71.08
9 CHILDREN ARE WARNED	2	1.20	120	72.29
POLICE ARE INFORMED WHEN OWNERS AWAY	2	1.20	122	73.49
NO CHILDREN IN NEIGHBOURHOOD	1	.60	123	74.10
1 AND 3	2	1.20	125	75.30
1 AND 5	15	9.04	140	84.34
1 AND 6	1	.60	141	84.94
1 AND 9	1	.60	142	85.54
BUBBLE COVER MAKES POOL UNSAFE (*)	1	.60	143	86.14
NEIGHBOURS DON'T LET CHILDREN WANDER	1	.60	44	86.75
2 AND 5	1	.60	145	87.35
NEIGHBOURS DON'T KNOW ABOUT POOL	1	.60	146	87.95
POOL NOT DEEP ENOUGH TO BE UNSAFE	1	.60	147	88.55
NO CONTROL OVER VISITORS (*)	2	1.20	149	89.76
OWN CHILDREN/FAMILY CAN SWIM	4	2.41	153	92.17
YOUNG NONSWIMMER IN FAMILY (*)	1	.60	154	92.77
COMMON SENSE	1	.60	155	93.37
4 AND 5	1	.60	156	93.98
OPEN POOL (ENCLOSED POOL IS DANGEROUS)	1	.60	157	94.58
5 AND 8	1	.60	158	95.18
1 AND NO CHILDREN IN NEIGHBOURHOOD	3	1.81	161	96.99
1 AND POOL NOT DEEP ENOUGH	1	.60	162	97.59
9 AND NO CHILDREN IN NEIGHBOURHOOD	1	.60	163	98.19
2 AND 9	1	.60	164	98.80
1 AND 2	2	1.20	166	100.00

TABLE 51: REASONS WHY POOL OWNERS CONSIDER THEIR POOL TO BE SAFE OR UNSAFE
(REASONS WHY POOL CONSIDERED UNSAFE ARE MARKED WITH AN ASTERISK *)

DO YOU USE A POOL COVER(S)	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES, CURRENTLY	150	83.80	150	83.80
YES, IN THE PAST	16	8.94	166	92.74
NO	13	7.26	179	100.00

TABLE 52: THE NUMBER OF POOL OWNERS WHO CURRENTLY USE A POOL COVER(S) OR HAVE DONE IN THE PAST

1ST COVER TYPE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	18	10.06	18	10.06
BUBBLE	142	79.33	160	89.39
WINTER MESH	7	3.91	167	93.30
FOAM	6	3.35	173	96.65
AUTO. FLEXIBLE	5	2.79	178	99.44
OTHER	1	.56	179	100.00

2ND COVER TYPE	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	87	48.60	87	48.60
BUBBLE	1	.56	88	49.16
WINTER MESH	68	37.99	156	87.15
AUTO. RIGID	1	.56	157	87.71
AUTO. FLEXIBLE	2	1.12	159	88.83
OTHER	1	.56	160	89.39
WINTER TARPAULIN	9	5.03	169	94.41
WINTER PVC	6	3.35	175	97.77
WINTER WATERBAG	2	1.12	177	98.88
"BOARD"	1	.56	178	99.44
FRAMED	1	.56	179	100.00

TABLE 53: THE NUMBER OF POOL OWNERS WHO OWN A COVER AND THE TYPES USED; 2ND COVER TYPE INDICATES THOSE POOL OWNERS WHO USE TWO TYPES OF COVER

AGE OF COVER	N	Min	Max	Mean	Std.Err.	Std.Dev.	Skewness	Kurtosis
1ST COVER	147	.5000000	15.00000	2.955782	.2047182	2.482076	2.405971	7.402325
2ND COVER	91	.2500000	20.00000	5.579670	.4477232	4.271007	1.166714	1.189387

TABLE 54: AGE OF FIRST AND SECOND COVERS

REASON FOR USING 1ST COVER	BUBBLE	WINTER MESH	FOAM	AUTOMATIC FLEXIBLE	OTHER	Row Total
HEAT RETENTION	95 60.51%	0 .00%	5 3.18%	2 1.27%	0 .00%	102 64.97%
CLEANLINESS	1 .64%	4 2.55%	1 .64%	0 .00%	1 .64%	7 4.46%
SAFETY	0 .00%	1 .64%	0 .00%	0 .00%	0 .00%	1 .64%
HEAT RETENTION + CLEANLINESS	34 21.66%	0 .00%	0 .00%	0 .00%	0 .00%	34 21.66%
HEAT RETENTION + SAFETY	2 1.27%	0 .00%	0 .00%	2 1.27%	0 .00%	4 2.55%
CLEANLINESS SAFETY	0 .00%	1 .64%	0 .00%	0 .00%	0 .00%	1 .64%
HEAT RETENTION CLEANLINESS + SAFETY	7 4.46%	0 .00%	0 .00%	1 .64%	0 .00%	8 5.10%
Col.Tot.	139 88.54%	6 3.82%	6 3.82%	5 3.18%	1 .64%	157 100.00%

REASON 2ND CVR	BUBBLE	WINTER MESH	AUTO RIGID	AUTO PVC	OTHER	WINTER TARPLN	WINTER PVC	WINTER WTRBAG	BOARD	FRAME	Row Total
CLEAN'S	0 .00%	23 25.56%	0 .00%	1 1.11%	0 .00%	3 3.33%	4 4.44%	1 1.11%	0 .00%	0 .00%	32 35.56%
WINTERING	0 .00%	2 2.22%	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	3 3.33%
SAFETY	0 .00%	4 4.44%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	4 4.44%
SUPPLIER SUGGESTN	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	1 1.11%
HEAT RTN + SAFETY	1 1.11%	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	2 2.22%
CLEAN'S +WINTER'G	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	0 .00%	2 2.22%
CLEAN'S +SAFETY	0 .00%	35 38.89%	0 .00%	0 .00%	1 1.11%	5 5.56%	2 2.22%	0 .00%	1 1.11%	1 1.11%	45 50.00%
CLEAN'S +ANIMAL	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	1 1.11%
Col.Tot.	1 1.11%	67 74.44%	1 1.11%	2 2.22%	1 1.11%	9 10.00%	6 6.67%	1 1.11%	1 1.11%	1 1.11%	90 100.00%

TABLE 55: POOL OWNERS STATED REASONS FOR USING THEIR FIRST AND SECOND COVER(S)

1ST COVER SAFETY	BUBBLE	WNTMESH	FOAM	AUTOPVC	OTHER	Row Total
MUCH SAFER	3 1.92%	3 1.92%	0 .00%	4 2.56%	0 .00%	10 6.41%
SLIGHTLY SAFER	28 17.95%	3 1.92%	1 .64%	1 .64%	1 .64%	34 21.79%
NO DIFFERENCE	49 31.41%	0 .00%	0 .00%	0 .00%	0 .00%	49 31.41%
SLTLY MORE DANGEROUS	40 25.64%	1 .64%	2 1.28%	0 .00%	0 .00%	43 27.56%
MUCH MORE DANGEROUS	15 9.62%	0 .00%	3 1.92%	0 .00%	0 .00%	18 11.54%
DONT KNOW	2 1.28%	0 .00%	0 .00%	0 .00%	0 .00%	2 1.28%
Col.Tot.	137 87.82%	7 4.49%	6 3.85%	5 3.21%	1 .64%	156 100.00%

COVER2 SAFETY	BUBBLE	WNTMESH	AUTO RIGID	AUTO PVC	OTHER	WNTR TARP	WNTPVC	WTRBAG	BOARD	FRAMED	Row Total
MUCH SAFER	1 1.09%	40 43.48%	0 .00%	0 .00%	1 1.09%	4 4.35%	3 3.26%	0 .00%	1 1.09%	1 1.09%	51 55.43%
SLTLY SAFER	0 .00%	19 20.65%	1 1.09%	2 2.17%	0 .00%	4 4.35%	0 .00%	1 1.09%	0 .00%	0 .00%	27 29.35%
NO DIFF	0 .00%	6 6.52%	0 .00%	0 .00%	0 .00%	1 1.09%	1 1.09%	1 1.09%	0 .00%	0 .00%	9 9.78%
SLT MR DANGER	0 .00%	1 1.09%	0 .00%	0 .00%	0 .00%	0 .00%	2 2.17%	0 .00%	0 .00%	0 .00%	3 3.26%
MCH MR DANGER	0 .00%	2 2.17%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	2 2.17%
Col. Tot.	1 1.09%	68 73.91%	1 1.09%	2 2.17%	1 1.09%	9 9.78%	6 6.52%	2 2.17%	1 1.09%	1 1.09%	92 100.00%

TABLE 56: QUESTION 29; HOW DO YOU CONSIDER THAT THE USE OF THIS COVER (1ST AND 2ND COVER) AFFECTS THE SAFETY OF YOUR POOL COMPARED TO IF THERE WAS NO COVER AT ALL. DOES THE COVER MAKE YOUR POOL: MUCH SAFER, SLIGHTLY SAFER, NO DIFFERENCE, SLIGHTLY MORE DANGEROUS, MUCH MORE DANGEROUS OR DON'T KNOW?

HOW EFFECTIVE 1ST COVER	BUBBLE	WINTER MESH	FOAM	AUTO FLEXIBLE	OTHER	Row Total
EXTREMELY	22 13.84%	1 .63%	1 .63%	3 1.89%	0 .00%	27 16.98%
VERY	57 35.85%	3 1.89%	0 .00%	2 1.26%	0 .00%	62 38.99%
MODERATELY	55 34.59%	2 1.26%	3 1.89%	0 .00%	1 .63%	61 38.36%
SLIGHTLY	6 3.77%	1 .63%	0 .00%	0 .00%	0 .00%	7 4.40%
NOT AT ALL	0 .00%	0 .00%	1 .63%	0 .00%	0 .00%	1 .63%
DON'T KNOW	1 .63%	0 .00%	0 .00%	0 .00%	0 .00%	1 .63%
Col.Tot.	141 88.68%	7 4.40%	5 3.14%	5 3.14%	1 .63%	159 100.00%

HOW EFFECTIVE 2ND COVER	BUBBLE	WINTER MESH	AUTO RIGID	AUTO PVC	OTHER	WINTER TARPLN	WINTER PVC	WINTER WATER BAG	BOARD	FRAMED	Row Total
EXTREMELY	1 1.11%	19 21.11%	0 .00%	1 1.11%	1 1.11%	2 2.22%	1 1.11%	1 1.11%	1 1.11%	1 1.11%	28 31.11%
VERY	0 .00%	26 28.89%	1 1.11%	1 1.11%	0 .00%	2 2.22%	3 3.33%	1 1.11%	0 .00%	0 .00%	34 37.78%
MODER'TLY	0 .00%	21 23.33%	0 .00%	0 .00%	0 .00%	5 5.56%	1 1.11%	0 .00%	0 .00%	0 .00%	27 30.00%
SLIGHTLY	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	1 1.11%	0 .00%	0 .00%	0 .00%	1 30.00%
NOTATALL	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%
Col.Tot.	1 1.11%	66 73.33%	1 1.11%	2 2.22%	1 1.11%	9 10.00%	6 6.67%	2 2.22%	1 1.11%	1 1.11%	90 100.00%

TABLE 57: QUESTION 27; HOW EFFECTIVE DO YOU CONSIDER THE COVER TO BE? (1ST AND 2ND COVER)

LABEL ON 1ST COVER	BUBBLE	WNTMESH	FOAM	AUTOPVC	OTHER	Row Total
YES	51 31.88%	0 .00%	0 .00%	1 .63%	0 .00%	52 32.50%
NO	87 54.38%	7 4.38%	5 3.13%	4 2.50%	1 .63%	104 65.00%
DONTKNOW	3 1.88%	0 .00%	1 .63%	0 .00%	0 .00%	4 2.50%
Col.Tot.	141 88.13%	7 4.38%	6 3.75%	5 3.13%	1 .63%	160 100.00%

LABEL ON 2ND CVR	BUBBLE	WNTMESH	AUTO RIGID	AUTO PVC	OTHER	WNTARP	WNTPVC	WTRBAG	BOARD	FRAMED	Row Total
YES	1 1.12%	9 10.11%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	10 11.24%
NO	0 .00%	54 60.67%	1 1.12%	2 2.25%	1 1.12%	9 10.11%	6 6.74%	2 2.25%	1 1.12%	1 1.12%	77 86.52%
DONTKNOW	0 .00%	2 2.25%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	0 .00%	2 2.25%
Col.Tot.	1 1.12%	65 73.03%	1 1.12%	2 2.25	1 1.12%	9 10.11%	6 6.74%	2 2.25%	1 1.12%	1 1.12%	89 100.00%

TABLE 58: QUESTION 28; DOES THE COVER HAVE ANY PERMANENT SAFETY LABELLING? (1ST AND 2ND COVER)

BUY COVER YOURSELF?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	145	90.63	145	90.63
NO	15	9.38	160	100.00

TABLE 59: QUESTION 30; DID YOU PURCHASE YOUR COVER(S) YOURSELF?

SUPPLIER?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	84	57.14	84	57.14
NO	62	42.18	146	99.32
DONTKNOW	1	.68	147	100.00

TABLE 60: QUESTION 32; WAS/WERE THE COVER(S) SUPPLIED BY YOUR SWIMMING POOL INSTALLER?

ADEQUATE INFORMATION	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	107	72.79	107	72.79
NO	34	23.13	141	95.92
DONTKNOW	6	4.08	147	100.00

TABLE 61: QUESTION 31; WHEN YOU BOUGHT THE COVER(S) DO YOU THINK YOU WERE GIVEN ADEQUATE INFORMATION ABOUT THE DIFFERENT TYPES OF COVER AVAILABLE?

PAGE NUMBERS CUT OFF IN ORIGINAL

1ST COVER INFO USEFUL?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
VERY USEFUL	15	11.36	15	11.36
USEFUL	44	33.33	59	44.70
ADEQUATE	58	43.94	117	88.64
INADEQUATE	10	7.58	127	96.21
USELESS	3	2.27	130	98.48
DONTKNOW	2	1.52	132	100.00

2ND COVER INFO USEFUL?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
VERY USEFUL	10	14.08	10	14.08
USEFUL	31	43.66	41	57.75
ADEQUATE	26	36.62	67	94.37
INADEQUATE	2	2.82	69	97.18
USELESS	1	1.41	70	98.59
DONTKNOW	1	1.41	71	100.00

TABLE 64: QUESTION 34: HOW DO YOU FEEL ABOUT THE INFORMATION YOU WERE GIVEN? WAS IT: VERY USEFUL, USEFUL, ADEQUATE, INADEQUATE, USELESS OR DON'T KNOW.

AWARE OF SAFETY COVERS?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
YES	60	33.52	60	33.52
NO	111	62.01	171	95.53
DONTKNOW	8	4.47	179	100.00

TABLE 65: QUESTION: ARE YOU AWARE THAT THERE ARE "SAFETY" SWIMMING POOL COVERS AVAILABLE?

DID THIS INCIDENT INVOLVE A POOL COVER?	HAVE THERE EVER BEEN ANY POTENTIALLY OR ACTUAL DANGEROUS INCIDENTS AROUND YOUR POOL?			
	NO ANSWER	YES	NO	Row Total
NO ANSWER	1 .56%	1 .56%	161 89.94%	163 91.06%
YES	0 .00%	1 .56%	0 .00%	1 .56%
NO	0 .00%	15 8.38%	0 .00%	15 8.38%
Col.Tot.	1 .56%	17 9.50%	161 89.94%	179 100.00%

TABLE 66: THE NUMBER OF POOL OWNERS THAT HAVE EXPERIENCED AN ACCIDENT AROUND THEIR POOL AND HOW MANY OF THOSE ACCIDENTS INVOLVED A POOL COVER

AGREE WITH LEGISLATION?	Freq.	Percent	Cumulatv Freq.	Cumulatv Percent
NO ANSWER	36	20.11	36	20.11
STRONGLY AGREE	28	15.64	64	35.75
AGREE	27	15.08	91	50.84
DON'T MIND	2	1.12	93	51.96
DISAGREE	48	26.82	141	78.77
STRONGLY DISAGREE	28	15.64	169	94.41
DON'T KNOW	10	5.59	179	100.00

TABLE 67: QUESTION 40; SOME COUNTRIES HAVE INTRODUCED LEGISLATION WHICH REQUIRES ALL DOMESTIC SWIMMING POOLS TO BE FENCED OR GUARDED TO A SPECIFIED STANDARD. HOW WOULD YOU REACT TO SIMILAR LEGISLATION IN THE UK?

Appendix 6.4

Swimming pool covers: Hazard scenarios developed for each type of cover

1 Floating covers

1.1. Most floating covers are blue and opaque. On a settled pool the cover could give the impression of a solid surface. This will alter how the pool is perceived by adults and children. It could mislead a child into thinking its a safe area to walk on to fetch a toy, ball etc. The cover may be attractive to children or adults wanting to 'explore' the covers behaviour.

1.2. While probably supporting some weight in the middle, the edges of a floating cover are very unlikely to support the weight of even a small child. Most small children would only be able to jump, step or fall a small distance from the side of the pool. At this distance from the edge the cover would probably give way.

1.3. A child falling into the water may get held under by the cover due to surface tension or the nature of the material, whereas without a cover they may float face upwards and have some chance of survival.

1.4. The behaviour of the material may physically restrict the movements of anybody underneath the cover trying to get out.

1.5. Anyone falling underneath a cover is likely to panic and/or become disorientated.

1.6. The cover may wrap around and envelope anyone falling into the water and hinder efforts to get out.

1.7. If someone fell underneath the edge of a cover it may quickly resume its position floating on the water giving no indication of having been disturbed.

1.8. The opacity of the covers makes it difficult to see anyone underneath the cover. This delays rescue. Immersion time greatly affects the likelihood of recovery.

1.9. Floating covers should, but often aren't, cut to fit around pool furniture such as ladders. If not the cover folds back leaving a gap of exposed water which may encourage someone to try to enter the pool with the cover on.

1.10. Covers are often attached to a roller by a series of straps at one end. Unless fitted properly this end can "sit up" off the water. This could again encourage someone to get under the cover with the added risk of getting entangled in the straps.

1.11. Anyone trying to swim underneath a cover faces possible entrapment. The cover may disorientate them and make it difficult to get to the edges. Surface tension and the behaviour of the material may make it difficult to lift the cover in the middle and get air. A "half-covered" pool poses a risk to anyone trying to swim.

1.12. Collected water on the cover (from the pool and rainwater) would offer a hazard to anyone supported on top of the cover.

1.13. The material of the cover will degrade through contact with chemicals and ultraviolet light thus affecting its strength.

2 Winter Mesh Covers

2.1. The cover may disguise the pool and encourage exploration.

2.2. The effectiveness of this type of cover as a barrier to the pool depends on an effective securing system. Any system used should be 'child resistant'. The most common system uses buckles which children may be able to undo and pegs which they may be able to remove.

2.3. The securing system should ensure that once installed the edge of the cover cannot be lifted high enough for a child to climb underneath. The most common system requires very careful adjustment to obtain the tension required to stop the edges being lifted. The cover may also "loosen" with time.

2.4. Since they are secured all round the pool anyone managing to get under these covers would have difficulty getting out and may get trapped.

2.5. Anyone underneath the cover is likely to panic and/or become disorientated.

2.6. The covers are quite tightly woven and opaque and so anyone under the cover may be concealed and discovery would be delayed.

2.7. Children and adults may be tempted to walk on top of the cover but it is unknown what weight it will support.

2.8. The weight of a person may depress the cover into the water, causing a hazardous pool of water "seeping" through the mesh from the swimming pool.

2.9. A cover that is carelessly installed or maintained will sag below the water line creating a pool of water into which anyone venturing onto the cover may fall or roll.

2.10. The cover should always be fully removed in order to ensure that no one tries swimming under the cover risking entrapment.

2.11. The material of the cover will degrade through contact with chemicals and ultra violet light and affect the strength of the cover. Close maintenance will be needed to check for ageing.

3 Winter Waterbag Cover

3.1. The cover may disguise the pool and encourage exploration.

3.2. The cover may give the impression that it is strong enough to walk on, but it is unknown what weight it will support.

3.3. If a person fell or stepped onto the cover the behaviour of the cover may cause entanglement and make it more difficult to get out of the water than if there were no cover.

3.4. A person underneath the cover may be held under the water by the surface tension or weight of the cover.

3.5. A person under the cover is likely to panic and/or become disoriented.

3.6. The cover is opaque and would obscure a person underneath and delay discovery.

3.7. The water bags are not secured to the cover and may be moved allowing the edge of the cover to be lifted and access to the pool gained.

3.8. The bags are not fixed to positions around the cover so it may be possible to lift the edge of the cover if some bags are further apart than others.

3.9. The bags may puncture or wear which would let out water and make them easier to move.
3.10. The bags may not be heavy or stable enough to hold the cover in place in the event of heavy rainfall.
3.11. The cover will collect rainwater unless a drainage system is installed and will offer a drowning hazard to anyone falling on the cover.
3.12. The cover should always be fully removed since swimming with the cover half on will increase the risk of entrapment.

4 Automatic Flexible Covers

4.1. The covers may disguise the pool and encourage exploration.
4.2. The covers may appear as a play area when closed and are often marketed as such. This gives confused information to children about the safety of the pool area. Potential dangers when closed include collected rainwater and the hidden sharp edges of the pool.
4.3. The covers are designed to completely enclose the pool and therefore form a barrier to the water. In order to do this no access should be allowed at any point around the cover. Access could be gained underneath the cover if:
4.4. The leading edge is flexible and can be lifted up enough for a child to climb under (type B).
4.5. The cover is not closed properly and a gap is left between the end of the cover and the pool edge (both designs).
4.6. a fault occurs in the tracking system (due to design, age or misuse) and the sides of the cover come free from the tracking.
4.7. If the cover is left partially open anyone tempted to swim under the cover may risk entrapment.
4.8. If the cover starts to close while someone is in the pool again there is danger of entrapment.
4.9. Anyone swimming or trapped under the cover is likely to be disoriented or panic.
4.10. The cover will obscure anyone underneath and delay discovery.
4.11. Both designs have inadequate drainage systems (either manually activated or requiring a high depth of water to be self activated) so that rainwater may collect and present a hazard to anyone walking or falling on the cover.
4.12. Since the covers are motorised the pool will be easily accessible if the control box can be misused.

5 Automatic Rigid Covers

5.1. The covers may disguise the pool and encourage exploration.
5.2. On covers using handrails or safety ledges it may be possible to lift up the edge of the cover and so gain access to the water.
5.3. If the cover is left partially open anyone tempted to swim under the cover may risk entrapment.
5.4. If the cover starts to close while someone is in the pool again there is danger of entrapment.
5.5. Anyone swimming or trapped under the cover is likely to be disoriented or panic.

5.6. The cover will obscure anyone underneath and delay discovery.
5.7. When depressed the covers allow water from the pool to seep through and collect on top of the cover so that anyone falling onto the cover will be lying in a pool of water.
5.8. Since the covers are motorised the pool will be easily accessible if the control box can be misused.

6 Framed Pool Covers

6.1. The covers may disguise the pool and encourage exploration.
6.2. The cover is secured to the deck with rubber straps which may be easy to remove and so gain access to the pool by either lifting the cover up or sliding it across the pool.
6.3. Since the cover is framed with aluminium poles it would be difficult to lift up once caught underneath.
6.4. Anyone under the cover is likely to panic and/or become disoriented.
6.5. The cover will obscure anyone underneath and delay discovery.
6.6. If the cover is left partially open anyone tempted to swim under the cover may risk entrapment.
6.7. Since the cover has no drainage system rainwater will collect on top of the cover and offer an added hazard.
6.8. These scenarios combined with the accident statistics outlined in section 4 can be used to prioritise the potential risks of all cover designs. In order of greatest risk these are suggested as:
   i. falling under the edge of a bubble/foam cover
   ii. access under the edge of a secured winter mesh cover
   iii. access under a waterbag cover
   iv. collected rainwater on top of a waterbag or automatic flexible cover
   v. access under the edge of an automatic rigid cover
   vi. access under the free end of some types of automatic flexible covers
   vii. water seeped through from the pool on top of automatic rigid cover

Appendix 6.5

Subject details used in the SPC user trials.

Sex	Age (months)	Weight (kg)	%ile	Stature (mm)	%ile	Head Breadth (mm)	%ile
f	20	12	*86.0*[1]	838	*48*[2]	134	*79*[2]
f	30	16.2	*98.5*[1]	975	*98.5*	154	-
f	32	13	*57.0*[1]	905	*64.5*	135	*89.5*
f	36	13	*9.0*	945	*29*	144	*99.75*
f	36	14	*22.0*	1002	*75.6*	148	*99.99*
f	37	14.6	*32.0*	1025	*88*	130	*50*
f	37	12.8	*8*	989	*66*	131	*58*
f	37	13.8	*19*	1020	*86*	142	*99.4*
f	41	13.6	*15*	1000	*74*	143	*99.5*
f	44	24.6	*99.99*	1170	*99.99*	145	*99.99*
f	45	20.6	*99.5*	1095	*99.5*	144	*99.75*
f	46	18.8	*9.6*	1120	*99.99*	138	*94.5*
m	44	13	*4*	1005	*62*	147	*88*
m	45	13.5	*6.5*	1023	*75*	138	*38*
m	46	17.4	*67*	1035	*82*	141	*56*
f	48	15.5	*20*	1068	*62*	142	*88*
m	48	20.2	*87*	1167	*98.5*	147	*98*
m	48	16.5	*24*	1105	*85*	149	*99*
m	51	20.6	*90*	1180	*99.5*	155	*99.99*
f	54	17.1	*34*	1090	*80*	142	*62*
f	56	14.9	*7*	1067	*64*	147	*88*
f	59	20.5	*88*	1170	*66.5*	155	*99.5*
m	61	20.6	*89*	1175	*89*	142	*66*
m	87	21.8	*21.5*	1200	*29*	153	*99.5*

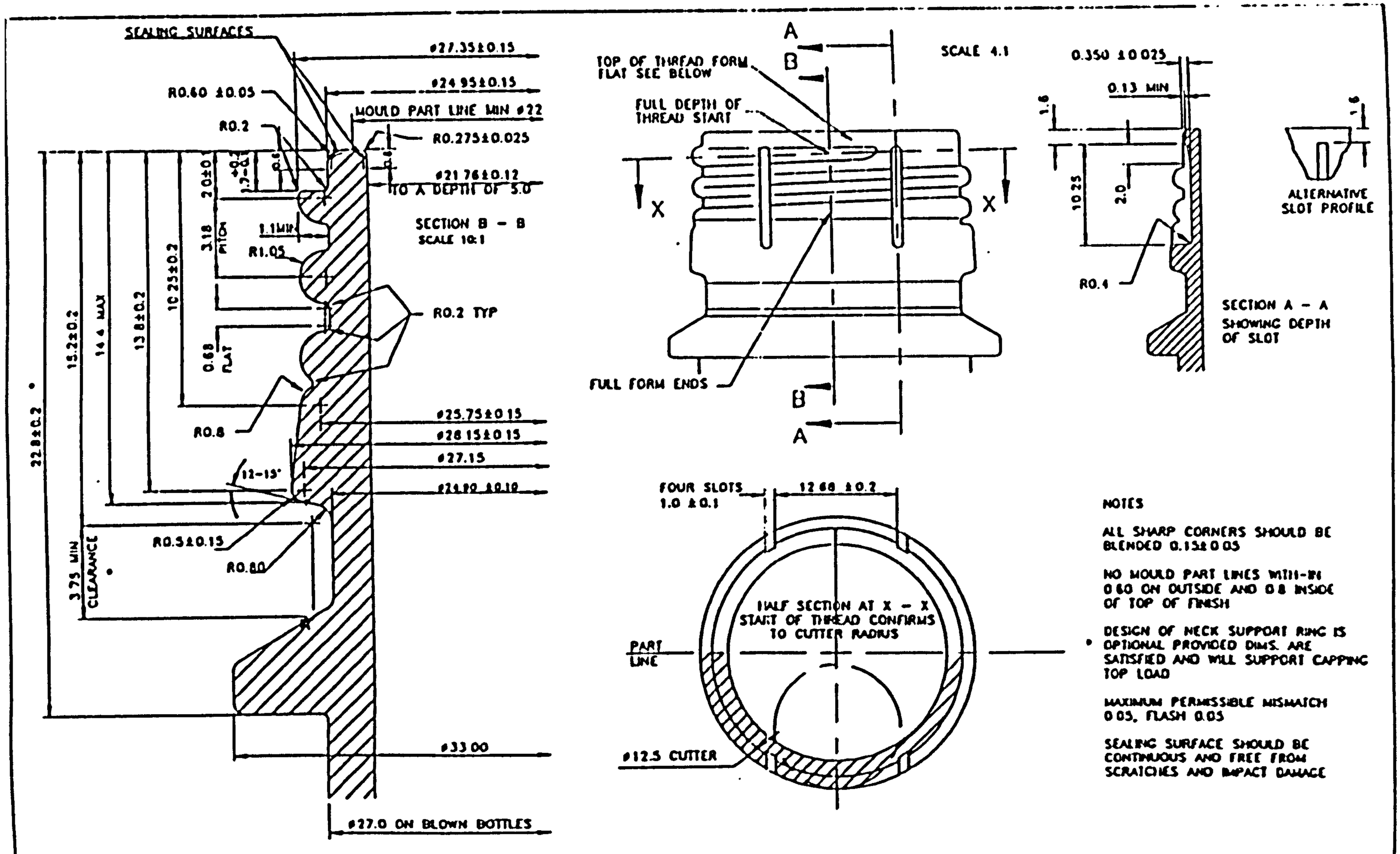
Percentile values (%ile) calculated with reference to Pheasant (1996) and refer to single sex populations except:

[1] *with reference to Snyder, 1975.*

[2] *compared to a combined sex population*

Appendix 7.1

Carbonated drinks bottles: PET standard neck and bottle



NOTES

ALL SHARP CORNERS SHOULD BE BLENDED 0.15±0.05

NO MOULD PART LINES WITH-IN 0.60 ON OUTSIDE AND 0.8 INSIDE OF TOP OF FINISH

• DESIGN OF NECK SUPPORT RING IS OPTIONAL PROVIDED DIMS. ARE SATISFIED AND WILL SUPPORT CAPPING TOP LOAD

MAXIMUM PERMISSIBLE MISMATCH 0.05, FLASH 0.05

SEALING SURFACE SHOULD BE CONTINUOUS AND FREE FROM SCRATCHES AND IMPACT DAMAGE

6	OUTSIDE SURFACE TO BE FREE OF PART LINES WAS 0.68 NOW 0.60, BORE DIMENSION NOW SPECIFIED TO A 5.0 DEPTH, • REMOVED FROM SUPPORT RING DIA. TO ALLOW THE LARGER DIA. 41.0 STYLE	9.9.91
5	REDRAWN FROM CMD DRAWING, MIN CLEARANCE BETWEEN SUPPORT RING AND P.P BEAD WAS 4.4, MIN DISTANCE TO SPLIT LINE ON OUTSIDE WAS 0.8 FROM T.O FINISH	31.5.91
LEVEL	DESCRIPTION	DATE

MATERIAL PET	WEIGHT	BPF
DRAWN RIM	CAPACITY	
SCALE AS STATED	MOULD No	TITLE 28mm NECK DETAIL
DATE 30.5.91	No OFF / SHEET 6	DWG No 0001DPF
	1 PLACE OF DECIMAL ± 0.25	
	2 PLACE OF DECIMAL ± 0.1	

Appendix 7.2

Carbonated drinks bottles: Subject details for the user trials

First programme:

Age (years)	Sex	Height (mm)	Weight (kg)	Hand length (mm)	Hand breadth (mm)	Span (mm)
4	m	1128		124	64	129
5	m	1157		130	72	156
6	f	1225		128	70	147
6	f	1272		130	72	165
7	f	1251		139	67	155
7	f	1219	20	125	72	142
8	m	1275	29	143	79	165
8	m	1315	28	143	70	157
9	m	1335	30	149	76	163
9	m	1315	31	141	83	164
9	f	1317	34	155	83	168
10	m	1357	29	146	81	162
11	f	1457	39	149	77	178
11	f	1520	45	172	91	198
12	m	1492	37	164	84	181
12	f	1575	51	166	82	160
12	f	1607	48	170	88	181
12	f	1520	37	173	88	184
13	m	1479	38	153	86	176
13	m	1727	59	192	103	229
13	m	1587	43	172	97	160
13	f	1605	53	171	87	196
13	f	1624	48	179	89	187
14	m	1706	44	191	109	201
16	m	1727	54	195	98	188
17	m	1676	66	192	105	199
18	m	1955	82	212	115	209
18	m	1930	88	214	116	211
19	m	1701	69	186	10	206
19	f	1549	44	161	87	164
19	f	1727.2	57	195	94	176
20	m	1803.4	76	184	105	232
20	f	1739.9	53	190	99	195
21	m	1828.8	73	178	103	180
26	f	1727.2	65	179	80	170
26	f	1625.6	61	179	93	169
27	m	1803.4	85	206	112	218
29	m	1854.2	108	180	11	206

30	m	1701.8	84	183	102	204
32	f	1676.4	68	181	99	195
32	f	1625.6	48	171	85	166
36	f	1524.0	61	176	85	171
38	f	1625.6	72	194	100	194
40	f	1587.5	9	184	91	175
43	f	1689.1	63	184	96	184
44	f	1676.4	61	178	95	183
45	m	1828.8	114	198	110	217
51	m	1701.8	95	182	102	188
53	f	1689.1	73	179	92	188
56	m	1727.2	69	174	95	184
56	m	1701.8	68	191	103	201
56	m	1778.0	82	185	105	206
56	f	1574.8	88	168	86	171
62	m	1676.4	69	173	100	187
68	m	1727.2	63	184	100	190
68	f	1549.4	69	175	92	180
68	f	1625.6	63	186	93	183
69	m	1778.0	78	201	114	244
69	f	1549.4	60	161	88	160
73	f	1651.0	76	175	95	176
76	f	1473.2	9	156	92	175
79	m	1752.6	69	186	105	223
79	f	1574.8	57	165	79	153
79	f	1644.0	57	161	84	135
82	f	1477.0	70	179	97	181
84	f	1427.0	8	188	95	178
84	f	1397.0		175	78	154
86	f	1310.0	38	172	76	145

Second programme:

Age (years)	Sex	Height (mm)	Weight (kg)	Hand length (mm)	Hand breadth (mm)	Span (mm)
22	m	1828.8	73	207	98	225
22	m	1803.4	75	191	109	232
29	m	1828.8	76	194	109	212
30	m	1803.4	76	198	114	232
32	m	1778	67	184	106	210
22	f	1651	51	168	85	185
26	f	1638.3	57	178	196	189
28	f	1663.7	54	176	93	194
29	f	1869.1	57	185	94	198
30	f	1638.3	54	174	185	205

Appendix 7.3

Carbonated drinks bottles: Home study questionnaire

USE OF POP BOTTLES

QUESTIONNAIRE

1 Please write down the first names and ages of everyone who lives in your home.....
.....
.....

2 Where do you usually store bottles of pop at home?.....
.....
.....

3 Do you ever find pop bottles difficult to open?.....
If so, what do you do to help you open difficult bottles?.....
.....
.....
.....

4 Have you ever used a pair of special openers to open a pop bottle?....
.....
.....
.....

5 Have you ever used a pair of nutcrackers to open a pop bottle?.....
.....
.....
.....

6 Have you ever used your teeth to open a pop bottle?.....
.....
.....
.....

7 Have you ever opened a pop bottle using a door frame/jamb?.....
.....
.....
.....

8 Have you ever used anything else to help you open a pop bottle?
If so, please describe .....
.....
.....
.....
.....

9 If there are children in your home, or any who regularly visit, do they open pop bottles themselves?.....
.....
.....
.....

10 What do they do if they find pop bottles difficult to open?.....
.....
.....
.....
.....

11 Have you ever seen them use any of the above to open a pop bottle?
If so, please describe .....
.....
.....
.....

12 Which way do you turn the cap on a pop bottle to open it?.....
.....
.....

13 Have you ever turned the cap on a pop bottle the wrong way while trying to open it?.....
.....

14 Have you ever had, or witnessed, an accident involving a pop bottle?.....
If so, please describe what happened .....
.....
.....
.....

15 Have you ever seen the top fly off a pop bottle?.....
If so, please describe what happened .....
.....
.....
.....
.....
.....

Thank you very much for helping us with our research.

Please return the completed questionnaire in the envelope provided.

Appendix 8.1

ATBs : Background information

a) Features of ATBs

b) Glossary of terms used with ATBs

c) Other bicycles not included in the study

Appendix 8.1 b) Glossary of terms used with ATBs

Bar ends
Small removable extensions to the handlebars, normally fitted to face up and in front of the handlebar to aid the rider s grip when riding uphill.
Bonding
Similar to lugging and brazing except glue is used to secure tubes, allows the use of non-metals and the joining of different metals (eg titanium seat tube with cro-mo top tube).
Bosses
Studs on the forks and seat stays used to locate and provide a rotation point for the cantilever arms.
Bottom Bracket
Metal shell at the intersection of the down tube, seat tube and the chain stays, contains the chainset axle and bearings.
Bullhorn
Elongated handlebars with end sections which curve forwards and upwards to aid rider s grip especially when ring uphill.
Butting
Thickening of tube walls at ends where extra strength is required.
Chainset
Collective term given to front sprockets, axle and bearings.
Cluster/Cassette
Collective term for the rear sprockets.
Crank Arms
Metal shaft joining the pedals to the chainset.
Derailleurs
Mechanisms connected to the seat tube and right rear dropout for pushing the chain onto different sprockets for a gear change.
Dropouts
Located at the ends of the forks and the intersection of the seat and chainstays, these are slots into which the wheel hubs are located and secured.
Gripshift
Gear changing mechanism activated by the rider twisting a section of the handlebar grips.
Groupsets
Group of components fitted to a bike. Usually consists of the braking and transmission systems but may include pedals, bottom bracket and other components.
Gumwalls
Tyres with wide sidewalls.
Hub
Housing for the wheel axles, connected to the spokes.
Indexed systems
Gear systems which move the derailleurs from one sprocket to the next in discrete steps rather than by analogue movement.
Kevlar
An aramid based fibre reinforced composite material which provides a high strength to weight ratio components, mainly used for bike tubes
Lugging and Brazing

Method of joining tubes by placing tubes into lugs (collars) and securing them by brazing, now becoming redundant for bike construction.

Ring Welding

Used to join thick walled steel tubes together, leaves a larger weld bead than TIG welding.

Sidewalls

Side of the tyre, not intended for contact with the ground.

Shimano

Japanese company which dominates the cycle component market.

Skinwalls

Tyres with thin side walls.

SPDs

Pedals made by Shimano which clip to specially designed shoes to provide a good grip and safety when falling off a bike.

TIG Welding

(Tungsten Inert Gas) Method for welding tubes, very popular in the manufacture of bikes as it leaves a thin weld bead (except when used with aluminium).

Wheelbase

The distance between the front and rear dropouts.

Appendix 8.2

Details of ATB variables considered for classification

Bicycle specifications change frequently as new models are introduced and the information provided here is valid only for 1994, and some 1993 models. New models and specifications are released throughout the year but the major new ranges for 1995 will become available towards the end of this year. In addition to new models, manufacturers and suppliers retain the right to change the specifications of all models at any time and components and materials are frequently changed according to availability. This can include different frame materials and even different groupsets to those incorporated into the model names.

1. Retail price
See discussion in Chapter 8.

2. Frame material
See discussion in Chapter 8.

3. Method of construction
Method of construction is dependent on frame material but appears independent of retail price. The commonest method of constructing ATB frames is TIG welding, throughout all price ranges and for all frame materials, with the exception of Reynolds 600, titanium and carbon fibre frames. All Reynolds 600 frames are lugged and brazed and this method seems to be favoured by individual manufacturers rather than according to material. Titanium frames are nearly all adhesively bonded, probably since these frames often involve joining two types of metal eg titanium and cro-mo. Carbon fibre is bonded/moulded since the adhesive is incompatible with the frame material.

4. Wheel rim material
Most wheel rims are 'metal alloys' and this includes those sold under trade names although their exact composition will be unknown. Steel wheel rims (which are considered less effective than 'metal alloy' rims) are only found on ATBs less than £250. The addition of brand name wheel rims are often a selling feature of a bike and this is reflected in that no named wheel rims are found below £250. The three most popular named rims tend to be related to retail price. Wheel rims are not associated with frame material.

5. Handlebar material
Handlebar material is not known for many of the cheaper bikes as it is not considered an important feature whereas it is often part of the specification of more expensive bikes. Steel is found throughout the range of bikes, even on expensive bikes, because

handlebars are a feature where weight is sacrificed for strength. Aluminium handlebars are rare, probably because of the need for strength and stiffness. Titanium bars are found at all levels from £250 illustrating this material s popular image. Brand name handlebars are also common above £250. Handlebars are mainly associated with retail price but also to some extent with frame material, in that aluminium and titanium bars are found almost exclusively on bikes with frames of the same material.

6. Bar ends

Less than half of the sample of ATBs have bar ends and these are spread through out all price ranges and frame materials. Bullhorn (one piece) handlebars are found in all categories up to £1000 and are common in the lowest price category; this suggests that having a choice of bar ends and bar end material is more important in the more expensive bikes. Metal alloys are the commonest material and found across all price ranges and frame materials. The more expensive materials (magnesium and titanium) are only found in the top price range. Bar ends do not therefore seem to be related to either price or frame material.

7. Fork material and/or suspension forks

Suspension forks are found throughout the range of ATBs but are most common in the top price range where one third of ATBs have suspension forks. Despite the high price of suspension forks when bought separately (up to £350) they are found on bikes in the under £250 price range, indicating the popular image of suspension. For non-suspension forks, fork material is associated with price and frame material. Steel is the most common material under £250 whereas no steel forks are found over £500, indicating the importance of weight saving on more expensive bikes. On entry level bikes (£250-500), steel forks on cro-mo frames are more common than all-steel frames, again indicating weight saving considerations. Aluminium forks are usually found on aluminium frames and on bikes over £500.

8. Rear suspension

Rear suspension is very rare and was found only on thirteen bikes in the sample, and most of these were over £1000. However two bikes under £250 have rear elastomeric suspension, which although it is considered less effective than other types of suspension, again indicates the popular image of suspension. Otherwise, rear suspension is only found on bikes over £500 and predominantly, (5 out of 7), on aluminium bikes, often with designer geometry to accommodate the suspension.

9. Brake type

Only four ATBs were found to have sidepull brakes and these are all under £250; the rest are all cantilever. The groupset (which includes the brakes) is the major named component on any ATB, even those under £250, and nearly all are made by Shimano (340 out of 359 named brake sets). Only 25 of the 383 bikes over £250 have unnamed brakes. The different Shimano brake series tend to be reflected by retail price and are not associated with frame material.

smallest available frames are 11 inches (length of the seat tube) and these are only available in bikes over £1000; the next smallest is 12 inches and these are only available in bikes over £500. 14 and 16 inch frames are the commonest smallest frame size and these are available throughout the range, although only three bikes under £250 have 14 inch frames. The very short seat tubes are sometimes used along with frames altered slightly from the traditional two-triangle shape and may be used to incorporate suspension into the frames.

Some bikes only *start* at frame sizes of 24 and 26 inches and these are all under £250. There appears to be no relationship between frame size and frame material.

17. Largest frame size
Largest frame size doesn't appear to be linked to price or frame material; 20, 21 and 22 inches are the most common largest frame sizes and these account for over 75% of the sample. A *largest* frame size of 19 inches is found throughout the range, including bikes over £1000.

18. Tyre type
Named brand tyres are more common as retail price increases; nearly all the bikes under £250 have unknown or unnamed tyres yet most of the bikes over £500 have named tyres. There are many types of tyres available and we have listed the four commonest brand names; Ritchey tyres are the commonest and these are found in all price ranges over £500. There appears to be no correlation with frame material.

Appendix 8.3

ATBs: Accident victims follow-up questionnaire

UNIVERSITY OF
NOTTINGHAM

QUESTIONNAIRE

Section 1 About your bike

1 What type of bike were you riding when you had your accident? (please tick)

- ☐ mountain bike
- ☐ hybrid
- ☐ road bike
- ☐ touring bike
- ☐ racing bike/racer
- ☐ BMX
- ☐ shopping bike
- ☐ folding bike
- ☐ child's bike
- ☐ other (please state).....

2 Please describe the following features of the bike: (if known)

manufacturer ..... model .....
frame material ..... wheel rim material .....
number of gears ..... sidepull/cantilever brakes (please delete)
did/does it have quick release wheels?.....
did/does it have any suspension?.....
purchase price ..... date ..... new/second hand (please delete)

3 Does/did the bike comply with the British Standard for cycles (BS 6102)?

- ☐ yes
- ☐ no
- ☐ didn't check
- ☐ don't know

4 Where did you buy the bike?

If the bike was new:

- ☐ bike shop
- ☐ Halfords
- ☐ department store
- ☐ mail order/catalogue shop
- ☐ toy shop
- ☐ garage
- ☐ market/one day sale
- ☐ other (please describe).....

If the bike was second hand:

- ☐ from a friend
- ☐ bike shop
- ☐ car boot sale/market
- ☐ private sale eg newspaper or shop advert
- ☐ other (please describe).....

.....

5 Please describe any assembly or adjustment you had to carry out, if any, before you could use the bike:

.....
.....

23 Were you wearing a helmet at the time of the accident?.....

24 Were you wearing any other protective clothing?.....

25 Please give a full account of the accident including the stages leading up to the accident, any other people or vehicles that were involved, details of your injuries and anything that you feel may have saved you from being more severely injured:.....
.....
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.....

26 How many bike accidents have you been involved in in the past five years while on the road: .....
elsewhere: .....(please state where)

27 Please describe any other serious accidents you have had whilst cycling:
.....
.....
.....
.....
.....
.....

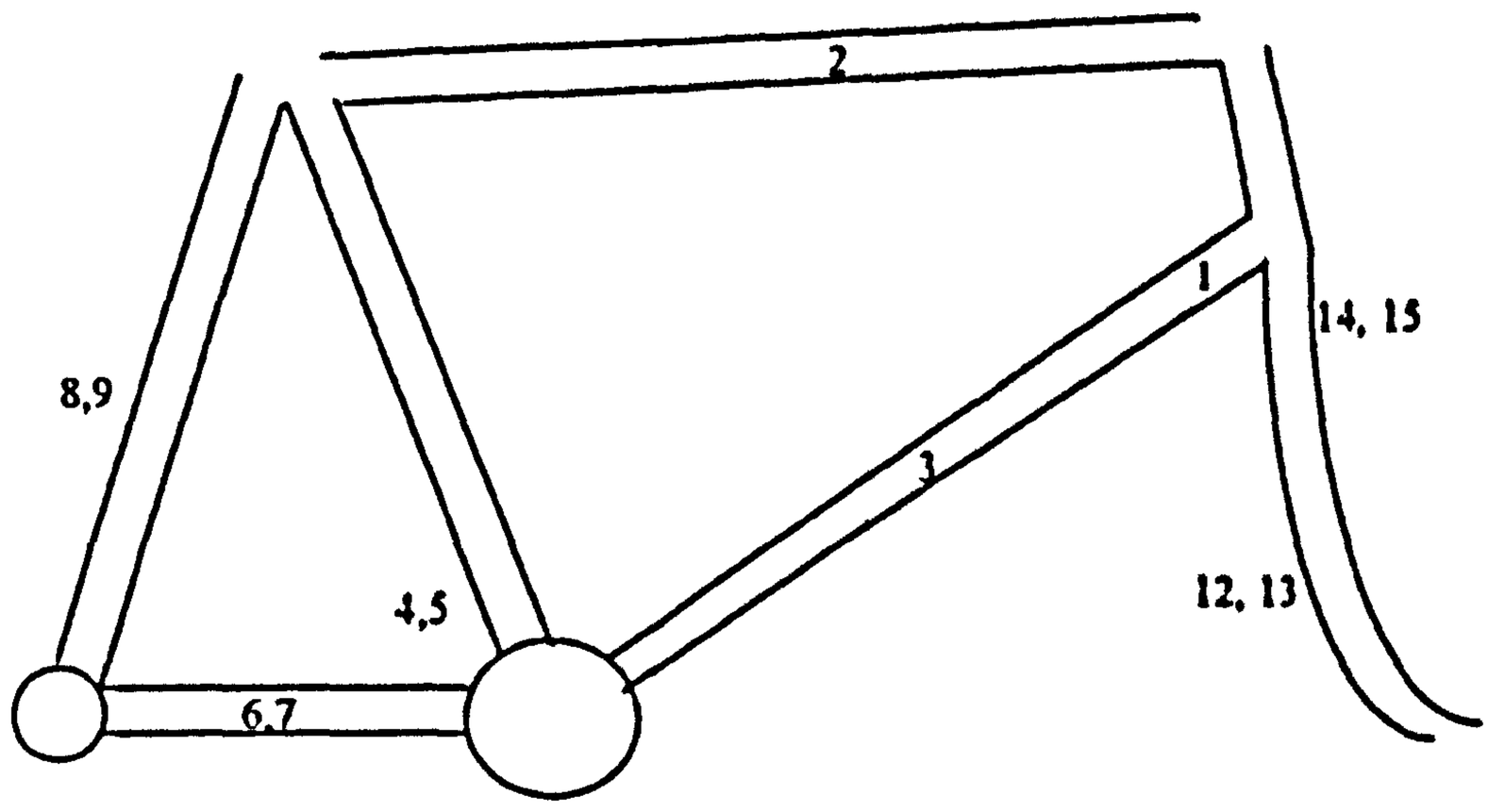
THANKS AGAIN FOR YOUR HELP!

Please return the questionnaire in the envelope provided or send it (no stamp needed) to:

Beverley Norris
FREEPOST
Institute for Occupational Ergonomics
Department of Manufacturing Engineering
University of Nottingham
Nottingham NG7 1BR
Tel: 0602 514039 Fax: 0602 514000

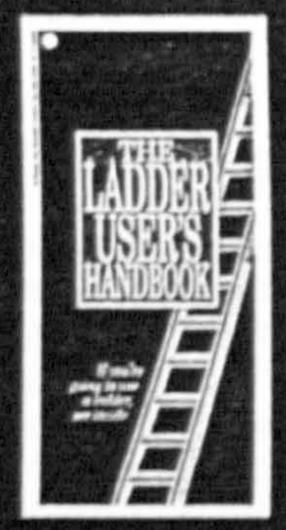
Appendix 8.4

Positions of strain gauges on the frame and forks of the test ATBs



Gauges 10 (left hand side of the handlebar) and 11 (stem) not shown

1. Under the down tube
2. Under to top tube
3. On top of the down tube
4. Bottom left of the seat tube
5. Bottom right of the seat tube
6. Left seat stay
7. Right seat stay
8. Left chain stay
9. Right chain stay
10. Top left of the handlebars
11. Top of the stem
12. Back of right fork
13. Side of left fork
14. Back of right fork 12
15. Side of left fork above 13



A companion to this Guide, *The Ladder User's Handbook*, contains expert advice and guidance on the safe handling and use of leaning ladders. It is available free from DIY stores, hire shops etc.

Produced by the Consumer Safety Unit of the Department of Trade and Industry with the support of the British Ladder Manufacturers' Association

dti

Department of Trade and Industry

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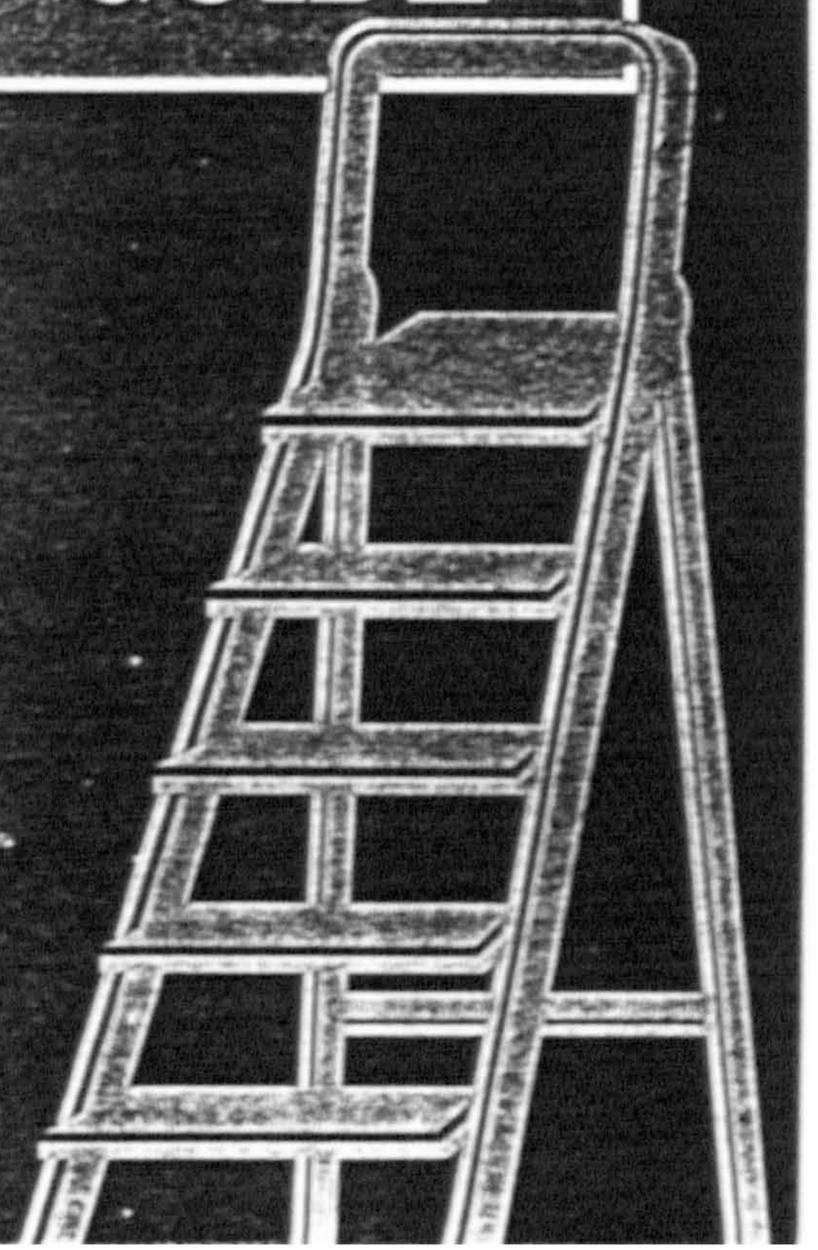
If you use a stepladder read this

THE STEPLADDER USER'S GUIDE



1 Choosing a stepladder

What to look for when you're buying or borrowing

Many different designs are available, from small 'step-stools' to larger stepladders and combination designs which can be converted into extending ladders.

The type bought most often are the 4 to 7 step folding versions, as illustrated in this Guide. These are suited to many jobs around the house, but it's very important never to use any stepladder that's the wrong height for the particular job you're doing. Some are too short for high work, and some – just as dangerous – are too tall for lower work. You must be able to do your work comfortably without over-reaching up, down or sideways.

All stepladders should meet the required British or European standards – check this whenever you buy, hire or borrow one.

- BS 1129:1990 (British) applies to wooden ladders
- BS 2037:1994 (British) applies to metal ladders
- BS EN 131:1993 (European) applies to both
- BS 7377:1994 (British) applies to step-stools

Is it strong enough?

In the British standards, there are now two classes of ladder. These are rated according to their safe working loads.

- **Class 1 (Industrial)**
  maximum static vertical load
  175kg (27.5 stone)
- **Class 3 (Domestic)**
  maximum static vertical load
  125kg (19.5 stone)

A previous Class 2 (Light Trade) is no longer used as classification. The European standard BS EN 131 (or EN 131) now covers this.

- **BS EN 131 (or EN 131)**
  maximum static vertical load
  150kg (23.5 stone)

2 Is it safe?

Most stepladder accidents are caused by human error, not by ladders failing. But any equipment in poor condition is potentially dangerous, so do this quick check before each job.

- **Is the stepladder generally sound?** No damage to the stiles (the outside uprights) or steps or top platform? Dents, bends, cracks and splits are all hazards. If you do find any structural damage, don't attempt to repair it – you need a new stepladder.
- Are the rubber or plastic non-slip feet all safely in position? Before you use the stepladder, any missing ones must be replaced – you can usually get these from the manufacturer.
- Make sure the steps are all clean and dry.

3 Get set

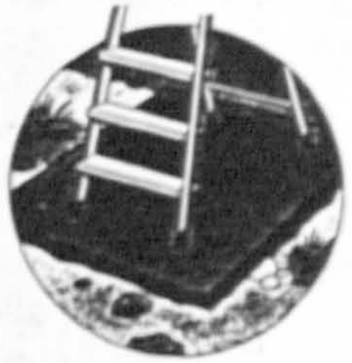
Avoid falls and injuries from equipment by following the points below for every job.

Getting ready

- Wear flat, firm soled shoes. Never work in high heels, bare feet or slippers.
- Check that there are no overhead hazards near where you're going to work.

Setting up

- Check that the stepladder is locked into its correct position. If it's a multi-way design, make sure it's in the right configuration for the job you're doing. Always follow the manufacturer's instructions.
- Rest it on a firm & level base. If you're working outside, place a large, flat board on any soft ground to make a suitable base.



- Position it **front-on** to the work.
- **Never work sideways.**

On the stepladder

- Keep a secure grip at all times.
- Never have more than one person on the stepladder at a time.
- Don't put loose tools where they could move or fall and cause an injury. Use a fixed-on work tray if necessary.
- Always have both your feet on a step. Never stand on the top handrail to gain extra height.

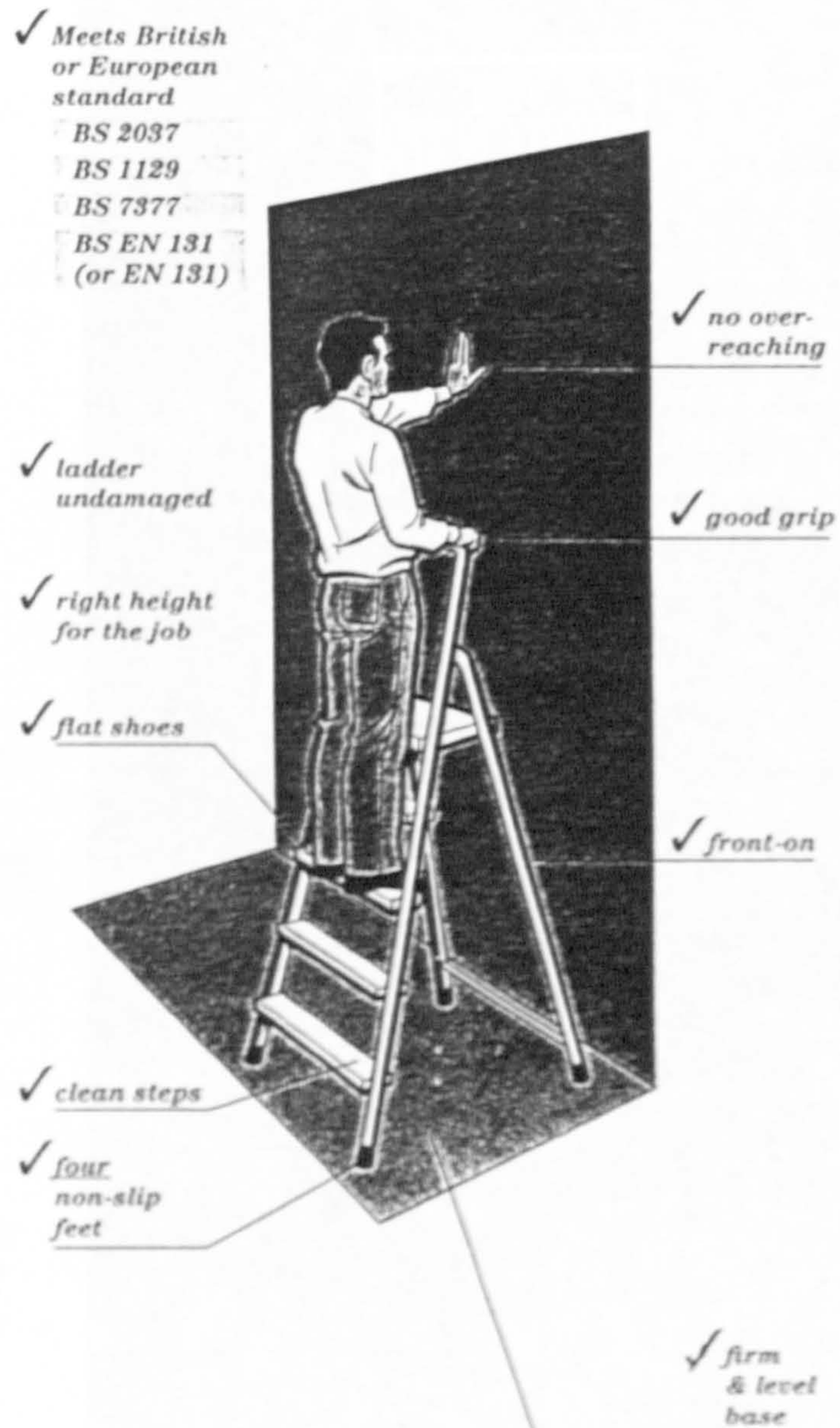
And don't forget...

- **Never over-reach.**

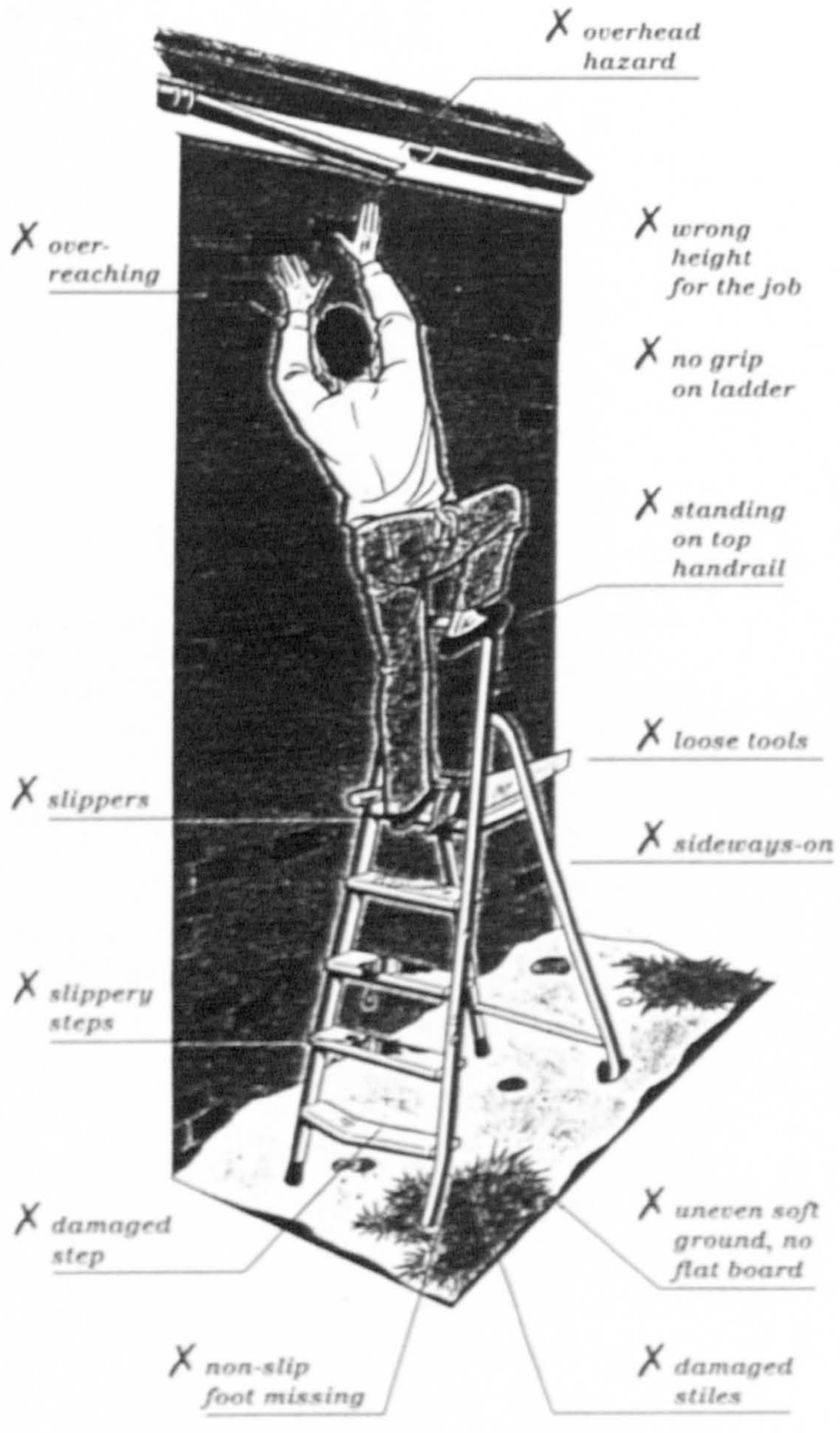
When the job's done

- Keep your stepladder protected from the weather in a covered, ventilated area.
- Never hang it vertically from one of its steps.
- Keep it out of the way of children.

✓ The right way



The wrong way



THE STEPLADDER USER'S GUIDE

Every month, more than a thousand people need hospital treatment because of accidents at home involving stepladders.

This Guide gathers together expert advice and guidance. Follow it, and you'll lessen the risks to yourself and to others.

Designing safety into products

Making ergonomics and safety part of your design process

This is a handbook for designers and producers of consumer products, written by The Product Safety and Testing Group at the University of Nottingham and funded by the Department of Trade and Industry (DTI).

The Product Safety and Testing Group was established in 1991 to carry out investigations into the safety and design of consumer products. The group is multi-disciplinary, being based jointly within the Institute for Occupational Ergonomics and the Department of Manufacturing Engineering and Operations Management at the University of Nottingham. The work of PSTG draws on ergonomics, psychology, materials and engineering expertise and includes evaluations of product safety for Government Departments and for industry, and fundamental research into ergonomics, product design and consumer safety issues.

The authors would like to thank Drs Alison Black, Samantha Porter and Christine Haslegrave for their advice and comments.

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This document is concerned with ergonomics factors. It does not include the suitability of materials used in products. Many products are subject to legal (minimum) safety standards and this guide in no way replaces such requirements. If in any doubt you should contact the Department of Trade and Industry's Consumer Affairs and Competition Policy Directorate at 1 Victoria Street, London SW1H 0ET

Foreword

Product safety in the UK is achieved through a number of different but complementary measures – regulations (National and European), voluntary standards, voluntary agreements/codes of practice and consumer safety awareness initiatives. There is however a more basic means of improving product safety, which is sometimes overlooked: the ergonomics evaluation of safety of the product throughout the design process. This requires the designer to take account of the characteristics, abilities and limitations of potential users throughout the process of designing, developing and marketing products.

In the past, the application of ergonomics to the product design process has been limited, sometimes due to a lack of specific, applicable data but always by a lack of practical methodological advice. The dearth of operational guidance does in part reflect the difficulty of providing such advice, in a form which is sufficiently general to be appropriate to a range of products and users, yet sufficiently specific to be directly applied by those involved in design and production. A vital part of any ergonomics contribution to product development is the testing of the product-user interaction, but assessing this can be extremely complex both in the methods used and also during development.

The University of Nottingham has combined with the Department of Trade and Industry and the Design Council to develop this guidance document to help improve the design process and 'build in' safety. Ergonomics evaluation within product design will have a number of benefits for both the producer and the user. Greater emphasis on safety at the design stage will lead to reduced frequency and severity of accidents for users and thus to fewer legal problems, either with dissatisfied customers or with the enforcement authorities. At the same time usability and product quality will be improved, developments which will boost UK business, as they increase business competitiveness, and also benefit the consumer. Indeed early and continuing ergonomics evaluation, if applied at the right times and with the appropriate level of sophistication, can give significant gains in the efficiency of the development process, thus accelerating the development of a new and better products.

dti
Department of Trade and Industry

Design Council

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About this book

What this handbook contains

Who should read it

What this handbook contains

This handbook will help you:

- understand the issues involved in ergonomics evaluation, and their importance in product safety
- gain competitive advantage from improving your evaluation
- develop a more formal and valuable evaluation process.

■ The things we suggest are neither prescriptive nor definitive and we don't tell you in detail how to evaluate your own products. Our advice is generic, and covers the basic factors. What parts of it you choose to follow will vary, depending on your product, its possible users and the circumstances in which it is used.

The advice we give is wide enough to be relevant to most sectors and types of products. Similarly it is adaptable enough to be used by small and large companies alike. We show how ergonomics evaluation can help when you are:

- developing a completely new product concept (for example mobile phones, car airbags)
- designing a new product within an existing concept (a new stair gate)
- redesigning an existing product to incorporate a new:
  - function (multi-function infant carrier)
  - feature (cordless power tools)
  - control/operating procedure (remote versus hands-on)
  - display (head-up car display)
  - mechanism (child resistant lighters)
  - structure (railings on the side of a cot)
  - styling (change of colour for controls).

Who should read it

This handbook is aimed primarily at product designers, but can also be read by design managers, directors and marketing managers – anyone who is concerned with product safety. If you have a basic understanding of ergonomics you will be familiar with some of the issues we discuss.

Design safety and ergonomics

Approaches to ergonomics evaluation 5

How evaluation can help you: competitive advantage and commercial gain 6

Bringing safety into the product development process 7

What should you evaluate? 8

This handbook is about improving the safety of your products. As we shall see this can also mean enhancing the effectiveness of your product as well as customer convenience and satisfaction. To understand how to do this we need to introduce the concepts of design safety, ergonomics and evaluation.

Safety of a product has two broad components. *Construction safety* depends on appropriate use of materials, components that do not wear out, quality of manufacturing – anything related to how the product is constructed, no matter what the design. All producers should have in-house total quality procedures, and access to test houses where necessary, to ensure the construction safety of their products.■

■ Evaluating for design safety does not include testing for construction, electrical, chemical and materials safety. These are outside the remit of this handbook

Design safety is determined by whether the concept and presentation of a product provides anyone who might come into contact with it a level of safety that might reasonably be expected. This safety should extend to users, bystanders and even misusers – for instance, children who may 'play' with a product in a way not intended.

Because we are interested in design safety we are interested in interactions. The study of how people interact with products, tasks, environments and other people is called *ergonomics*. More importantly, ergonomics uses the knowledge from such study to improve effectiveness, efficiency, comfort, satisfaction, health and safety of people at work, in the home, on transport and at leisure.

Ergonomics evaluation is a process that incorporates ergonomics data, knowledge and testing within the whole design process. It helps you to:

- ensure your product is reasonably safe for its intended use and its intended users
- extend such safety to include foreseeable misuse, including use by unintended users such as children
- identify those at risk
- identify the likelihood of injury
- quantify the likely severity of any injury
- highlight possible design improvements.

This handbook encourages you to see ergonomics evaluation as something which takes place throughout the design process.

Approaches to ergonomics evaluation

There are *four* main approaches to ergonomics evaluation:

- Checking against sources of ergonomics data and guidelines (see page 13) – ergonomics data describe the physical, motor and cognitive capabilities of humans, for instance average arm length, the force required to turn a handle, stride distance, reaction times and so on. Ergonomics guidelines will be general design rules derived to take account of the user – avoiding sharp edges, colour coding of controls, varying surface temperatures. Taking data and guidelines into account when designing will give you some basic parameters within which your product must fit in order to be usable, but are fairly limited in terms of safety. This is because most data and guidelines are generic and they do not enable you to take specific conditions or environmental factors into account, they don't allow for people's attitudes or preconceptions to a product or safety, and because they don't enable you to consider misuse. They give standard information, but people rarely behave in standard ways.
- Modelling (see page 15) – modelling involves using some kind of representation of potential users to assess a design. The representation (or model) can be paper-based or computer-based and can represent the user to varying levels – two- and three-dimensional models through to dynamic computer models. Modelling is most useful for assessing the physical 'fit' between users and products, for instance, reach to controls, movement spaces around products, and the lines of vision around a product.
- Design appraisal (see page 16) – design appraisal involves asking people with some specialist knowledge (often other than the design team) to assess a design or product. This aims to provide an insight into the product, and particularly its safety, which would not be provided by the design team alone. The assessors can be people with a background in safety or in a particular group of products, specialists with knowledge about a specific groups of users (such as the elderly), or users themselves, such as those who have experience with a product or even who have never used it.
- User trials (see page 17) – this is the name we use to describe observing and measuring a sample of 'users' carrying out a task with a product and assessing how they do it. A user can be anyone who may potentially come into contact with the product (see page 10 for ways of identifying them). This is most useful for safety, as the tests can closely resemble real life. User trials are vital if you want to understand how a product will be used, to understand how an accident might happen, or to identify unknown hazards, and are generally necessary when there are no directly applicable data, guidelines or models.

How evaluation can help you: competitive advantage and commercial gain

Any of the four approaches to evaluation can lead to improved usability, better interfaces, presentation and styling as well as safety. These improvements will help to make your products competitive and increase customer satisfaction. Further commercial advantages can also be realised by making ergonomics evaluation an integral part of your design process.

You must consider the issue of compliance with standards and regulations.■

■ Safety standards and regulations

All products are subject to a general safety requirement by law. For many products there are European or even international safety standards to help clarify safety requirements.

Of course designers take these standards seriously, and companies make sure that their products comply with regulations. But in many companies this is where concern with safety starts and finishes: 'As long as we comply with the regulations and don't do anything wrong, then we're doing our bit, aren't we?'

While standards and regulations ensure a basic level of consumer safety, a higher level of safety can only be achieved by thorough and systematic evaluation of products.

This guide encourages you to make safety an initial concern, from early prototypes onwards. Doing so saves costs and time. It is usually easier to adapt a product while it is still at an early design stage, rather than change it later. Safety 'designed in' costs less than safety 'bolted on'. Although the up-front costs of ergonomics evaluations can seem high, they should be recouped through:

- increased sales
- reduced alteration costs in later stages of design and manufacturing
- improved company and product image
- reduced accidents and associated legal costs.

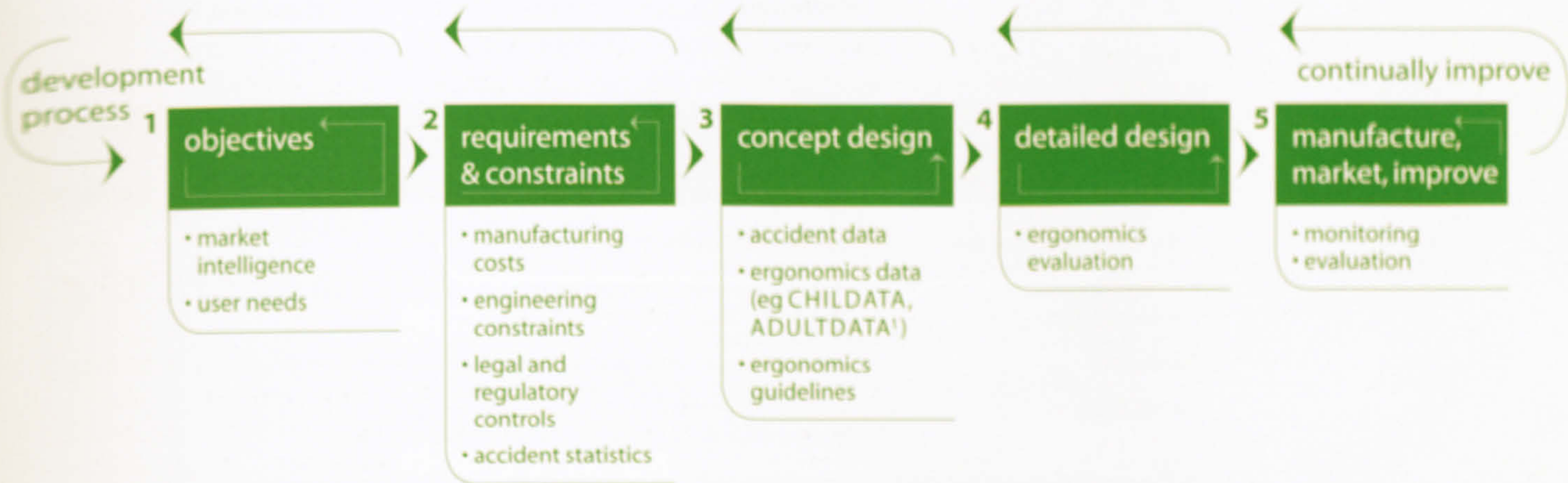
Ergonomics evaluation is particularly helpful in sectors or product ranges where:

- there are few standards. A well-run evaluation process can help you become a best-practice company, ahead of the competition and in a position where you are not so much complying with standards as setting them. In some markets you could then advertise safety advantages. Furthermore, over time your record could lead to a good relationship with consumer groups, strong showings in consumer tests (eg *Which?* magazine) and a word-of-mouth reputation for safety, with consequent strong commercial advantages.
- regulations are constantly changing. If you find yourself having to change products or even manufacturing processes to comply with new regulations, then the costs involved can harm your competitiveness. Your aim should be to get ahead of the game in terms of safety, rather than being reactive.
- regulations vary throughout the world. If you are selling your product in different geographical markets, you may find that safety levels acceptable in one are insufficient in another. The ideal approach is to achieve safety levels that exceed the standards of the most stringent market. This may mean you need to work harder at safety than previously. Ergonomics evaluation will help you achieve this.

Bringing safety into the product development process

There are a number of ways in which ergonomics can be used to bring safety into the product design process, and there are various stages at which this can happen.

The diagram below indicates where ergonomics design considerations and inputs fit into a typical product development process:



[1] CHILDATA: *The handbook of child measurements and capabilities* is a collection of data on over 180 measurements on children, aged from birth to 18 years from Europe and elsewhere, published by the DTI. The data include anthropometry, strength, psychological characteristics and product-related performance. The handbook is a designer's resource aimed at increasing the use of ergonomics data in designing for children. Available from R. Rose, CACP1, 4. G. 9, 1 Victoria Street, London SW1H OET, tel 0171 215 0383.

A similar publication on adults – ADULTDATA – will be published at the end of 1997.

What should you evaluate?

The interaction between a product and its user is affected by four factors:

- the features of the product: structure, moving parts, power sources, casings, packaging, controls, displays, information and instructions, fixings and ancillary equipment
- the physical and psychological characteristics of the user (see diagram below)
- what the user wants to do with the product
- environmental factors such as the visual, thermal and auditory environments of use and social conditions.

User characteristics	examples
Personal characteristics	age, gender, family, literacy, education
Anthropometric characteristics	static body measurements *stature, weight, limb lengths, head size, hand size* dynamic measurements *reach, movement*
Strength	momentary or sustained forces that can be exerted *pushing strength, bite strength*
Motor skills	psychomotor skills *hand-eye co-ordination, reaction times* gross motor skills *movement, balance, climbing stairs*
Psychological characteristics	perceptual abilities *visual perception and auditory perception* cognitive abilities *information processing related to labelling, attention, memory*
Experience and exposure	of a product, environment or tasks *years of driving, use of power tools*
Personality	motivation, risk taking, perseverance, attitude
Physiological characteristics	fatigue, endurance, energy expenditure
Behaviour	skilled performance at tasks specific to a product
Sensory characteristics and tolerance	vision, hearing, taste, smell, touch, sensitivity to temperature, vibration
Socio-economic background	related to exposure and experience with products, tasks or environments *housing, income*
Cultural differences	physical, social, language
Disabilities	permanent and temporary conditions *pregnancy, fatigue, prescribed drugs*

You must consider all of the above factors when evaluating safety. You should also look at every stage of your product's lifecycle, embracing:

- manufacture
- transport
- packaging
- assembly
- installation
- use by all potential users
- misuse by all potential users
- storage
- maintenance
- cleaning
- dismantling
- disposal
- re-use (second-hand life)
- recycling.

Suggested evaluation process

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Checking against ergonomics data and guidelines 13

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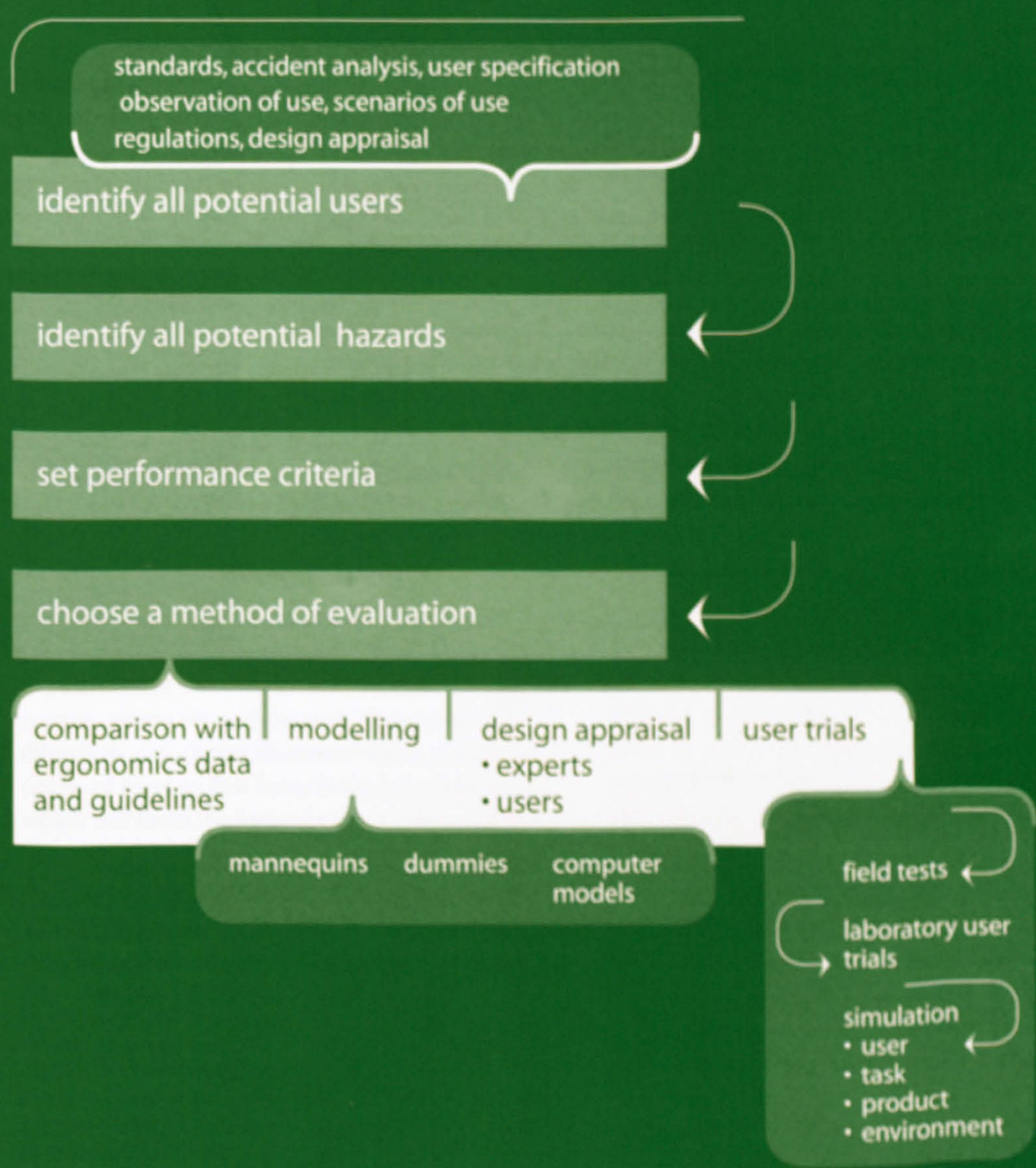

First steps in evaluation

Identify all possible users	10
Identify potential hazards	11
Set performance criteria	11
Choose a method of evaluation	11

The issues discussed in the following pages are not presented as step-by-step instructions. They cover a generic process, which you can pick and choose from and adapt into an approach of your own. You don't need to do everything we suggest, nor do you need to do things in this order, though they are arranged logically.

In some areas we set out a best case scenario, and then outline the implications of concessionary steps away from it. 'Perfect' testing is not always possible in the real world, where time, cost, personnel resources and other factors need to be taken into account.

While this process is aimed primarily at improving safety, it will also contribute to other aspects of your design and manufacturing process, leading to improved product quality all round.

The first steps in the evaluation process are to identify all possible users of your product and then all potential hazards. You can then choose the best type of evaluation.

■ Children and the elderly are vulnerable where a fit and healthy adult may not be. This extra vulnerability, coupled with a lack of data on such groups, means that evaluation is even more important. However, user trials can be more problematic with these groups. Interactions may not be understood, questionnaires not properly filled in and instructions not followed consistently. With children there are also potential ethical problems in exposing them to the risks of a test procedure or, less obviously, encouraging a habit or interest in a product or product feature which we would not want them to retain after the test.

Identify all possible users

Think about everybody who might come into contact with your product. This means looking at:

- intended users – your target market
- potential users – other people who might use the product
- unintended users – people who are not expected to use the product but may come into contact with it anyway, such as children.

If this process identifies vulnerable users (for instance children, the elderly, or people with special needs), then you must focus on *their* use of the product.■

If your product will be used internationally, or by different cultures or groups within the same country, then the users may have differing experiences or previous exposure to it. These will affect the way the product is perceived and used.

Outcome
A list of intended users, potential users and unintended users, plus their characteristics, abilities and perceptions as they relate to the product.
Example
Designing a new product concept – a mobile phone
Intended users: adults from teenage upwards
Other potential users: elderly, physically impaired
Unintended users: small children

Identify potential hazards

Anticipate everything about your product that could go wrong or be dangerous – its hazards. It helps to look at them in a structured way and come up with a considered and thorough list.

How to identify potential hazards

There are a number of things you can do and sources of information you can use to draw up a list of potential hazards:

- review regulations and standards. If these exist for your product, then some potential hazards will already have been identified and minimum safety criteria set for them.
- analyse accident statistics to see what types of accidents are occurring, who is being injured, where, when and how.■
- produce a user specification based on your list of potential users (see page 10)
- build up scenarios of how different people might use a product in different circumstances
- observe and analyse how similar products are used.■■
- carry out design appraisal (see page 16) with people other than the design team who may have an idea about the way the product will be used and its potential hazards.

■ You can get accident statistics from the DTI (see page 28). Their Home and Leisure Accident Surveillance Systems record the details of consumer accidents treated at a sample of hospital Accident and Emergency departments. Estimates of injury rates and details of cases are available on a national basis (the systems also operate on a European level).

Fatal accidents are recorded by the Home Accidents Deaths Database.

Other sources include:
- Royal Society for the Prevention of Accidents (RoSPA)
- Child Accident Prevention Trust (CAPT)
- Home Office – fire statistics.

You could follow up non-fatal accidents by contacting the injured person through a postal questionnaire, telephone or face-to-face interview. Fatal accidents can be followed up using coroners' reports, although these can be difficult to access and coroners often have scarce information on the cause of accidents and products involved.

All companies should keep a record of customer complaints and returns, for good business practice. Following these up may yield information on potential hazards.

Set performance criteria

Once you have a list of potential hazards, you must assess how likely they are. This is known as the element of risk. To do this you must set performance criteria for each hazard. These criteria are effectively design specifications which your product must meet so that hazards do not occur, and which will form the basis of your testing procedures. (The process of setting performance criteria is shown as an example within 'User trials', see page 20.)

In cases where a hazard cannot be completely 'designed out' and you cannot avoid some level of risk, then make the most of other means of accident prevention such as instructions, labelling and safety education.

Outcome

A list of potential hazards, consequent risks and corresponding performance criteria.

Example

Child safety gate

In the example of a child safety gate, a potential hazard might be the inadvertent operation of the catch by a child. The performance criterion for this hazard would be that the catch cannot be opened by any child under five years old.

If a hazard cannot be completely 'designed out', performance criteria may have to be set for an acceptable level of risk. For instance, a catch on a safety gate that can be opened by 10% of two-year-old children would be an unacceptable risk, but a mechanism with .001% risk of a bruised finger might be acceptable.

Choose a method of evaluation

You now need to work out which type of evaluation best suits the hazards and users you have identified. The chart on page 12 gives some example suggestions. We explain these evaluation methods in the next sections. Sources of more detailed information on most of the methods described here are given in the bibliography (see page 29).

■■ Hazard analysis

There are a number of techniques that have been developed specifically for analysing the way in which people use products and identifying the cause of accidents; methods such as task analysis, predictive human error analysis and link analysis. A brief description of task analysis is given since it is a common and useful tool. For more information see bibliography (page 29)

In the context of design safety task analysis aims to analyse functions of the product and user during an interaction to help predict hazards and their solution. It is the systematic analysis of what is required of the user during the operation of a product, to meet certain goals. This can include the physical or the information processing requirements of the user to understand the ways accidents are caused. The information gathered in task analysis can include:

- the frequency and sequence of tasks
- the objectives of each task
- how well performance criteria are met
- priorities amongst different tasks
- what 'triggers' realisation that a task must be carried out and understanding of how to perform that task
- what information is required or used for each task, and what decisions and choices are made
- how tasks are ordered or grouped (hierarchical, clustering, temporal or functional groups)
- what common issues or relationships between tasks emerge.

Remember to look at potential misuse, such as people not following instructions or applying more force than normal. If the task analysis is based on observing a sample of users, it is almost always best to resist 'directing' users if they start to go wrong – this is what you're after, after all. But if necessary you can help users complete a task – for example if they need to complete something in order to progress, onto the next task.

Evaluation chart

hazard	hazard scenario	how to evaluate the hazard
Mechanical hazards		
access to hazard (by whole body or body part)	reach through guarding, child climbing over a stair gate, finger in electrical socket	check against anthropometric data, user trials possibly with simulated users
entrapment/jamming/ pinching/shearing • between moving parts • in an aperture • between structures	 – fingers trapped in doors – head in cot sides – open stairs	check against anthropometric data, computer simulation, user trials possibly with either simulated hazards or users
impact • user into product • product into user • powered • sharp edges	 – trip into furniture – insecure fittings – slipping with a power tool – dropping/falling onto a knife	user trials, possibly with simulated users or product, or by protecting user during test
fall • between levels • on same level • unstable product	 – fall down stairs – slippery floor surface – fall from stepladder	
Ingestion hazards **toxic substances** **choking**	 – cleaning products – small parts swallowed by children	user trials, with simulated users
Explosive hazards	batteries, pressurised containers or mobile phones in contact with fire	
Fire hazards	children's use of lighters, clothes in contact with naked flames	ergonomics guidelines, user trials, technical evaluation
Electrical hazards	not unplugging product before maintenance, handgrip too close to live component	
Thermal hazards (extremes of ambient and surface temperatures)	contact with cooker surfaces, metal surfaces in extremes of heat or cold, fires and room heaters, radiators, freezer parts	
Vibration hazards	sustained use of power tools	ergonomics guidelines, user trials with simulated users, checking against data on human exposure rates, technical evaluation
Noise hazards	prolonged exposure to alarms	
Chemical hazards	carbon monoxide poisoning, cosmetics	
Radiation hazards	checking against data on exposure rates	

Checking against ergonomics data and guidelines

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How and where data can help

Checking your product against standard ergonomics data is a useful starting point for evaluating safety. Some examples are:

user interacts with	examples	how data could help	examples of what data to check
Information	**safety pictograms**	recognition and comprehension by all users	understanding of colour codes, symbols, perception of hazards
	warning alarms	recognition and comprehension by specific occupational users	auditory perception
Social environment	**supervision**	recognition of child hazards by adults, design of warning systems	adult knowledge/perception of child capabilities
Physical environment	**window and door handles**	make usable by adults, elderly and disabled but inoperable by children	overhead reach height, opening strength, specific behaviour related to window handles
	public movement areas	optimal movement space for general use and in emergencies	general ergonomics guidelines and national building regulations for movement spaces
Personal space	**machine guarding**	prevent access to hazard through or around guard	maximum and minimum adult finger size, hand size, pushing and pulling strength
	stairs	prevent tripping and falls	step height, balance, foot length
	fireguard	prevent access and operation of catch by children	child finger size, hand strength, pushing and pulling strength, specific behaviour related to mechanism
Product	**medicines and packaging**	make child resistant (inoperable and unattractive) whilst accessible to adults, elderly and the disabled	opening strength, psychomotor skills, cognitive/problem solving abilities of all potential users
	infant soother or pacifier	prevent swallowing by child	mouth and throat size
	bicycle	reach to pedals and handlebars, size of handlebars	arm length, leg length, sitting height, hand size

Limitations of using ergonomics data and guidelines

There are a number of issues to bear in mind before using published data and guidelines:

- anthropometric or strength data may have been measured on a different population to that for which you are designing. Early anthropometric data were measured on military personnel – fairly inappropriate for the wider population. There are less, or less accessible, data on children and the elderly because they were not needed for occupational or military design. Check who the data were collected for.
- anthropometric data can also be out of date as some human characteristics change over time: for instance people are bigger now than they were fifty years ago. Check when the data were collected.
- the conditions in which 'performance' data are collected should be similar to those in which they will be applied: task conditions (eg size and position of controls), environmental conditions (lighting, temperature) and social conditions (time of day) will affect how people will perform. For instance, opening strength measured on a 5cm diameter horizontal door handle cannot be applied with confidence to assessing the strength required to open a 2cm screw-top on a drugs container
- ergonomics guidelines can sometimes be too general to apply with confidence, or else too specific to the application for which they were originally derived.
- guidelines often do not take account of users' psychological characteristics – their previous experience with a product, expectations, perception of risk, attitude – which will all affect how a product is used.

Data can also often be difficult to find and access (see bibliography page 29).

Outcome

Identify data relevant to your product and its users. Turn these data into basic design parameters. If no appropriate data are available, consider how such data could be measured or estimated.

Example

Redesigning an existing product to incorporate a new mechanism – a child-resistant lighter.

The designer might look at data for:

- child finger and hand size
- children and adult grip strength
- child cognitive capabilities with prevention devices
- motivation to explore and play with the product.

When you have found useful data, check when they were collected and who they were measured on, and make sure you used the most up-to-date, applicable and reliable source.

Modelling

Modelling involves user representation, usually to assess the physical 'fit' of the product to the user. Methods include two- and three-dimensional computer modelling to evaluate, for instance, reach to controls, movement spaces around products, and lines of vision around a product. Modelling methods can be quick, cheap and simple to use and can provide early answers to questions of fit and avoid the need for user trials.■

■ User trials themselves (see page 17) can involve an element of modelling in that sometimes it may be necessary to use a representation of the user, because of ethical or practical restrictions (weighting a bike during crash-testing instead of using a rider for instance). This is referred to as simulation in user trials and is discussed in that section.

Two- and three-dimensional techniques include static and moveable mannequins and dummies. The limitations of these techniques are:

- they usually only represent a selection of the population you are designing for
- the usefulness of dummies and mannequins depends on how relevant the anthropometric data on which they are based are to your design – check the data they are based on
- they cannot account for human behavioural or psychological characteristics and the effect they have on safety, for instance the effect that motivation and stretching can have on maximum reach.

Commercially-available computer software enables designers to model some aspects of the product/user interaction. Most programs contain a model of the user which can be manipulated to some degree. These vary from stick drawings to Virtual Reality. Programs can model dimensional fit between the human, product and environment, force exertions and the effects of manual handling on the body.

Computer modelling is most useful when you are assessing 'fit' – the size of the products, reach, movement and visual fields. Advantages are:

- the ability to visualise things clearly
- the ability to calculate safety tolerances (for instance the minimum distance allowed between the user and a moving part of a product)
- models can be re-used and adapted indefinitely
- evaluations are quick once models are established
- the ability to integrate with other computer techniques such as CAD, and presentation software
- low running costs after initial purchase.

Disadvantages are:

- models may have unrealistic or limited movement
- accuracy depends on the data on which the program is based
- getting the modelling started can be time-consuming.

Design appraisal

Design appraisal uses the knowledge and insight of groups of people, usually other than the design team, to give an alternative view of the design and its safety. This can be especially useful in identifying hazards or usability problems that the design team will not have predicted. Design appraisal will rarely provide any 'measurements' of safety or quantifiable results, for instance that all elderly people will be able to operate a fire extinguisher.

Appraisals work best when they bring together a panel drawn from as many as possible of:

- ergonomists
- safety professionals
- engineers
- other designers
- experts in the product (manufacturers, suppliers, installers, repairers, servicers)
- experts in the environment (school teachers, gardeners, residential care suppliers)
- experts in the task (parents, DIY enthusiasts)
- experts in the user groups (nursery staff, carers)
- existing users
- new/potential consumers
- people who have some experience with the product, the task, the environment or in design appraisals
- people who have experienced injuries or difficulties with similar products.

Design appraisal techniques include:

Interviews

Show the appraisal panel your design, or ask them to use it, and then interview them for their impressions and views. Interviews can be structured or semi-structured, but need to focus on safety issues.

Focus groups

Lead an open and/or focused discussion of the product, stimulating ideas and thoughts. Focus groups usually work best with real or potential users of the product, who may be unused to other assessment techniques or to safety issues.

Checklists

Ask the appraisal panel to provide lists of factors relating to safety. These can be:

- checked against for a particular product
- used to stimulate ideas if people are new to the appraisal process
- returned to later in the evaluation process.

Walk-throughs

The appraisal panel 'walks-through' imaginary tasks or scenarios to highlight potential problems.

Participative methods

These focus 'user' appraisers' attention on design issues and call on their intuitive knowledge of the product or task. Typical exercises include:

- word map – participants volunteer words associated with the product in order to suggest potential problems
- round robin – an open-ended questionnaire is passed around in which each person has to find a new answer to each design problem
- users are asked to draw their own version of how the product is used
- ergonomics issues are discussed, then users draw their own ideal solutions to the design problem which are again presented and discussed
- solutions are sought by working in pairs, first drawing the design, then working through to modelling layouts and building mock-ups.

The results of these exercises can then be used in user trials, if appropriate.

User trials

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Collect the results	22
Working out statistical significance	24
Applying test results	25

User testing can be defined as any evaluation process where the user is represented in the test. This most commonly takes the form of user trials, where a sample of subjects, representative of the intended users, is observed using the product or carrying out an example of a task. The observation can be of 'natural use' or can be controlled so that measurements can be taken. Sometimes it may be necessary to simulate some or all of the features of the user, product, task or environmental conditions because of practical or ethical restrictions.

■ You must consider the 'quality' of the results you obtain. Quality, when evaluating product safety, largely consists of reliability and validity.
- reliability is the extent to which the same results would be obtained if the test were repeated.
- validity is the extent to which the results truly represent what they are supposed to be measuring.

These factors are discussed in more detail on page 22, together with ways of increasing both.

Choose your users

Ensuring a representative sample of users

It is clearly helpful to have a sample as representative as possible of all potential users.

However, to make this feasible, it helps to think about what characteristics are important. Think about what 'representative' actually means in relation to the tasks you intend to test. For example, a person's physical characteristics will have little bearing on how they interpret safety labelling, but their literacy and educational levels, socio-economic background, first language, prior experience and preconceptions of the product will almost certainly be critical.

Recruiting users

Recruiting users can be difficult. You need to cast your net wide enough to gather a sufficient range, yet small enough to recruit quickly and efficiently.

Users can come from an existing group such as members of clubs or residents of a specific area. Advertising can be used to attract subjects. However this involves self-selection (people's knowledge of their own characteristics is often unreliable, due to forgetfulness or tendencies to exaggerate or underestimate) and produces a certain type of subject – motivated, but not necessarily for the right reasons. You can always discount the results from inappropriate people after the test, but this is not an efficient approach.

You could keep a permanent 'bank' of users. You will gain from having experienced, available people, but lose because they may become over-familiar with general ergonomics and safety issues or with the testing process and, as a result, may cease to be representative of the eventual users (findings may have little *validity*).■

How many to choose

You'll need enough users to ensure *reliable* and *valid* results. If your sample is too small then the results may not be a very good prediction of what would happen in real life. There may not be enough variation (size, strength, attitudes), and there could be disproportionate influence from someone whose performance is very different to the 'norm'.

The 'right number' depends on what is being tested. While generally the more the better, it is not worth increasing subject numbers past the point where no new information is being gathered or where reliability is not being improved.

Research suggests that if you are collecting 'opinions', then as few as five users will do for any specific group (eg if your sample is all-female, the results can only predict female performance). Such results best indicate ideas or trends, and are most useful when you are looking to generate design improvements, identify potential problems, or for initial stages of evaluation.

If you are after more specific or critical data, then a *minimum* of 10 people is recommended for 'informal' testing (where statistical significance will not be assessed), and 15–20 for 'formal' testing (where statistical significance is important).

On page 24 we discuss statistical significance, and extrapolating the findings of a sample into population-wide judgements.

Motivating your sample of users

People's attitudes to safety, and their reasons and motivations for taking part in your test may affect their performance. They may make things seem more of a risk than they are, or ignore problems in order to appear co-operative. You will need to be on your guard for these things, and account for them in the way you plan your test.

Evaluating for safety often means you want people to show extremes of abilities or behaviour, for example their maximum pushing strength or fastest reaction times. Your results will depend on whether people are motivated to produce their maximum effort. This can be particularly difficult for children, who may not understand instructions, or for the elderly, who may fear injury or over-exertion.

You can actively encourage people, give them feedback to let them know how well they are doing or offer rewards/incentives, so long as this is the same for all users and does not put them at risk of injury.

How much to tell them

Give everyone consistent instructions and information, so that you can compare performance on equal terms. Plan the information you're going to give, and keep a written record in case more than one person is running tests.

Ethically, you should tell people exactly what the test will involve, and obtain their written consent. However, there are times when providing full information may compromise the usefulness of the test. For instance, you may be looking at an unsafe behaviour such as whether people unplug electrical equipment before maintenance, or how far they are willing to over-reach when using stepladders. Here the conditions of the experiment need to be as natural as possible: you may need the subjects to be unaware they are being observed, or you may have to disguise the real experiment.

This lack of openness about the reasons for the test is a useful tactic but can only be justified if:

- the results cannot be collected any other way
- users will not be induced to do something they would not otherwise agree to
- the importance of the results justifies lack of openness.■

■ Regardless of how safe the actual experiment may be, you should not expose children to a potentially hazardous product or feature until they are old enough to understand its dangers. Otherwise any exposure is likely to raise their interest in a product. Tests in such a case could therefore be disguised so that children cannot connect what they see and use to real life.

Outcome

A large-enough sample of users, who represent all potential users, are motivated, have no or few preconceptions about the product and who understand the test.

Example

Redesigning an existing product to incorporate a new function – a multi-purpose infant carrier.

In this example, a designer wants to test how easily a child carrier can be secured into a car seat. An informal test is developed using a doll instead of a child, and two groups of subjects are recruited. The first is a sample of ten parents from a local playgroup and the second is ten new parents from an ante-natal class. There are 15 women and 5 men; one is physically disabled, and one is visually- impaired. Their ages range from 17 to 42.

The purpose of the test is explained to them from a prepared set of instructions. They are encouraged to be as 'rough' on the carrier as possible.
The same group is reconvened at later stages to test improved designs.

Prepare the test

How realistic can you be? – using simulation

The closer to real-life conditions your test is, the more useful your results are likely to be. But sometimes a 'real' interaction is impossible, because of practical or ethical restrictions. In such cases you need to simulate aspects of the test.

Reasons for simulation include:

- you cannot make a full working model of the product
- you cannot find a representative sample of users
- there are ethical restrictions as to what you can ask people to do (particularly children, the elderly and disabled)
- there are practical restrictions on what you can ask people to do, such as children who cannot understand instructions
- there are time limitations where, for instance, something needs to be used for longer periods or more frequently than is feasible to ask people
- a hazard cannot be tested on people, such as head entrapment or the ability of the body to withstand an impact.

The aim of any simulation is to ensure a safe, ethical and efficient test while maintaining enough realism, reliability and validity and thus applicability of results (these issues are discussed on page 25). The major requirement of any simulation is that you must account for all features which could affect the human-product interaction. For instance, finger probes used to test gaps in a fire guard should not only cover the range of finger sizes and shapes, but should also account for the force with which a finger would be pushed and the resistance of the materials in the probe and guard.

Simulation is often thought of as just making a mock-up of the product ■■. But you can also simulate:

■■ Mock-ups are cheap and easy ways to test products, particularly during early design stages when a full product cannot be manufactured. You only need to mock-up the aspects you are testing. For instance, if you are testing portability the mock-up doesn't need operational controls but would need to be the correct weight. If your test will look at all stages of use, including maintenance, assembly and disassembly, then the mock-up should be internally and mechanically fully functional. Factors that can be mocked up include:

- product dimensions, including weight
- product stability
- dynamics between user and product
- power source
- moving parts
- surface and texture
- positionandorientationofproduct in relation to the environment
- positionandorientationofproduct in relation to the user
- dimensions of controls
- resistance of controls
- design and realism of displays, information and labelling styling.

User characteristics

- anthropometric variables (whole body, body part)
- strength
- impacts on the body
- movement (whole body, body part)
- weight (impact, weight distribution, dynamic loading)

Tasks

- operation of controls
- hazardous contents or materials
- emergency conditions
- distance of movement

Product characteristics

- packaging
- controls
- displays
- size
- weight
- dynamic characteristics
- physical contact points
- power source

Environmental conditions

- temperature
- noise
- vibration
- interactions with other products.

Where to test

As with the considerations above, the location of your test will affect the usefulness of your results. Environmental factors and conditions can have a serious effect on safety. For instance:

- environmental conditions
  - temperature: extreme temperatures can affect motor skills such as dexterity
  - visual conditions: glare, or general ambient lighting can affect visual performance
  - noise: background noise can affect reaction times to auditory warnings
  - vibration: vibration of machinery can affect motor skills
- conditions of use
  - indoors/outdoors: weather conditions, terrain, lighting
  - home/work: use will be different due to responsibility to others, ownership of products
  - supervision and training: will the product be used without formal training or supervision
  - supporting literature: will instructions/labelling usually accompany the product
  - power supply: a real power supply will affect the way a product is used
- social conditions
  - private/public/observed: use will be different according to who else is present
  - group use: group effects can include quicker use, competitiveness, distraction.

Ideally tests should be held in realistic conditions, often called field work – the home, workplace, street or school. However this is often impractical, and you may need to carry out your tests in a 'laboratory' environment, either in your company's facilities or at a site provided by a third party. Both real-life situations and laboratory replications have advantages and disadvantages (see diagram on page 21).

Ergonomics and safety consultants and other bodies may be able to provide facilities for testing, such as suites with video-recording and one-way mirror services (see page 28).

Prepare your questions and tasks

Although by now you have identified what hazards exist, what level of risk is acceptable and what performance criteria to set, it helps to formalise the questions you will be asking and the tasks you will be setting in your user trials.

This will help:

- eliminate wasted time during the test
- make sure everyone completes the same tasks
- concentrate the test on ergonomics and safety factors and avoid redundant side issues.

If you do not do this, you may end up with a room full of people all looking at different aspects of your product, unsure what exactly they're supposed to be testing and getting sidetracked into aesthetic value judgements about whether they 'like' the product.

You should already have set your performance criteria which define whether your product will be safe (see pages 11 and 22). Using these, start generating general questions about the way the product will be used, and try to turn these into specific questions. The tasks you set people to do in the user trials should answer these specific questions. This process is shown on the next page using the example of designing a stair gate (more information on how to select measurements is given in 'Working out statistical significance' on page 24).

Outcome

A full set of questions and measurements.

Example

Designing a new product within an existing concept – new stair gate.

The designer might draw up the chart on the next page.

Generating performance criteria and test questions for evaluation of a stair safety gate[2]

hazard	examples of general questions	performance criteria	examples of specific questions	measurement
Child gets past the stair gate				
Child opens lock	Is lock operable by children?	No child in a specified age group should be able to open catch	Define 'operable'	Time to open, amount opened
Child climbs over gate	Can children climb over gate?	No child should be able to climb over gate or get injured trying to	What is a successful climb and how likely is a fall?	Time to climb, stability of gate and child during climb
Child pushes or pulls gate open	Can children push or pull gate open?	No child should be able to push or pull gate open	Define 'open'	Time to open, amount opened
Child gets stuck in the stairgate				
Child forces head/arm/ hand/foot through gap(s)	Can a child's head/arm/ hand/foot pass through any gap and get stuck?	Ideally no child should be able to pass their head/any part of body into gap and if they can without risk of injury	What is maximum size of gaps that prevents head/ body part of smallest child entering? What level of entrapment may cause injury?	Specify minimum head size/body part to be excluded and use data (eg CHILDATA[3]) or replicas to test gaps
Child's limb is pinched by the stair gate				
Child pinches arm/hand/ finger/leg /toe in gate or lock	Are there any moving parts where child's arm/hand/ finger/leg/toe could get caught?	No child should be able to insert their finger/leg/toe into any moving parts	Can the smallest/largest child reach moving parts? Can the smallest child insert a finger/leg/toe? What cognitive elements are involved?	Check anthropometric data (eg CHILDATA[3])to assess reach and test ability to reach or access parts
Adult gets stuck in the stair gate				
Adult forces arm/leg through gap(s)	Can an adult's arm/leg pass through any gap?	No adult should be able to insert an arm or leg in any gap	What level of entrapment is likely to cause injury? What is the maximum gap that still prevents the arm/ hand of the smallest adult entering?	Specify the minimum hand/foot size to be excluded and use data (eg ADULTDATA[3]) or replicas to test gaps
Adult falls over the stair gate				
Adult climbs over gate when in place	How easily can an adult climb over the gate?	Ideally all adults should be ableto climb over the gate with acceptable ease	What is considered a successful climb? Can those users likely to fall be identified?	Time taken to successfully climb over. Identify differences in climbing ability and techniques between adults
Adult hurts themselves assembling the stair gate				
Ease of assembly	How could injuries occur during assembly?	All adults should be able to assemble the gate with no risk of injury	Identify assembly tasks and rate of occurrence. If safe assembly is achievable by some users, identify which may have difficulty (eg elderly)	Identify differences in assembly ability between adults.

[2]CEN committee TC252 are drafting a European safety standard on stair gates which addresses these issues

[3]see page 7

Types of testing: real life versus laboratory

	real life situation	laboratory simulation
Realism	a high level of realism is offered as all the variables that affect the use of the product (other people, equipment and environment) are represented as they would be in real life	the important variables must be recreated in the laboratory but some realism will always be lost
Control	there is a lack of control over external factors	important variables can be controlled but it is difficult to control everything
Generality	it is easier to generalise to real life	an artificial situation reduces the ability to generalise and therefore validity
Bias	there is least bias as there is less control over other variables	controlling variables can lead to bias
Repeatability	as each situation only happens once, repeating makes the situation artificial	the evaluation is repeatable as the equipment and subjects are available, allowing more analysis or tests to be done if necessary
Comparing designs	it's difficult to compare alternative designs in a real life situation because subjects get used to the product and realism is lost if they repeat the task	experimental is repeatable as the make comparisons between alternative designs
Practicalities	it can be difficult to set up and run	it's much easier to set up and run evaluations in real-life situations
Time and resources	it can be time consuming to run evaluations in real life due to the availability of situations to observe	recreating conditions in the laboratory can be expensive especially if special equipment and rigs have to be built
Equipment	experimental and recording equipment needs to portable, and technical support may have to be taken to the site	experimental 'space' can be designed to suit the evaluation and technical support is on hand
Users	users may be found more easily 'in-situ' if they are specific to the environment eg children and carers in a playground, but if they're not in-situ, you need to consider how practical it is for people to get there	you can establish a 'bank' of users who are used to going to one laboratory, so long as familiarity is not an issue
Confidentiality	confidentiality and security can be a problem as the product needs to be taken out to the public	the product can be kept in private and secure conditions

Selecting variables

By identifying hazards or hazard scenarios (see page 11), you can specify the behaviours that might be found in normal safe use of the product that have some level of risk associated with it – either acceptable or unacceptable – and in the misuse of the product. Examples of each of these types of behaviour are:

- reaching out to the side when on a stepladder
- not unplugging an electrical appliance before cleaning it
- undesirable opening of a container by a child.

For some products there is only one behaviour or interaction of interest for safety – for example, can children under five years reach a window catch? For other products there may be several critical behaviours or interactions; with a stepladder we might want to know how far people are prepared to reach sideways, how high they go willingly, and whether they lock the stepladder correctly. Identifying these behaviours helps us decide what will be our measures of safe performance – in experimental design these are called *dependent variables*. Our examples could be:

- the distance subjects are freely prepared to reach sideways
- the proportion of times a sample of users do not unplug the appliance
- the average time taken by children to open the container, and the success rate at opening the container.

It is not enough only to test and measure the dependent variables. We need to consider all of the hazards and risks associated with a product in use and measure them. Examples of these might be: the stepladder does not tip up when anybody reaches out as far as they are prepared to; the appliance is only left plugged in on 5% of occasions; 99% of children aged 2–3 years cannot open the container in ten minutes.

While our measurements (dependent variables) tell us how safe the design is we have to decide which factors influence behaviour and interactions; how safe the design is. In experimental design these are called *independent variables*. They can be any aspect of the product design, person, environment or circumstances of use. Our examples could be:

- the width of stepladder treads
- the size of warning on the appliance
- the diameter of the container closure.

In user trials we systematically manipulate the key independent variables and record how the combinations of these affect the critical behaviours – our measurements or dependent variables.

Collect the results

The way you collect results should intrude as little possible into the test, while getting all the information you need. The following three methods are in increasing order of intrusion:

Directly recording users' actions

This involves an observer noting and interpreting the users' actions or else making a record to be interpreted later.

Work out beforehand what to record, and what not to record. This will help you avoid the problems of having too much to analyse, or not being able to keep pace with the speed or amount of events.

Recording methods include:

- Hidden or unobtrusive observation – observe users from another location through either one-way mirrors or cameras. This encourages natural behaviour (if the camera is hidden), but be aware of the ethics of not telling someone they are being observed. If you do tell them then the point of being hidden may be diluted.
- Paper-based recording – use prepared recording sheets, with as many tick boxes, codes, marking diagrams and other short-cuts as possible. Train the people who will be recording, and assess them against a standard and each other to make sure they are consistent.
- Video recording – allows repeated analysis, and is good for things that happen quickly or when several things happen at once. Useful for precise measurements of parameters such as reach, time, height and distance. Video recording can be public or hidden. Do not just video everything and assume you'll get round to analysing it later – analysing a video can take up to ten times as long as the event itself.
- Automated data collection – there are computer and mechanical methods for collecting human performance data (heart rate, oxygen uptake) and product performance data (stress in a structure). These may have to be developed specifically for each application, though some commercial versions exist such as equipment to record eye-movement.
- Automatic event recording – these techniques record specified events such as the activation of

a movement sensor, the force imparted between product and user, reach beyond certain distances and so on. Again these usually have to be developed specifically for each application.

Users recording their own actions

These methods rely on users either recording or interpreting their own actions. They are useful for field work, assessing use over longer time periods and in gaining 'honest' assessments of a product.

- Commentary – ask the user to comment on what they are doing and thinking during a task, the information they are using and the decisions they are making (known as protocol analysis). They should give concurrent, unprompted and natural descriptions. This is different to interviews, which are interviewer-led and which can be focused more on strategies than processes. Bear in mind it can be time-consuming and difficult to interpret commentaries.
- Private video booths – encourage users to discuss their use of a product in a more open and honest manner than if interviewed. The user is left alone with a camera to explain their behaviour and preferences without any outside interference.
- Diaries – users can self-record their behaviour in a diary over longer periods than is possible in an observed test. Alternatively tags can be placed on the product for them to fill in regularly. Less information can be recorded in this way, and tags can be difficult to use, but it does enable naturalistic use of the product in a real environment without any intrusive observation. Diary methods are particularly useful for recording information such as frequency, time, circumstances of activity and use in combination with other products.

Recording users' opinions

These methods ask users for their verdicts in a structured format. Use them when:

- there are no direct measures of safety available
- you want to back up direct performance measures with subjective data
- you want to find out attitudes towards using a product – for example asking people whether they follow instruction labels.

You will find these methods described in detail in a number of standard texts (see bibliography page 29). Some of the methods include:

- Ranking – ask users to rank lists of design options (different types of controls, handle sizes, methods of assembly) in order of preference against several criteria (ease of use, comfort, safety). Do not ask them to rank more than nine options at a time. Often only the rankings at either end of the scale can be considered of most value.
- Rating – ask users to rate on a scale (usually 1–5 or 1–7) how they feel about something. An example is Likert scales, where people are asked to respond to statements such as 'the catch is easy to open' using a scale of possible answers. A 5-point Likert scale may be: 'Strongly agree – agree – uncertain – disagree – strongly disagree'. Rating scales with an even number of points (ie no neutral point) can be used to force a decision. Rating is less sensitive to differences between options than is ranking, but allows you to calculate the absolute positions on a scale related to each criterion.
- Paired comparisons – a powerful method where every possible combination of pairs of design options is presented to the users in turn. The users must say which option of each pair best meets the particular criterion. For instance, if we wanted users to evaluate the comfort of four bicycle seats (A, B, C, D), we would ask each user to say which is more comfortable out of the possible pairs (A/B, C/D, A/D, B/C and so on). Once all comparisons have been made, the preferences can be converted into a rating scale with each item given a score. Because the possible number of pairs can get large the method works best with four to six and no more than eight items, especially if more than one criterion is used. Iterations of the process may be needed if the results highlight contradictions in people's judgements.
- Questionnaires ■ – are a flexible and widely used method of collecting data. They can be administered face-to-face, by mail or on the telephone. While questionnaires can allow fast access to the views and opinions of many people in a consistent fashion (they are the only feasible way of gathering data from thousands of people) there are drawbacks. They can require considerable resources to administer, analyse and interpret properly. Also, because they must usually be relatively short, they work best if the investigators and respondents share a common culture, language and at least some understanding of the issues.
- Interviews – these allow data to be collected in more detail than from questionnaires and are more controllable and responsive. Disadvan-

■ Questionnaires

A questionnaire should motivate people and elicit accurate and full responses.

Pilot your questionnaire, first on colleagues to highlight basic problems and then on a sample of users. Use these basic guidelines:

- arrange questions in an order that is logical from the point of view of the person filling it in
- use filter questions ('if 'no' go to question seven' etc) to guide respondents past inapplicable questions, which otherwise can de-motivate them
- questions should be: short, clear, unambiguous, specific, precise, non-leading, avoid bias, based on real information (avoiding hypothetical questions)
- questions can be: factual (yes/no), mutually exclusive (what type of product was used), multiple (what was the product used for), of responses (who the product is used by, how often and why), open ended (allows unrestricted response, but means more effort later in interpreting and collating results), and closed (people can only choose one specific answer). You must cover all possible answers, including 'other' and 'don't know' categories. This may bias or force an answer, but it does allow easier analysis, and generates more meaningful responses.

(See bibliography for more guidance on questionnaire design).

■ Remember that a result which may not be significant statistically – eg only a minority of users show hazardous behaviour – may be of great practical importance. If that hazard carries risk of serious injury, then it may not matter if the chances are one in a hundred or one in a thousand, it is still unacceptable.

■■ If a measure is normally distributed (which we assume for most anthropometric variables), we know that 95% of the population lies within a range of at least two standard deviations either side of the mean. Since we can never know the standard deviation of the whole population, we calculate the next best thing, the Standard Error, (SE) which is a measure of the variability of the best estimate of the population. We say then that 95% of the population will lie within two Standard Errors either side of the mean we have calculated from our sample. This range is also called the confidence interval or confidence level – we say that we are 95% certain that the figures we have calculated will lie within this range.

We can calculate the Standard Error using the following equation:

$$SE = \frac{s}{\sqrt{n}}$$

Where s = standard deviation of the sample and n = sample size

You can see from this equation that as you increase the number of subjects, the SE will decrease. This also means that as we increase the number of subjects, our confidence interval decreases, and we can be more accurate in our predictions.

We can use these equations to calculate how many subjects we need to test to give us an acceptable confidence interval. Research has shown that there are limited advantages to having more than 50 users in a user trial, as doing so does not dramatically affect the Standard Error.

tages can be the time and planning needed, the need to train interviewers and the possibility of bias introduced by individual interviewers.

- Checklists – use checklists to record a user's reactions and perceptions. The list can be drawn up by other users, 'experts' or evaluators. Checklists are limited by the fact that they are prescriptive and are based on someone else's perceptions of the product.

Working out statistical significance

In some cases you can be very confident about the results produced by user trials. For example, it may be possible to prove that no child, however small their limbs or however hard they try, will become stuck between the bars of a new stair gate. In other cases, probably the majority, your findings will only indicate degrees of probability. Furthermore your sample, even if it is large, cannot contain the entire user population. In such cases you may need to work out exactly how confident you are in your results. This means working out statistical significance, which can be daunting at first. In the section below we run through the basic calculations for generating statistically significant results.■

Extrapolating your results to the whole population

Because you cannot test the whole population and can only test a sample of users, you need to know how well your results predict the performance of the whole user population (which may be all potential users, or just those at risk, for instance children under five or the elderly). For this we need to know the *sampling error*.

Provided that your sample of users has been randomly selected, you can work out the sampling error, or how representative your sample is of the general population, by calculating the Standard Error (SE)of the results. The SE is the way in which we quantify the representativeness of our samples and we can use this to work out how many users we need to test in a user trial.■■

Sampling

Being able to calculate the sampling error depends on whether the measure we are interested in is normally distributed and whether the sample we use is selected randomly.

Random selection means that every person in the target user population has an equal chance of being selected for the experimental sample. Techniques for randomly selecting (known as probability sampling) include things like random number tables – it must be possible to assign chance (or a number) to the whole population.

Some common methods of selecting subjects do not actually produce a random sample, for instance accidental or availability sampling (people on the street or telephone numbers from a directory). If the sample is not random the sampling error cannot be calculated in the way shown above.

If you can't select your users randomly, you can estimate sampling error by comparing your results to statistical information on the target population, such as the mean and standard deviation of a critical characteristic (for example opening force).

However, such information is often not available, either because:

- no one has ever collected data relevant to the characteristic you are testing, or
- data exist for the characteristic, but do not fit with your target population.

In these situations you may have to estimate the relationship between your subjects and the target population by comparing a similar, related characteristic. For instance, if you are evaluating opening strength on a particular size and shape handle but no data exist on that exact operation, then standardised grip strength (data on which are widely available) could be compared between your sample and the target population. Take care when selecting characteristics for comparison to ensure that they:

- are related
- involve the same part of the body
- involve the same physiological function.

If you can neither extrapolate your results nor make comparisons, then make your sample as representative as possible of the target population, for example by increasing the number of users.

Comparing designs

In some cases you may want to compare alternative designs and you will need to know whether the differences in performance you may find are true differences, due to the changes you have made to your design, and not due just to chance. That is, that the differences are statistically significant. You will need to consider formal statistical analysis of your results, and think about this before you start any evaluation. Guidance on experimental design and statistical testing is beyond the remit of this

document, but there are plenty of texts to help you (see bibliography).

How confidently can you use your results?

The reliability and validity of your results will determine how confidently you can use them to improve safety.

Reliability is the extent to which the same results will be obtained if the test is repeated with different users or at a different time. You can increase your reliability by:

- increasing the number of users
- ensuring that everyone has the same instructions and is exposed to the same conditions such as light, temperature and time of day.

Validity is the extent to which results truly represent what they are supposed to be measuring. Internal validity is the extent to which your company can use the results to draw conclusions. External validity is the extent to which results can predict performance under different but similar circumstances, and for the rest of the population beyond your sample.

You can increase validity by:

- choosing users carefully to represent the whole range of possible users
- selecting sensitive measures
- making experiments as realistic and as representative as possible.■

■ Sometimes the needs of reliability (strictly controlled conditions) can contradict validity by making the situation artificial. Alternatively, real life tests may give validity to results, but their lack of control may mean low reliability.

Applying test results

How you use the results of user trials (and the outcomes of modelling and design appraisal) will depend on what is being evaluated. Most often the trials will be:

(1) assessing the expected safety of people using (or misusing) the product, or

(2) comparing safety across different circumstances (independent variables) of:

- the person (age, wearing gloves)
- the social/environmental conditions (time pressure, lighting)
- the product itself (two versions of a control, several types of warning label).

In the first case the purpose will be usually to 'prove' the safety of the final design before going to production and market – sometimes such trials will be carried out on a very early prototype to see if further development can be justified. In the second case the trials will normally be a part of the development process, to help decision making about design features, the targeted user population or product suitability for different circumstances.

Whichever the case, well thought-out user trials within ergonomics evaluation, as an integral part of the total development process, will improve the product quality, the satisfaction and safety of consumers and the market position of the producer.

Acting on the results

Once you have carried out your tests, you need to turn the results into a safety assessment or design solutions. Remember tests are part of the evaluation process, not an end in themselves. For instance, you may need to retest your altered design to check that a hazard has been eliminated.

Ergonomics and design safety evaluation should not be, as has already been emphasised, a 'bolt-on' towards the end of product development. Properly and efficiently implemented, such evaluation will inform and improve product design and presentation at all stages of development (this is formative evaluation) as well as provide benchmarking and final assessment against performance criteria for the eventual production prototype (summative evaluation).

The outcomes of any ergonomics evaluations – whether the evaluation be data/guidelines, modelling, design appraisals, simulations or user trials – will be a mixture of ideas, approvals, measurements and statistically supported quantitative results. These outcomes must then be amalgamated and interpreted in terms of degrees of design safety (as well as product usability), and also will be used to generate ideas for improved designs.

The information and ideas in this guide should have given a first explanation of the ergonomics and design safety evaluation process. This guide should also have given a clear understanding of the business gains as well as improved consumer safety to be obtained from such a process.

Further information

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Sources of help and advice

Points of contact

Consumer Affairs and Competition Policy Directorate
Department of Trade and Industry
1 Victoria Street
London SW1H 0ET
tel 0171 215 0383
fax 0171 215 0357

Product Safety and Testing Group
Department of Manufacturing Engineering and Operations Management
University of Nottingham
Nottingham
NG7 2RD
tel 0115 9514039
fax 0115 9514000

Design Council
Haymarket House
1 Oxendon Street
London SW1Y 4EE
tel 0171 208 2121
0171 839 6033

Ergonomics Information Analysis Centre
The University of Birmingham
School of Manufacturing and Mechanical Engineering
Edgbaston
Birmingham B15 2TT
tel 0121 414 4239
fax 0121 414 3476?

The Ergonomics Society
Devonshire House
Devonshire Square
Loughborough
Leicestershire LE11 3DW
tel/fax 01509 234904

ICE Ergonomics
Hollywell Building
Hollywell Way
Loughborough
Leicestershire LE11 3UZ
tel 01509 283300
fax 01509 283360

Royal Society for the Prevention of Accidents (RoSPA)
Edgbaston Park
353 Bristol Road
Birmingham B5 7ST
tel 0121 248 2000
fax 0121 248 2001

Child Accident Prevention Trust (CAPT)
Clerks Court
18–20 Farringdon Lane
London EC1R 3AU
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fax 0171 608 3674

Consumer Safety Institute
Rijswijkstraat 2
PO Box 75169
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British Standards Institute
389 Chiswick High Road
London W4 4AL
tel 0181 996 9000
fax 0181 996 7400

Ergonomics and safety consultancies

These offer advice, training and assessment on general ergonomics and product safety, and for example:

- provide advice on the issues to be considered in a particular application – types of hazards, the types of users at risk, whether or not data exist for a particular problem
- provide anthropometric and design data and guidelines
- highlight gaps and inadequacies in your existing methods, and guidelines on how to evaluate more effectively
- carry out 'expert' evaluation of a product, either in full or in part.

Consultancies have the facilities, equipment and expertise to carry out tests, including access to testers, video-recording suites and one-way mirror services. The cost of hiring these facilities or asking a consultancy to do part of a test for you may be less than trying to do it yourself. Research bodies aligned to university or academic institutions may sometimes be interested in becoming involved in a product development or evaluation project.

A list of ergonomics consultancies is available from the Ergonomics Society.

Bibliography

Anthropometric data and ergonomics guidelines

Corlett, E.N. and Clark, T.S. (1995) *The ergonomics of workspaces and machines – a design manual.* Second edition. Taylor and Francis, London

Norris, B.J. and Wilson, J.R. (1995) *Childata – a handbook of child measurements and capabilities: data for design safety.* Department of Trade and Industry, London

Pheasant, S. (1990) *Anthropometrics – an introduction.* Taylor and Francis, London

Pheasant, S. (1996) *Bodyspace – anthropometry, ergonomics and the design of work.* Second edition. Taylor and Francis, London

General

Abbott, H. and Tyler, M. (1987) *Safer by design – a guide to the management and law for designing for product safety.* Gower, London.

Granjean, E. (1988) *Fitting the task to the man – a textbook of ergonomics.* Taylor and Francis, London

Pheasant, S. (1996) *Bodyspace – anthropometry, ergonomics and the design of work.* Second edition. Taylor and Francis, London

Sanders, M.S. and McCormick, E.J. (1992) *Human factors in engineering and design.* McGraw-Hill, New York

Usability and general evaluation techniques

Corlett, E.N. and Wilson, J.R.(eds)(1995) *Evaluation of human work – a practical ergonomics methodology.* Second edition. Taylor and Francis, London

Jones, J.C. (1980) *Design methods.* J. Wiley and sons, New York

Jordan, P.W., McClelland, I., Thomas, B., and Weerdmeester, B.A. (1996) *Usability evaluation in industry.* Taylor and Francis, London

McClelland, I. (1995) 'Product assessment and user trials' in: *Evaluation of human work – a practical ergonomics methodology*, edited by J.R. Wilson & E.N.Corlett. Second edition. Taylor and Francis, London

Zeisel, J. (1981) *Inquiry by design: tools for environment -behaviour research.* Cambridge University Press, Cambridge

Recording users' opinions

Breakwell, G. (1990) *Interviewing.* British Psychological Society, Leicester

Cassell, C. and Symon, G.(eds) (1994) *Qualitative methods in organizational research – a practical guide.* Sage Publications, London

Edwards, A.L. (1983) *Techniques of attitude scale construction.* Irvington Publishers Inc, New York

Frankfort-Nachmias, C. and Nachmias, D. *Research methods in the social sciences.* Arnold, London, 1996

Meister, D. (1985) *Behavioural analysis and measurement methods.* John Wiley and Sons, New York

Oppenheim, A.N. (1994) *Questionnaire design, interviewing and attitude measurement* Pinter Publishers, London

Osgood, C.E., Suci, G.J., and Tannenbaum, P.H. (1957) *The measurement of meaning.* University of Illinois Press

Sinclair, M.A. (1995) 'Subjective assessment' in: *Evaluation of human work – a practical ergonomics methodology*, edited by J.R. Wilson & E.N.Corlett. Second Edition. Taylor and Francis, London292

Experimental design

Barker Bausell, R. (1994) *Conducting meaningful experiments –40 steps to becoming a scientist.* Sage Publications, London

Frankfort-Nachmias, C. and Nachmias, D. (1996) *Research methods in the social sciences.* Arnold, London

Kraemer, H.C. and Thiemann, S. (1987) *How many subjects? Statistical power analysis in research.* Sage, London

Design appraisal

Wilson, J.R. (1991) 'Design decision groups – a participative process for developing'. In: *Participatory ergonomics*, edited by K. Noro and A.S. Imada. Taylor and Francis, London

Accident analysis

Weegels, M.F. (1996) *Accidents involving consumer products.* Delft University Press, The Netherlands

Task analysis

Kirwan, B. and Ainsworth, L.K. (1992) *A guide to task analysis.* Taylor and Francis, London

Glossary

confidence (interval)

The likelihood (usually 95% or 99%) that a measurement of the population will lie within a range that has been measured on a sample of users

construction safety

Product safety through appropriate materials, manufacturing, assembly or inspection.

design process/development process

The creative and problem-solving process by which a concept becomes a product ready for manufacture.

design safety

Product safety through an appropriate concept, presentation and associated information.

ergonomics

The study of people's interactions with products, environments and other people and use of the knowledge gained to develop safer, healthier, more satisfying, effective and efficient interactions.

ergonomics evaluation (of products)

The process of assessing ergonomics aspects of product use against safety and usability criteria. Excludes any assessment of quality of materials or manufacturing.

hazard

A situation, event or object that, in particular circumstances, could lead to harm.

hazard scenarios

Sets of circumstances by which a hazard does lead to harm through interactions of personal, task, product and environmental factors.

population

The complete group of potential users/misusers.

product

Any item or artifact that is used or interacted with by people. Can include architectural and construction features, or packaging and instructions.

product design

The form, function, methods of use, features, structure, materials and styling of a product.

product safety

The extent to which a product, whether used in expected or unexpected ways, does not cause harm to people.

reliability

Consistency of measurement; the extent to which a testing process would produce the same results if repeated again with different subjects or at a different time.

risk

Probability that a particular adverse event will occur as a result of a hazard, per unit of time, usage or population.

risk perception

Individuals' assessments of degree of risk associated with a hazard.

safety criteria

The level of a measurement (of dependent variable) deemed to constitute reasonable safety.

test

Assessment of how well a product performs in comparison to safety criteria.

user

In context of product safety, anyone who comes in contact with a product, whether intentionally or inadvertently, using, misusing or abusing it.

user sample

Group of people representing the population of product users, taking part in an ergonomics and design safety evaluation – usually in user trials.

user trials

Controlled process by which a sample of users test aspects of product performance and product use with the results assessed against safety criteria (characteristics of product, task, environment or even people may be simulated in such trials).

validity

Relevance of measurement; the extent to which what was intended to be measured was actually measured.