THE RELATIONS BETWEEN AGE INACTIVITY AND PHYSIOLOGICAL RESPONSES TO EXERCISE

by

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The investigations reported in this thesis have depended upon team rather than individual effort and it will be clear to the reader that this was because of the nature of the work. Therefore, although I am competent to use all the techniques described, understand them fully and can accept complete responsibility for them, I have not carried out every experiment myself.

I am grateful to my supervisor Professor P.H.Fentem for his scrupulous care and unstinting patience, to my first supervisor, Dr. R.Goldsmith, now Professor of Physiology at Chelsea College, for setting my feet on this path, and to Professor A.D.M.Greenfield for the opportunity to work here.

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C O N T E N T S

ABSTRACT

The studies described have been concerned with two previously untried techniques for measuring the response to exercise.

The general aim in both studies was to investigate the relations between age, activity and the response to exercise (physical condition).

In the first study (Part A) the response to exercise was measured using a bicycle ergometer pedalled with one leg. The subjects were in hospital for a meniscectomy. The results showed that bedrest as a model of inactivity caused a decline in physical condition. It also showed that the decline was greatest in those who were initially in the best condition. The older subjects deteriorated less and this appeared to be because their initial condition was the poorest.

In the second study (Part B) a method for measuring the response to exercise was developed which is suitable for use with elderly and frail subjects who could not be tested using existing methods. The method consists of self-paced walking at several speeds in a free situation, combined with the tape recording of heart rate and footfall. The assessment of physical condition which can be obtained is the heart rate at a standard walking speed. It was found to correlate with a conventional assessment made using a bicycle ergometer in which the heart rate was standardised on oxygen uptake adjusted for body weight.

No age differences have been found in physical condition measured in this way but significant differences were found in performance. The older subjects (aged between 60 and 80 years) of both sexes walked more slowly than the younger subjects (aged about 20 years) and the older men were found to walk with a shorter stride. These differences may also reflect levels of daily activity.

CHAPTER 1

GENERAL INTRODUCTION AND BACKGROUND

"How are you keeping then?"

"Not so bad, up and down like the weather. Got to keep going, that's the important thing".

"Trouble is, the older you get the harder you have to work because everything takes longer".

"Yes, but at least you can have a rest when you like".

A conversation overheard in
a Post Office in
Nottinghamshire. April 1974.

PROBLEM AND HYPOTHESIS

Amongst the elderly population there are large numbers of people whose customary levels of physical activity have fallen very low. These are the people who spend their days alone at home or in institutions, their activities including nothing more strenuous than walking slowly from bed to chair and back again. Their range of activities may be so impoverished and the quality of their life so poor that they are merely existing. This is the problem with which our studies began and this thesis describes the first stage in our efforts to analyse the significant factors which lead to this deteriorated state.

The hypothesis which we chose to examine is that the causes of physical deterioration and inactivity with age include inactivity itself.

There are prevalent social attitudes in this country which militate against even moderate physical activity in the elderly. Vague fears that too much exercise will precipitate injury, catastrophic exhaustion or overt illness bedevil the situation and have fostered disapproval of all but the mildest exertion. The elderly are encouraged to play safe and we suspect that this is to their sorrow.

If our hypothesis is correct then it might be possible to arrest or reverse physical deterioration in elderly people by ensuring that their levels of physical activity are maintained as far as possible. Thus some of the inevitable effects of aging and chronic disease might be offset.

De Vries (1971) and Strandell (1964) have shown that capacity for physical activity can be significantly improved with training. This was true for the elderly as well as for young people which encouraged us in our belief that physical deterioration with age is not inevitable and could be ameliorated by suitable activity.

The problem affects large numbers and already gives rise to social concern. The Registrar General's Annual Report for 1973 stated that 17% of the people in England and Wales were over 65 years of age and that the proportion was expected to increase. The Registrar General's Sample Census for 1971 indicated that there were 163,455 people over 65 years of age in homes for the old and disabled in England and Wales; this amounted to over 3% of the population aged over 65 years.

The figures for the City of Nottingham for 1972 were similar; 15% of the population were over 65 years, and the Department of Social Services stated that there were 1500 housebound persons over the age of 75 years. This figure did not include housebound persons aged between 65 and 74 years, but nevertheless amounted to 3.3% of the population aged over 65 years.

According to our hypothesis many of these people might still be living independent lives had they maintained better levels of physical condition by maintaining higher levels of physical activity.

In order to investigate this possibility a study of changes in physical condition before and after a period of reduced activity has been made. It was thought that older subjects might show a more marked decline in physical condition or a slower recovery. The aim of the study was to relate the changes observed to the age of the subjects.

Major problems have been the effective measurement of physical condition and of activity levels. The latter difficulty has been avoided because a clear-cut bedrest/non-bedrest situation was studied.

Physical condition is a concept which describes how well the body adapts to the environmental demands made upon it. (Denolin, Fox, Goldsmith, Hellerstein, Lange Anderson, Shephord and Varnauskas, 1968). The demands are many and various and the adaptive responses equally so. In consequence physical condition is a complex multifactorial phenomenon for which no single definition is entirely satisfactory.

For this study the relevant demand was that of active muscles for oxygen during physical work. The most important way in which this demand is met by the body is by adjustments in the respiratory and particularly the cardiovascular system. This led us to define physical condition as the heart rate at a given oxygen uptake during moderate physical work. The higher the heart rate the poorer the physical condition. Physical condition defined in this way can be measured under any circumstances in which oxygen uptake and heart rate can be recorded while the subject is working physically at a steady and vigorous rate. It is not a measure of performance capacity and takes no account of how effectively the muscles and skeletal system convert the oxygen supplied by the cardiovascular system into work. This aspect remains to be explored in future studies. The maintenance of adequate function of muscles and joints is also of importance for mobility and independence in the elderly.

BACKGROUND INFORMATION FROM THE LITERATURE

In this section other authors' studies of the interrelations between physical condition, physical working capacity, age and inactivity are considered and their implications discussed.

Age and Inactivity

It is generally assumed that elderly people are less physically active than young people but, because of the difficulty of measuring customary levels of physical activity, there is little evidence. Such subjective evidence as there is, based on diary methods, bears out the general assumption. Espenschade (1969) reported that, in a group of 197 women aged 35-80 years, the younger women were significantly more active, but she states that the sample may not have been typical because of a bias towards activity and health.

The Framingham study, among others, attempted to examine the suggested link between inactivity and heart disease. Some of the data gathered from 874 men and women in the community described their activity levels. This data supports the view that customary daily physical activity diminishes with age (Kannel & Gordon, 1970).

Physical Condition and Inactivity

It is a common experience that rest in bed brings an aftermath of lethargy and malaise but it is not possible to blame rest and inactivity alone for this. The reasons include the after-effects of disease and restrictions caused by orthopaedic problems. Therefore healthy subjects have been used to study the effects of bedrest alone. Deconditioning under these circumstances was first reported by Deitrick, Whedon & Shore (1948) and by Taylor, Tipton, Henschel, Brozek & Keys (1949); it was reviewed by Vallbona, Vogt, Cardus, Spencer & Walters (1965) for the American Space Research Programme and studied more recently by Saltin, Blomqvist, Mitchell, R.J. Johnson Jr., Wildenthall & Chapman (1968). It is consistently reported that after a period of recumbent bedrest there is a reversible decline in physical condition and in physical working capacity measured as maximum oxygen uptake.

Saltin et al found a mean change of 25 bts min^{-1} in heart rate at an oxygen uptake of 1.5 l min^{-1} and a decline of 27% in maximum oxygen uptake. This is a change which might curtail customary daily activities a good deal. Recovery to pre-bedrest condition is reported to take many weeks (Deitrick et al, 1948; and Taylor et al, 1949).

Under these circumstances the drop in activity levels, physical condition and physical working capacity appear to be causally linked and support the view that inactivity is a root cause of decline in physical condition at least in the young.

One similar study on elderly persons is reported by I. Gore (1972) in a review. She cites the work of Chebotarev, Korkushko & Kalinovskaya (1969) who submitted 22 fit elderly persons to 6 days of strictly enforced bedrest. The results of this were signs of deficient oxidative processes, raised levels of urinary non-protein nitrogen and subjective feelings of being unwell. The subjects took 1-2 weeks to return to their previous state. No direct measurements of physical condition or physical working capacity were reported in this study.

All these studies have been made on people who have submitted to a regime of bedrest for the sake of the investigations, but it has also been shown that inactivity alone,without any increase in the proportion of time spent in the recumbent position,leads to deconditioning (Lamb, Johnson, Stevens and Welch, 1964; and Rodahl, Birkhead, Blizzard, Issekutz and Pruett, 1967). It remains to be established whether older people under natural circumstances of slowly diminishing activity or more sudden immobilisation due to illness or injury, also decline in physical condition in this way.

Physical Condition and Age

If it is true in general that age is associated with diminished activity then it would be expected that age would show a negative correlation with physical condition. Many studies have been made which include information about the relationship between age and physical condition. Table I (p7) summarises the relevant results. They cover an age range of 18-92 years, both sexes and various occupational groups which are listed where known. Physical condition is measured in terms of the heart rate at a fixed level of work or of oxygen uptake.

Most of these authors report no change with age in the relationship between heart rate and oxygen consumption (or work rate).

The interpretation of this evidence is difficult for several reasons arising from the cross-sectional nature of the studies. There is a large variation within each age group which would obscure small age differences, and there may be a sample bias towards good physical condition in the older age groups.

Unless the test is suitable for and acceptable to all members of the group under study the sample measured will not be representative of the whole group. This is particularly likely to happen when a work test, maximal or submaximal, is used with a group of old people. It would probably exclude just those individuals of low physical working capacity that are of most interest in this study, either because the test would be prejudicial to their health or because they would feel disinclined to do it.

Two notable exceptions occur to the general picture of no age changes. Borg and Linderholm report a small but significant drop in heart rate with increasing age over a range of work rates, in one of their two groups of subjects, the lumberjacks, and Becklake, Frank, Dagenais, Ostigny & Guzman (1965) also found a drop in heart rate with increasing age at a given work rate. This implies an improvement in physical condition with increasing age!

However, in their longitudinal study Dill, Robinson & Ross (1967) found a decrease in the oxygen pulse (oxygen uptake per heart beat) in 7 out of 9 athletes after 20 years. This implies a rise in heart rate for a given oxygen consumption and a decline in physical condition. The authors attribute this in part to a decline in customary levels of activity rather than to age alone.

TABLE I Results of investigations in which age differences in the relationship between heart rate and work rate or oxygen consumption have been reported

Authors	Year	Subjects				Work Rate	Age Difference
		No.	Sex	Age Range	Occupation		
Robinson	1938	50	♂	20-69	Various non-athletic	Treadmill, 15 min, 5.6 km hr^{-1} 8.6% grade	None
Norris, Shock & Yiengst	1953	140	♂	20-92	Various	Step test, 1½ min, 220 kpm	None
Durnin & Mikulicic	1956	24	♂	20-65		Treadmill, 8 min, 3.7 + 4.3 mph level	None
I. Astrand	1958	81	♂	50-64	Brewery workers	Bicycle ergometer 900 kg m min^{-1}	None
	1960	44	♀	20-65	Various	Bicycle ergometer 300, 450, 600 kg m min^{-1}	None
Grimby & Soderholm	1963	115	♂	20-65	Various	Bicycle ergometer 300, 600, 900 kg m min^{-1} → maximum	None
Strandell	1964	121	♂	30-83	Various	Bicycle ergometer fH 130 & 170	None

continued overleaf

TABLE I (continued)

Becklake et al	1965	46	♀	20-69	Various	Bicycle ergometer 150, 350, 550 kg m min^{-1}	None
		48	♂	22-85	Various	Bicycle ergometer 150, 350, 550 kg m min^{-1}	Older had lower heart rates
Wessel et al	1966	98	♀	20-60	Various Middle class	Treadmill 120 kg m min^{-1}	None
Grimby & Saltin	1966	33	♂	42-68	Athletes (Orienteers)	Bicycle ergometer 600-1200 kg m min^{-1}	Older had higher heart rates (no statistics)
Julius et al	1967	54	♂	18-68	Sedentary	Bicycle ergometer 300 kg m min^{-1} - max	None
Brown & R.J. Shephard	1967	62	♀	41-69	Employees of a Dept. store	Treadmill 1.75 mph	None
Van Dobeln et al	1967	84	♂	30-70	Building workers	Bicycle ergometer	None
Higgs et al	1967	18 118	♂ ♀	31-53 28-53	Various	}Bicycle ergometer }300-900 kg m min^{-1}	None

continued overleaf

TABLE I (continued)

Borg & Linderholm	1967	61	♂	27-63	Lumberjacks	)Bicycle ergometer))	Older had lower heart rates
		216	♂	18-79	Various	)300-1200 kg m)min^{-1}	None
de Vries & Adams	1972	24	♂	16-70	Various	Bicycle ergometer 70-100 watts	None

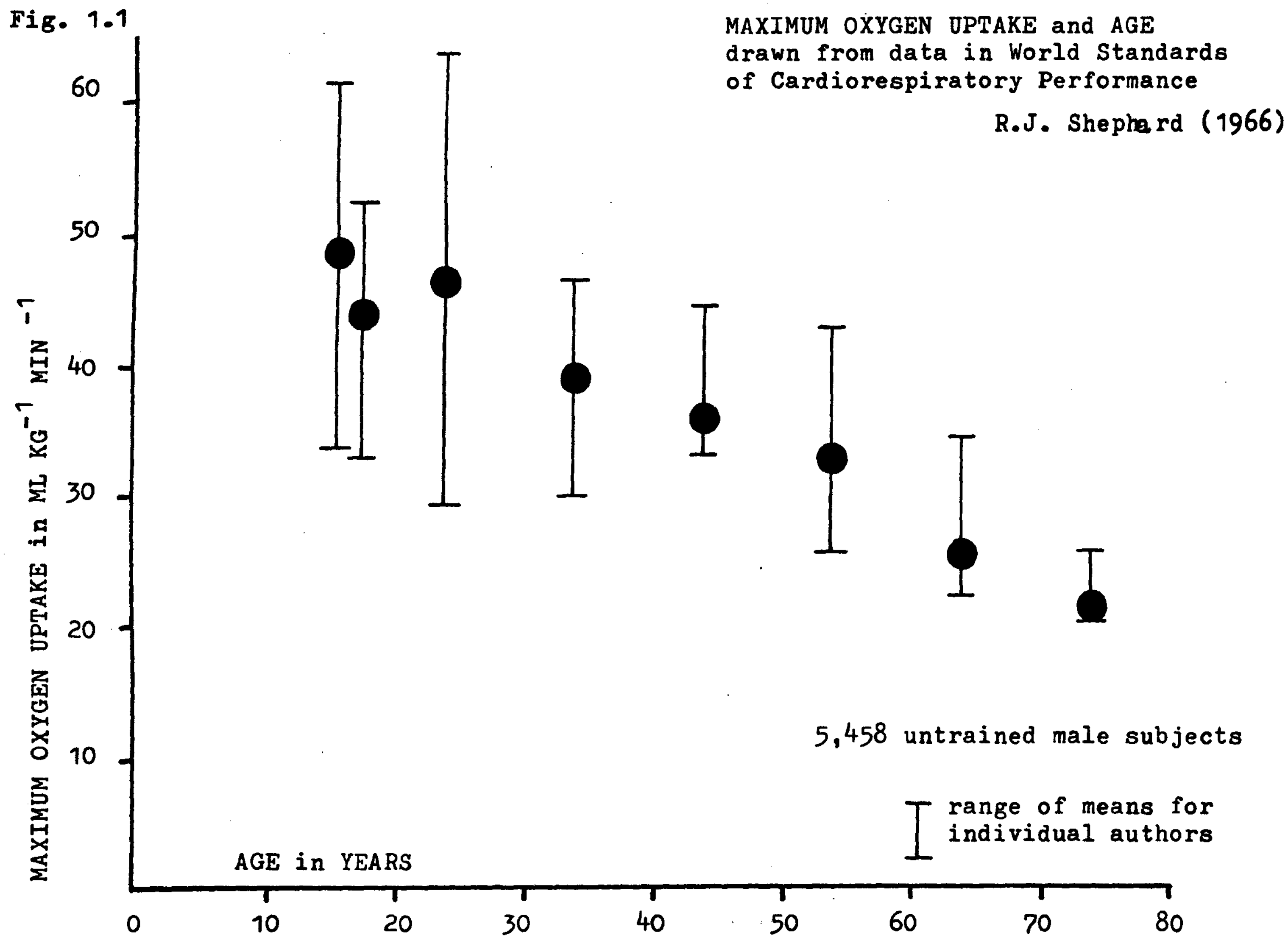
The reason why most of the cross-sectional results reported in Table I do not reveal a change with age may be because each author chose a group that was homogeneous with respect to customary levels of physical activity, or groups in which there was no significant change with age in levels of physical activity. No measurements were made of activity levels and so no firm conclusions can be drawn about this.

Physical Working Capacity and Age

In contrast to the confused evidence on physical condition derived from sub-maximal tests the evidence from age-related measurements of physical work capacity, measured as maximum oxygen uptake, reveal a marked decline with increasing age. Fig.1.1. (P.11) summarises the results from a large number of cross-sectional studies which combined represent data from 5,458 untrained healthy male subjects of various nationalities and ranging in age from 16 to 80 years (R.J. Shephard, 1966). The graph shows that those in their seventies can muster only half the oxygen uptake of those in their twenties and thirties. If the efficiency of converting oxygen into external work does not change with age (Fischer, Parizkova & Roth, 1965) this represents a 50% decline in physical working capacity.

The vertical bars in Fig. 1.1 represent the ranges of means from individual authors rather than the full ranges because a large amount of data has been compressed into one graph. It can be seen even with this limitation that the variation is large and that the range for the 60 year olds overlaps with the range for the 20 year olds. The graph also suggests that the greatest deterioration occurs at the greatest ages. Since only the fittest of the older groups would be able to undertake a maximum test this phenomenon is probably much more marked.

Fig. 1.1


MAXIMUM OXYGEN UPTAKE and AGE
drawn from data in World Standards
of Cardiorespiratory Performance
R.J. Shephard (1966)
MAXIMUM OXYGEN UPTAKE in ML KG^{-1} MIN^{-1}
60
50
40
30
20
10
AGE in YEARS
0
10
20
30
40
50
60
70
80
5,458 untrained male subjects
range of means for
individual authors

More recently the decline in maximum oxygen uptake has been confirmed by Andersen (1969), Astrand (1968) and de Vries (1971) in further cross-sectional studies.

The studies mentioned so far have all been made on male subjects. There is ample evidence for a similar decline in maximum oxygen uptake in females. The studies are summarised by R.J. Shephard (1966) and Profant, Early, Nilson, Kusumi, Hofer and Bruce (1972).

The cross-sectional study is the most practical way of amassing evidence of age-changes but it could be affected by changes other than age, for example better nutrition of the younger groups at critical stages in their growth and development. However the pattern of results is confirmed by longitudinal studies.

Dill, Robinson & Ross (1967) re-tested 16 athletes after 20 years and found a decline of about 30% in their maximum oxygen uptake which is larger than the changes reported in the cross-sectional studies of Shephard's review.

Dehn & Bruce (1972) report an annual decrement of 0.94 ml kg^{-1} min^{-1} over 2.3 years in 40 subjects. This rate of decline is similar to that found by Dill _et al_ and Hollman (1965) but is faster than that revealed by cross-sectional studies (0.40 ml kg^{-1} min^{-1} is quoted by Dehn & Bruce from 17 combined studies on 700 subjects). The difference is likely to be due to the methodological problem of sample bias in the older age groups in the cross-sectional studies.

Physical Working Capacity and Inactivity

Dill _et al_ assumed that their athletes were less active when re-tested 20 years after their time of competitive performance, and this was confirmed in the subjects' reported verbal statements. It is therefore possible that the observed decline in their physical working capacity is due to their decreased levels of physical activity rather than their increased age. This view is supported by Grimby, Nilson and Saltin (1966) who found that sedentary athletes declined with age much more than their active counterparts who were matched when young for maximum oxygen uptake; and by Dehn and Bruce (1972) who found that the active subjects in their sample who took part in weekly running activity declined three times less rapidly with age than the sedentary subjects. Profant et al (1972) found that activity affected the age-related decline in women and that active subjects had capacities which were similar to those of sedentary subjects 10 years younger.

It is therefore a plausible assumption that a low capacity for physical work in the elderly is partly due to low levels of customary physical activity.

Physical Working Capacity and Physical Condition

The considerable decline in physical working capacity which occurs with age is not matched by any measured decline in physical condition, at least not in cross-sectional studies, whereas in young people inactivity has been shown to affect both.

The inactivity of bedrest appears to change the relationship between heart rate and oxygen uptake by a shift in the line towards higher heart rates, without any change in the slope of the line. (Saltin et al, 1968. Fig. 1.2, p14). This results in a decline in physical condition and maximum capacity.

Age appears to bring no change at all in the relationship between heart rate and oxygen consumption but a progressive reduction in maximum capacities only. This has been demonstrated clearly in the same group of subjects (Borg & Linderholm, 1967. Fig. 1.3, p14).

Physical condition is a measure of the performance of the

Fig 1.2 CHANGES in HEART RATE and OXYGEN UPTAKE with BEDREST. Redrawn from Saltin et al (1968).

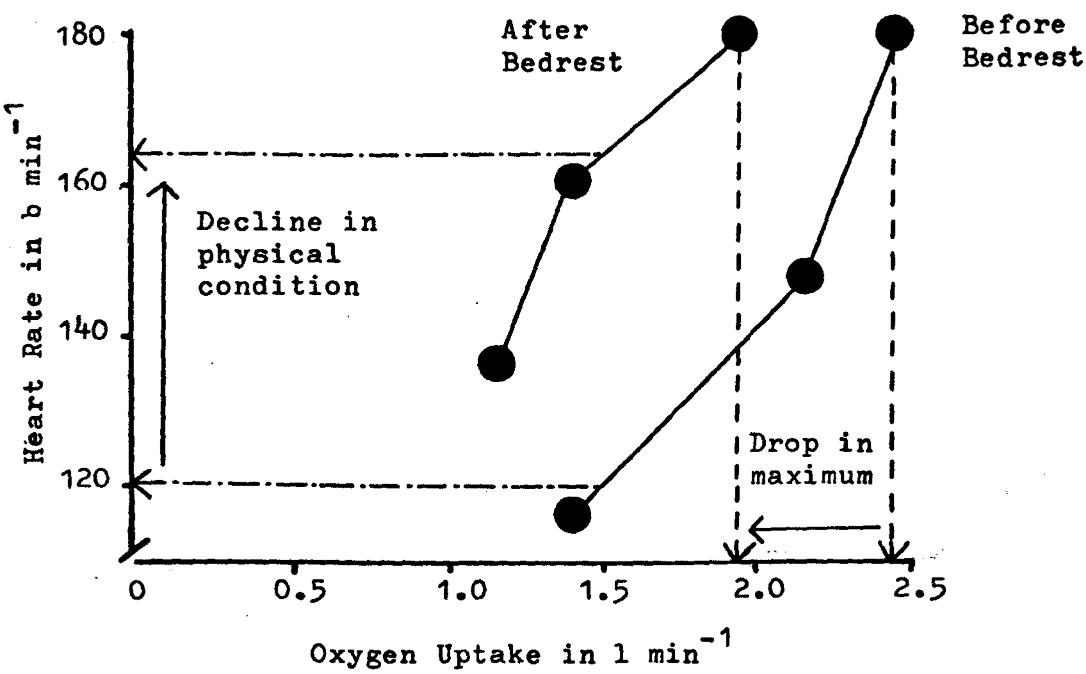
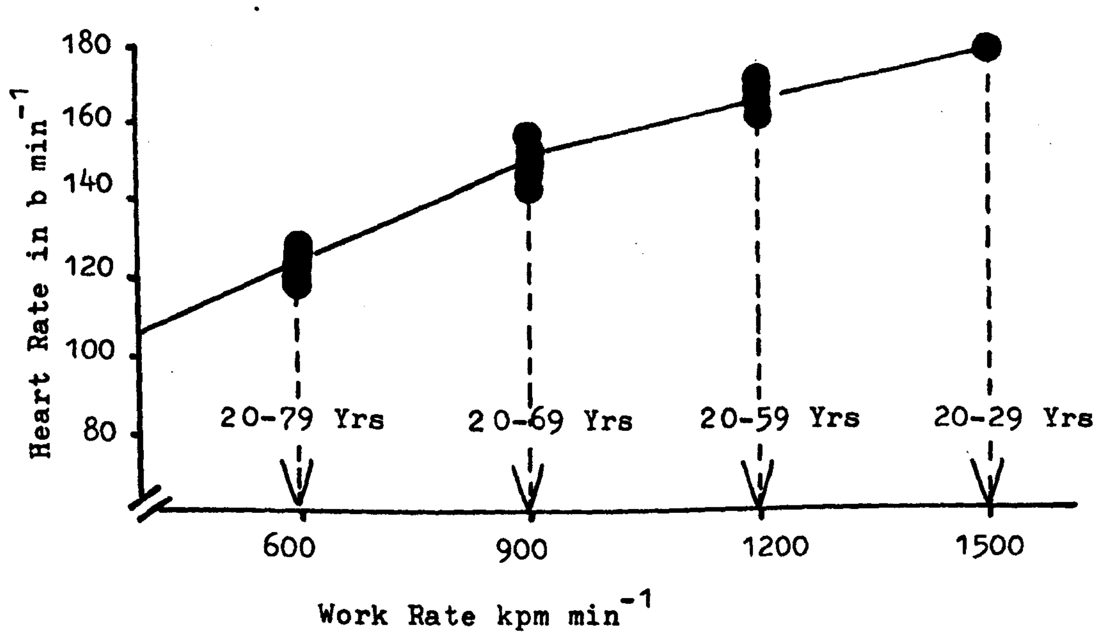


Fig 1.3 CHANGES in MAXIMUM HEART RATE and WORK RATE with AGE. Redrawn from Borg & Linderholm (1967).



This shows that there is no change in the relation but that the maximum values decline with increasing age.

cardiovascular and respiratory systems in response to exercise but physical working capacity depends also upon the effective functioning of muscles and joints. It might therefore be concluded that age brings a deterioration in neuro-muscular or skeletal systems which does not affect the performance of the cardiovascular system in response to exercise. There is much evidence for a decline in the strength of muscles. Asmussen & Heebøll-Nielsen (1962) report a 10% decrease in many muscles and Campbell, McComas & Petito (1973) have demonstrated that there is considerable motorneurone degeneration in the elderly which is reflected in the loss of functional motor units in the forearm. Another potent factor may be an increased distaste for strenuous and uncomfortable exertion with its attendant risks, real or imagined.

Andersen (1959) reports reduced lung function in old age but except for a few individuals it is not a limiting factor in exercise. There is a drop in maximum heart rate but this may be largely a function of decreased demand provided the subject is free from heart disease.

There is an increase in blood pressure with age which will add to the work of the heart, but the evidence for a change in cardiac output or stroke volume with age is controversial. Becklake, Frank, Dagenais, Ostigny & Guzman, (1965) report an increased cardiac output for a given work load with increasing age; Strandell (1964) and Brandfonbrewer, Landowne & Shock (1955) report a decrease; and Julius, Amery, Whitlock & Conway report no change.

Training and Age

Despite the evidence of declining function and possible irreversible degeneration of the nervous system, an increase in activity levels in the form of training can improve physical condition and physical working capacity in the elderly as well as in the young. De Vries (1970) trained 66 men aged 52-87 years for six weeks and reports improvements of 29% and 35% in oxygen pulse and minute ventilation, respectively, at a heart rate of 145 b min^{-1}. Barry, Daly, Pruett, Steinmetz, Page, Birkhead & Rodahl (1966) trained 8 subjects of mean age 70 years for 3 months and achieved a 76% increase in their physical working capacity.

Deshin (1969) has claimed that exercise can arrest the usual decline with increasing age. His study was a longitudinal one covering ten years. His 22 subjects ranged from 51-74 years at the beginning. Their physical condition improved over a period of several years and did not deteriorate thereafter during the 10 years over which the exercise was maintained.

This provides encouraging support for our belief that the rapid deterioration in physical condition with increasing age is not inevitable.

von Hollman (1965) made a 14 year study of subjects who were already making habitual use of public facilities to train regularly. He compared 17 elderly subjects who trained twice a week with 39 control subjects who were sedentary and did not train. Over the 14 years the sedentary group declined by 31% in maximum oxygen uptake whereas the active subjects who maintained their training declined by only 10%. Their level of activity was evidently sufficient to offset the decline but not to prevent it completely as Deshin appears to have done.

Suitable programmes of activity and exercise for maintaining physical condition are not easily quantified. They depend upon the particular physiology of the individual, his initial physical condition and the condition to which he aspires.

De Vries (1971) recommends an exercise level which raises the heart rate through 40% of its range from resting to maximum, and considers that older men need to be stressed less in absolute and relative heart rate terms than younger men in order to improve their physical condition. This study was based on 52 subjects aged 60-79 years (de Vries & Adams, 1972).

Strandell (1964) on the other hand alleges that the effect of training is less marked in old than in young men. He trained 6 old men by giving them 4 maximum work tests a week for a month. He found no change in maximum heart rate and a mean decrease of 10 b min^{-1} at an oxygen uptake of 1.5 l min^{-1}. It is possible that the subjects were atypical or that they were in better physical condition to start with than those of de Vries.

If subjects are already well-trained then further training will not produce more improvement, and conversely subjects in poor physical condition will be "easy" to train because moderate levels of work represent a big increase in their customary activity patterns and will therefore produce a big improvement in physical condition. This is borne out by Tzankoff, Robinson, Pyke & Brawn (1972) who found that older men had lower work capacities before training and that their percentage improvement was greater both in physical condition and in maximum oxygen uptake.

Stamford (1972) studied chronically institutionalised geriatric mental patients who had a history of many years sedentary existence, and similar patients who had been recently hospitalised and who were in significantly better physical condition. Training at 50% of the heart rate range for 18 weeks improved the physical condition of the chronic patients and a further 6 weeks training at 60% improved both the chronic group and the recently admitted group.

Stamford's work provides evidence for a positive correlation between customary activity levels and physical condition and also for the greater "trainability" of those in poorer physical condition.

It is clear that training can improve the physical condition and maximum capacities of the elderly and that the dose required depends upon the initial condition. Training is a special case of increased activity levels and so has the opposite effects to inactivity. It is a useful way of initiating improvement in physical condition but will bring no lasting benefit unless it catalyses a change to a more active life style which incorporates an appropriate amount of spontaneous exercise.

PLANS

The Choice of Subjects

In view of all the evidence it seemed likely that inactivity could be a major cause of decline in physical condition in post-retirement age groups, both insidiously over the years, or more suddenly following illness or accident. We set out to investigate the acute situation in which the inactivity of bedrest follows surgery in the hope of finding age differences.

The choice of subjects for investigating this hypothesis was confined to those who were about to undergo a period of enforced rest on their own account. There were two reasons for this. We wished to study a real-life situation rather than an artificial one and secondly we did not feel ethically justified in imposing an unnecessary bedrest regime on older subjects because of the risk of venous thrombosis and the likelihood of a deterioration in physical condition which might take a long time and much effort to reverse.

Having made this decision hospital patients were chosen rather than those bedbound at home because it was convenient to have all the subjects in one place and desirable to have a relatively well-controlled experimental situation. Moreover the protected environment of the hospital and its staff provided a necessary substitute for that of the physiology department.

The final choice of subjects was based on the following criteria. The patients had to be:-

1. about to undergo a well-defined period of strictly enforced bedrest;
2. in a good state of general health;
3. numerous because submaximal tests are not very sensitive and large samples are needed to reveal differences between groups unless the differences are very large (see [16] p8);
4. representative of a wide age span because we wished to investigate the age factor;
5. capable of performing an exercise test involving large muscle groups working at rates of up to 400 kg m min^{-1} both before and after their period of bedrest.

These considerations led to the choice of male patients undergoing removal of a knee cartilage (meniscectomy) in an Orthopaedic Hospital. They appeared to meet all our requirements.

1. The operation is always followed by a period of bedrest and rehabilitation physiotherapy.
2. The subjects are healthy apart from their knee trouble.
3. 4. The operation is common among young footballers and also among middle-aged coal miners for whom it is an occupational hazard. The hospital is fully equipped for the complete rehabilitation of miners. Therefore it seemed likely that two age groups of a reasonable size differing in age could be measured.
5. The operation only affects one leg and there is no respiratory or abdominal involvement, therefore the subjects can use the other leg to do an exercise test.

There was no space in the hospital buildings available for our use and so a mobile laboratory was acquired and suitably equipped.

This investigation was a pilot project with several major objectives. It was an attempt to prove our hypothesis that the deconditioning effects of bedrest and inactivity are more severe or longer lasting for older subjects. It was also an introduction for the research team to field work and to the problems of work tests with untrained and uncommitted subjects, a first step towards the more difficult problems of testing elderly subjects from the general population.

CHAPTER 2

GENERAL METHODS

METHODS

Measurement of Physical Condition

Physical condition was defined in terms of the linear relationship between heart rate and oxygen uptake (see p3). The lower the heart rate at any given oxygen uptake the better the physical condition was considered to be (I. Astrand, 1957). Cotes (1971) measured the response to exercise in a similar sense by relating the cardiorespiratory response to the physiological task.

Oxygen uptake represents the total energy expenditure of the body. The amount of energy expended for unit uptake of oxygen depends upon the proportions of fat and carbohydrate being oxidised. With a mixed diet (respiratory quotient 0.85) the energy equivalent of 1 l of oxygen is 4.85 kcals. Within the variations due to the substrate being oxidised, the oxygen uptake represents the cost of all the work being done by the body, including the external work output from skeletal muscles, work done in overcoming internal friction, work done in maintaining posture, and internal metabolic work. At very high external work rates the muscles derive significant amounts of energy from anaerobic processes which would not be revealed by the oxygen uptake but it was not envisaged that subjects would work at such levels in this study.

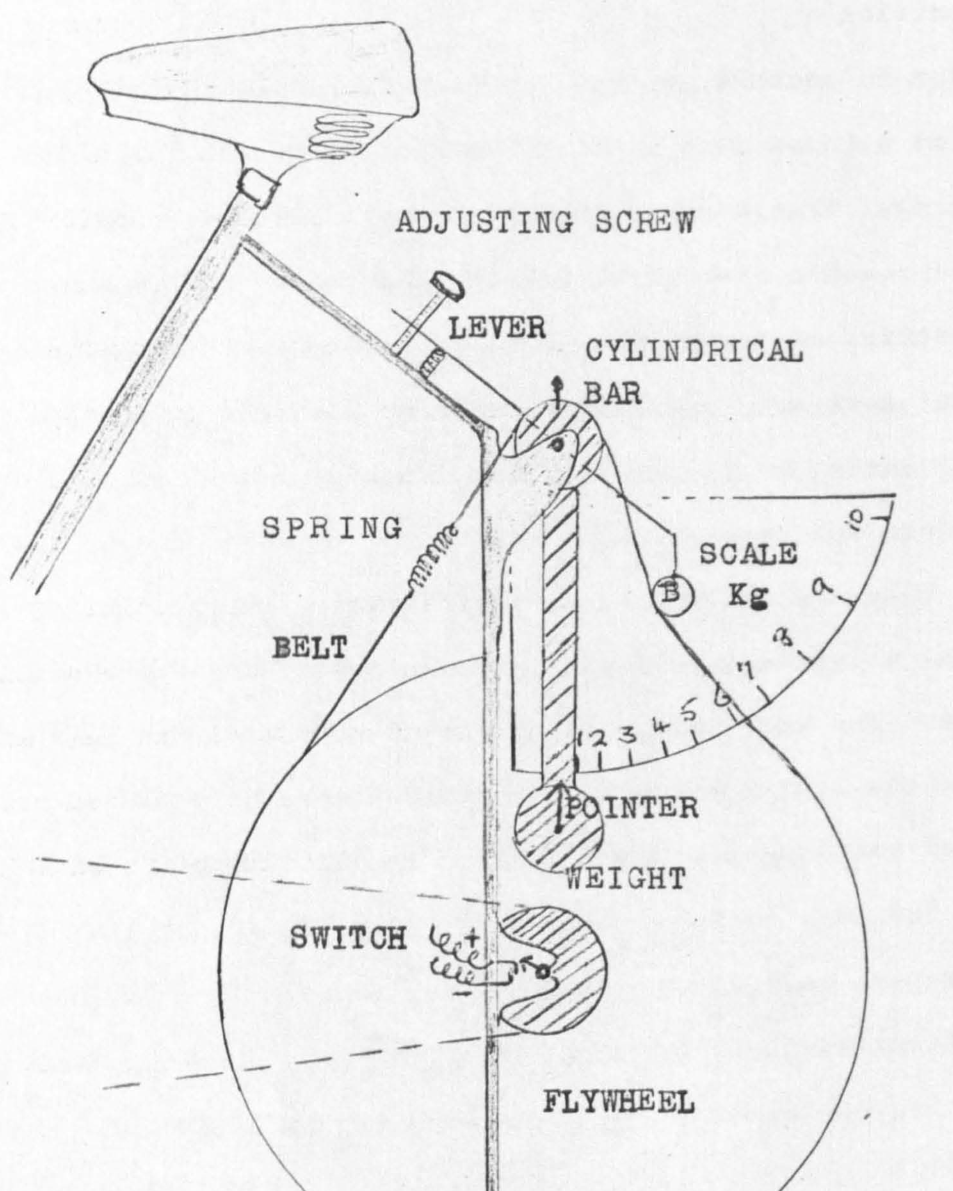
Heart rate was taken as a measure of the way in which the body responds to demands for increased oxygen transport. An increased oxygen supply to exercising muscles is achieved by increased blood flow to those muscles and a greater oxygen extraction from the blood by the muscle cells. The heart rate has a linear relationship with cardiac output provided that there is no change in stroke volume. Astrand, Cuddy, Saltin & Stenberg (1964) have shown that this holds good at heart rates of over 90 b min^{-1}. The heart rate is therefore proportional to the cardiac output during exercise. If there is an optimum redistribution of the blood flow to working muscles from areas such as the splanchnic bed, and an increased oxygen extraction, then the increased demand for oxygen can be met with a small increase in heart rate rather than a large increase, and the subject is considered to be in good physical condition.

In order to measure physical condition in this way the subject should work at a known rate until the body systems adapt to that rate of working. This happens within minutes. The heart rate and oxygen uptake reach a plateau at a level related to the work rate and representative measurements may then be obtained. The subjects should work at several grades in order to furnish several points on the line relating heart rate and oxygen uptake. The points should be spaced out over the subject's range of working capacity. This reduces inaccuracies due to the continuous variation of the heart rate and allows comparisons to be made at standard levels of oxygen uptake. The work should be performed with large muscle groups, otherwise fatigue limits the number of grades of work which can be undertaken and the length of time for which strenuous work can be maintained. For this reason work with the legs during cycling on a bicycle ergometer, walking on a treadmill or stepping up and down have been extensively used and found satisfactory. (Fundamentals of Exercise Testing: Andersen, R.J. Shepherd, Denolin, Varnauskas & Masironi, 1971.)

The bicycle ergometer was preferred in this study for a number of reasons. It is a convenient size for field studies in a mobile laboratory, the rate of working can be finely graded within wide limits, there is no anxiety about tripping, subjects learn to perform consistently quickly (Allen, Benade, Davies, di Prampero, Hedman,

Fig.2.3.

DIAGRAM OF THE RALEIGH BICYCLE ERGOMETER



Merriman, Myhre & R.J. Shephard, 1968), and the body is stationary above the waist so that making the measurements of blood pressure and collection of expired air is convenient.

Measurement of Rate of Working.

Description of Bicycle Ergometer

A mechanically braked bicycle ergometer made by Raleigh Ltd., was used. It is similar in principle to the van Döbeln ergometer, (van Döbeln, 1954).

The flywheel is mounted at the back of the ergometer and rotated by a fixed pedal system against a variable load provided by the drag of a friction belt (see Fig. 2.3 opposite). The external work rate is thus the work done in unit time in over-coming the belt friction and rotating the flywheel, (work done = force applied to the belt x circumference of flywheel x no. of revolutions per unit time of flywheel).

Measurement of Work Load. The load against which the subject pedals is the force applied to the friction belt. The force applied depends upon the tension developed by the tightness of the belt and the rotation of the flywheel against it. The load was, therefore, measured during pedalling. The mechanism is illustrated in Fig. 2.3 (opposite).

The belt is rivetted to a cylindrical bar, shown in cross-section in the diagram, so that it cannot turn with the flywheel. The bar is attached to the bicycle frame by a spindle through its centre which allows it to turn within the limits imposed by the attached belt. The tension in the belt can be increased by a lever which is also pivotted on the bar spindle. The lever arm (B) presses against the belt. The load adjusting screw at the other end of the lever moves the arm (B) in against the belt in order to increase its tension and thus increase the load.

A sinus balance provided by a weighted pointer rigidly attached to the cylindrical bar opposes the torque on the bar during pedalling and acts as a measuring device. When the subject pedals the drag of the flywheel against the belt moves the bar round and lifts the weight. The movement of the weight is proportional to the drag on the belt and is thus a measure of the load. The scale is calibrated in kg units by removing the belt and hanging weights over the front of the bar from the rivets. The mass of the weight on the end of the pointer determines the sensitivity of the load measurement. A small weight would swing over the whole scale with a small load. A strong spring incorporated in the belt damps out oscillations caused by the pedalling subject. It is necessary that the belt is as inelastic as possible and resistant to wear. Cross-woven nylon webbing intended for use by climbers was found suitable. The belt groove on the flywheel needed cleaning from time to time with emery paper as it rusted if not in constant use.

Measurement of Work Rate. The work rate is the product of the work load, the circumference of the flywheel, and the number of revolutions per minute. The circumference was conveniently 1 metre. A rate of 150 rpm of the flywheel was imposed by asking subjects to pedal at 50 rpm (pedal ratio 3:1). This pedalling rate corresponded to a speedometer reading of 10 mph. Subjects first watched the speedometer but then were expected to maintain this rate during the measurement of oxygen uptake. The pedalling rate varied to some extent during work tests and this is discussed on p115. A stricter adherence to the required rate of 50 rpm might have been obtained by the use of a metronome, but this idea was rejected because it was considered that it would add to the psychological stress of the test which we wished to keep to a minimum. At 50 rpm the efficiency of pedalling is maximal and both heart rate and oxygen uptake are at a minimum in relation to the external work rate, (Eckermann &

Millahn, 1967).

The work rate was thus known and was conveniently expressed as kg m min^{-1} rather than in the S.I. equivalent of watts because of the way in which it was measured.

Errors. The errors arose almost entirely from the error in the load adjustment. This was ± 0.2 kg which amounts to an error of ± 20% in the rate of working at a load of 1 kg and ± 10% at a load of 2 kg. The revolutions of the flywheel were known to the nearest whole number and therefore carry an error of ± 0.5 revs, which will give rise to an error of ± 0.3% in the rate of work. This is negligible. The frictional losses in the transmission are of the order of 5-10% provided the chain and bearings are properly lubricated, (van Döbeln, 1954), so the measured external work is always less by this amount than the true value.

Adjustments for Height. The handle bars and saddle height of the bicycle were adjustable. In practice it was seldom found necessary to adjust the height of the handlebars. They were designed so that most of the subject's weight rested on the saddle. The saddle height was adjusted for each subject so that the legs were almost completely extended when the pedal reached its lowest point and the foot was horizontal, (Hamley & Thomas, 1967).

Modifications for One-Legged Pedalling

The subjects were patients with a damaged knee cartilage, and therefore they could pedal with only one leg. First attempts in the laboratory at pedalling with one leg revealed that it was difficult to keep the pedals turning and that as the load increased it rapidly became impossible. This is because the momentum imparted to the system on the downstroke is insufficient to drive the working pedal full circle, ready for the next down stroke. It was therefore necessary to provide some means of helping the working pedal to return to the top of its circle.

This was done by fitting an adjustable toeclip of the kind used by racing cyclists to the pedal and increasing the momentum of the pedal system by replacing the pedal not in use with a lead counterweight. This allowed the one active foot to store energy on its downstroke and so increase the momentum of the pedal system sufficiently to keep it rotating during the relatively quiescent upstroke of the active foot.

Subjects were asked to use a "butcher's boy" technique rather than the ankling technique of the racing cyclist so that there was a rest pause for the muscles while the energy stored in the counterweight returned the pedal. In "butcher's boy" pedalling the working leg pushes the pedal down with sufficient force to give the counterweight enough momentum to complete the revolution without further effort from the leg. In "ankling" the leg pulls the pedal up by means of the toeclip as well as pushing it down, so that the total effort is spread over the whole pedal cycle rather than being concentrated in the down stroke.

Three counterweights were made of 1.6 kg, 3.2 kg, and 4.8 kg which correspond to belt loads of 1 kg, 2 kg and 3 kg respectively. The belt load was adjusted while a subject pedalled to a load of 1, 2 or 3 kg, then the appropriate counterweight would just move the flywheel from rest when the pedal shaft holding the counterweight was 45° of arc past its highest point from the floor.

There is no reason why the counterweight should increase the load significantly during pedalling. The weight of the flywheel is not considered to affect it. A heavy flywheel imposes a heavy load at the onset of exercise and the stored energy keeps it turning briefly at the end of exercise, but during steady pedalling the

Fig. 2.4

The Bicycle Ergometer with the Counter-Weight in place of one Pedal

weight of the flywheel does not affect the load. The counterweight behaves in the same way.

The thrust on the bearings in both the pedal shaft and the flywheel shaft causes small frictional losses, which increase with increasing load. The thrust on the working pedal was increased by the use of the counterweight and this would have increased the frictional losses slightly but the change was probably small.

A stool was provided for the inactive foot and a protective metal flange, attached to the stool, curved over the path of the rotating counterweight.

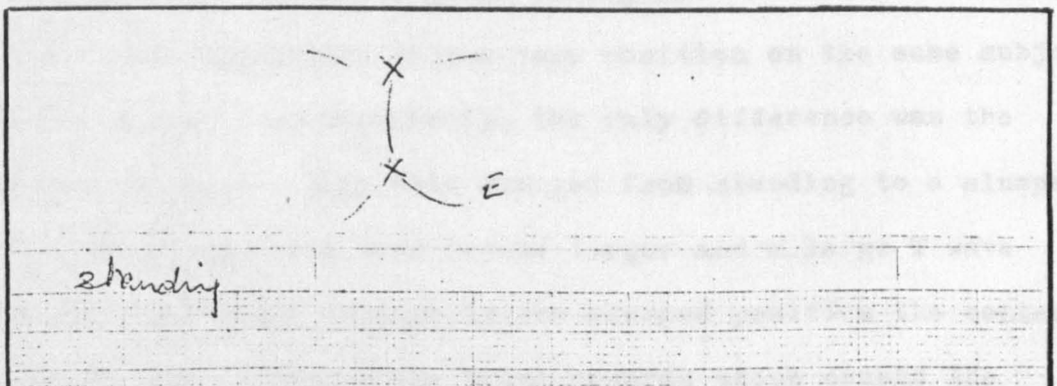
Measurement of Heart Rate

The ECG. Heart rate was measured by recording the ECG. The standard technique is highly satisfactory for recording resting heart rates but, when the subject is working, problems arise. The signals are only a few millivolts in amplitude and are therefore easily obscured by small signals arising from any other source especially if these are similar in frequency to the ECG signals and impossible to filter out.

Electrode Application. It was essential to reduce the skin resistance to as low a value as possible in order to obtain as large a signal as possible to start with. The skin was prepared by rubbing with acetone to remove the oils and then abrading with a pumice stone to remove the stratum corneum, (Blackburn and Rose, 1968). This reduced the impedance between the electrodes from about 1,000 Kohms to 5 Kohms or less. Silver self-adhesive T.E.M. electrodes were used.

Electrode Position. The electrodes were positioned over bony areas in the V_5 position and over the manubrium or at opposite ends of the sternum so that they picked up a large R wave with a minimum of interference from other thoracic muscles. The V_5 position usually gave the

Fig. 2.5 THE EFFECT OF POSTURE ON THE EGG
Two electrocardiographs showing how the amplitude and configuration of the signal changes according to changes in posture which affect the position of the heart relative to the electrodes.



biggest signal with short subjects of mesomorphic or endomorphic build and the sternal position with tall thin subjects of ectomorphic build. This is because the electrical axis of the heart is nearer to 180° in tall thin subjects when standing and nearer to 135° in short stocky subjects. The effect of the relative configurations of the electrical axis and the surface chest electrodes is demonstrated in Fig.15. The two records are from the same electrodes in the same position on the same subject and were recorded consecutively, the only difference was the subject's posture. When this changed from standing to a slumped sitting position the R wave became larger and a large T wave appeared, presumably because in the slumped position the contents of the abdomen displaced the heart upwards which caused the enlargement of the R wave and tilted the apex sideways so that the transverse wave of repolarisation became detectable. Large T waves were avoided if possible because they would trigger the ratemeter as well as the R waves if they were of similar amplitude. <u>Recording Equipment</u>. Having achieved an ECG with a clear R wave of at least 1 mv it was necessary to see that no substantial interference arose in the leads and connections on the way to the ECG amplifier. Low noise cable was used and earth loops and induced currents from other electrical equipment were avoided as far as possible.

Measurements of the heart rate were obtained by counting the QRS complexes recorded on one channel of a Devices (M 19) multichannel hot pen recorder. This recorder was used because with the hospital patients 9-lead resting ECGs were recorded before and immediately after exercise and examined for abnormalities by medically qualified staff.

During a work test a ratemeter (Devices Instantaneous 2750) was used for continuous visual monitoring of heart rate so that the stress of the on-going exercise was known for each subject and a permanent record was also made on another channel of the recorder so that it was known when the heart rate became steady and measurement of oxygen uptake could begin.

The ECG signal was also continuously displayed on a cathode ray oscilloscope with a slow sweep and long persistence. This provided an instantaneous monitor of the form of the complexes and made it possible to watch for extra-systoles and other abnormalities.

Measurement of Oxygen Uptake

The oxygen uptake during exercise was obtained by collecting expired air for a measured period of one minute or two minutes at low levels of oxygen uptake. The expired air was collected by asking the subject to breathe through a valved mouthpiece into a Douglas bag. The air could then be analysed for oxygen and carbon dioxide content. The information thus obtained could be used to calculate the oxygen consumption, the carbon dioxide production, the respiratory quotient and the minute ventilation.

Collection of Expired Air. Expired air was collected in Douglas bags of 100 l capacity. The necks of the bags were of 25 mm diameter tubing and the whole was made of poly-vinyl chloride (Plysu). Subjects breathed into the bags through a valved light-weight mouthpiece (see Fig.2.6 p35). The mouthpiece was attached to the bag via a metal two way tap.

The mouthpieces were made in the Medical School workshop. They have a small dead space (50 ml), a wide bore (40 mm), and valves of thin mica. The inspiratory resistance was 5 mm of water at 85 l min^{-1} air flow and the expiratory resistance was 11.5 mm at 85 l min^{-1} air flow. These values are below the maximum acceptable values for moderate ventilation rates (Cotes, 1965).

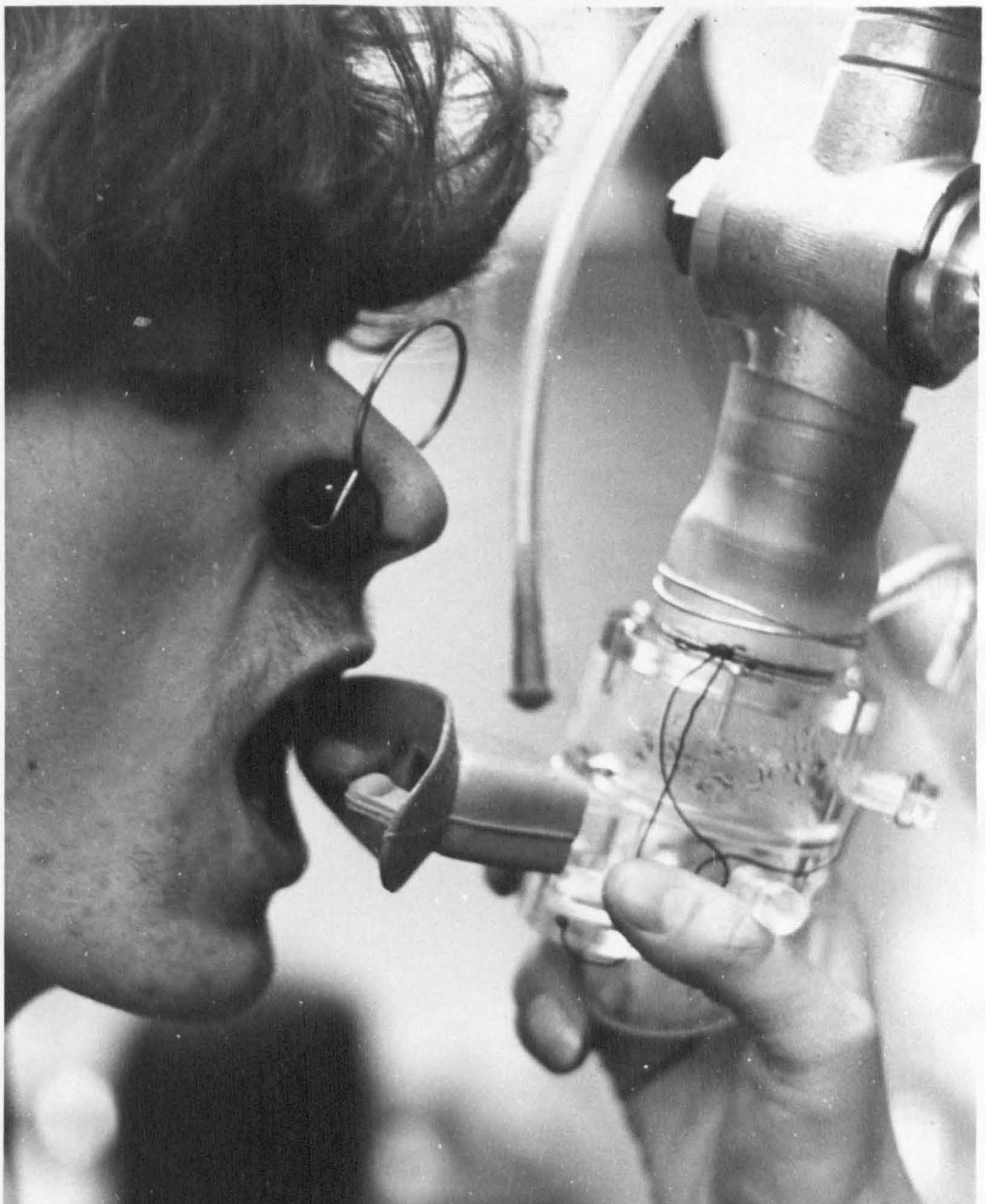


Fig. 2.6

THE MOUTHPIECE USED to COLLECT EXPIRED AIR

The bags were always emptied before use to a constant negative pressure. The bags are slightly permeable to carbon dioxide. The loss occurred at a uniform rate of 0.05% in the meter reading per hour at approximately 15 l volume except for the first hour at 6.20% carbon dioxide (Fig.27). Over a period of days the loss is considerable (Fig.28) and would limit the value of measurements made under field conditions where a delay between collection and analysis was inevitable. The loss can be reduced if the bags are filled with a larger volume of gas (Fig.29). With volumes of 40-45 l the loss in three hours was only 0.05%, it would presumably be too small to measure in one hour.

It is advisable, therefore, to analyse the air collected within one hour and to fill the bags with at least 40 l if accurate estimates of carbon dioxide production are required.

The bags are less permeable to oxygen. There was no detectable loss after one hour from bags filled with 15 l (approximately) of 13.55% oxygen (in nitrogen and carbon dioxide) after three hours there was a loss of 0.05% (Fig.27). Over a period of days the losses became substantial (Fig.28). Provided the delay between collecting and analysing the expired air is no longer than an hour, there will be no detectable change in the concentration of oxygen even at low volumes of expired air. In practice the bags were usually analysed and emptied within minutes of collecting the expired air and always within an hour.

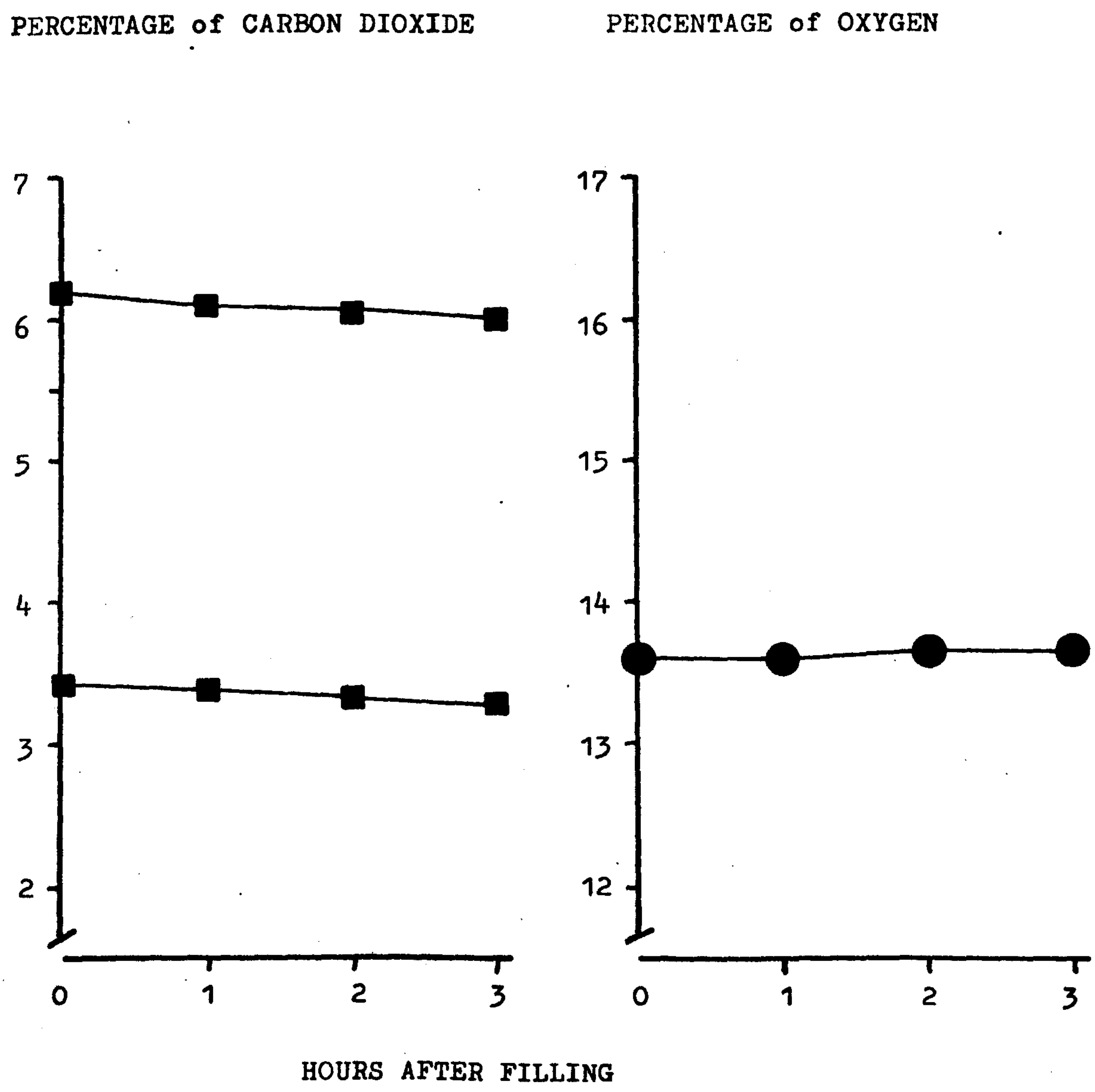
Analysis of Expired Air. A sample of 1 l was drawn off for analysis through a narrow side tube. It passed over phosphorus pentoxide crystals (Aquasorb) to dry it and then through the two analysers in series; first the carbon dioxide meter which contained a pump and then the oxygen meter.

Fig. 2.7 DIFFUSION of RESPIRATORY GASES THROUGH PLYSU PLASTIC BAGS, OVER HOURS

100 l bags filled with 15 l (mean) of dry gas.

Each point is a mean of 4 determinations, one on each of 4 bags.

(S.E.M. = zero or $<$0.03)



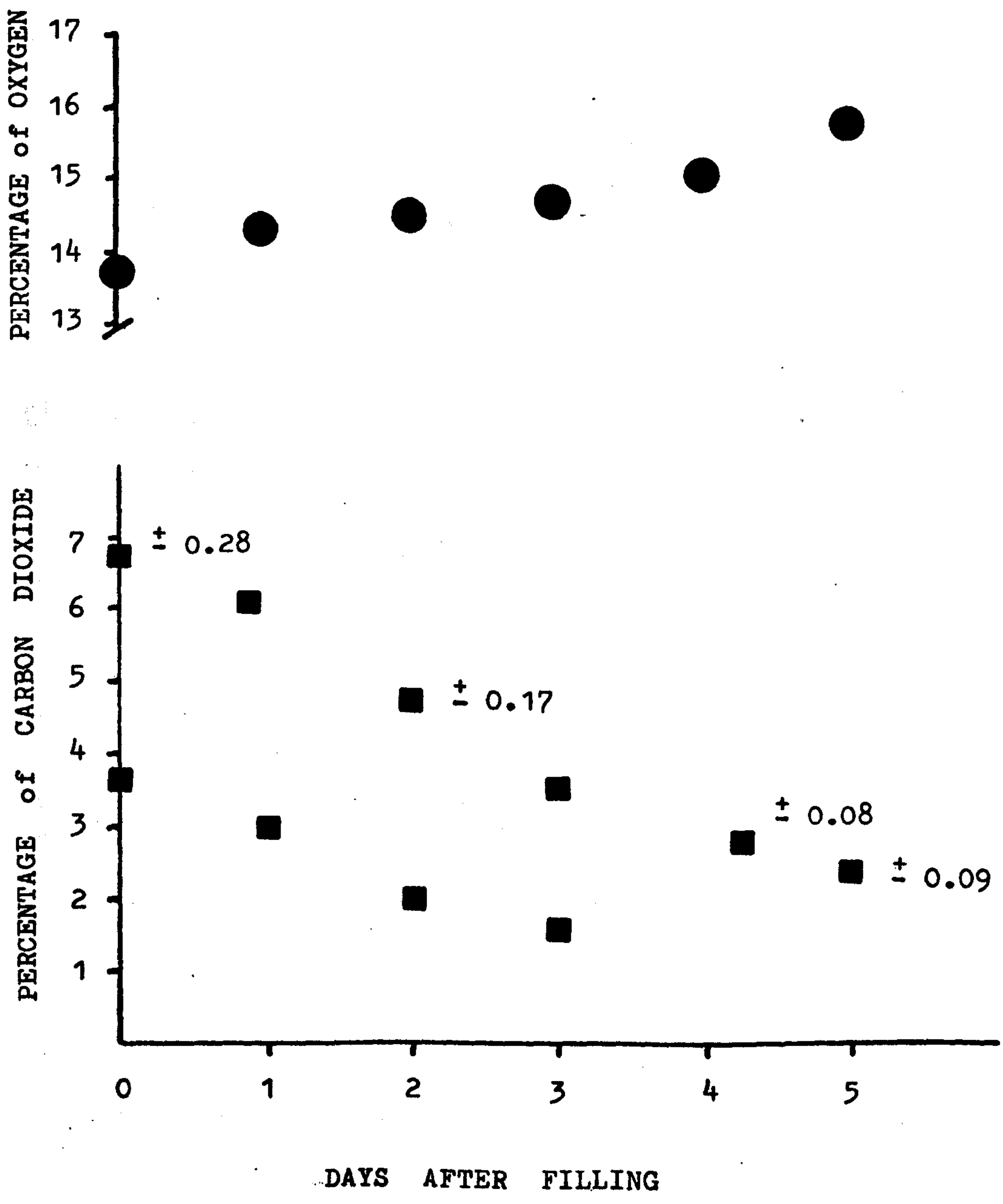
Room temp 23°C ; P_B 764 mm Hg

Fig. 2.8 DIFFUSION of RESPIRATORY GASES THROUGH PLYSU PLASTIC BAGS OVER DAYS

100 l bags filled with 28 l (mean) of dry gas.

Each point is a mean of 4 determinations, one on each of 4 bags.

(S.E.M. < 0.06 if not shown)

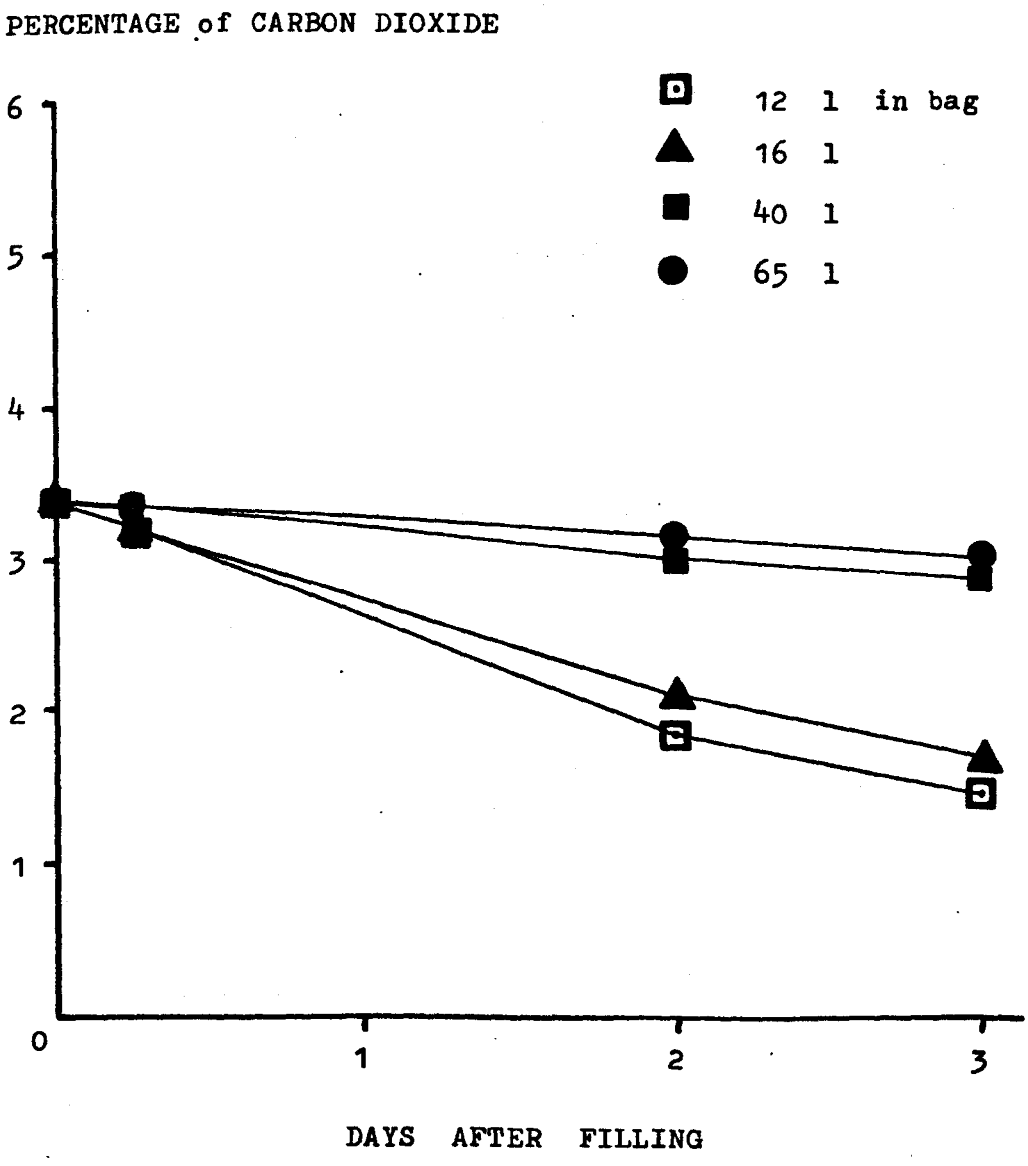


Room temp range 19.5-24.5°C ; P_B range 748-765 mm Hg

Fig. 2.9 DIFFUSION of CARBON DIOXIDE through PLYSU PLASTIC BAGS CONTAINING DIFFERENT VOLUMES.

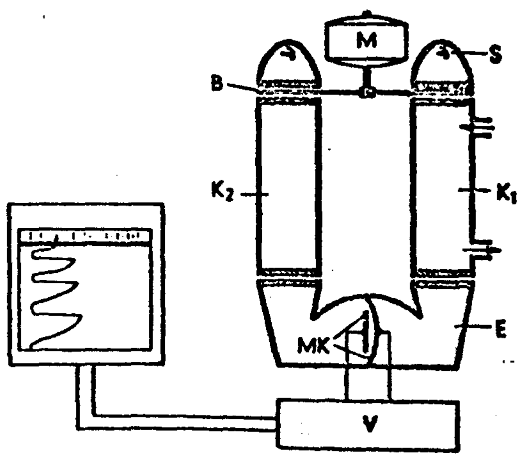
100 l bags filled with various volumes of dry gas.

Each point represents one determination from one bag.



Room temp range 20.5-21°C

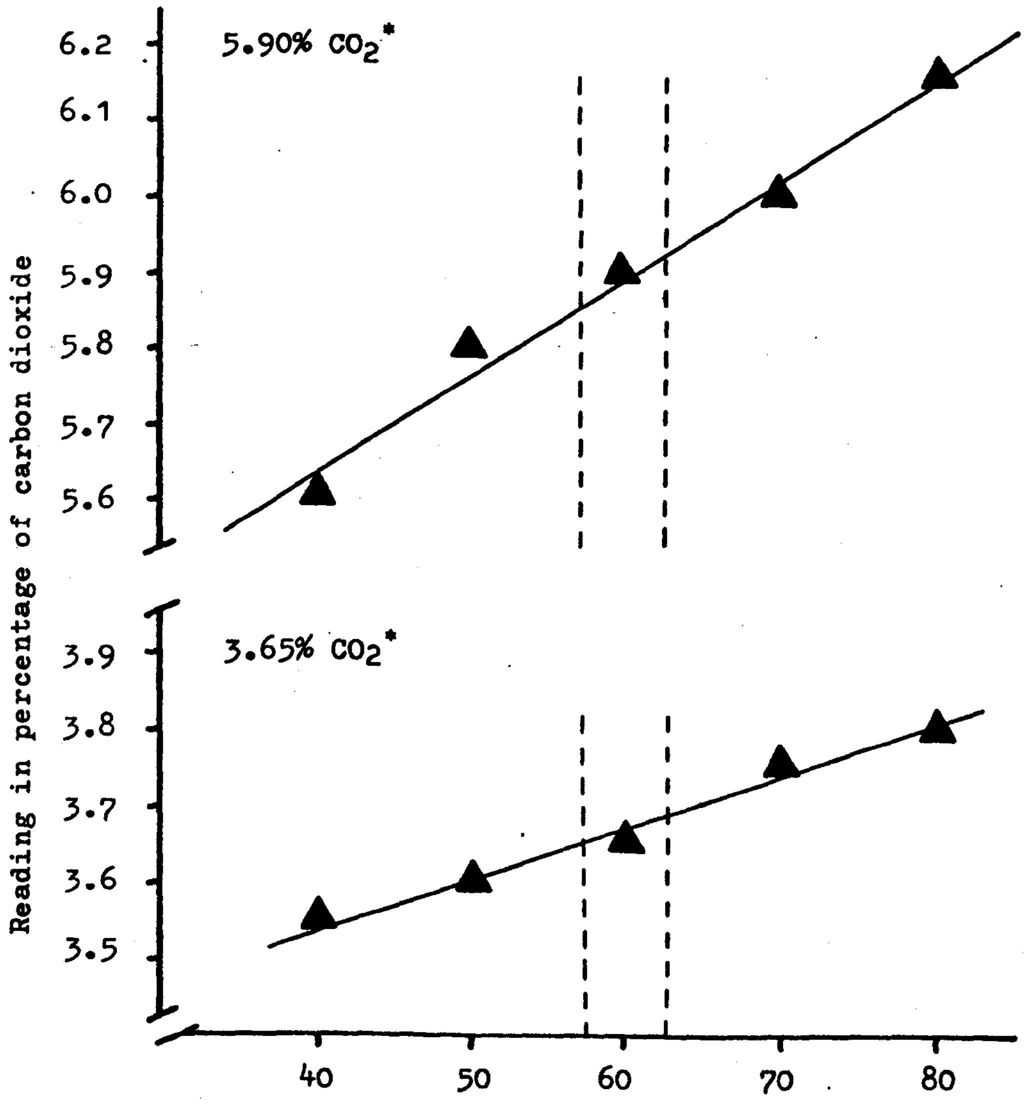
Fig. 2.10 DIAGRAM OF HARTMANN & BRAUN CARBON DIOXIDE METER SHOWING OPERATING PRINCIPLE



M = motor
S = radiator
B = shutter wheel
K_1 = analysing chamber
K_2 = reference chamber
E = receiver
MK = diaphragm capacitor
V = amplifier

Fig. 2.11 FLOW DEPENDENCE of the HARTMANN-BRAUN CARBON DIOXIDE ANALYSER

Vertical dotted lines delineate the limits of accuracy of the flow meter setting ($\pm$ 2.5 l hr^{-1}).



Flow Rate in l hr^{-1} of gas through the meter

Room temp 23°C

* from Lloyd-Haldane analysis.

The carbon dioxide meter (Hartmann & Braun. Uras 4) measures the partial pressure of carbon dioxide in the sample. It depends upon the absorption of infra-red rays by carbon dioxide and consists of a reference chamber containing a standard gas and an analysing chamber for the sample. Two beams of infra-red rays pass through the chambers and the unbalanced heating of the two chambers is converted to an electrical output by means of a variable condenser between the two detecting chambers (see Fig. 2.10). This is known as a Luft cell and acts as a differential manometer. The pump could be set to draw air through this analyser at rates varying from 0-120 l $hour^{-1}$. The meter was flow dependent (see Fig. 2.11) because an increased rate of flow increased the pressure of the test gas in the meter. A rate of 60 l $hour^{-1}$ was consistently used and checked frequently; provided this is done the error from variation in flow rate is undetectable. ($\pm$ 0.025%). The dial gave a direct reading in % carbon dioxide and was read while the gas was flowing. It could be read to the nearest 0.05% and had a range of 0-10%.

The oxygen meter (Servomex DCL. 101. Mk II) depends upon the paramagnetic properties of oxygen. It contains a silica dumb-bell suspended in a non-uniform magnetic field. If there are oxygen molecules present they become aligned in the field around the dumb-bell. Because of the way it is suspended this causes the dumb-bell to rotate. The torque can be balanced by a restoring torque produced by allowing a current to flow in a coil wound on the dumb-bell. The amount of current required to restore the dumb-bell to its resting position is proportional to the partial pressure of oxygen present. The balance position is achieved by manual adjustment of a calibrated source of current and indicated by a triangular beam of light reflected from the dumb-bell onto a ground glass screen in the front of the instrument. A black wire divides the triangle vertically and the null deflection position is achieved when the wire exactly bisects the beam. The flow rate of gas into this meter must not exceed 150 ml min^{-1} so a by-pass is used to reduce the flow from the carbon dioxide meter which was 1 l min^{-1}. The oxygen meter must be read under static conditions and so an extension tube to the gas outlet was attached to prevent back diffusion of room air during the ½ min. required for the beam to settle. This meter could be read to the nearest 0.05% and had a linear range of 0-100%.

Both meters were calibrated shortly before use using two different gas mixtures of a composition similar to that of expired air. The response of the carbon dioxide meter was non-linear so it was necessary to calibrate it over the range required for the ultimate measurements. This meter also took 20 min to warm up and reach an internal temperature equilibrium before it would hold a steady calibration.

The reading of these meters can be affected by observer bias but with practice consistent results can be obtained. Inter-individual biases remain (of the order of ± 0.1% for both meters), so it is advisable for one person to do all the analyses in one series if possible.

The volume of the remaining expired gas was measured in an industrial gas meter (Parkinson - Cowan). The gas was first passed through cooling tubes in a heat exchanger to ensure that the gas volume was measured at room temperature. A thermometer inserted into the gasmeter inlet tube was used to check this.

The air was drawn through by a domestic vacuum cleaner with its power stepped down by a thyristor control. When the Douglas bag has been emptied by this method the bag and cooling tubes are at a pressure slightly below atmospheric. This introduces an offset error due to air being sucked out of the cooling tubes. At a flow rate of 110 l min^{-1} it amounts to 1.05 l (mean of 4 determinations corrected to S.T.P.). At lower flow rates the error is reduced and at 70 l min^{-1} amounts to 0.56 l (3 identical determinations corrected to S.T.P.). It is therefore desirable to keep the flow rate to a minimum in order to reduce this error and also to allow time for temperature equilibration in the heat exchanger. Moreover powerful suction would introduce a further error because the measurements of gas volume would be made at a pressure significantly below atmospheric. The meter can be read to 0.05 l and is accurate to $\pm$ 1%.

Recording of Respiration Rate. Respiration rate was recorded by using the temperature difference between inspired and expired air detected by a glass bead thermistor inserted through the side of the mouthpiece so that it lay in the gas stream.

Calculations of Gas Exchange. The recorded data was typed into a computer which was programmed to calculate the following information:-

work rate	oxygen consumption
heart rate	carbon dioxide production
respiration rate	respiratory quotient
minute ventilation	

The calculations are given in the appendix pi.

Errors in the Calculation of Gas Exchange. The original measurements of gas concentrations in the expired air were made by one observer within one hour of collection, therefore there were no detectable errors due to the observer or to gas leakage. The remaining error was due to the oxygen meter which can be read to the nearest 0.05% oxygen giving an error of $\pm$ 0.025% oxygen in a

4% oxygen extraction. This produced an error of ± 0.62% in oxygen uptake.

The gasmeter has an accuracy of ± 1% and can be read to the nearest 0.05 l. The error arising from the reading was a fixed error which became negligibly small in ventilation volumes of 20-30 l min^{-1}.

The extra gas drawn out of the cooling tubes by the negative pressure when the volume measurement is made at a flow rate of 110 l min^{-1} which was the highest used gave rise to a fixed offset error of +1 l in the ventilation volume. In tests made in the department the flow-rate was reduced to 45 l min^{-1} which gives an offset error of +0.2 l. No correction was made for this because the flow-rate in the gas meter in any particular experiment was not known. The error it gave rise to in the oxygen uptake depended upon the flow-rate in the gasmeter and the subjects' ventilation rate. At 110 l min^{-1} gasmeter flow and 30 l min^{-1} ventilation the error would be +3.3% in oxygen uptake. At lower ventilation rates the error would be larger.

The errors in carbon dioxide production were similar except that the offset due to residual gas was in the opposite direction, and there was an additional error due to the flow dependence of the meter (± 0.025% carbon dioxide). This brings the total error in carbon dioxide production to ± 1.24% with an additional offset error of -3.3% at a ventilation rate of 30 l min^{-1}.

Care of the Subject

At all times the subjects' well-being was a prime consideration. We wished them to understand the procedures as far as possible, we did not want them to feel anxious and we did not want to put them to undue risk.

Introductory Information. The hospital patients received a written account of what was to happen and what they would be expected to do (see appendix piii). They were left alone to read it. The patients tested in the Medical School received the same information more informally; many of them were already familiar with the test procedure. All subjects gave their consent in writing.

Preliminary Screening. The hospital patients (Chap. 4) were formally screened using a questionnaire and a clinical examination (see appendix piv-viii) and finally a resting 9-lead ECG was recorded and checked for abnormalities. The other subjects (Chap. 3), who were known to us, were screened in a similar way by informal questionning, and a 3-lead ECG was recorded while the subjects sat on the bicycle. The questions elicited information about age, customary physical activity and medical history. Subjects found to have a history of heart disease or any other contra-indications to vigorous exercise in a test situation were not admitted to the tests.

Precautions During the Tests. Throughout a work test both heart rate and the wave form of the ECG were visually monitored (see p34) so that the test could be stopped immediately if any abnormalities were detected. Subjects were watched for signs of undue pallor or distress and they were told beforehand to stop work if they felt ill in any way. With subjects who were middle-aged or unused to exertion the work loads were increased with caution so that these subjects were not over-taxed.

Precautions in the Event of Accidents. There was always a medically qualified person available and an emergency suitcase and defibrillator were kept on hand. The latter was switched on during a test. The incidence of deaths during submaximal exercise tests is 2 in 40,000 and of infarcts 4 in 40,000 (Hornstein & Bruce, 1968), but this may not be significantly different from the incidence in a similarly screened population indulging in their normal exercise. However, ventricular fibrillation can be brought on by exercise, especially in subjects who have ectopic beats and so these precautions were taken.

Precautions after the Tests. The subjects were required to keep pedalling for a short time when the load was reduced because of the slight risk of blood pooling in the legs if movement ceases abruptly. They were also required to lie down for 5 min after working at a heavy load.

The Mobile Laboratory

A mobile laboratory was required for the hospital study and also for future field work of various kinds in human physiology. Ministry of Transport regulations set an upper limit to the size of a van that may be towed by a landrover. Therefore the maximum internal floor space would be 22' by 7' into which all the necessary equipment and at least three people had to fit.

Scale plans were drawn up of the possible disposition of the equipment avoiding fixed internal features which might impose restrictions in the future (see appendix pix). Specifications were listed for weight-carrying capacity, access to the inside, power supply, water supply, drainage, ventilation, heating and lighting, bearing in mind the need for maximum flexibility, (see appendix px).

A second-hand mobile showroom was purchased from the East Midlands Electricity Board. It was solidly built (unladen weight nearly 3 ton) and had a considerable load-carrying capacity as it had been used to display night storage heaters. It was 22' long and 7' wide with an 8' long section of one wall which could be completely removed for the installation of large pieces of equipment. There were abundant power points, a long external 60 amp cable and ample ventilation and lighting. The trailer was well suited to our purpose and our initial specifications were met.

The transformation of the trailer into a physiological laboratory proceeded with the emphasis on saving space and maintaining flexibility. A roof grid over the bicycle area provided almost infinitely flexible opportunity for hanging light equipment. A space-saving heat exchanger was achieved by using a Slimline W.C. cistern containing 9' of 1½" copper pipe in 2 gal water. Spur shelving provided adaptable accommodation for the gas analysers and other equipment and also a support for the bars which held the Douglas bags. A portable Stallette sink unit was convenient because it required no plumbing but it had to be filled by hand and proved rather too small. Two fan heaters were sufficient to maintain a reasonable working temperature. Most of these features are illustrated in the photographs on p50 (inside) and p51 (outside), and in the plan of the interior design (Fig. 2.14, p52).

Many field projects in human physiology could be undertaken in this mobile trailer, including temperature regulation studies using a "Hampstead" bed, or studies in blood flow using lower body negative pressure. However, it would not have been possible to undertake anthropometric studies which require heavy equipment such as X-ray machines, screened counters for measuring total body potassium or water tanks for measuring body density by immersion.

Fig. 2.12

Inside View of

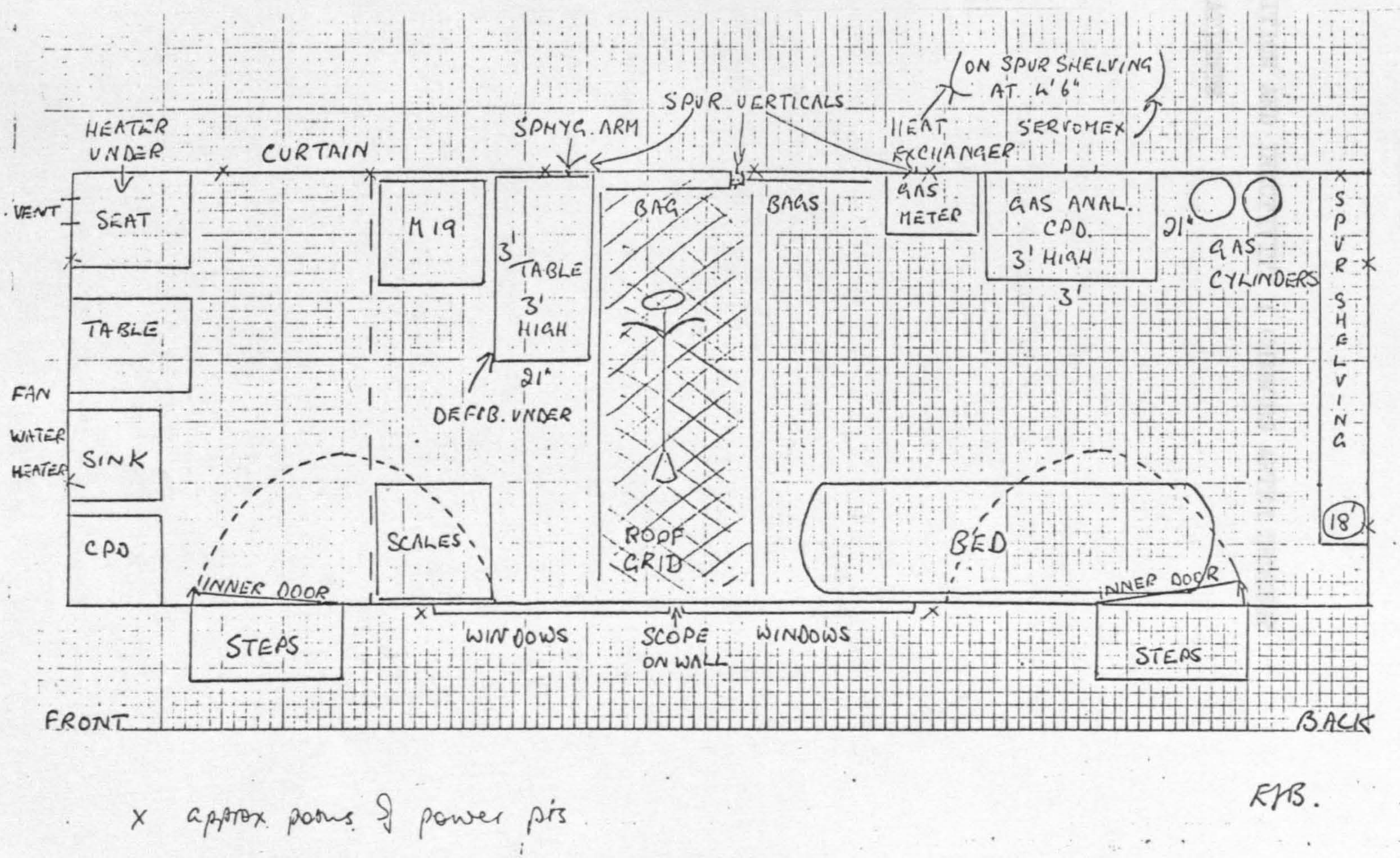
Mobile Laboratory

Fig. 2.13

The Mobile

Laboratory

Fig. 2.14   PLAN OF MOBILE LABORATORY



PART A

PHYSICAL CONDITION AND INACTIVITY : CHANGES AFTER BEDREST IN DISABLED PATIENTS

CHAPTER 3

PRELIMINARY STUDIES WITH NORMAL SUBJECTS

INTRODUCTION

The group of subjects chosen for the study of the effects of post-operative bedrest on physical condition were patients undergoing meniscectomy. Therefore they would not be able to undertake an orthodox test of physical condition involving work with two legs. However it seemed likely that a bicycle ergometer pedalled with one leg would be effective as a basis for testing these patients. Suitable modifications were therefore made to a normal bicycle ergometer (see p28) so that it was possible to work on it with one leg up to a rate of at least 450 kg m min^{-1}.

The patients could equally well have worked with their arms but this alternative was rejected for the following reasons. It has been shown that arm work results in a more variable relationship between heart rate and oxygen uptake than leg work, that the heart rate is higher at a given oxygen uptake during arm work, and that the differences in heart rate become larger the higher the oxygen uptake. (Stenberg, 1966; Assmussen & Hemmingson, 1958; Bevegard, Freyschuss & Strandell, 1966). It is also possible that arm work is more susceptible to re-test variation and habituation since it is a less familiar type of work. One-legged work was therefore preferred.

Several studies have been made involving one-legged pedalling, Dunér (1959) compared one- and two-legged work on an upright bicycle, at rates up to maximum, in five young men. He found that during one-legged pedalling subjects had a work capacity which was only 20-27% less than when they used both legs. Pernow, Wahren & Zetterquist (1965) have made a similar study and their four subjects worked with one leg at rates up to at least 1.8 l min^{-1} in oxygen uptake.

Von Hollman, Wenrath, Bonchard & Werne (1964) studied ten young physical education students working with one leg and two legs on an upright bicycle at rates of up to 150 watts (900 kg m min^{-1}). Freyschuss & Strandell (1968) compared one and two legged work in the supine position in eight trained young men and the highest rate of work with one leg elicited a mean oxygen uptake of 1.9 l min^{-1}.

This evidence suggested that one-legged pedalling could form the basis of a test of physical condition for our study. A preliminary investigation was needed to confirm this.

It was necessary to ascertain whether a heterogeneous group unselected for athletic ability and ranging widely in age could work with one leg at rates sufficiently high to allow several grades of work to be included in the test. All the previous studies were made on small numbers of well-trained young men.

It was important to establish that during work with one leg the relationship between heart rate and oxygen uptake was linear. It was in terms of this relationship that physical condition was to be measured. In order to make comparisons of physical condition and assess changes it is necessary to standardise the data to a fixed level of either heart rate or oxygen uptake. This procedure is only justified if the relationship is linear.

Pernow et al (1965) presented graphs of heart rate and oxygen uptake during one- and two-legged work at several grades which indicated that the relationships were linear for three out of the four subjects but there was no statistical analysis.

It was of interest to know whether an assessment of physical condition based on work with one leg would be the same as that based on work with two legs. The evidence from other authors is conflicting. Dunér (1959) and Pernow et al (1965) found that there is no difference in the heart rate at a given oxygen uptake whether the work is done with one or two legs, but Freyschuss et al (1968) found that the heart rates are significantly higher during work with one leg than during work with two legs.

A comparison was therefore made of the two ways of working in a group of 21 subjects (the main group). These subjects were untrained, non-athletic and ranged widely in age and so the results could also be used to establish the general feasibility of one-legged cycling. The linearity of the relationships was investigated in a small group of young subjects.

Procedure (common to both young and main groups)

The equipment and procedures were explained to subjects who were unfamiliar with the laboratory and all gave their informed consent in writing. The subjects were weighed without shoes and measured for height. They wore light clothing and the room temperature remained within 18-21.5°C (dry bulb) and 12-16°C (wet bulb); it remained constant to ± 0.5°C during any single experiment.

Chest electrodes were attached and continuous ECG monitoring began straight away. Subjects warmed up before their work test by pedalling at zero load for 5 min using both legs (Högberg & Ljunggren, 1947).

During one-legged work a counterweight was used to return the empty pedal, a toeclip held the active foot on the pedal and the inactive leg rested on a stool in the extended position, protected from the rotating counterweight by a metal flange (see Fig. 2.4, p30).

Heart rate, respiration rate and work rate were recorded and expired air collected during the last minute of work when subjects had reached a "steady state" of circulatory adjustment. Oxygen uptake, minute ventilation and carbon dioxide production were calculated from the analysis of expired air. Detailed descriptions of the methods used are given in the appropriate Methods section (see pps 26-44).

Investigation of Relationships during One-Legged Work (Small Group)

This group consisted of four healthy young men who were medical students. Their mean age was 22 years (range 20-26 years) and mean weight 74 kg (range 70-82 kg). They each performed a submaximal work test consisting of four grades of work so that the data could be used to assess the linearity of the relationships between oxygen uptake and the other parameters.

Experimental Design

One Leg		Supine Rest	One Leg	Supine Rest	One Leg
6 min at 1.0 kg	5 min at 2.0 kg	5 min	5 min at 2.5 kg	5 min	4 min at 3.0 kg

These loads corresponded to work rates of 150, 300, 375 and 450 kg m min^{-1} provided the pedalling rate was 50 rpm. The first load was imposed for an extra minute in order to collect expired air for two minutes. This is necessary when the load and consequently the minute ventilation are low in order to minimise errors (see p44). The last load was imposed for the minimum time consistent with the establishment of a steady heart rate because pedalling at this load with one leg fatigues the thigh muscles within a few minutes.

Comparison of One- and Two-Legged Work (Main Group)

This group consisted of 21 healthy untrained male subjects of mean age 34 years (range 20-61 years) and mean weight 72.9 kg (range 60.3-97.2 kg). They each performed a submaximal work test according to the experimental design below so that the data could be used to compare the effects of one- and two-legged pedalling at the same rate of work.

Experimental Design

Two Legs		Supine Rest	One Leg	
8 min at 1.0 kg	8 min at 2.5 kg	5 min	8 min at 1.0 kg	8 min at 2.5 kg

This amounts to a total of 32 min work, 16 min with one leg and 16 min with two legs.

Half the subjects, randomly selected, worked with one leg first and the other half with both legs first. Half the subjects used the right leg alone and the other half the left leg alone.

Expired air was collected and work rate measured during the last two minutes at each grade of work since the load was low. Heart rate and respiration rate were counted during the last minute of work.

Results

Relationships during One-Legged Work (Small Group)

The results for the four young subjects working with one leg only are shown individually as graphs of heart rate and oxygen uptake (Fig. 3.1, p59); minute ventilation and oxygen uptake (Fig. 3.2, p60); carbon dioxide production and oxygen uptake (Fig. 3.3, p61). In all cases linear regressions were obtained with correlation coefficients of over 0.95 for which P is <0.05. The validity of the standardisation procedure for the results obtained during work with one leg in the main group was confirmed by these results.

Results

Comparison of One- and Two-Legged Work (Main Group)

All the subjects were able to complete the test and although some complained that their one leg ached during work at the higher

Fig. 3.1 HEART RATE and OXYGEN UPTAKE during ONE-LEGGED PEDALLING.

Each point represents one measurement made on one subject.

r is the correlation coefficient of the line, values over 0.9500 are significant.

Subjects:- ● PR (r = 0.950) ▣ VT (r = 0.995) ▲ AS (r = 0.958) ■ ML (r = 0.978)

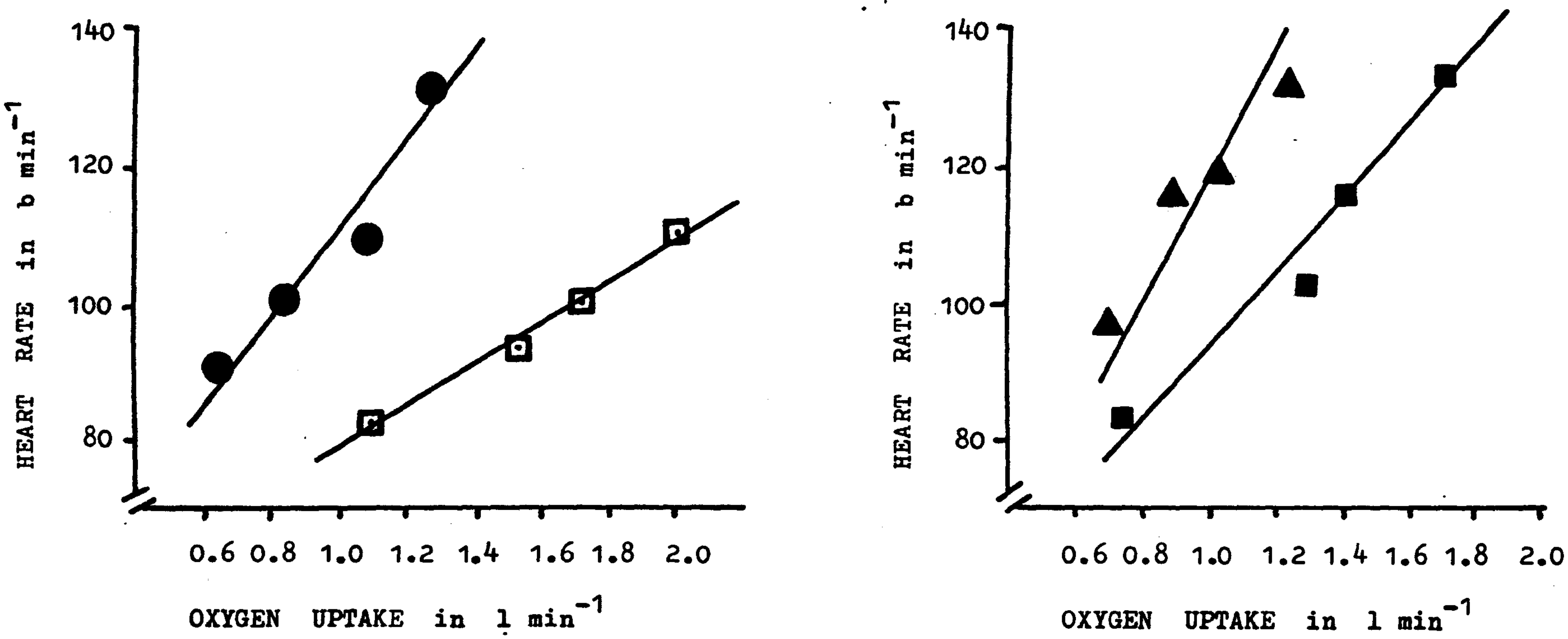


Fig. 3.2 MINUTE VENTILATION and OXYGEN UPTAKE during ONE-LEGGED PEDALLING.

Each point represents one measurement made on one subject.

r is the correlation coefficient of the line, values over 0.9500 are significant.

Subjects: ● P.R. (r = 0.990) ▣ V.T. (r = 0.994) ▲ A.S. (r = 0.991) ■ M.L. (r = 0.994)

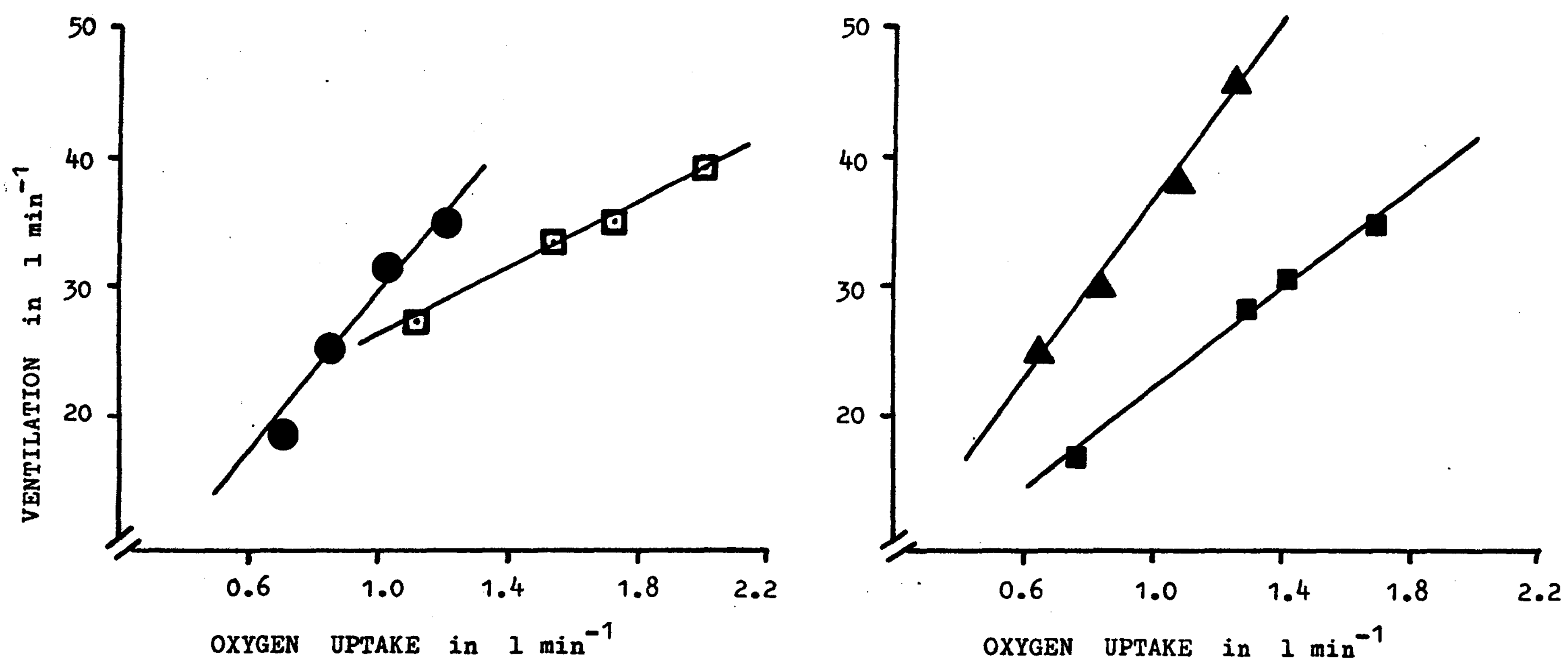
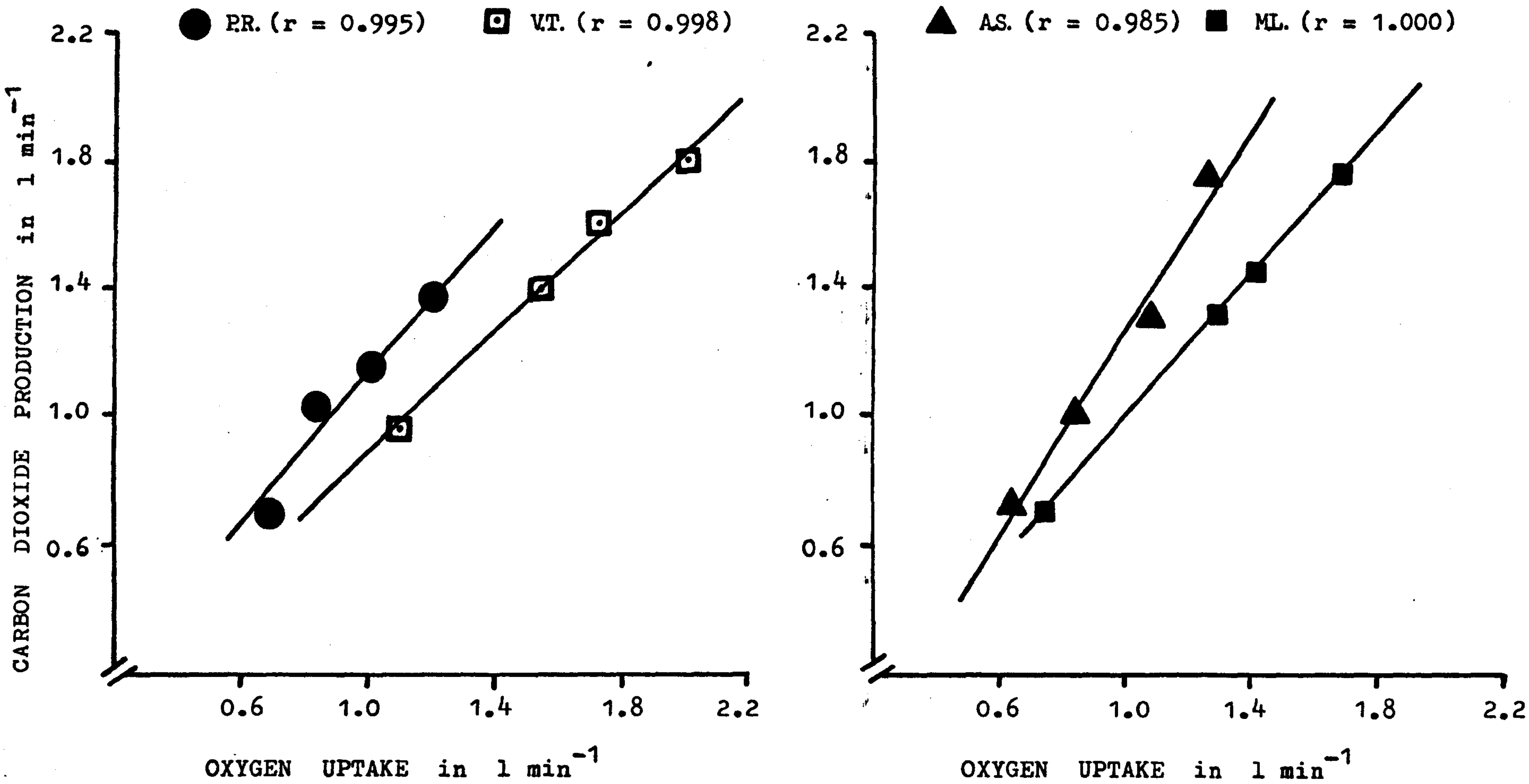


Fig. 3.3 CARBON DIOXIDE PRODUCTION and OXYGEN UPTAKE during ONE-LEGGED PEDALLING.

Each point represents one measurement made on one subject. r is the correlation coefficient.



load no stiffness or other after effects were reported.

The results are summarised in Tables 3.1 and 3.2 (pps 63 and 66); the inter-individual variation observed was large, but the group means reveal some significant differences between one- and two-legged pedalling particularly at the higher load.

Work Rate. (Table 3.1, p63) It was found that the achieved work rates during one-legged pedalling were significantly higher than during two-legged pedalling at both loads; the mean values were 170 (± 3.96) kg m min^{-1} and 341 (± 8.77) kg m min^{-1} with one leg against 159 (± 3.85) kg m min^{-1} and 318 (± 7.92) kg m min^{-1} with two legs. This happened because subjects pedalled significantly faster with one leg in order to keep the pedals turning. The pedalling rates at 1 kg load were 56 (± 6.4) rpm with one leg and 53 (± 5.8) rpm with two legs; and at 2 kg load they were 56 (± 7.0) rpm with one leg and 53 (± 6.0) rpm with two legs ($P<0.05$).

Oxygen Uptake. (Table 3.1, p63) The oxygen uptake was similar during one- and two-legged work at the lower load, but at the higher load it was very significantly higher during one-legged pedalling. The mean values were 1.20 (± 0.049) l min^{-1} with one leg against 1.05 (± 0.28) l min^{-1} with two legs.

Heart Rate. (Table 3.1, p63) The heart rates were significantly higher during work with one leg than with two legs at both loads. The mean values were 101 (± 3.22) and 122 (± 3.93) b min^{-1} with one leg against 96 (± 2.31) and 109 (± 2.34) b min^{-1} with two legs.

This may have reflected only the higher oxygen uptake so the comparison was made again at a standard oxygen uptake.

This was done by plotting graphs for each individual, of heart rate against oxygen uptake, and interpolating or extrapolating to an oxygen uptake of 1.0 l min^{-1} (see Fig. 3.4, p65). For twelve subjects it was possible to interpolate; four were extrapolated over a range

TABLE 3.1

COMPARISON of RESULTS from ONE- and TWO-LEGGED WORK TESTS.

The values stated are the means ± S.E.M., n = 21. Significance of differences determined using Student's t test for paired means.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$; N.S. = not significant.

	Load 1.0 kg			Load 2.5 kg		
	Two Legs	One Leg	P	Two Legs	One Leg	P
Oxygen Uptake $l\ min^{-1}$	0.75 ± 0.027	0.77 ± 0.023	N.S.	1.05 ± 0.028	1.20 ± 0.047	***
Heart Rate $b\ min^{-1}$	96 ± 2.31	101 ± 3.22	**	109 ± 2.34	122 ± 3.93	***
Ventilation $l\ min^{-1}$	20.7 ± 0.91	22.3 ± 1.00	N.S.	25.8 ± 1.12	32.9 ± 1.63	***
Carbon Dioxide Production $l\ min^{-1}$	0.66 ± 0.028	0.70 ± 0.030	N.S.	0.90 ± 0.032	1.11 ± 0.053	***
Work Rate (achieved) $kg\ m\ min^{-1}$	159 ± 3.85	170 ± 3.96	**	318 ± 7.92	341 ± 8.77	**
Pedalling Rate rpm	53 ± 5.8	56 ± 6.4	*	53 ± 6.0	56 ± 7.0	*

not exceeding 0.05 l min^{-1} and three over a range not exceeding 0.20 l min^{-1}. Two subjects results were rejected because the heart rate went down with increasing oxygen uptake.

It was then found that there was no significant difference between the two types of work. This is illustrated in Fig. 3.5 (p67) where the standardised values for heart rate for one- and two-legged work are plotted against each other. It can be seen that there was no systematic difference in the values for standardised heart rate since they fall on both sides of the line of coincidence. The mean standardised heart rates were 107 ($\pm$ 2.31) b min^{-1} with one leg and 111 ($\pm$ 3.70) b min^{-1} with two legs (see Table 3.2, p66). The slopes of the lines were also compared and no significant difference was found indicating that there is no difference in the oxygen pulse (ml oxygen taken up per heart beat).

<u>Minute Ventilation</u>. (Table 3.1, p63) The minute ventilation was similar during one- and two-legged pedalling at the lower load and significantly higher during one-legged pedalling at the higher load, 32.9 ($\pm$ 1.63) l min^{-1} with one leg and 22.3 ($\pm$ 1.00) l min^{-1} with two legs. This may also have been due to the higher oxygen uptake during work with one leg. When the minute ventilation was related to the oxygen uptake and standardised in the same way as the heart rates to an oxygen uptake of 1.0 l min^{-1}, a significant difference between the paired values for one and two legs remained (see Table 3.2, p66). The mean difference was 3.4 l min^{-1} ($P < 0.001$). This is illustrated in Fig. 3.6 (p68) where the standardised values for minute ventilation for one- and two-legged work are plotted against each other. The points fall above the line of coincidence showing that the values were higher during one-legged work.

Fig. 3.4 GRAPH showing STANDARDISATION PROCEDURE for HEART RATE at an OXYGEN UPTAKE of 1.0 l min^{-1}

Each point is a recorded value for one subject at each of two loads.

Subject:- A.G. (working with one leg)

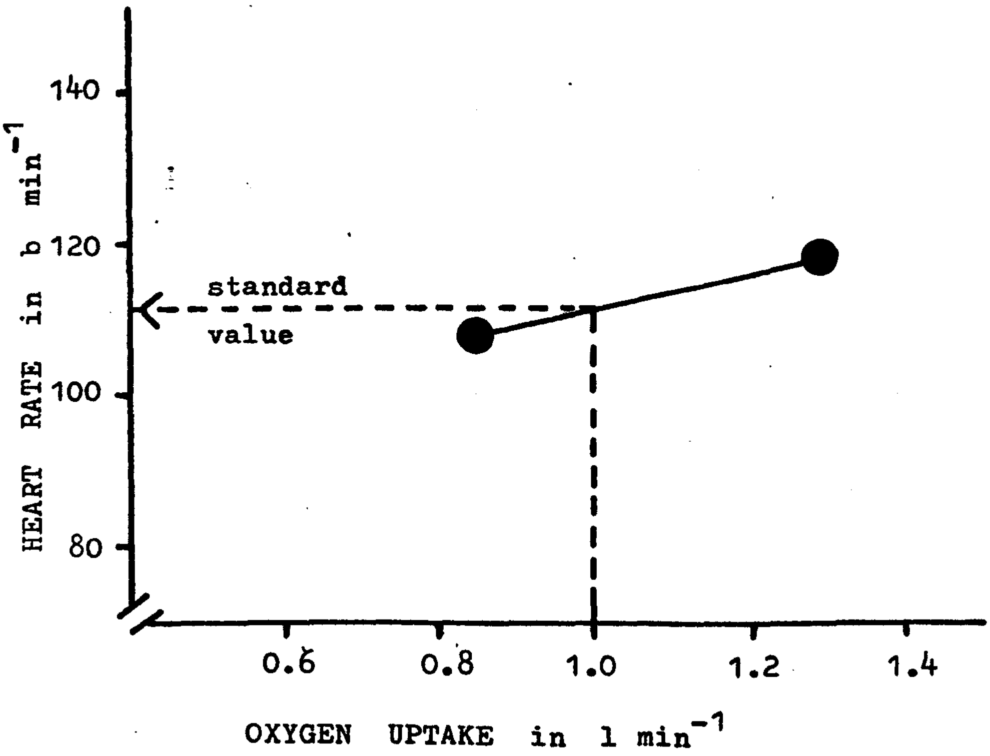


TABLE 3.2

COMPARISON of STANDARDISED RESULTS from ONE- and TWO-LEGGED WORK TESTS.

Values for each subject are standardised to an oxygen uptake of 1 l min^{-1}. Values stated are the mean $\pm$ S.E.M. for the group. (n = 20)

	Two Legs	One Leg	Difference for paired values compared by Student's t test
Heart Rate b min^{-1}	107 $\pm$ 2.31	111 $\pm$ 3.70	N.S.
Ventilation l min^{-1}	25 $\pm$ 0.90	28 $\pm$ 0.96	*** $0.001 > P$
Carbon Dioxide Production l min^{-1}	0.86 $\pm$ 0.021	0.91 $\pm$ 0.111	** $0.01 > P > 0.001$

Fig. 3.5 HEART RATE RESULTS from TESTS using ONE LEG plotted against RESULTS from TESTS using TWO LEGS

The data is standardised at an oxygen uptake of 1 l min^{-1}.

Each point refers to one subject.

The dotted line is the line of coincidence.

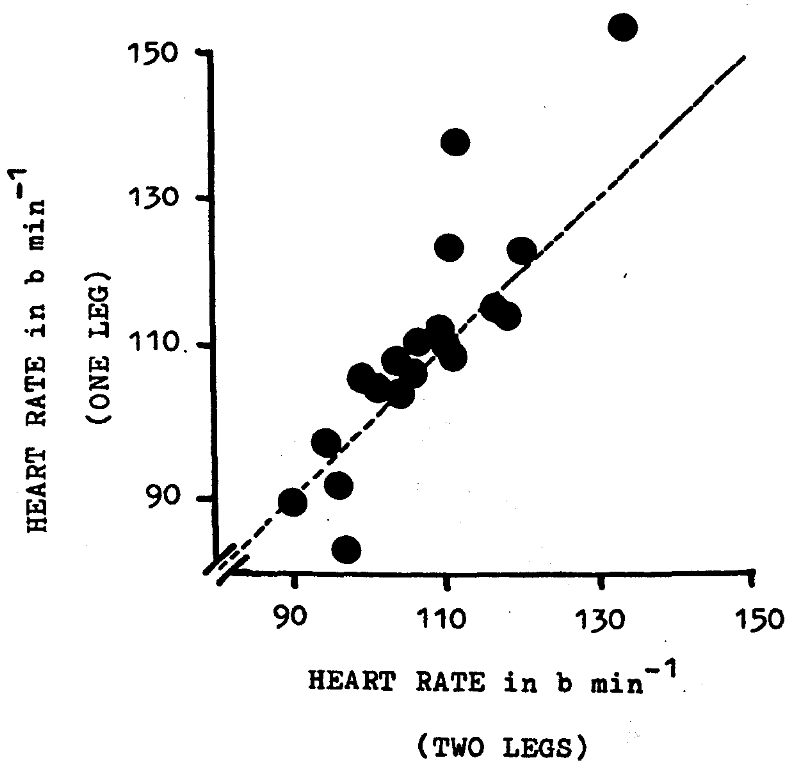
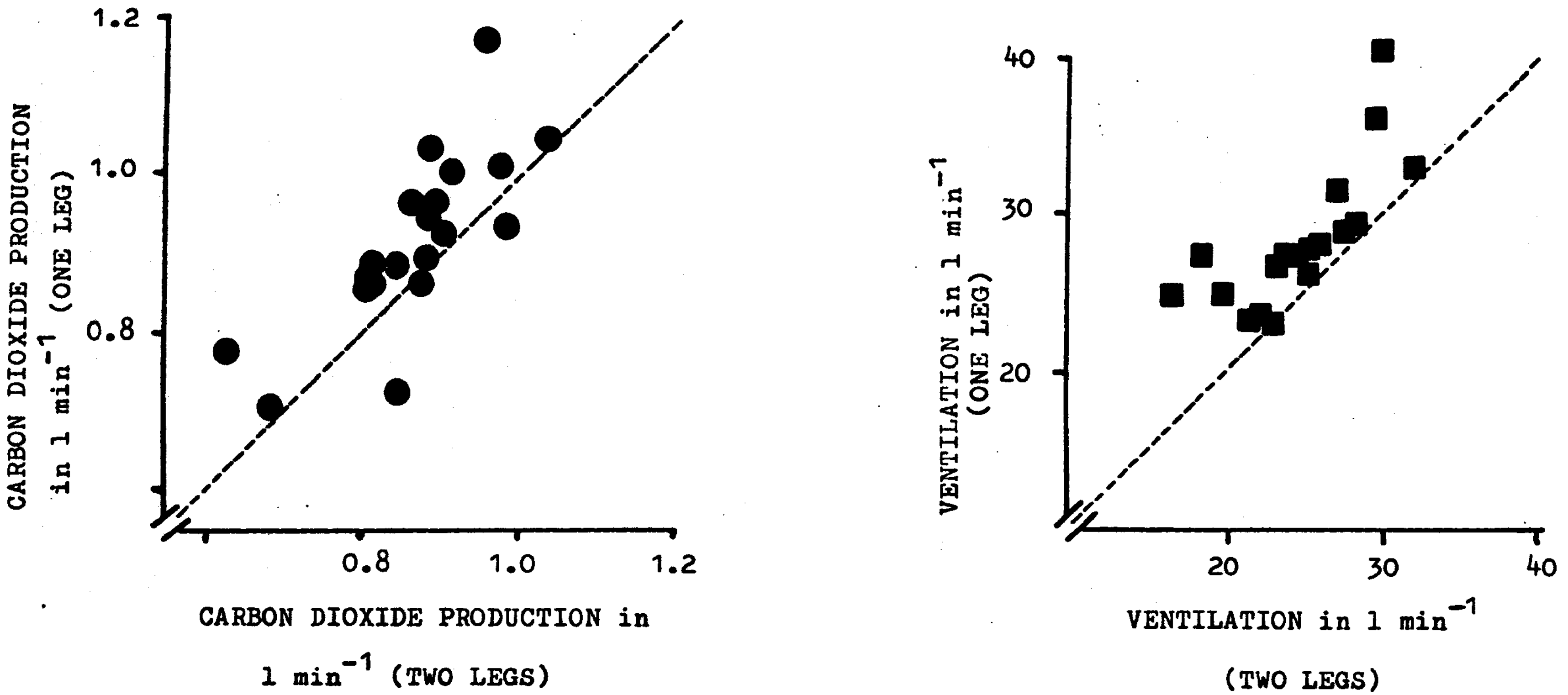


Fig. 3.6 DATA from TESTS using ONE LEG plotted against DATA from TESTS using TWO LEGS. The data is standardised at an oxygen uptake of 1 l min^{-1}. Each point refers to one subject. The dotted line is the line of coincidence.



Carbon Dioxide Production. (Table 3.1, p63) The carbon dioxide production was similar during one- and two-legged pedalling at the lower load and significantly higher during one-legged pedalling at the higher load. This would also be expected from the higher oxygen consumption during one-legged pedalling. When the carbon dioxide production was standardised to an oxygen uptake of 1.0 l min^{-1} as was done for heart rate and minute ventilation, a significant difference remained (see Table 3.2, p66). The mean difference was 0.05 l min^{-1} ($0.01 > P > 0.001$). This is also illustrated in Fig.3.6 (p68) where the standardised values fall above the line of coincidence showing that they are higher during work with one leg than during work with two legs.

Discussion

Feasibility of Method

The first objective of these tests was to ascertain whether one-legged pedalling was a feasible method for a graded submaximal work test. This was adequately established for a heterogeneous group ranging up to 61 years of age. The subjects were healthy but not distinguished for athletic ability or high levels of activity and no subject refused to complete the test.

The higher load of 2.5 kg resulted in a mean rate of working of 340 kg m min^{-1} ($\simeq$ 60 watt). This appeared to be near to the maximum rate for 8 min of work for some subjects, judging by their complaints of fatigue, although it was well below the highest rates of work achieved with one leg by the young athletic subjects of other authors, which ranged from 600 kg m min^{-1} for 6-7 min (Freyschuss et al, 1968) to 1000 kg m min^{-1} for 6 min (Dunér, 1959).

The period of 8 min instead of the commonly used 5 min (Davies, 1968a) was chosen to ensure that a steady response from the subjects was obtained but it was found to be unnecessarily long. A comparison of the heart rates at the 5th and 8th min of work revealed no significant differences (15 subjects). Therefore it was concluded that 5 min work would be adequate and no more than that was imposed in subsequent tests.

Local fatigue limits the work capacity of one leg but not until rates of work are achieved which are much greater than half the maximum capacity of both legs. Gleser (1973) found a maximum oxygen uptake of 77% that of two-legged work and concluded that the limiting factor was probably the ability of the muscle vasculature to dilate and accept higher blood flow.

Linearity of Relationships

In the tests with the small group of subjects which were based on four submaximal grades of work with one leg the relationships were found to be linear ($r > 0.95$; $p < 0.05$) between oxygen uptake and heart rate, minute ventilation and carbon dioxide production respectively. This has long been accepted for two-legged work. Astrand (1956) demonstrated linear relations between heart rate and oxygen uptake, Cotes (1965) for minute ventilation and oxygen uptake at moderate loads and Bennett & Morgan (~~in print~~ 1976) for carbon dioxide production and oxygen uptake. At near maximum oxygen uptake the minute ventilation rises more steeply and the relationship becomes curved, this was not observed in one-legged work at the levels achieved in this study.

Comparisons based on a standardisation of results to a given oxygen uptake are therefore justified whether the work is done with one leg or two.

It was possible in the one-legged tests to obtain four points on the regression lines which was sufficient to establish linearity on a statistical basis. There is always some variation in heart rate which is independent of oxygen uptake and due to factors such as fluctuations in respiration, blood pressure, temperature, venous return and central control; the ideal steady state is in practice non-existent. Therefore in any assessment of the heart rate/oxygen uptake relationship the more grades of work that can be included the more representative the assessment becomes. However it is not practical to include a large number of grades in one test because the subject would become fatigued. An alternative would be to spread a multi-grade test over several days but this is not a practical solution either because the day-to-day re-test variation is much larger than the within-test variation. Davies (1968b) recorded a day-to-day variation of $\pm$ 0.5 1 min^{-1} at submaximal heart rates. In the comparison of the effects of one- and two-legged work the assessment had to be based on two points only, since both types of work were included in the test, making four loads in all. This was felt to be as much as could be asked of the subjects.

Comparison of One- and Two-Legged Work

The second objective of this study was to ascertain whether there were systematic differences in the responses of the circulatory and respiratory systems when work on a bicycle ergometer is performed with one leg instead of two.

The finding that the mean values for all the measured parameters were significantly higher during one-legged pedalling at the heavier load was due at least in part to the faster pedalling rate with one leg. This led to a higher work rate and subsequently a higher oxygen uptake. The higher pedalling rates were probably due to the difficulty of maintaining a steady rate with one leg. Changes in pedalling rate affect the efficiency of cycling but they do not affect the relation between heart rate and oxygen uptake (Eckermann & Millahn, 1967).

The heart rate, minute ventilation and carbon dioxide production were standardised as described on p62 to an oxygen uptake of 1.0 l min^{-1}, and it was then found that there was no significant difference in the mean standardised values for heart rate but that those for minute ventilation and carbon dioxide production were significantly higher when the work was done with one leg instead of two.

The finding that heart rate is not significantly affected whether the work is done with two legs or one is not supported by other authors. Dunér (1959) found that 4 out of his 5 subjects had slightly lower values for oxygen uptake at a heart rate of 170 b min^{-1} but there is no statistical assessment of this difference and it may not be significant.

Von Hollman _et al_ (1964) found that during one-legged pedalling the heart rate was higher than during two-legged pedalling at the same rate, but the oxygen uptake was also higher which could explain the higher heart rates.

Pernow _et al_ (1965) found no difference in the relationship between heart rate and oxygen uptake in 3 out of 4 subjects but in the 4th subject the heart rate was higher during one-legged work. This subject was the only one who worked with two legs first. There was an interval of 1½ hours between each exercise test so although it is unlikely, it is possible that the second test was affected by the first. It is therefore not possible to draw any firm conclusions from these results.

Freyschuss & Strandell (1968) provide the only clear evidence for a higher heart rate at a given oxygen uptake when work is done with one leg instead of two; the mean difference appears to be less than 10 b min^{-1} at 1.9 l min^{-1} oxygen uptake. Their study differed from the current one in several ways. The 8 subjects worked in the supine position rather than a sitting in an upright position; springs were used rather than a counterweight to return the pedal to the working foot; the subjects were trained for 3-4 weeks before the study began; and they worked at a higher load so that the comparison was made at the higher oxygen uptake of 1.9 l min^{-1}.

It is possible that the higher mean heart rate became apparent in their study because the subjects worked at a higher rate. However there was no statistical difference in our study between the paired slopes of the heart rate/oxygen uptake lines for one- and two-legged work and when the results were extrapolated further to an oxygen uptake of 1.5 l min^{-1} no significant difference in the heart rates appeared. The discrepancy with the results of Freyschuss & Strandell remains unexplained.

The finding that the standardised values for minute ventilation and carbon dioxide production were significantly higher during one-legged work is in agreement with the results of Freyschuss et al (1968) and Pernow et al (1965). Both these groups of authors also found higher lactate levels during one-legged work which suggests that the proportion of anaerobic work is higher in one-legged pedalling than in two-legged pedalling at the same oxygen uptake. This was borne out by the subjective experience of discomfort and fatigue in the thigh muscles, and the accepted view that in cycling anaerobic work begins to make a contribution to the total work done at levels of 50% working capacity (Allen et al, 1968). It is likely that the 50% level for one-legged work was exceeded at the higher load with these untrained subjects.

In conclusion, one-legged work appeared to form a reasonable basis for assessing physical condition. There was no demonstrable difference in the relationship between heart rate and oxygen uptake when work was done with one leg instead of two but some differences arose in the respiratory response in the two situations. Comparisons made across the two kinds of test would not be fully justified and were not envisaged for our study.

CONCLUSIONS

Exercise on a modified upright bicycle ergometer in which the subjects pedalled with one leg was found to be a satisfactory basis for assessing physical condition in terms of the heart rate at a standard oxygen uptake of 1.0 l min^{-1}. The subjects were 21 healthy males unselected for athletic ability or age. The tests included three grades of work up to 350 kg m min^{-1} (60 Watt) which provoked a mean oxygen uptake of over 1.0 l min^{-1}.

The relationships between oxygen uptake and heart rate, minute ventilation, and carbon dioxide production, respectively, were found to be linear in one-legged work as in two-legged work. The standardisation was therefore justified.

There was no significant difference in physical condition assessed in this way whether it was based on one-legged work or two-legged work. However, we could not exclude the possibility that at higher levels of oxygen uptake there may be a difference.

There were differences in the minute ventilation and carbon dioxide production. Both were significantly higher with one-legged work at a standard oxygen uptake of 1 l min^{-1}. This is consistent with the view that more anaerobic work and lactate production occur when the work is done with one leg.

It was concluded that the one-legged work test formed the basis of a feasible and justifiable technique for assessing the physical condition of the hospital patients we wished to study.

CHAPTER 4

INVESTIGATION OF THE EFFECTS OF POST-OPERATIVE INACTIVITY AND SUBSEQUENT REHABILITATION

INTRODUCTION

This part of the study describes the investigation of changes in a group of patients undergoing bedrest following menisectomy. The reasons for choosing this group have been given in detail on p19. They were chosen chiefly because they remained able to undertake tests of physical condition involving exercise despite the injury and operation which made their period of enforced bedrest necessary.

These subjects gave us the opportunity to study the effects of bedrest on physical condition in a heterogeneous group and to look for age dependence in the changes we expected to observe. This was a first step towards an investigation of the possible ill effects of bedrest in the elderly.

It has been known for many years that enforced bedrest causes a decline in physical condition (Dietrick, Whedon and Shorr, 1948) but the subjects in whom it has been demonstrated were young and selected for good physical condition or athletic ability. Moreover these subjects were confined to bed for the purpose of the investigation and did not undergo surgery.

It was of interest to find out whether the changes found after contrived bedrest would be similar after the inevitable bedrest of hospital patients. It was possible that surgical procedures would exacerbate the changes. Taylor, Henschel, Brozek & Keys (1949) found in one subject that an operation for hernia repair did not affect changes due to bedrest and re-training.

It has become a widespread hospital practice to mobilise patients early and to keep their period of total bedrest as short as possible; the main reason being that early mobilisation is believed to reduce the incidence of deep vein thrombosis after surgery (Browse, 1965). It is likely also to reduce a decline in physical condition but this has not been evaluated.

For patients such as those in this study the possible benefits of early mobilisation in preventing deep vein thrombosis, or a deterioration in physical condition, must be balanced against possible harm to the operated knee. The uncertainty may lead to the adoption of different hospital regimes and this had happened among the patients we planned to study. There were two different regimes in the hospital for patients after meniscectomy. One group remained in bed for two weeks and the other group were allowed home in a plaster cast after four days bedrest, returning after ten days for physiotherapy.

We welcomed the chance to compare two groups undergoing different amounts of bedrest and to consider the effects of bedrest at two points in its time course.

The preliminary work described in Chap. 3 indicated that the modified bicycle ergometer formed a reasonable basis for testing the physical condition of those patients who could only work with one leg.

<u>Experimental Design</u>

We were fortunate that the hospital usually admitted patients a few days early so we were able to test subjects more than once before operation. We aimed to test all subjects on three consecutive days before operation in order to measure the degree of habituation and the baseline variation against which changes after bedrest would be assessed. Large habituation effects would limit the usefulness of the test.

The two groups of subjects, with different post-operative regimes, were designated as follows:-

Group I (full bedrest) who remained in bed for two weeks

Group II (home) who remained in bed for four days and then went home for ten days with the leg in a plaster cast

Group II4 (home) who followed the same regime as Group II except that they were tested at four days after operation just before going home.

Two weeks after operation all the groups were re-tested and thereafter they followed a common regime which included physiotherapy and exercise designed mainly to rehabilitate the knee joint and restore function in the operated leg. Subjects were tested once more after two weeks of rehabilitation at four weeks after operation.

The experimental design is summarised below:-

GROUP I Full Bedrest n = 9	GROUP II Home n = 12	Day of test relative to operation
FIRST TEST		-3
SECOND TEST		-2
THIRD TEST		-1
OPERATION		0
Bedrest 14 days	Bedrest 4 days*	
	Home 10 days	
TWO WEEK TEST		14
Rehabilitation physiotherapy 14 days		
FOUR WEEK TEST		28

* Group II_4 (n = 6) tested at four days after operation

Subjects

The subjects were 27 male patients aged between 17 and 55 years with a mean age of 33 years. They all underwent major surgery of one leg ~~and~~ for removal of a knee cartilage.

The patients were approached first through a written note explaining the purpose of the investigation and inviting their participation (see piii). If they agreed then a health and activity questionnaire was completed (see piv) and a clinical examination made. Subjects who were unsuitable on the grounds of ill health apart from their knee trouble were excluded by the medically qualified members of the team.

Only one man was excluded and that was on grounds of a high resting heart rate (120 b min^{-1}) coupled with a history of anxiety neurosis.

Initially 42 subjects agreed to take part in our investigation and embarked upon their first test; 27 of them completed the minimum number of tests (two pre-operative and one post-operative test two weeks later). The drop-out was due partly to the difficulty of fitting our tests, each of which took an hour or more, into the existing hospital routine and partly to minor operative complications which disturbed the normal regime. One man was excluded from further testing because of multiple ventricular ectopics which did not disappear on exercise.

The characteristics of these 27 subjects are listed in Table 4.1, p81. Most of the information is from the preliminary questionnaire and clinical examination (App. iv-ix). The resting blood pressure and heart rate data were occasional measurements made during the clinical examination. The weight and height measurements were made shortly before the first test. The figures for initial physical condition are the standardised heart rates from the second test (see p88).

TABLE 4.1

Characteristics of the Hospital Patients

b.p. = blood pressure fH = heart rate $fH_{1.2}$ = initial physical condition

Subject	Age	Weight kg	Height cms	Resting b.p. mms Hg	Resting fH b min^{-1}	$fH_{1.2}$	Minor Abnormalities	Smoker ≥ 10/day	Occupation	≥ 4 hrs walking at work	Leisure (self-assessed)
Group I (full bedrest)											
Bi	20	86.9	167	130/90	68	149	No	No	Bus Conductor	Yes	inactive
Ch	47	97.0	176	130/90	72	116	No	No	Miner	Yes	active
Ke	36	75.1	176	110/70	72	110	No	No	Breadman	No	active
La	21	69.4	177	140/90	70	90	No	Yes	Lathe Turner	No	inactive
Le	37	67.5	170	145/85	64	127	Yes	No	House Painter	No	active
Ne	46	76.7	170	115/80	62	138	Yes	No	Depot Foreman	Yes	active
Ro	26	61.0	171	110/70	70	108	No	No	Graduate Chemist	No	very active
Th	25	80.8	183	130/85	60	102	No	No	Fitting Consultant	Yes	inactive
Ri	43	57.2	160	125/80	72	130	Yes	Yes	Vehicle Fitter	Yes	active
Mean	33	74.6	172			119					

TABLE 4.1 (continued)

Subject	Age	Weight kg	Height cms	Resting b.p. mms Hg	Resting fH $b\ min^{-1}$	$fH_{1.2}$	Minor Abnormalities	Smoker ≥ 10/day	Occupation	≥ 4 hrs walking at work	Leisure (self-assessed)
Group II (home)											
Bf	34	91.7	177	145/75	60	116	Yes	Yes	Electrician	No	active
Bh	45	80.5	172	130/80	74	98	No	No	Electronic Engineer	No	sedentary
Bw	29	79.0	179	140/80	74	109	No	No	Van Driver	No	active
Bs	23	76.0	187	130/80	80	123	No	Yes	Joiner	No	inactive
Cl	44	76.0	184	140/80	80	111	No	No	Colliery Electrician	No	active
De	47	68.5	172	145/80	100	154	No	No	Foreman Motor Mechanic	Yes	active
Kn	39	65.5	182	120/70	60	113	No	No	Teacher	No	sedentary
Ka	30	84.6	180	130/85	64	118	No	No	Machine Operator	No	active
Se	32	85.1	185	135/75	80	110	No	Yes	Miner	No	sedentary
Sp	17	70.0	183	115/70	60	123	Yes	No	Fabric Clerk	No	inactive
St	26	83.0	183	160/80	80	122	No	No	Plumbing Supervisor	No	very active
Wr	55	68.6	176	145/90	62	112	Yes	Yes	Miner	Yes	sedentary
Mean	35	77.4	180			117					

TABLE 4.1 (continued)

Subject	Age	Weight kg	Height cms	Resting b.p. mms Hg	Resting fH b min^{-1}	$fH_{1.2}$	Minor Abnorm-alities	Smoker $\geq$ 10/day	Occupation	$\geq$ 4 hrs walking at work	Leisure (self-assessed)
Group II4 (home)											
Al	31	68.3	178	130/90	80	95	Yes	Yes	Bus Driver	No	inactive
An	23	73.0	174	140/90	72	119	No	No	Baths Manager	Yes	inactive
Co	28	72.1	168	135/95	90	138	No	No	Electrician	Yes	very active
Fi	31	93.0	180	130/100	60	102	No	No	Policeman	No	active
Fr	41	61.5	168	145/95	72	108	No	Yes	Miner	No	active
Hi	22	109.8	192	150/85	72	113	Yes	No	Colliery Electrician	Yes	sedentary
Mean	29	79.6	177			113					

The subjects included 19 patients aged 17-39 years and 8 aged 40-55 years. Four were miners and 15 were footballers. Ten spent more than 4 hours per day walking while at work; 15 described themselves as active "now". Ten reported reduced activity levels due to their injury. The length of time which had elapsed since first injuring their knees ranged from 2 months to 3 years. Ten subjects had previously been in hospital for a damaged knee cartilage. Six subjects presented minor symptoms when questioned and examined but none of these indicated a serious condition of the heart, lungs or vasculature which would preclude an exercise test.

Methods

The methods used are as described in detail in the main Methods section (pps 23-48). They differed from Chap. 3 in the following ways.

All the tests were performed with one leg and so it was possible for subjects to complete three work bouts without undue fatigue. (In Chap. 3 each test consisted of four work bouts, two with one leg and two with two legs).

Physical condition was assessed in the same way as before but from a three point regression line instead of the two points which was all that was possible in Chap. 3.

The standardisations were made as before but to an oxygen uptake of 1.2 l min^{-1} (see Fig. 4.1, p85) because this value involved the least number of extrapolations of recorded data (i.e. one subject on two occasions).

The two major differences in method, therefore, between Chap. 3 and Chap. 4 were the number of work bouts and the standard level of oxygen uptake.

Procedure

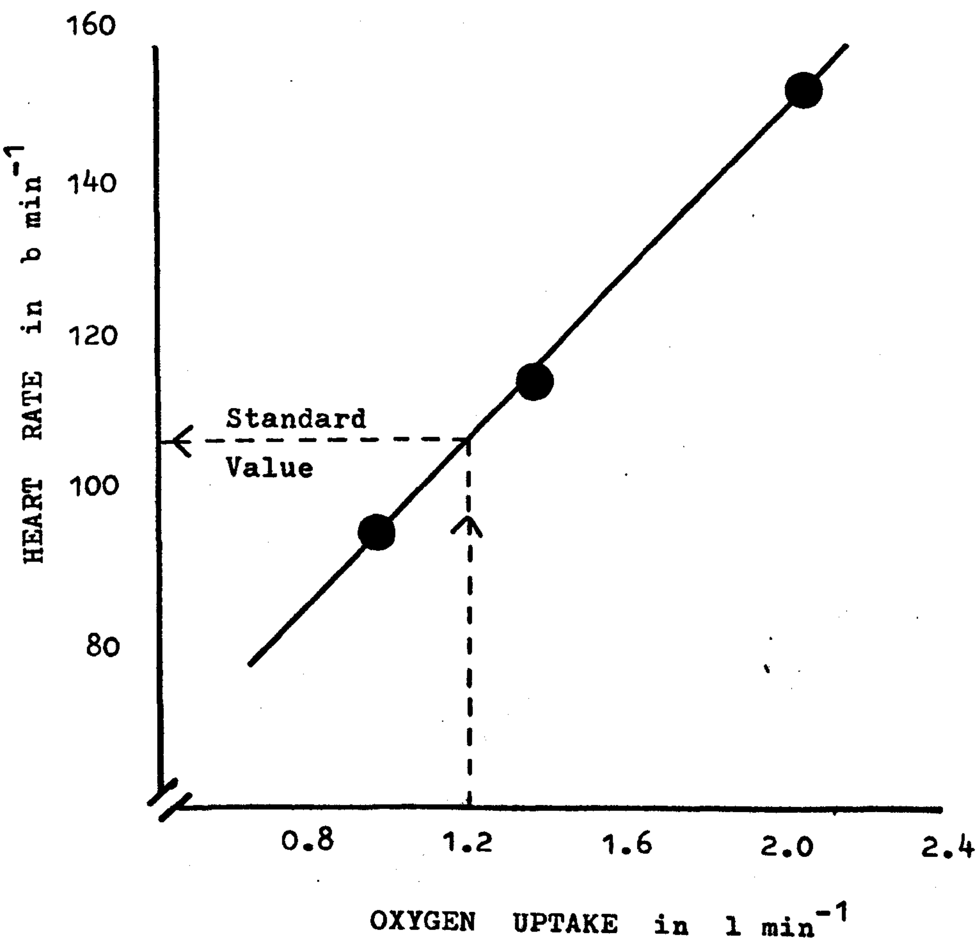
The equipment was explained and each subject signed a consent form. They were then weighed and measured for height. Electrodes

Fig. 4.1 Regression Line of Heart Rate on Oxygen Uptake Showing Standardisation to 1.2 l min^{-1}.

Each point is a recorded value for one subject at each of three loads.

r = 1.000

Subject:- F.R. (working with one leg)



were attached to the chest in positions V 2, 4 and 6 and a 9-lead resting ECG was recorded for medical inspection. A blood pressure cuff was fitted and resting arterial blood pressure was measured while the subject sat on the bicycle.

All work tests were performed with the un-injured leg on the modified bicycle ergometer. The injured leg rested on a stool, a counterweight of 3.2 kg replaced the empty pedal (see p29) and a toeclip held the active foot on the pedal.

The subjects then cycled with no load for at least 5 mins in order to warm up and then worked at 3 submaximal rates (nominally 150, 300, and 450 kg m min^{-1} corresponding to loads 1, 2 and 3) for a time sufficient for the heart rate to appear steady. This took 5 min at the lower load and 3 min at the highest load and could be confirmed by the ongoing ratemeter record. The subjects rested for 5 mins between the second and third loads.

During the last minute(s) of work at each load expired air was collected for analysis; heart rate, respiration rate and work rate were recorded; and blood pressure checked.

Comparisons were made using Student's test and in all cases differences were not considered significant if P exceeded 0.05. P levels of 0.01 and 0.001 were also identified.

RESULTS

Comparisons were made between the first and second tests and between the second and third tests to see if habituation effects were apparent. The pre-operative results were then compared with the post-operative results to see whether the operation and subsequent bedrest had affected them in any way. Finally the pre-operative results were compared with those obtained after the subjects had had two weeks physiotherapy to see whether this restored them to their initial condition.

The subjects were considered in their groups and also all together when appropriate. The numbers in the samples appear less than the full complement in some of the tables because of loss of data due to minor technical errors.

Baseline Observations

The pre-operative tests were considered first to reveal any habituation effects or systematic differences between groups and to establish baseline data for making post-operative comparisons. The re-test variation within subjects was also considered.

Habituation

The First Tests Compared with the Second Tests (pre-operative)

Oxygen Uptake. (Table 4.2 , p90). In Group I (full bedrest) in the second test at the highest work load the oxygen uptake was significantly lower. The mean values were 1.69 l min^{-1} in the first test and 1.53 l min^{-1} in the second test. There were no other significant differences in the groups treated separately or when all the subjects were considered together.

Heart Rate. (Table 4.3, p91). When the groups were considered separately no significant differences appeared. When all the subjects were considered together the heart rates were significantly lower in the second test at the two higher work loads. The mean values were 130 and 149 b min^{-1} in the first test and 123 and 144 b min^{-1} in the second test ($P<0.05$).

Standardised Heart Rate. This was calculated for each individual from the 3 point regression line as described on p84 to an oxygen uptake of 1.2 l min^{-1}. The standardised heart rates were then found to be significantly lower at the second test than at the first. The mean values (S.E.M.) were 117 ($\pm$ 2.97) b min^{-1} at the second test and 122 ($\pm$ 2.83) b min^{-1} at the first test ($P<0.01$) for all the groups together.

Standardised Minute Ventilation and Carbon Dioxide Production. These were calculated on the same basis as the standardised heart rates and compared for all subjects. No significant differences were found between the results for the first and second tests. The mean values (S.E.M.) were 33.2 (± 0.98) l min^{-1} for ventilation and 1.03 (± 0.03) l min^{-1} for carbon dioxide production at the second test.

The Second Tests Compared with the Third Tests. (Table 4.4 p92)

Twelve subjects were tested three times before operation and their results for oxygen uptake, heart rate and standardised heart rate revealed no significant differences (see Table 4.4, p92). The mean standardised heart rates were 116 b min^{-1} in both sets of tests.

It was not practical to use a mean of the second and third test results as the baseline because it was not possible for all the subjects to perform three pre-operative tests. The second test results were, therefore, taken as the baseline with which the post-operative tests were compared.

Re-test Variation

Since there were no significant differences the results from the second and third tests were used to assess re-test variation. The results for heart rate, oxygen consumption, standardised heart rate and pedalling rate were plotted against each other separately (see Figs. 4.2-4.4). The standard error of the estimate for the regression lines for oxygen uptake and heart rate is noted on the graphs, and is of the order of 10%. Pedalling rate was included because it is a source of variation in the oxygen uptake.

The standard deviation of the paired differences between the second and third test values for standardised heart rate was 10.01 b min^{-1}. Therefore the coefficient of variation was 9% (mean values for standardised heart rate were both 116 b min^{-1}).

Initial Comparisons Across the Groups

Physical Condition. The results for the second test were used to compare the three groups to see whether there were initial differences between them in physical condition which might affect the change due to bedrest. The standardised heart rates at the second test were as follows:-

Group I	(full bedrest)	119 $\pm$ 6.20 b min^{-1}
Group II	(home)	117 $\pm$ 3.91 b min^{-1}
Group II4	(home)	113 $\pm$ 6.13 b min^{-1}

No significant differences were found between any two groups.

Age. There were no significant differences in age between the groups. The age of the subjects was plotted graphically against their initial physical condition measured at the second test as standardised heart rate at an oxygen uptake of 1.2 l min^{-1}. There was no indication of a relationship between age and physical condition (see Fig.4.5 p97).

The assessment of physical condition is influenced by body size. A large person with a proportionally large heart will be able to achieve the same oxygen uptake with a lower heart rate than a small person with a proportionally small heart. When subjects are considered in relation to one another, rather than in relation to themselves under different circumstances, then body size may be a source of variation which obscures differences due to other factors such as age. No measurements of lean body mass had been made so a crude correction for body weight was applied by standardising the heart rates to an oxygen uptake of 15 ml kg^{-1} min^{-1}.

It then appeared that younger subjects considered themselves more inactive than older subjects. The difference was significant according to a chi-squared test based on two age groups (17-35 years and 36-58 years).

TABLE 4.2

A COMPARISON BETWEEN THE FIRST AND SECOND TESTS

(both before operation)

OXYGEN UPTAKE in $l\ min^{-1}$ during 3 grades of submaximal work.

(Mean values ± S.E.M.)

	n	1st Test	2nd Test	Probability of no Difference
Group I (full bedrest)				
Load 1	9	0.84 ± 0.04	0.86 ± 0.06	N.S.
2	9	1.25 ± 0.04	1.25 ± 0.06	N.S.
3	7	1.69 ± 0.06	1.53 ± 0.06	$P<0.01$
Group II (home)				
Load 1	12	0.87 ± 0.05	0.91 ± 0.04	N.S.
2	12	1.37 ± 0.07	1.30 ± 0.05	N.S.
3	12	1.74 ± 0.07	1.79 ± 0.07	N.S.
Group II4 (home)				
Load 1	6	1.08 ± 0.06	1.01 ± 0.05	N.S.
2	6	1.43 ± 0.08	1.43 ± 0.08	N.S.
3	5	1.82 ± 0.07	1.81 ± 0.09	N.S.
All Groups				
Load 1	27	0.90 ± 0.03	0.90 ± 0.03	N.S.
2	27	1.33 ± 0.04	1.29 ± 0.03	N.S.
3	24	1.74 ± 0.04	1.71 ± 0.05	N.S.

TABLE 4.3

A COMPARISON BETWEEN THE FIRST AND SECOND TESTS

(both before operation)

HEART RATE in b min^{-1} during 3 grades of submaximal work.

(Mean values ± S.E.M.)

	n	1st Test	2nd Test	Probability of no Difference
Group I (full bedrest)				
Load 1	9	102 ± 4.4	102 ± 4.2	N.S.
2	9	124 ± 5.6	121 ± 6.2	N.S.
3	7	141 ± 5.6	133 ± 7.0	N.S.
Group II (full bedrest)				
Load 1	12	105 ± 4.0	101 ± 3.7	N.S.
2	12	131 ± 5.0	123 ± 4.3	N.S.
3	12	150 ± 5.6	148 ± 3.9	N.S.
Group II4 (full bedrest)				
Load 1	6	109 ± 4.1	104 ± 6.4	N.S.
2	6	133 ± 3.8	124 ± 7.0	N.S.
3	6	151 ± 7.7	145 ± 6.5	N.S.
All Groups				
Load 1	27	105 ± 2.6	103 ± 2.5	N.S.
2	27	130 ± 3.1	123 ± 2.1	$P < 0.05$
3	25	149 ± 3.6	144 ± 3.3	$P < 0.05$

TABLE 4.4

A COMPARISON BETWEEN THE SECOND AND THIRD TEST

(both before operation)

n = 12 from all groups (Mean values ± S.E.M.)

	n	2nd Test	3rd Test	Probability of no Difference
Oxygen Uptake in l min^{-1}				
Load 1	12	0.92 ± 0.04	0.83 ± 0.02	N.S.
2	12	1.31 ± 0.05	1.26 ± 0.04	N.S.
3	12	1.72 ± 0.06	1.62 ± 0.03	N.S.
Heart Rate in b min^{-1}				
Load 1	12.	103 ± 3.0	100 ± 4.2	N.S.
2	12	122 ± 4.1	121 ± 4.8	N.S.
3	12	142 ± 3.7	141 ± 4.6	N.S.
Standardised heart rate in b min^{-1}	12	116 ± 2.7	116 ± 3.4	N.S.

Fig. 4.2

A COMPARISON between the SECOND and THIRD TESTS: OXYGEN UPTAKE at 3 grades of submaximal work. Each point represents the recorded values for one subject at one grade of work in one test. n = 36 (3 for each of 12 subjects). The dotted line is the line of coincidence.

S.E.M. = 0.15 l min^{-1}

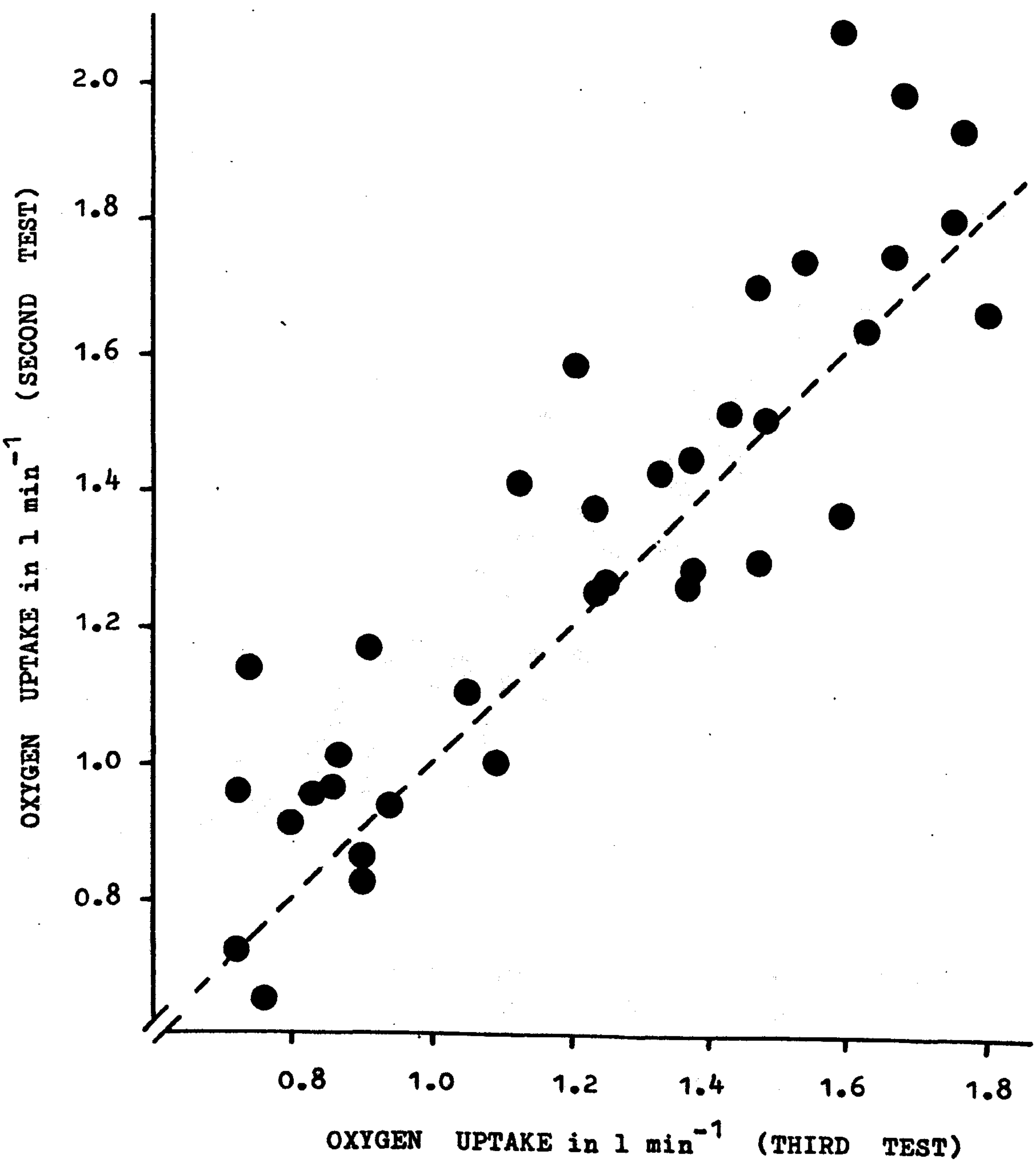


Fig. 4.3

A COMPARISON between the SECOND and THIRD TESTS:

HEART RATE at 3 grades of submaximal work.

Each point represents the recorded values for one subject at one grade of work in one test.

n = 36 (3 for each of 12 subjects)

The dotted line is the line of coincidence.

S.E.M. = 10.6 b min^{-1}

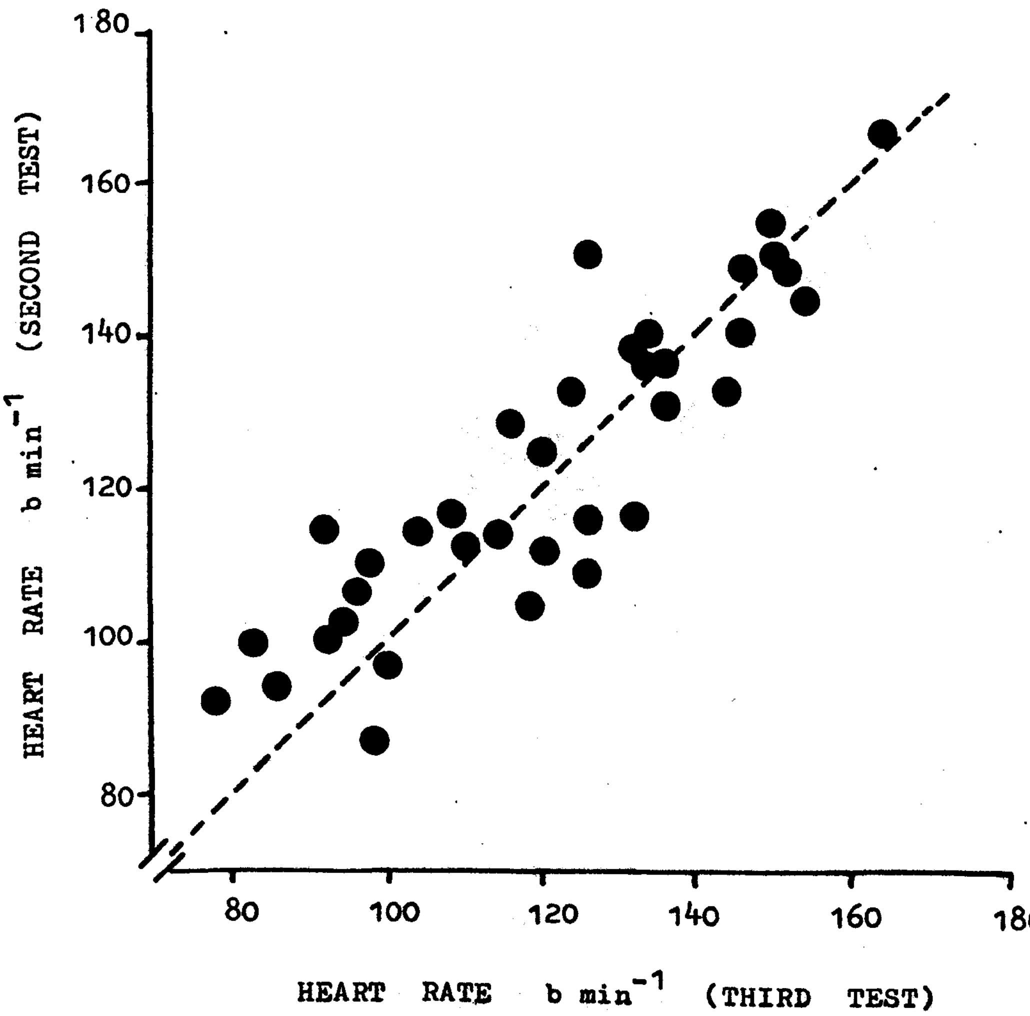
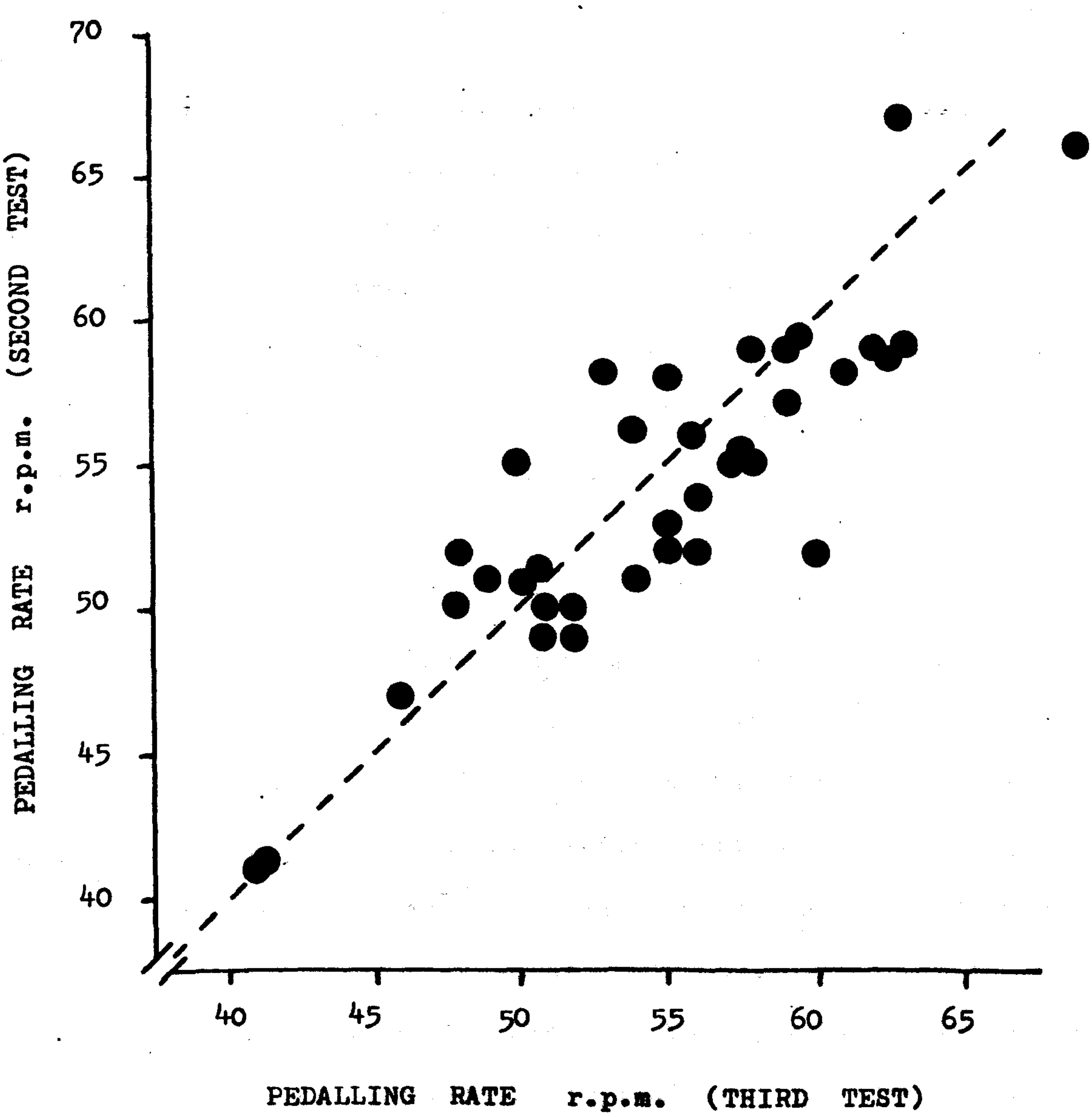


Fig. 4.4

A COMPARISON between the SECOND and THIRD TESTS:
PEDALLING RATE at 3 grades of submaximal work. Each point represents the recorded values for one subject at one grade of work in one test.
n = 36 (3 for each of 12 subjects)
The dotted line is the line of coincidence.



Activity. There were no objective measurements of the subjects' customary levels of daily activity only their answers to the questionnaire. Those who described themselves as very active or active "now" were in no better initial physical condition than those who made no such claim (see Fig. 4.5, p97).

Height and Weight. It is clear from Table 4.1 that there were no systematic differences between the groups for height and weight.

The Changes Two Weeks after Operation

The two groups of subjects underwent different post-operative regimes and are described in the introduction (p78) as

Group I (full bedrest) and

Group II (home)

Oxygen Uptake. (Table 4.5, p99). No significant differences appear in Group I (full bedrest) or Group II (home), but in Group II4 the oxygen uptake was significantly lower at all 3 loads at 2 weeks after surgery. The mean differences were about 0.2 l min^{-1}.

When all the subjects are considered together the oxygen uptake was significantly lower after operation than before but only at the lowest and highest work loads. The mean differences were about 10%.

Heart Rate. (Table 4.6, p100). Despite the lower oxygen uptake after operation there was no significant change in the heart rates either in the groups considered separately or together.

Standardised Heart Rate. (Table 4.7, p101). This was significantly higher in Group I (full bedrest) after operation than before. The mean values were 119 b min^{-1} for the baseline test and 127 b min^{-1} for the test at 2 weeks afterwards ($P<0.05$). There was no significant difference in the Group II (home) values. These subjects had spent only 4 days in bed in hospital and the other 10 days at home. The Group II4 subjects experienced the same regime as the rest

Fig. 4.5 AGE and INITIAL PHYSICAL CONDITION expressed as heart rate at an oxygen uptake of 1.2 l min^{-1}.

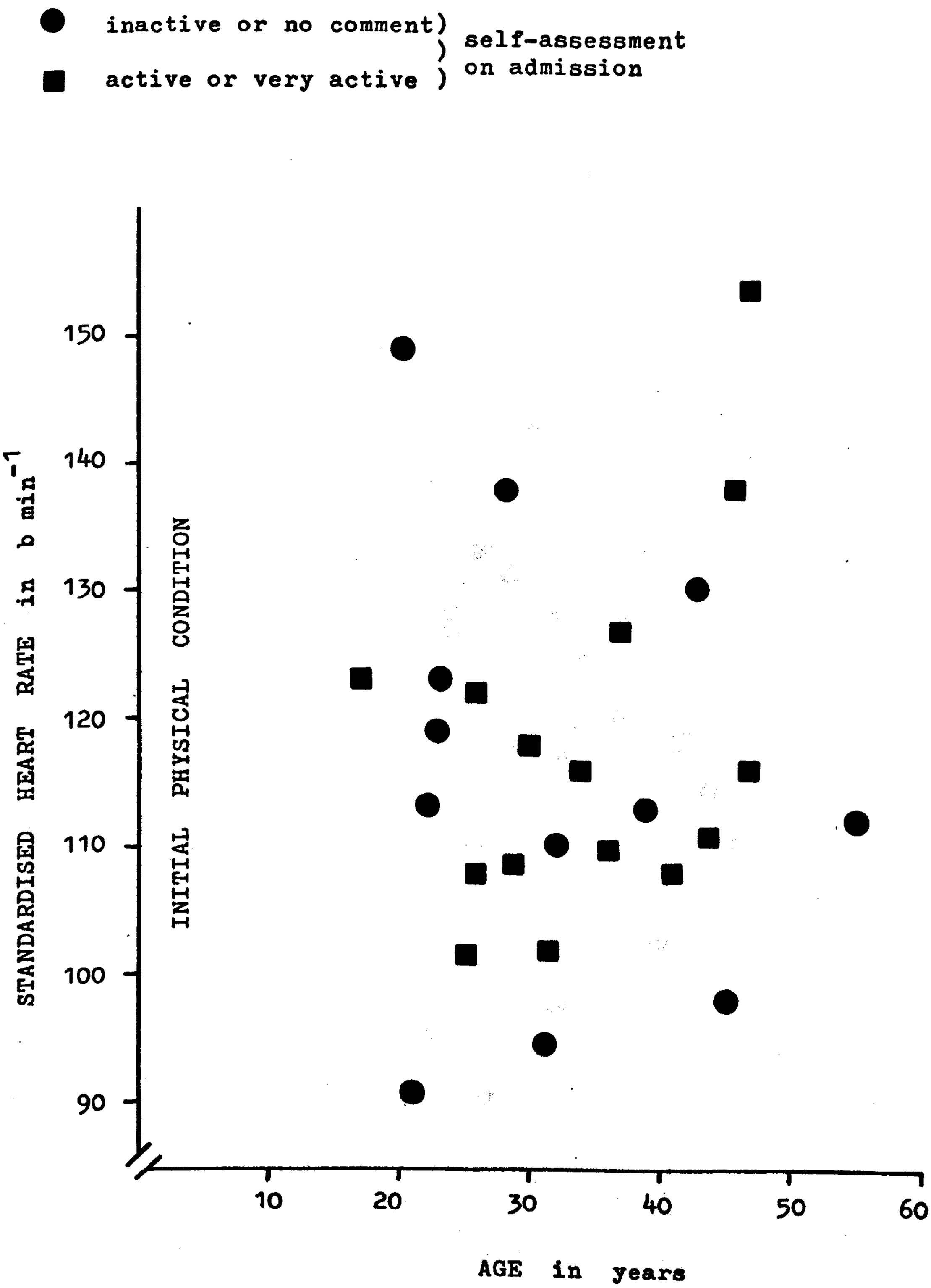


Fig. 4.6 AGE and INITIAL PHYSICAL CONDITION expressed as heart rate at an oxygen uptake of 15 ml kg^{-1} min^{-1}.

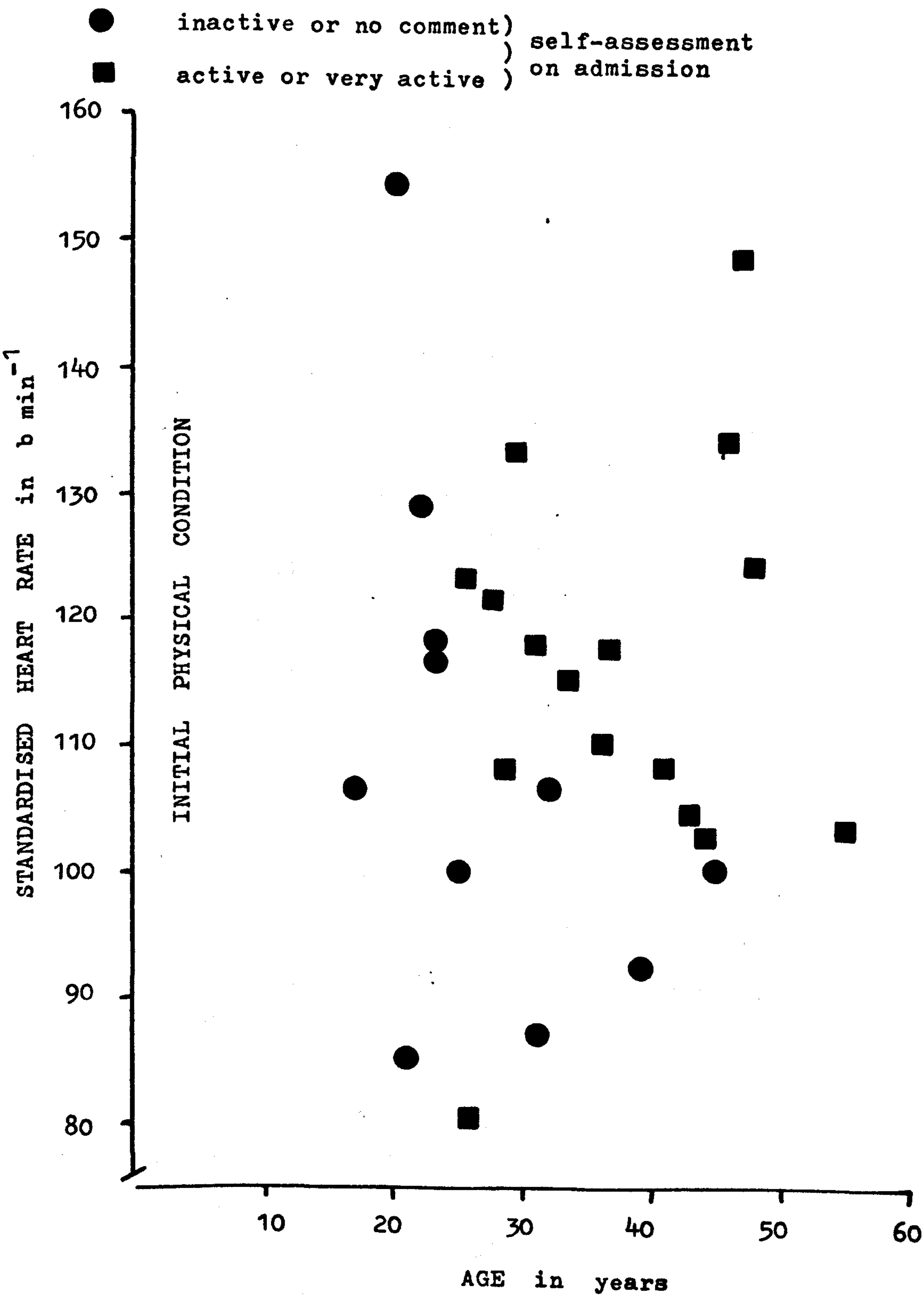


TABLE 4.5

A COMPARISON between TESTS performed BEFORE and AFTER TWO WEEKS BEDREST:

OXYGEN UPTAKE in $l\ min^{-1}$ at 3 grades of submaximal work.

(Mean values ± S.E.M.)

	n	Before		After 2 weeks	Probability of no Difference
Group I (full bedrest)					
Load 1	9	0.86 ± 0.06		0.80 ± 0.07	N.S.
2	8	1.26 ± 0.07		1.14 ± 0.10	N.S.
3	7	1.53 ± 0.06		1.47 ± 0.08	N.S.
Group II (home)					
Load 1	12	0.91 ± 0.04		0.86 ± 0.04	N.S.
2	12	1.30 ± 0.05		1.29 ± 0.07	N.S.
3	12	1.79 ± 0.07	SURGERY and BEDREST	1.65 ± 0.03	N.S.
Group II4 (home)					
Load 1	6	1.01 ± 0.05		0.83 ± 0.03	P <0.05
2	6	1.43 ± 0.06		1.24 ± 0.05	P <0.05
3	5	1.75 ± 0.09		1.43 ± 5.47	P <0.05
All Groups					
Load 1	27	0.92 ± 0.03		0.82 ± 0.03	P <0.05
2	26	1.33 ± 0.03		1.23 ± 0.05	N.S.
3	24	1.71 ± 0.05		1.55 ± 0.03	P <0.01

TABLE 4.6

A COMPARISON between TESTS performed BEFORE and AFTER TWO WEEKS BEDREST:

HEART RATE in b min^{-1} during 3 grades of submaximal work.

(Mean values ± S.E.M.)

	n	Before		After 2 weeks	Probability of no Difference
Group I (full bedrest)					
Load 1	9	102 ± 4.17		107 ± 3.72	N.S.
2	9	121 ± 6.17		127 ± 4.33	N.S.
3	8	132 ± 6.11		139 ± 5.58	N.S.
Group II (home)			SURGERY and BEDREST		
Load 1	12	101 ± 3.71		101 ± 3.80	N.S.
2	12	123 ± 4.33		124 ± 4.84	N.S.
3	12	148 ± 3.94		145 ± 5.04	N.S.
Group II4 (home)					
Load 1	6	104 ± 6.44		109 ± 3.04	N.S.
2	6	124 ± 7.02		128 ± 4.60	N.S.
3	6	145 ± 6.50		144 ± 5.47	N.S.
All Groups					
Load 1	27	103 ± 2.52		105 ± 2.36	N.S.
2	27	123 ± 3.14		126 ± 2.79	N.S.
3	26	143 ± 3.21		144 ± 3.05	N.S.

TABLE 4.7

A COMPARISON between TESTS performed BEFORE and AFTER TWO WEEKS BEDREST:

STANDARDISED HEART RATE in b min^{-1} at 1.2 l min^{-1} oxygen uptake.

(Mean values ± S.E.M.)

	n	Before		After 2 weeks	Probability of no Difference
Group I (full bedrest)	9	119 ± 6.20	SURGERY and BEDREST	127 ± 3.98	P<0.05
Group II (home)	12	117 ± 3.91		120 ± 3.30	N.S.
Group II4 (home)	6	113 ± 6.13		129 ± 5.19	P<0.01
All Groups	27	117 ± 2.94		124 ± 2.33	P<0.01

of the Group II subjects, except for an exercise test at 4 days after operation, but they showed a highly significant increase in standardised heart rate 2 weeks after operation. Every subject showed an increase and the mean values were 117 b min^{-1} for the baseline test and 124 b min^{-1} 2 weeks later ($P<0.01$).

There were no significant changes in the slope of the heart rate/oxygen uptake relationship in any group.

Standardised Minute Ventilation and Carbon Dioxide Production. No significant differences were found between the baseline results and those at 2 weeks after operation, either in the groups or for all the subjects together. The mean values ($\pm$ S.E.M.) at the 2 week tests for all subjects were 33.2 ($\pm$ 1.06) l min^{-1} for minute ventilation and 1.05 ($\pm$ 0.03) l min^{-1} for carbon dioxide production.

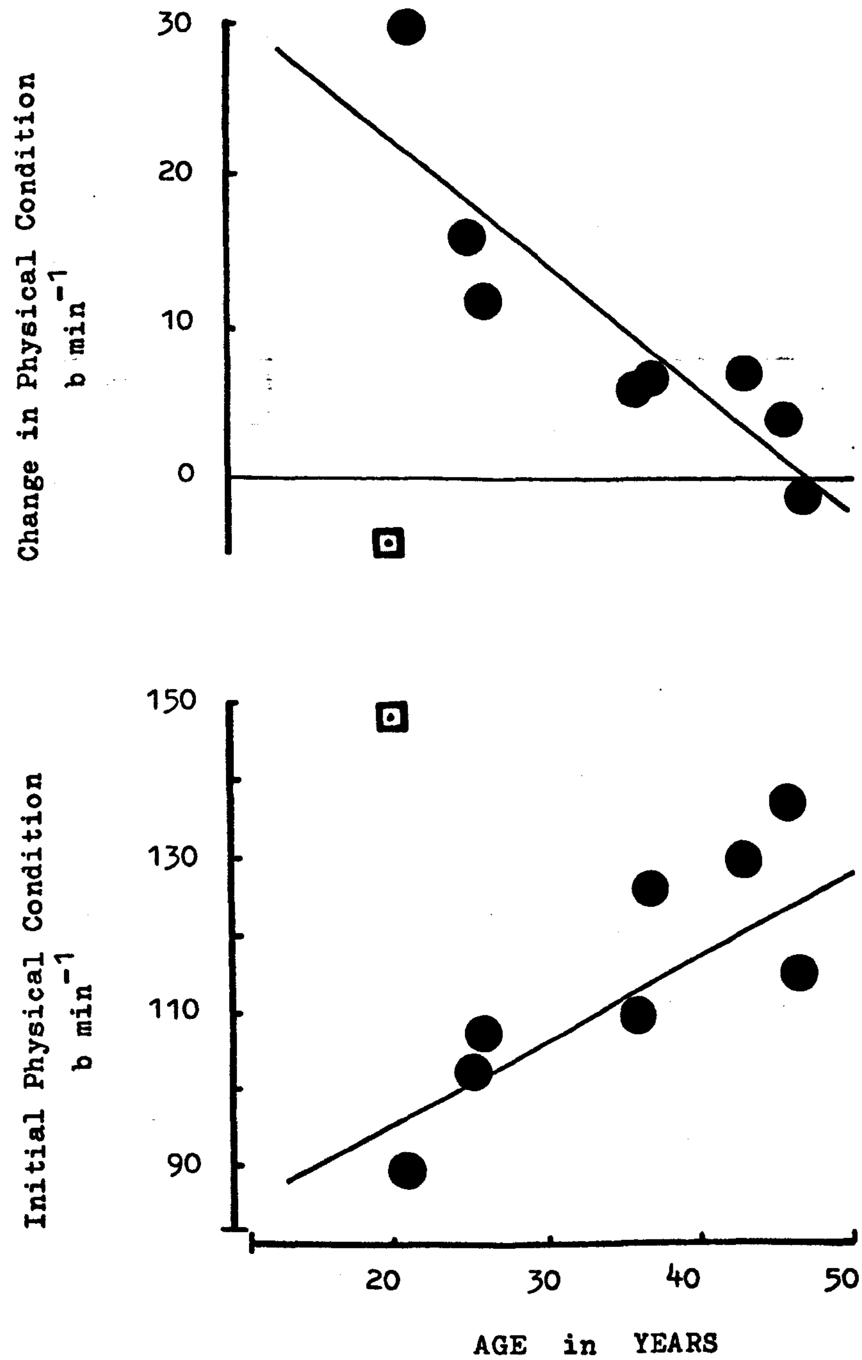
Weight. There was no significant change in the weights of the subjects (all groups together). The mean values ($\pm$ S.E.M.) were 77.0 ($\pm$ 2.3) kg for the baseline tests and 76.7 ($\pm$ 2.2) kg for those at 2 weeks. Twenty four subjects gained or lost 2 kg or less, one man lost 4.8 kg from an initial weight of 109.8 kg and two gained 3.3 kg and 2.5 kg on 57.2 kg and 86.9 kg respectively. All the changes were less than 6%.

Lung Function. Measurements were made in the first 12 subjects (Groups I and II) of vital capacity, forced expiratory volume (F.E.V. 1 sec) and peak flow. There were no significant differences between the measurements made at the first test and those made at 2 weeks. The mean values at the first test were 4.78 l (vital capacity), 3.25 l (F.E.V. 1 sec) and 496 l sec^{-1} (peak flow).

Age. The changes in physical condition after two weeks bedrest in Group I were plotted against age (Fig. 4.7, p103). Except for one subject aged 20 years the values fell about a linear regression line ($P<0.01$). The 20 year old subject was judged to be over-weight at

Fig. 4.7

Regressions of Initial Physical Condition and the Change after Two Weeks Bedrest on Age.
(Physical Condition expressed as heart rate at an oxygen uptake of 1.2 l min^{-1}).



▣ omitted from regressions

clinical examination (86.9 kg and 167 cm in height). The initial physical condition was also plotted against age (Fig. 4.7, p103) and with the exception of the 20 year old subject there was a linear relationship ($P<0.01$).

The Changes 4 Days after Operation

Six subjects (Group II4) were tested at 4 days after operation, before they went home for 10 days, and the results compared to the baseline results.

Oxygen Uptake. (Table 4.8, p107). This was highly significantly lower 4 days after operation than before, at all 3 loads, by 15-20% ($P<0.01$).

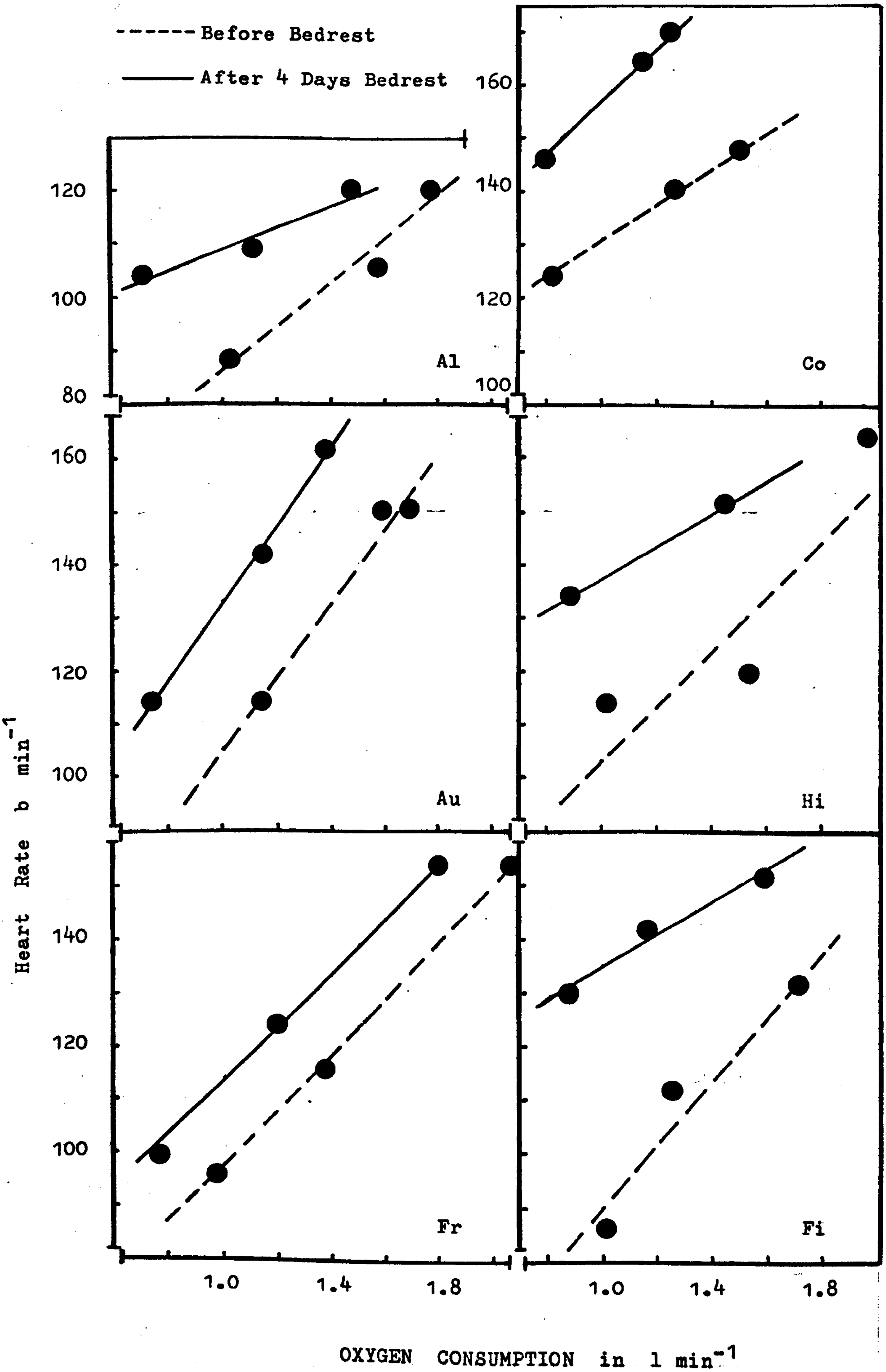
Heart Rate. (Table 4.8, p107). This was significantly higher at 4 days after operation than before, at the lowest load only. The mean values at this load were 121 b min^{-1} at 4 days and 104 b min^{-1} at baseline ($P<0.05$). There were no significant differences at the two higher loads.

Standardised Heart Rate. (Table 4.8, p107). The combination of a lower oxygen uptake and a higher heart rate resulted in a significantly higher standardised heart rate at 4 days after operation than at the baseline tests. The mean values were 139 b min^{-1} at 4 days and 112 b min^{-1} at baseline, ($P<0.01$).

The results for heart rate and oxygen uptake were also plotted graphically for these 6 subjects (see Fig. 4.8, p105). The graphs show clearly that the heart rates are higher for any given oxygen uptake at 4 days after surgery than they were before.

Standardised Carbon Dioxide Output. (Table 4.8, p107). This was significantly higher at 4 days after operation than at the baseline tests. The mean values were 1.20 l min^{-1} at 4 days and 0.89 l min^{-1} at baseline ($P<0.05$).

Fig. 4.8 REGRESSIONS of HEART RATE on OXYGEN UPTAKE in GROUP II4 SUBJECTS



Standardised Minute Ventilation. (Table 4.8 ., p107). This was also significantly higher at 4 days after operation than at the baseline tests. The mean values were 34.0 l min^{-1} at 4 days and 31.2 l min^{-1} at baseline ($P<0.05$). There were only 5 subjects in this comparison because one of the six had an abnormally high minute ventilation (84 l min^{-1}) coupled with a very low oxygen extraction (less than 2%) at 4 days after operation. His results were, therefore, omitted.

Oxygen Extraction. (Table 4.8, p107). There was no systematic increase in the oxygen extraction with increasing load, therefore, a mean of the three values for the percentage of oxygen in expired air was taken for each of the 5 subjects at each test. There was then a significant increase in the percentage of oxygen in expired air at 4 days. This indicates a significantly decreased oxygen extraction. The mean values for % oxygen were 16.52% before operation (2nd test) and 16.75% after 4 days ($P<0.05$).

The Changes 4 Weeks after Operation

Of the 27 subjects studied at 2 weeks after operation 10 were tested again at 4 weeks. These subjects were drawn from both groups (7 subjects from Group I (full bedrest) and 3 subjects from Group II (home)). They showed a significant rise in standardised heart rate at 2 weeks after operation ($P<0.05$) but no significant differences were found when the results at 4 weeks were compared with the pre-operative results. The mean values are given below:-

Standardised heart rates in b min^{-1} (n = 10)

Before	118 ± 5.25
After 2 weeks	127 ± 4.30
After 4 weeks	120 ± 3.58

TABLE 4.8

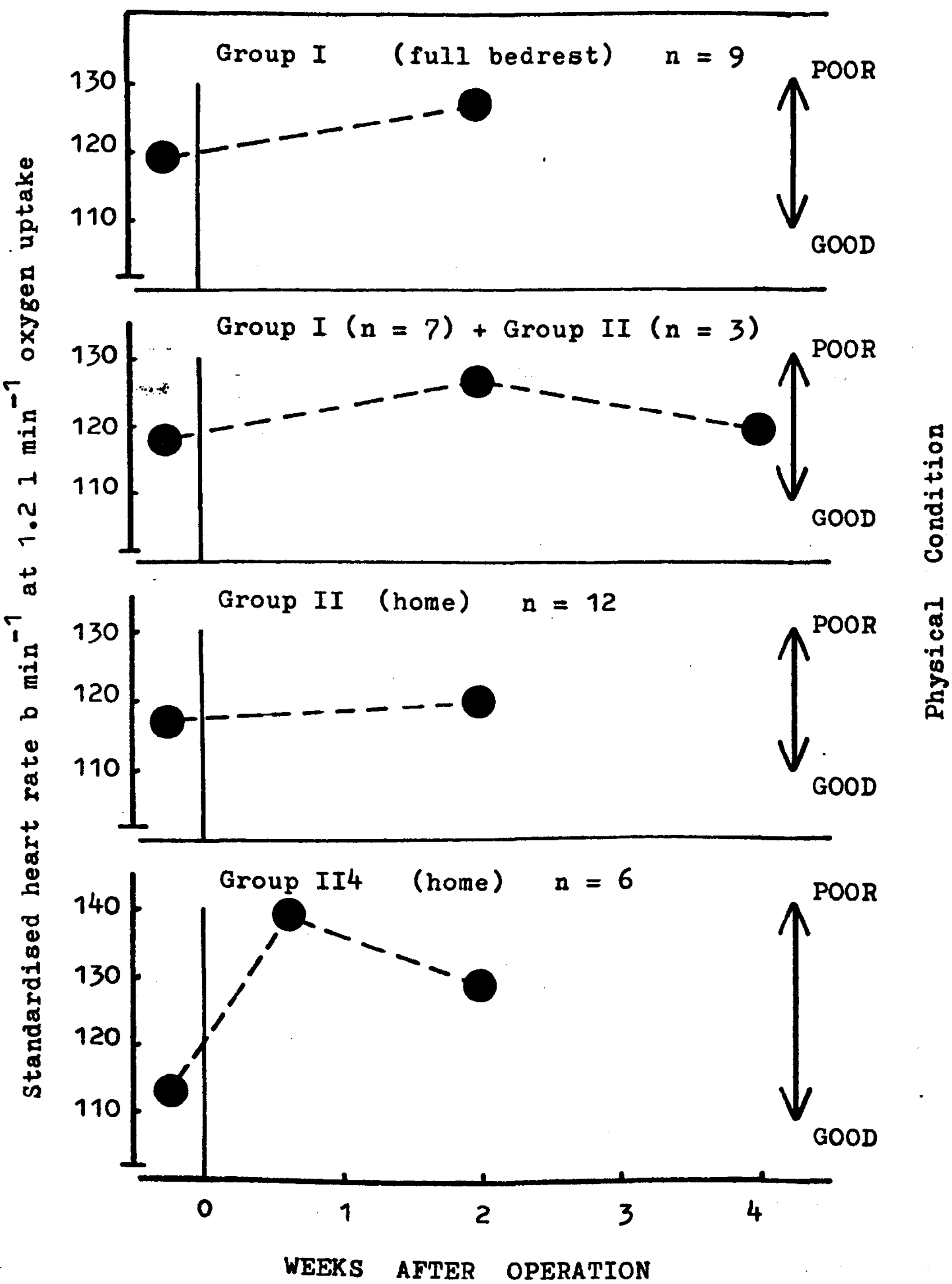
A COMPARISON between TESTS performed BEFORE and AFTER FOUR DAYS BEDREST

n = 6 (Mean values ± S.E.M.)

	Before		After 4 days	Probability of no Difference
Oxygen Uptake in l min^{-1}				
Load 1	1.01 ± 0.05		0.79 ± 0.03	$P<0.01$
2	1.43 ± 0.06		1.20 ± 0.05	$P<0.01$
3	1.75 ± 0.09		1.50 ± 0.09	$P<0.01$
Heart Rate in b min^{-1}				
Load 1	104 ± 6.44	SURGERY and BEDREST	121 ± 7.42	$P<0.05$
2	124 ± 7.02		139 ± 8.03	N.S.
3	145 ± 6.50		154 ± 7.25	N.S.
Standardised Heart Rate in b min^{-1}	113 ± 6.18		139 ± 8.02	$P<0.01$
Standardised Carbon Dioxide Production in l min^{-1}	0.89 ± 0.08		1.20 ± 0.09	$P<0.05$
Standardised Minute Ventilation in l min^{-1} n = 5	31.2 ± 0.73		34.0 ± 0.73	$P<0.05$
% Oxygen in Expired Air n = 5	16.52 ± 0.09		16.75 ± 0.07	$P<0.05$

Fig. 4.9 COLLECTED RESULTS

Changes in Physical Condition found in Association with Bedrest and Recovery.



Changes in Relation to Initial Physical Condition

The changes in physical condition in Group I (full bedrest) were considered in relation to their pre-operative physical condition. It was found that the better the pre-operative condition (i.e. the lower the standardised heart rate) the bigger the decline in physical condition. The regression line is given in Fig.4.10 p110 and the correlation was found to be significant ($P<0.01$). Data from Saltin et al were also plotted in the same way and it is possible that they follow a similar regression line at a higher level of change in physical condition ($P<0.05$).

After the subsequent two weeks of physiotherapy seven Group I subjects were re-tested. As a group they improved in physical condition relative to their state after bedrest ($P<0.05$ from analysis of co-variance). The group mean standardised heart rate was not significantly different from the initial pre-operative value (Student's t test for paired means).

The changes after rehabilitation are plotted with the changes after bedrest both relative to initial physical condition as before (see Fig. 4.11,p111). There is a linear regression line ($P<0.01$) for the change after rehabilitation on initial physical condition. This line is parallel to the line for change after bedrest indicating that rehabilitation causes a similar shift in physical condition for all subjects regardless of their absolute levels of physical condition. The shift consisted of a mean change of 8 b min^{-1} at an oxygen uptake of 1.2 l min^{-1}.

Saltin et al retrained their 5 subjects with a strenuous exercise programme lasting 8 weeks. When they were re-tested all the subjects had improved considerably (see Fig. 4.12 p112) the mean change was 39 b min^{-1}. The regression line of change after retraining on initial condition ($P<0.05$) was parallel to that for the change after

<u>Fig. 4.10</u> INITIAL PHYSICAL CONDITION and the CHANGE after TWO WEEKS BEDREST expressed as heart rate at an oxygen uptake of 1.2 l min^{-1}. Subjects with regression lines:-

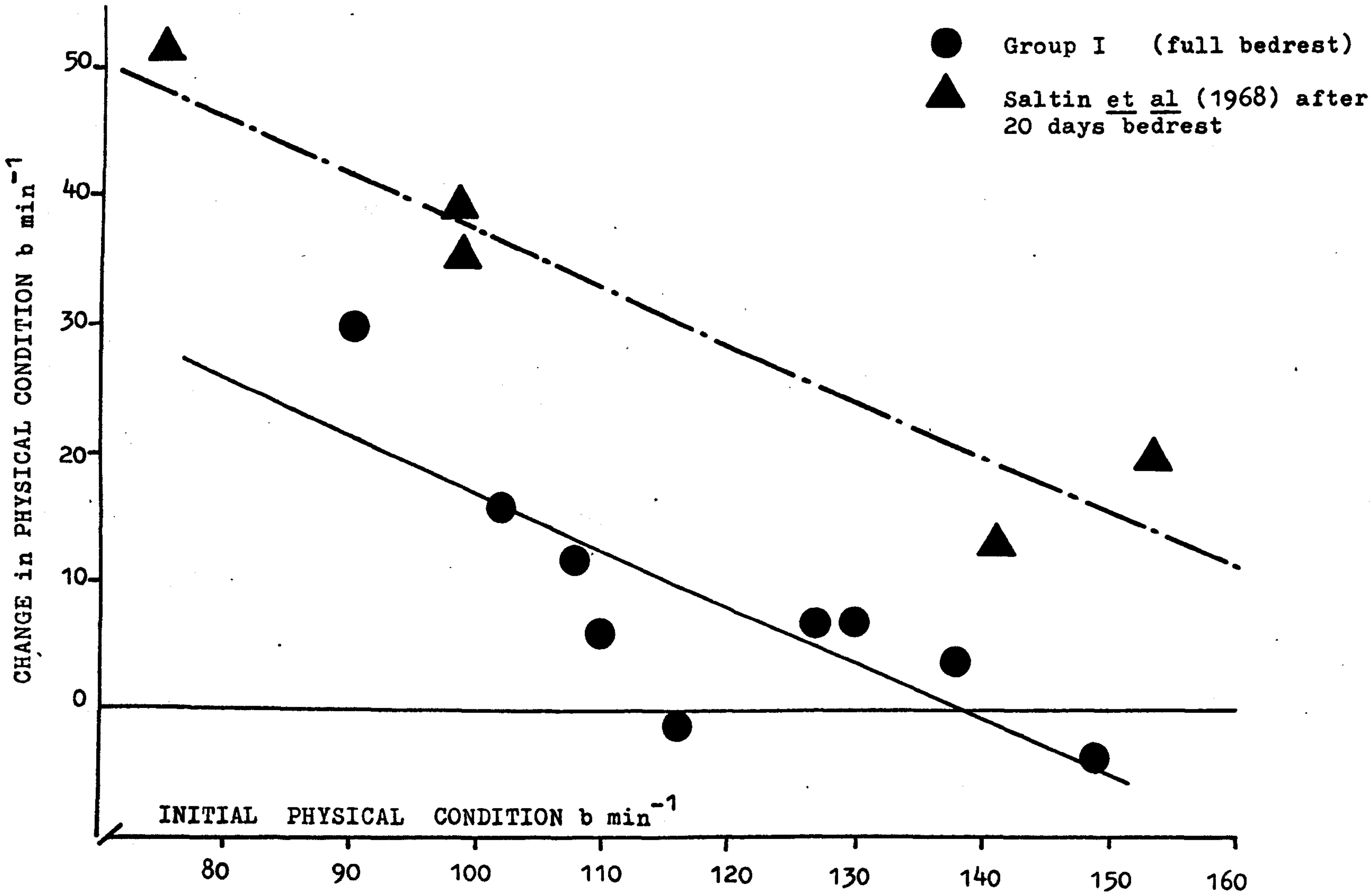


Fig. 4.10 INITIAL PHYSICAL CONDITION and the CHANGE after TWO WEEKS BEDREST expressed as heart rate at an oxygen uptake of 1.2 l min^{-1}. Subjects with regression lines:-

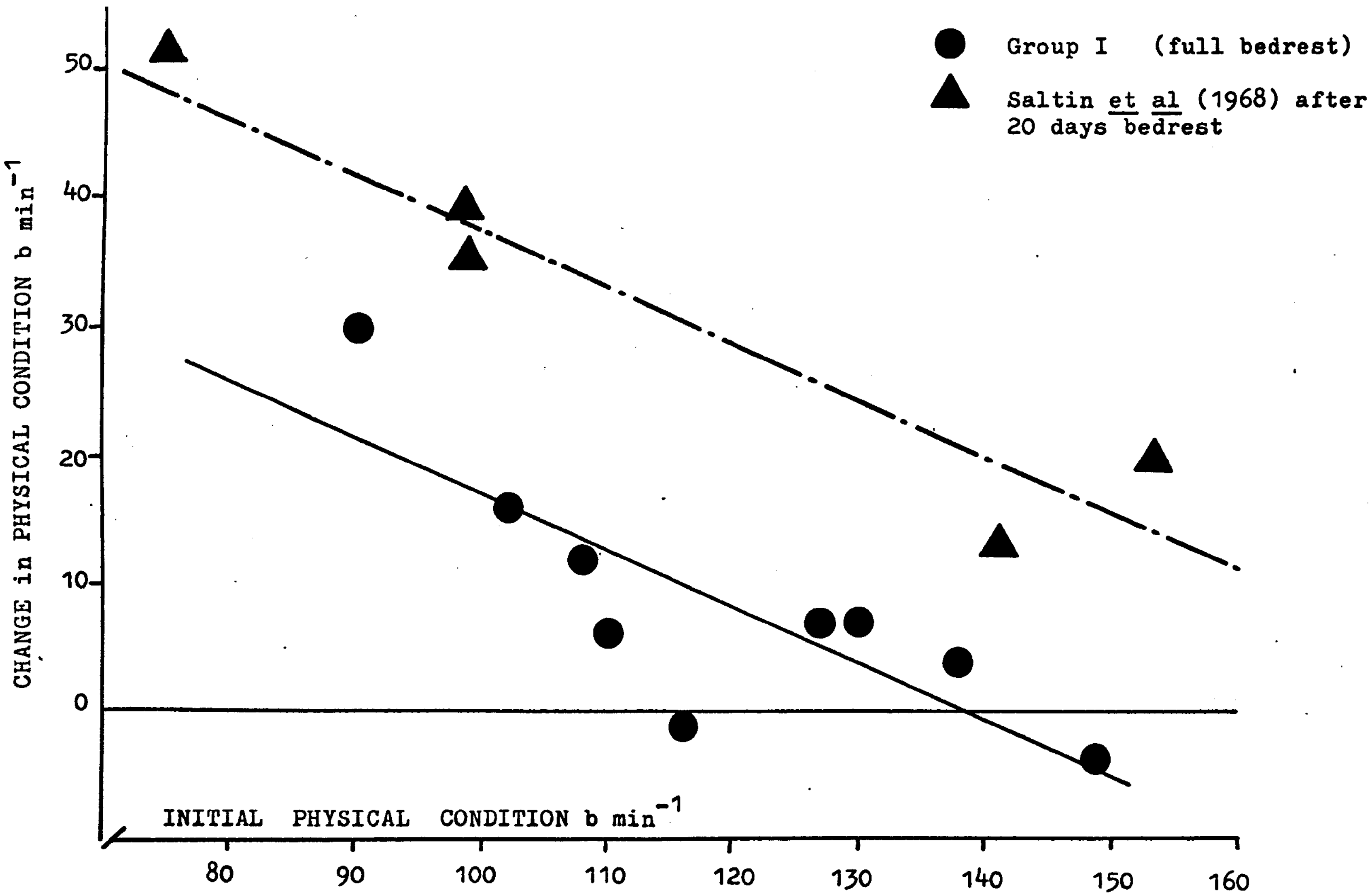


Fig. 4.11

INITIAL PHYSICAL CONDITION and the CHANGES after TWO WEEKS BEDREST and TWO WEEKS REHABILITATION expressed as heart rate at an oxygen uptake of 1.2 l min^{-1}. Subjects with regression lines :-

closed circles, after bedrest
open circles, after rehabilitation

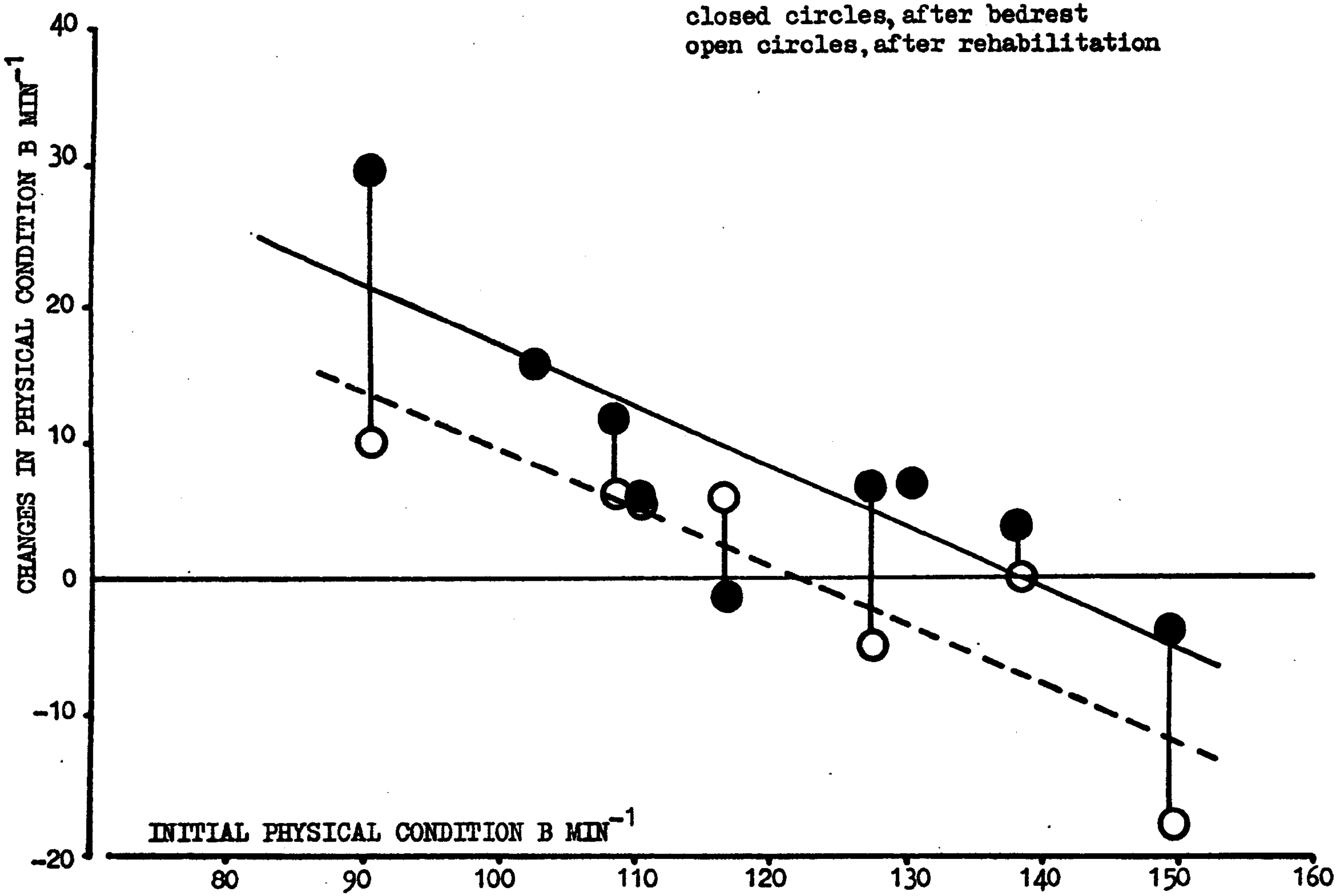
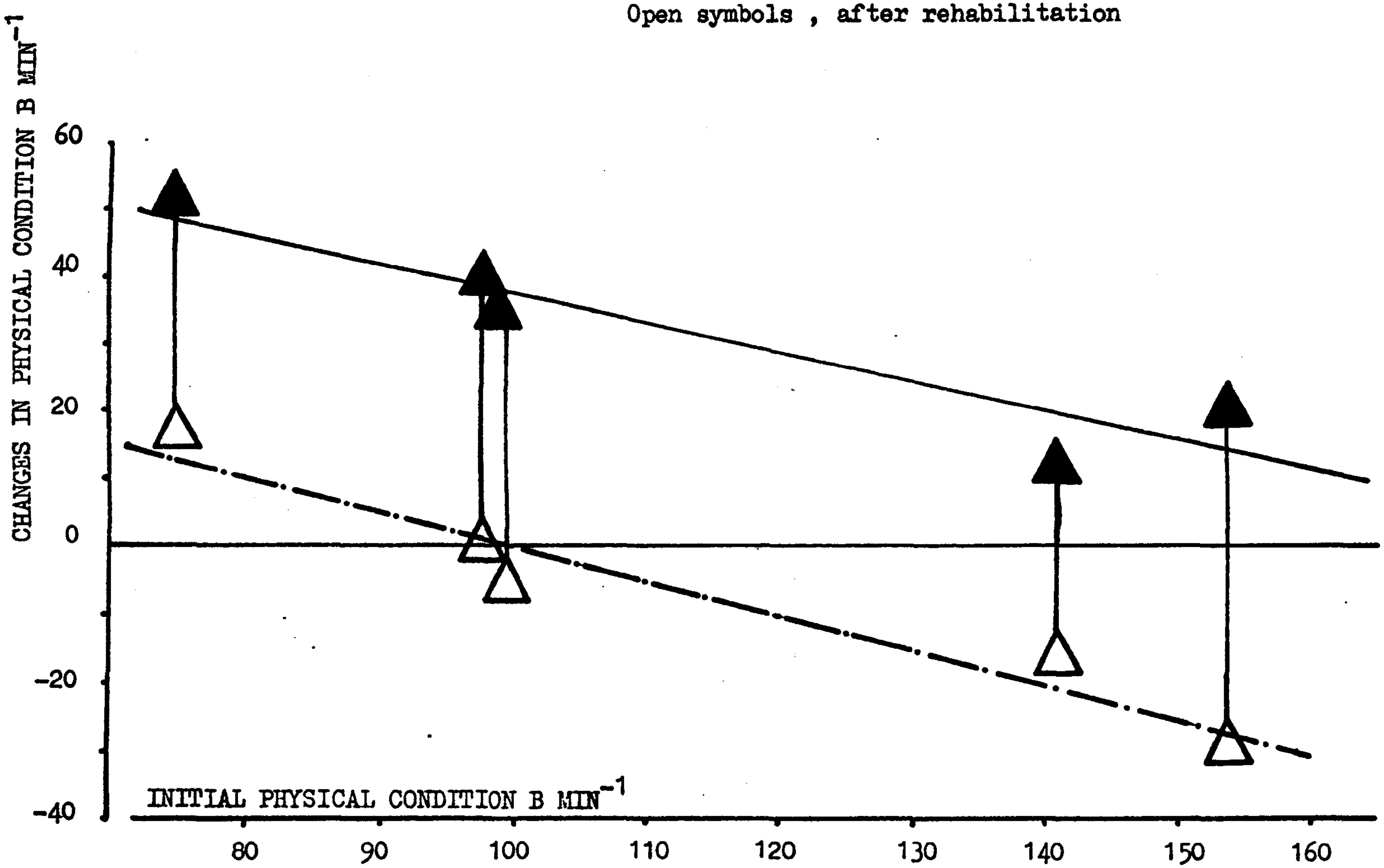


Fig. 4.12

INITIAL PHYSICAL CONDITION and the CHANGES after 20 DAYS BEDREST and 8 WEEKS REHABILITATION expressed as heart rate at an oxygen uptake of 1.2 l min^{-1}. Subjects with regression lines:-

Closed symbols, after bedrest
Open symbols , after rehabilitation



bedrest, indicating again that the improvement was independent of the absolute levels of physical condition.

DISCUSSION

Twenty seven subjects were successfully studied and the expected decline in physical condition with enforced bedrest was observed.

Subjects. The sample was selected in two ways from the general population. The subjects were all healthy apart from their knee injury and as a group they had engaged in the past to a marked extent in active pursuits. Of the 27 subjects there were 4 miners and 15 men who had regularly played football.

However, they had not recently been especially active. Some disability due to their knee injury had been present for at least some months for all of them and 10 subjects reported a drop in their activity levels due to the injury. The questionnaire revealed that only half the sample considered themselves to be active "now" and the graph on p97 shows the wide range of initial physical condition in the group. No relationship was found between the history of activity and physical condition, but in Group I those who were still regularly engaged in a vigorous sport despite their knee injury were in significantly better condition than the others in that group.

The age range was wide (17-55 years) but the sample was small for considering age differences; there was no indication that initial physical condition was age-related. However, when the assessment of initial physical condition was adjusted for body weight, it appeared that the younger subjects considered themselves less active (see p89). This was unexpected since younger people are usually more active than older people (see p 3). It may be a reflection of the different expectations of younger people and would then indicate that these subjects considered themselves inactive for their age. Moreover, they may have had to reduce their activity more as a result of their knee damage than the older subjects. This highlights the problems of interpretation which can arise from assessments made with questionnaires, especially with heterogeneous groups.

Studies in human physiology are always dependent upon the goodwill of the subjects and can be biased by refusals. All the 42 patients approached agreed to take part in the study but 2 declined to complete the first test. These 2 were aged 58 and 69 years and would have been the oldest in the sample. Their refusals were a disappointment since we had hoped our test was mild enough to be accepted by subjects from the whole available age range.

Studies of a longitudinal kind, even those stretching over a few weeks, suffer from dwindling sample size and this study was no exception. Of these 42 subjects who completed the first test only 27 completed the minimum of 3 tests.

The loss was due mainly to minor post-operative complications, no more than 3 subjects opted out. The loss does not imply any bias towards good or bad physical condition in the remaining sample.

The two hospital regimes, involving different amounts of bedrest, presented an opportunity to compare the effects of different amounts of bedrest, but reduced the sample size by splitting the group.

<u>Discussion of Methods</u>

In each work test the subjects were asked to undertake only three grades of work. This was a compromise between what seemed reasonable to ask of the subjects and what was desirable for representative results (see p24). The young subjects described in ~~Part A~~ Chap.3 completed work at four submaximal loads with one leg in one test, but the hospital patients were older and expected to be less highly motivated than the medical students.

<u>Variation in Pedalling Rate</u>. The pedalling rates ranged from

46-63 r.p.m. including all the tests. There was a tendency for the pedalling rate to decrease with increasing load. The rates with the first and third loads were compared using the data from the second and third pre-operative tests (12 subjects tested twice; n = 24). The pedalling rates were highly significantly lower with the third load than with the first load ($P<0.001$). The mean rates were 58 ($\pm$ 1.0) r.p.m. with the first load (1 kg) and 49 ($\pm$ 0.9) r.p.m. with the third load (3 kg).

These variations could be ignored because oxygen uptake was used as the measure of work rate and the other parameters were related to it at a standard level. The data of Eckermann & Millahn (1967), who studied the effect of pedalling rate on efficiency, also indicated that the pedalling rate does not affect the relationship between heart rate and oxygen uptake.

Standard Conditions. Ideally work tests should be done under standard conditions as laid down by Astrand & Rodahl (1970):-

1. The subject must be free of any infection. Grimby & Nilsson (1963).
2. Several hours must have elapsed between the last meal and the test.
3. The subject should not have engaged in any physical work heavier than the test load in the last few hours prior to the test. Astrand (1960).
4. The subject should not be allowed to smoke the last two hours before the test. Juurup & Muido (1946).
5. The subject should be relaxed.

It was not possible to enforce these conditions strictly in this study, but most subjects conformed in most respects. No infection would have been present as this would have been detected by the hospital staff and would have ruled out surgical procedures.

Most tests were performed in the morning at least one hour after breakfast when subjects would have been in a post-absorptive state, but some were performed in the early afternoon about an hour after lunch. This may have been a source of variation in the results. It is very unlikely that any subject engaged in exercise of any severity before the test. Smoking was discouraged and although some subjects may have smoked within 45 mins before the test, at least 20 mins would have elapsed before the test began during the preliminary preparations. The effects of smoking would, therefore, have been small. Every effort was made to create a relaxed and friendly atmosphere during the work tests, but inevitably some subjects would have experienced some tension which will affect the results. This was evident in the comparison of the first and second test results, but not in the comparison of the second and third test results. It is, therefore, not likely to have contributed significantly to variation in the final results. The first three tests may all have been affected by pre-operative anxiety. This would elevate the initial standardised heart rates and tend to offset the rise attributed to bedrest.

Baseline Observations

Habituation. Since there were no apparent initial differences between the groups, (see p89) the subjects were considered together.

All subjects performed two tests on consecutive days before their operation and a comparison of the results revealed some habituation. The standardised heart rates were lower at the second test (mean difference 5 b min^{-1}, $P<0.01$). (See p87). The difference was also revealed in the recorded data as significantly lower heart rates at the second test for all groups together and as a significantly lower oxygen uptake in Group I (see Tables 4.3 and4.2). The change is probably due to the subjects becoming more familiar with the test and less nervous about performing it, (Glaser, 1966; R.J. Shephard, 1970).

Habituation has been measured by Davies, Tuxworth & Young (1968) who report a mean drop of 14 b min^{-1} in heart rate at 2 l min^{-1} in oxygen uptake for a group of 17 subjects between the first and second test on a bicycle ergometer. This is a larger change than that recorded in this study. Other authors report no measurable habituation with the bicycle ergometer, in contrast to the treadmill and step test (Allen, Benade, Davies, di Prampero, Hedman, Merriman, Myhre & R.J. Shephard, 1968).

Baseline. Three sets of measurements were made on 12 subjects who were admitted early enough to allow time for this and the results of the second and third tests revealed no significant differences. The mean values were identical in the second and third tests for standardised heart rate. This result is in keeping with those of Davies et al (1968) who found a drop of 2 b min^{-1} between the second and third tests which is negligible. It was therefore concluded that the second test results formed a satisfactory baseline.

It would have been more satisfactory to take a mean of the second and third test results as the baseline in view of the variation on re-test (co-efficient of variation 9%) but this would have increased the difficulty of gathering samples of a reasonable size. To fit three daily pre-operative tests into a normal hospital routine was to make a big demand on both the patients and the staff. Moreover it is a demand that is not likely to be met in other situations, especially among the elderly and so it was of interest to see whether changes due to bedrest would be detectable against a one-test baseline despite the re-test variation.

Sensitivity. The second and third tests were used to assess the sensitivity of the test in relation to the numbers in the group, using the appropriate Students' t value for the number in the sample and a significance level of 5%. With the smallest group of 6 subjects mean changes of less than 10 b min^{-1} might not be detected as significant but when all 27 subjects were considered then mean changes as small as 4 b min^{-1} might be significant. It is unlikely that changes as small as 4 b min^{-1} would affect a person's sense of effort or customary range of activity but a change of 10 b min^{-1} might be relevant as well as significant (Borg, 1962). We were therefore satisfied that the test was sensitive enough to give us meaningful results.

The Changes Two Weeks after Operation in Group I (full bedrest)

The subjects in Group I who remained in bed for two weeks declined in physical condition. The standardised heart rates rose significantly by a mean of 8 b min^{-1}. The change was expected and is in accordance with other evidence.

Miller, Johnson & Lamb (1965) found an increase of 13-20 b min^{-1} during mild exercise in 6 subjects after 15 days bedrest and an increase of 40 b min^{-1} after 26 days bedrest, there was no change in the oxygen uptake. Cardus (1966) found an elevation in exercise heart rate after 10 days bedrest in 11 subjects. The evidence presented by Saltin et al (1968) is similar and can be directly compared with the present study.

These authors studied 5 young male subjects. They performed steady-state submaximal work at 3 grades on an upright bicycle ergometer. The study differed from the present one in several ways. The tests were based on work with two legs, the subjects were put to bed for the purpose of the investigation where they remained for 3 weeks, 1 week longer than our patients.

From the published tables of recorded data it was possible to standardise the heart rates to 1.2 l min^{-1} oxygen uptake from a 3 point regression line as in this study. The mean rise in heart rate was then 32 b min^{-1}. This is a larger rise than that found in the present study,

TABLE 4.9

SOME PAPERS in which CHANGES of BLOOD VOLUME ASSOCIATED with BEDREST or INACTIVITY have been MEASURED

Authors	Year	n	Regime	Duration	Loss in ml			Change in	
					Blood Volume	Plasma Volume	Red Cell Mass	Physical Condition	P.W.C.
Deitrick et al	1948	4	Immobilisation in a plaster cast.	3 weeks 7 weeks	250 140	200 80			
Miller et al	1964	12	Bedrest (horizontal) strictly enforced.	11 days 4 weeks	 750 (200-1300)	500 500	No change 200		
	1965	6	Bedrest (recumbent) + mild exercise.	4 weeks	1210	670	540	Decreased	
Vogt et al	1966	5	Recumbent bedrest	6 days 30 days	250 No change from control				
	1967	4	Strictly enforced bedrest (no movements of arms or legs)	3 days		250			

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	1967	4	Strictly enforced bedrest (no movements of arms or legs)	3 days		250			

TABLE 4.9 (continued)

Authors	Year	n	Regime	Duration	Loss in ml			Change in	
					Blood Volume	Plasma Volume	Red Cell Mass	Physical Condition	P.W.C.
Saltin *et al*	1968	5	Recumbent bedrest	20 days	365	225	140	Decreased	Decreased
Hyatt *et al*	1969	20		1 week	decrease	decrease	No change		
				2 weeks	No change from control	No change	No change		

which may be due to the longer time spent in bed but the difference is small (20 days instead of 16 days). Miller et al (1965) found that longer bedrest caused greater deconditioning. The patients in the present study were given sporadic general exercises in bed as well as isometric exercise for the operated leg and this may have offset the decline in physical condition. Apart from these exercises both groups had a similar amount of freedom to sit up and move around in bed. Neither group were allowed to support their weight on the legs.

A third possible explanation is that a longer time elapsed between the end of bedrest and the first post-operative test in our subjects than those of Saltin et al.

The increased heart rate may be associated with a decreased stroke volume. This is borne out by the results of several authors. Taylor et al (1949) reported a 17% decrease in heart volume (roentgen-kymogram) in six subjects after three weeks bedrest. Saltin et al (1968) reported a marked decrease in stroke volume and a decreased heart volume but no significant change in cardiac output at 600 kg m min^{-1}.

The decline in physical condition could be due to changes in blood volume, impairment of the control of the heart and vasculature, or deterioration in cardiac and skeletal muscle cells. These possibilities are in no way mutually exclusive and could interact in various ways.

Blood Volume. Seven papers which contain reports of the effects of bedrest on blood volume are listed in Table 4.9 . All of them report some drop in blood volume.

Three of them report an initial drop during the first few days of bedrest (Vogt, Mack & Johnson, 1966; 1967; Hyatt, Kamenetsky & Smith, 1969), and this can be explained by the recumbency diuresis occurring from the first day of bedrest reported by Lamb & Stevens (1965) and Hyatt et al (1969).

After longer periods of bedrest (more than a week) the evidence becomes more confused. Dietrick et al (1949) and Saltin et al (1968) report a decrease of between 5 and 10% in blood volume. Miller et al report larger changes of the order of 15-20%, but Vogt et al and Hyatt et al find that the initial drop is transient and that after the first week the levels do not differ significantly from pre-bed rest control values.

Hyatt et al suggested that the plasma volume is restored at the expense of extravascular water. This provides a satisfactory explanation of their observations of a continuing diuresis (and naturesis) of 250 ml day^{-1}, and also of the intolerance to tilt observed by them and most other authors in Table 4.9. If extravascular spaces are depleted of fluid, tissue pressure will be reduced and would therefore allow rapid capillary filtration and a temporary reduction of plasma volume during tilt.

However this explanation does not account for the results of Miller et al (1964; 1965) who report larger changes using similar methods (radio-labelled iodine). The higher values are not obviously attributable to differences in procedure except that the subjects of Hyatt et al were encouraged to maintain a high water intake. If Miller et al made their measurements of blood volume when the subjects were standing rather than recumbent then the large values would be expected according to Hyatt et al's theory of capillary filtration but it is likely that Miller et al made their measurements without disturbing the recumbent regime of their subjects although they do not state this.

There is a large variation in results from different subjects, Miller et al (1964) quote ranges of 200-1300 ml. No correlation has been found between the degree of orthostatic intolerance and the loss of blood volume (Hyatt et al, 1969) nor between the loss of physical condition and the loss of blood volume (Miller et al, 1965).

The losses in blood volume could be due to loss of plasma or red cells or both. Some authors find there is a drop in red cell mass (Miller et al, 1965; Lamb & Stevens, 1965; Saltin et al, 1968) and some find no change (Hyatt et al, 1969). It is likely that different processes are involved in changes in water balance and changes in red cell mass and that they follow a different time course.

The changes in water balance are rapid and probably to be attributed to the recumbent position rather than to inactivity. The change from an erect to a supine posture involves profound changes in the vasculature due to changes in the effects of gravity. There will be a redistribution of blood from the peripheral veins of the legs to central low pressure areas in the great veins and the pulmonary circulation.

Sjostrand (1952; 1953) reports that a volume of 640 ml is redistributed under these circumstances and that this amounts to 11% of the total blood volume. This amount is similar to that given for the loss due to bedrest (see Table 4.9 p119). It seems likely therefore that homeostatic mechanisms based on receptors in the low pressure areas get rid of the appropriate blood volume by altering urine flow.

The red cell losses are much slower and have not been detected after bedrest of less than 20 days (see Table 4.9, p119). They could be due to the diminished local hypoxia in the bone marrow under the quiescent conditions of bedrest. If this is so then gravitational effects would play no part in the loss of red cell mass during bedrest. Stevens, Miller, Lynch, Gilbert, Johnson & Lamb, (1966) have shown that hypoxia prevents the loss of red cell mass but not the loss of plasma volume, and a simulation of the effects of gravity using lower body negative pressure prevents the loss of plasma volume but not the loss of red cell mass (Lamb & Stevens, 1965).

It is unlikely that a significant drop in red cell mass would have had time to develop in the Group I (full bedrest) subjects during their two weeks bedrest.

Moreover Rowell, Taylor & Wang (1964) have shown that a 14% reduction in the red cell mass by phlebotomy does not produce any change in the heart rate at submaximal levels of work although it reduced the maximum cardiac output. Therefore even if the Group I subjects had suffered a drop in red cell mass it might not appear as a decline in physical condition. Whereas a 25% drop in plasma volume caused by thermal dehydration (Saltin, 1964) was associated with a rise in submaximal heart rates.

The evidence so far suggests that the exercise tachycardia observed in the Group I (full bedrest) subjects after two weeks in bed can be explained by a loss of blood volume consisting mainly of a loss of plasma. However, changes in water balance can be very rapid and considerable rehydration could have occurred between the end of bedrest and the test. Vogt _et al_ (1967) found the plasma volume restored in two days and it may be fully restored even sooner. Rummel, Michael & Berry (1973) report deconditioning after space flights of 8-11 days. They have measured physical condition in terms of the oxygen uptake at a fixed heart rate of 160 b min^{-1} and found that the reduction was much greater 2-5 hours after the flight than 1-2 days afterwards.

It is not clear that loss of plasma volume is the explanation of the results obtained although it may be a contributing factor.

Vasomotor Changes. Theoretically a reduction in vasomotor tone or a reduced reflex vasomotor response could give rise to an increased heart rate during exercise because of a less effective re-distribution of the available blood volume to the working muscles. However there is no good evidence for this.

The change from the upright to the supine position produces a decrease in vasoconstrictor tone (Neilson, Herrington & Winslow, 1939) but this may be a transient phenomenon.

Venous flow velocity in the legs has been found to decline by 40% in post-operative bedridden patients (Wright, Osborn & Edmonds, 1951) and in hemiplegic patients (Wright, Osborn & Hayden, 1952). The reduction in flow velocity appears to be caused by lack of muscle activity in the leg. It could be associated with a decreased venous tone and an increased venous capacity but could equally well be explained by a reduction in blood flow.

Saltin et al found a decrease in arterial blood pressure at submaximal levels of work which is tentative evidence for reduced peripheral resistance and arterial tone in the absence of a significant drop in cardiac output. However if the blood volume is reduced then a greater degree of vasoconstriction would be required to maintain peripheral resistance and blood flow to the working muscles during upright exercise. It is possible that vasoconstrictor function is unimpaired but cannot fully meet the extra demand imposed by the loss of blood volume.

In the absence of any clear evidence the role of possible vasomotor changes in the deconditioning of bedrest must remain speculative.

Changes in Skeletal Muscle Cells. The evidence for muscle wastage with prolonged inactivity is less speculative and degenerative changes are likely to occur even after two weeks of bedrest. Saltin et al (1968) observed a significant decrease in lean body mass after 20 days and Deitrick et al (1948) observed a loss of 53 gm of nitrogen (representing 4 lb of muscle) after 6 weeks and a reduction in the girth and strength of the calf muscle. The continuing loss of extravascular water observed by Hyatt et al (1969) may be from muscle tissue. Moreover, in addition to the loss of muscle mass there is evidence for changes in the systems responsible for energy release. Training has been shown to increase the oxidative capacity of muscle cells and the amount of stored glycogen (Gollink, Armstrong, Saubert, Piehl & Saltin, 1972). Inactivity may have the opposite effect. Therefore there may be a loss of both muscle substance and muscle function with inactivity.

If there are adverse changes in muscle cells then, for the same rate of work, more motor units may become active after bedrest than before. L.H. Hartley et al (1972) has suggested that there is a parallel between the number of motor units and the number of sympathetic nerve fibres which become active in order to explain his finding of lower levels of sympathetic nerve activity during exercise after training. If his theory is correct it would explain the increased heart rate after bedrest and also imply an increased degree of vasoconstriction which would compensate for lost plasma volume.

An increase in sympathetic tone has been proposed as a cause of the increase in resting heart rates observed with bedrest (Raab, 1960). Resting heart rates were not recorded in this study, but in a group of 7 other similar patients undergoing bedrest in the same hospital, the resting heart rates were found to increase significantly.

Hartley's theory provides an explanation of this and seems a more likely hypothesis for explaining the deconditioning of bedrest than that of a chronic reduction in vascular tone which causes a drop in blood pressure and a compensatory increase in heart rate mediated by baroreceptor reflexes.

The relative importance of the changes in blood volume and of muscle wastage might be assessed by a re-infusion experiment such as that of Robinson, Epstein, Kahler & Braunwald (1966), but made after bedrest. If the deconditioning was fully compensated by the restoration of an appropriate blood volume it could be concluded that changes in muscle cells were irrelevant although they would obviously affect maximum capacities.

It would also be of interest to compare upright exercise before bedrest with supine exercise after bedrest. In upright exercise the cardiac output is lower and the heart rate is higher than in supine exercise, and in upright exercise the stroke volume seldom exceeds 65 ml although in supine exercise it is often greater (Musshoff, Reindell & Kleipzig, 1959). If bedrest does not cause significant changes in the vasomotor control system or the muscle cells and if the loss of blood volume is compensating only for the changed posture then the differences normally seen between supine and upright exercise might disappear.

If it is found that the heart rates at a given oxygen uptake are higher during supine exercise after bedrest than during upright exercise before bedrest this must be due to changes other than adjustments in blood volume to posture and gravity.

It is possible that impaired myocardial function also contributes to the reduced stroke volume and increased heart rate. Saltin et al found that during maximum supine exercise when the blood has no opportunity to pool on the venous side there was still a decrease in cardiac output and stroke volume after bedrest although it was not so large.

Functional deterioration in skeletal and cardiac muscle cells may also be causes of the deconditioning of bedrest.

Bedrest as a Model of Inactivity. This study was undertaken partly to find out whether age affects deconditioning due to bedrest. It was also important for our hypothesis (that inactivity is a potent cause of physical deterioration in the elderly) to know to what extent bedrest can be considered as a model of inactivity. Bedrest involves postural changes as well as reduced activity and some of the changes found after bedrest such as the increased heart rate on tilting may be due to the recumbent posture rather than the inactivity.

One study has been made which sheds some light on this question. Inactivity due to being confined in a small space for two weeks (n = 36) caused a drop in blood volume of 520 ml, and a drop in red cell mass and a mean increase of 10 b min^{-1} in heart rate in a Master's exercise test (Lamb et al, 1964). There was no increase in the time spent in the supine position. The conclusion to be drawn from this is that the changes in physical condition due to bedrest are as much due to inactivity as the supine posture.

The final explanation of the increased heart rates after bedrest is not clear but it is likely to include a decrease in plasma volume and a degeneration of skeletal and cardiac muscle cells. The end result is that the necessary blood flow can be maintained but at a greater cost in terms of heart rate which is interpreted as a decline in physical condition.

The Changes Two Weeks after Operation in Group II (home)

The subjects in Group II who went home after 4 days in bed were tested when they returned to hospital 10 days later. Their physical condition was found to be not significantly different from before operation (see Table 4.7).

They are unlikely to have remained in bed at home, therefore sitting in a chair ambulation and moderate activity over 10 days would offset any changes due to their 4 days of rest.

The number of days spent at home varied and it is likely that the subjects' activity patterns varied. This was borne out by questionnaires which were sent to all Group II and II4 subjects after their discharge. Most subjects reported that they had attempted to live as normally as possible rather than to have rested most of the time and mentioned a variety of activities such as walking, gardening and exercises.

It seems likely that their levels of activity approached their levels before admission to hospital since knee damage was already restricting them then.

Unexpectedly the subjects in Group II4 showed a decline in physical condition when re-tested at 2 weeks. The standardised heart rates rose by a mean of 7 b min^{-1} which was highly significant. The load by load heart rates did not change but the oxygen uptake fell significantly (Tables 4.2 and 4.3). This was not due to a diminished pedalling rate and there was no evidence of an increase in anaerobic work since the standardised minute ventilation and carbon dioxide production did not change. It is possible that the decrease in oxygen uptake is due to a general drop in muscle tension. Patients in hospital are known to suffer from anxiety (Ramsey, 1972) and this could have given rise to muscle tension which disappeared after operation.

These Group II4 subjects differed from the other Group II subjects in that they were required to do a work test on the bicycle ergometer only 4 days after their operation. This would be expected to improve their physical condition rather than the reverse.

Another possible explanation of the difference in physical condition is that they spent their time less actively than Group II while at home. The follow-up questionnaires were intended to elucidate this point. A 66% return indicated that there was no difference in the activity patterns between the 2 groups. However questionnaire data based on recall over some weeks is not accurate and the returns were incomplete, so it remains possible that the Group II4 subjects were less active during their time at home and that that was why they were still in poorer physical condition 2 weeks after their operation than before.

It is evident from the Group II results, but not Group II4, that early mobilisation restores physical condition within 10 days after 4 days bedrest. However no comparisons were made of the condition of the operated knee in Group II who were mobilised early and Group I who remained in bed for a fortnight.

The Changes after 4 Days Bedrest in Group II4 (home)

The six subjects in Group II4 were tested 4 days after their operation and were found to have declined in physical condition to a greater degree than the Group I (full bedrest) subjects studied at 2 weeks. They showed an increase in mean standardised heart rate of 27 b min^{-1} and also an increased respiratory response which was not observed at 2 weeks in Group I.

The rise in standardised heart rate appeared in the recorded data as a lower oxygen uptake at all loads although the pedalling rates and, therefore, the work rates were almost identical. The heart rate was significantly higher at the lowest load only. This drop in oxygen uptake could be explained if the muscle cells were working under more anaerobic conditions.

The standardised minute ventilation and carbon dioxide production were significantly higher indicating an increase in the proportion of anaerobic work being done and this was borne out by the significantly lower oxygen extractions observed after bedrest (mean before bedrest 4.43% and mean after bedrest 4.20%).

The changes in blood volume already discussed would be evident after four days bedrest and might have been at a maximum. Moreover these subjects were tested within a few hours of getting out of bed for the first time whereas the Group I (full bedrest) subjects may have transferred more gradually from complete bedrest to activity. Both these factors could account for the larger decline seen at four days than at two weeks.

The change in ventilation after bedrest is not confirmed by other authors Cardus (1966), Hyatt et al (1969) and Rummel et al (1973) found no significant change.

Changes in muscle cells may have occurred in four days but are not likely to be greater than at two weeks. Other explanations must therefore be considered.

Many anaesthetics cause widespread vasodilation and the effects might still be apparent at four days after operation. An increase in forearm flow is still detectable after 24 hours (Lofstrom, J.,1969) and it might still be detectable after 4 days. Muscle relaxants used at operation also cause vasodilation, loss of skeletal muscle tone and maybe also vascular smooth muscle tone. It is not known how long lasting these effects are, but they may exert a residual influence even at 4 days after operation which becomes apparent during exercise.

The increased ventilation is indicative of increased lactate production perhaps due to inadequate flow through the muscles, if there is an inadequate vasoconstriction then there will be a failure in re-distribution of the blood to the working muscles, a drop in blood pressure and a reflex rise in heart rate. Some subjects had very high exercise heart rates after bedrest (170-190 b min^{-1}), and one subject had a very low oxygen extraction (less than 2%). This subject's oxygen extraction was poor before operation (3.4%) and as with all the other subjects it became worse after operation and bedrest.

Because of these acute changes which may be due to the after-effects of anaesthesia rather than the effects of bedrest, the study of this group cannot shed any light on the time course of changes in physical condition with bedrest alone. They are however pertinent in assessing the effects of early mobilisation and suggest for future investigation a comparison of different anaesthetics and their effects in situations not involving bedrest, such as dental surgery.

The Changes Four Weeks after Operation

The ten subjects who were tested at four weeks after their operation included 7 from Group I (full bedrest) and 3 from Group II (home). They showed a significant mean increase in standardised heart rate at two weeks after operation which was to be expected since they were predominantly Group I subjects and no change at four weeks after operation (see p106). It can therefore be concluded that two weeks of ambulation and physiotherapy were sufficient to restore their lost physical condition.

The time course of recovery from bedrest is reported to be 2-5 weeks by Taylor *et al* (1949) after 3 weeks bedrest and Deitrick *et al* (1948) report 7 weeks recovery for the strength and girth of calf muscle after complete immobilisation for longer than 4 weeks. Saltin *et al* (1968) report an improvement after 8 weeks over pre-bedrest levels but their subjects were trained vigorously. Our findings that two weeks physiotherapy is enough to restore the small decline in physical condition seen after two weeks bedrest is in keeping with the literature.

It was the policy of the hospital not to discharge patients until fully rehabilitated so that they could return to their previous occupations without further convalescence at home. This would have provided us with a recovery reference level as judged by the hospital if all the patients had had the same occupations, but these varied from the hard physical labour of coal mining to the sedentary paper shuffling of the office executive. In consequence the length of time spent on rehabilitation physiotherapy varied a great deal and was more closely related to the requirements of the patient's job than the state of his knee or his general physical condition.

The Changes in Group I in Relation to Initial Physical Condition

The patients in Group I, who remained in bed for two weeks, were found to decline as a group in physical condition, but there was considerable variation in their response to bedrest.
Some subjects deteriorated considerably and some not at all. When this variation was examined in relation to the initial physical condition of the subjects a linear relationship was found (see Fig.4.10, p110). Those with the best initial physical condition deteriorated the most and those with poorest initial physical condition showed no change. Subjects with heart rates of about 140 b min^{-1} at an oxygen uptake of 1.2 l min^{-1} are already in such poor physical condition that two weeks bedrest following surgery caused no deconditioning. The implication is that bedrest did not differ significantly from their customary daily activity in so far as that affects physical condition measured in this way.

Although the correlation coefficients for the regression lines were significantly high the curve might equally well be sigmoid or exponential rather than linear in form.

The data from Saltin et al confirms our findings of a relationship between initial physical condition and the change (see Fig.4.10, p110).

The rehabilitation programme for the hospital patients was sufficient to restore the subjects who were initially in the poorest physical condition and to effect a further improvement. However those who were initially in the best physical condition were not restored to pre-operative levels after two weeks of rehabilitation.

This may reflect the mildness of the rehabilitation programme.

The programme included exercises designed to restore the knee function and also activities such as walking, swimming and badminton which would be expected to improve physical condition as we have measured it, however the programme was adjusted according to the state of each patient's knee and some of them spent a good deal of time resting with the leg raised to reduce swelling.

The re-training programme which Saltin et al used for their subjects was very much more vigorous and including interval training based on running at rates near to maximum. Nevertheless the subject with the best initial condition was not fully restored even after 8 weeks (see Fig.4.11, p111). This strenuous programme resulted in a bigger improvement on post-bedrest levels than was seen in the hospital patients.

In both studies the improvement consisted of a shift which appeared to be related to changes in activity patterns and emerged in spite of the data from different laboratories and tests based on different numbers of legs and regardless of the absolute levels of physical condition of the subjects. Fig.4.13 (p137) is a summary of the changes due to bedrest and rehabilitation from both studies.

This finding is based on slender evidence but if it should prove to be general it opens up interesting possibilities in several fields.

The range of change in physical condition (40 b min^{-1}) between bedrest and vigorous training may represent the contribution that can be added by changes in activity to constitutionally determined levels of physical condition. Bedrest is then presented as one end of an activity spectrum which stretches through normal ranges of activity to athletic training and the emphasis is laid on inactivity rather than the recumbent posture as the main cause of deconditioning due to bedrest.

It has been suggested that, in order to offset the expected decline with bedrest, patients should be trained so that their pre-operative physical condition is good (Alvik, 1966). This was done by Adolfsson, (1969) who trained 63 female gall-stone patients for 6 weeks and achieved a 20% improvement in physical working capacity. However, after surgery and 10 days in bed their capacity had reverted to pretraining levels and after a further 4 weeks convalescence their capacity was not significantly different from that of control patients who had received no training. This confirms the present finding that good pre-operative condition offers no protection against the deconditioning of bedrest.

<u>Changes in Relation to Age</u>

The changes in physical condition in Group I (full bedrest) were considered in relation to age and it appeared that the younger subjects deteriorated to a greater extent than the older subjects. The regression line is shown in Fig.4.7, (p103) and was found to be significant ($P<0.01$) provided the subject aged 20 who is clearly unusual was omitted.

The reason for this may be that there is a relationship between initial physical condition and age. No such relationship was found when all the subjects were considered together (see Table I, p7) but when the Group I subjects alone were considered a relationship emerged. Omitting the 20 year old subject there was a significant relationship between age and initial physical condition ($P<0.01$). Therefore, it must be concluded that the apparent negative correlation between age and change in physical condition with bedrest is due to differences in initial physical condition which may be age-related.

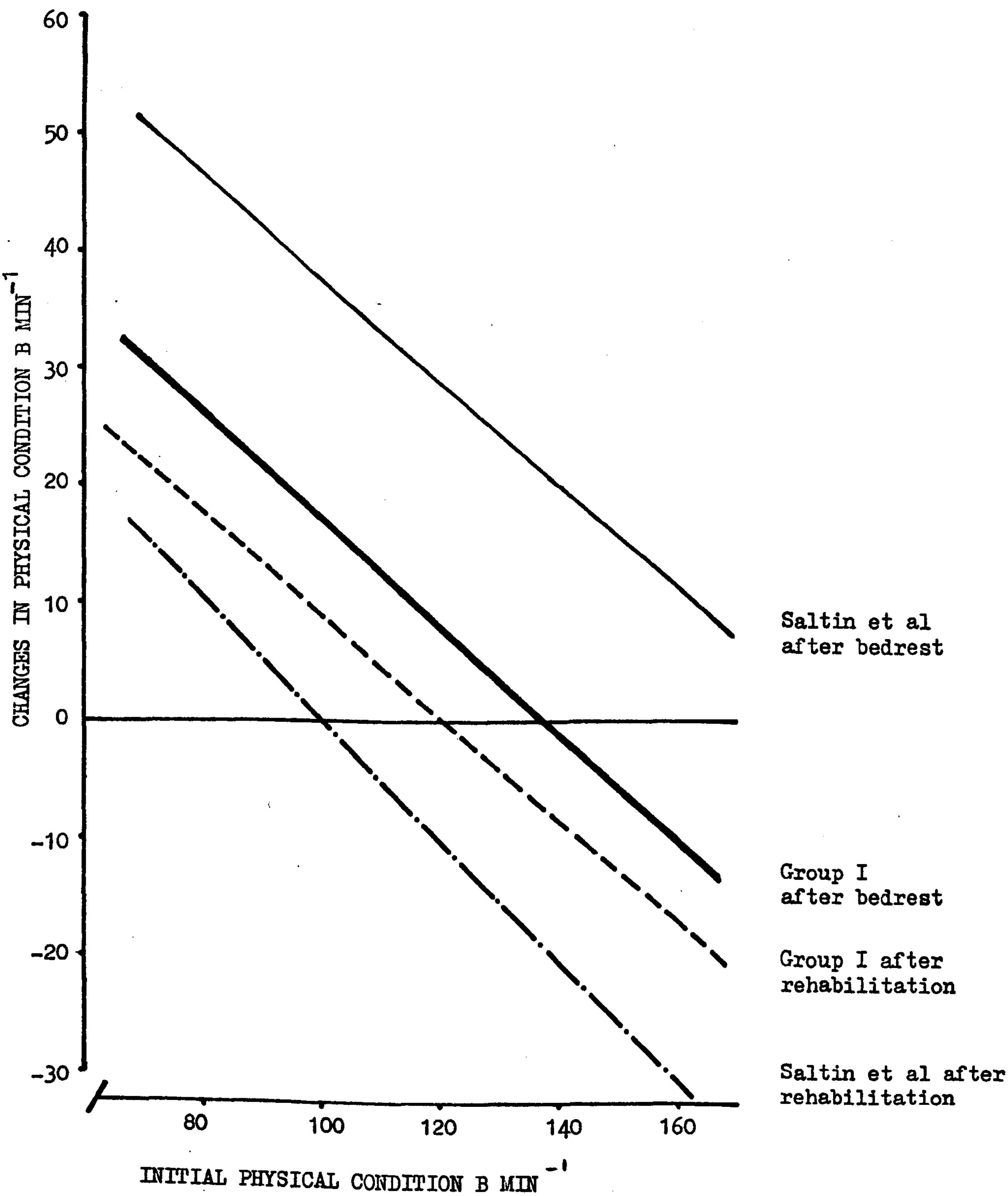
It is surprising that a relationship between age and physical condition should emerge in such a small group of subjects. Large studies have consistently failed to find such a relationship (see p 7). The reasons were sought in the answers to the preliminary questionnaires since these contained data relevant to customary daily activity. It was found that 4 subjects in Group I were, before operation, still taking part regularly in vigorous sport (football, swimming, squash or badminton) despite their knee injury. These 4 sportsmen were compared with the 5 others and found to have significantly lower initial standardised heart rates ($P<0.05$) indicating significantly better initial physical condition. They were also compared for age, omitting the 20 year old in poor initial condition who was not a sportsman. It was found that the sportsmen were significantly younger ($P<0.01$).

These findings bear out our hypothesis that inactivity is an important determinant of physical condition which can contribute to a decline with age.

Fig. 4.13

SUMMARY OF CHANGES DUE TO BEDREST AND REHABILITATION FROM OUR STUDY AND THAT OF SALTIN ET AL (1968)

The lines are the best fit regression lines for the recorded data



CONCLUSIONS

1. The exercise of pedalling an upright bicycle ergometer with one leg was a satisfactory method for assessing physical condition in a group of young and middle-aged patients undergoing surgery to one knee.
2. After four days of recumbent bedrest following surgery physical condition had deteriorated very significantly and there was a significant rise in standardised minute ventilation.
3. In another group, after two weeks of recumbent bedrest following surgery, physical condition had deteriorated significantly, but to a smaller extent than was found after 4 days. The reasons for the changes are discussed but could not be fully elucidated.
4. After four days of recumbent bedrest and ten days ambulation at home with a leg in a plaster cast, physical condition showed no significant change. It is presumed that the ten days ambulation restored any deterioration caused by the four days in bed.
5. Two weeks of physiotherapy and rehabilitation restored the physical condition of the group who remained in bed for two weeks to pre-operative control levels.
6. There was a linear relationship between the initial physical condition and the deterioration after two weeks bedrest ($P<0.05$). Those in the best initial condition deteriorated the most and those in the poorest initial condition showed no change. The changes after rehabilitation were unrelated to the absolute levels of physical condition and were similar for all the subjects.

7. The results of Saltin _et al_ (1968) were examined in the same way and the same relationships were found between initial physical condition and the changes due to bedrest and re-training.

8. There was a linear relationship between age and both initial physical condition and the change in physical condition in the subjects who remained in bed for two weeks.
   There was also a relationship in this group between initial physical condition and customary levels of physical activity.

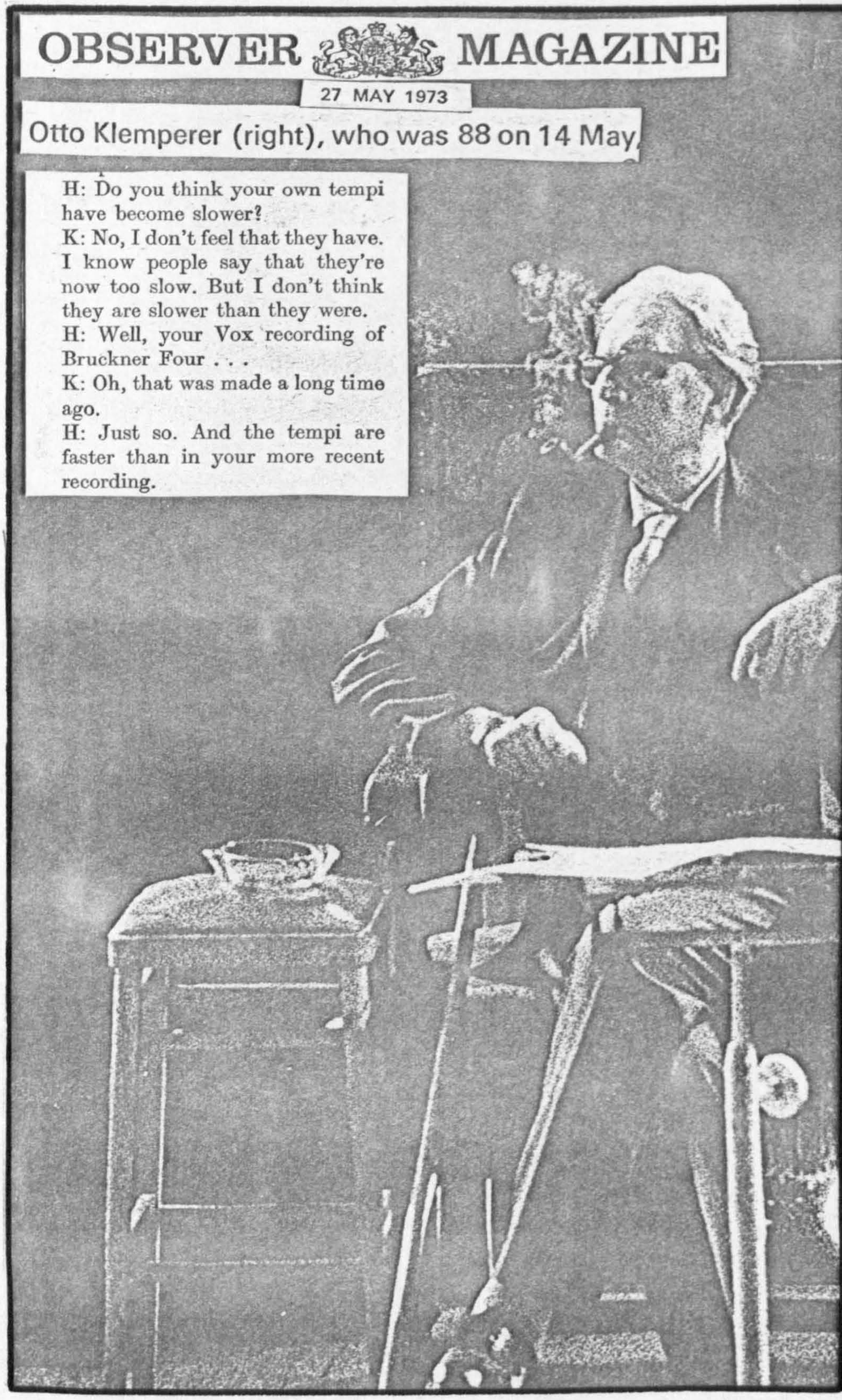
PART B

AGE AND THE RESPONSE TO EXERCISE : TESTS BASED ON FREE WALKING WHICH ARE SUITABLE FOR ELDERLY SUBJECTS

CHAPTER 5

THEORETICAL CONSIDERATIONS FOR SELF-PACED TESTS

DOES THE RATE OF PERFORMANCE CHANGE AS PEOPLE GROW OLDER?



OBSERVER MAGAZINE

27 MAY 1973

Otto Klemperer (right), who was 88 on 14 May

H: Do you think your own tempi have become slower?
K: No, I don't feel that they have. I know people say that they're now too slow. But I don't think they are slower than they were.
H: Well, your Vox recording of Bruckner Four . . .
K: Oh, that was made a long time ago.
H: Just so. And the tempi are faster than in your more recent recording.

INTRODUCTION

The general aim of our project was to explore the interactions between age, inactivity and physical condition. Our first study was of the effects of bedrest, as an extreme case of inactivity, upon physical condition. The results confirmed that such inactivity does cause a deterioration in physical condition and that the deterioration is greater in those who are initially in better condition. We found that the older the subject was the less he deteriorated, but that this could be explained by the poorer initial condition found with increasing age, which was in turn associated with lower levels of daily activity prior to admission. These findings confirmed our belief that with increasing age people fall victim to the insidious deconditioning effects of a slow reduction in daily physical activity levels.

The study underlined two problems, the difficulty of obtaining large enough cross-sectional samples to draw firm conclusions about the role of age, and the unsuitability of a standard exercise test for elderly subjects. It was disappointing that the two oldest subjects who were admitted to the study were the only ones who refused to complete the initial tests.

In the next stage of the project we sought to overcome both these problems by developing a more suitable exercise test which could then be used for a longitudinal study of the effects of age. Self-paced walking on the level in response to standard instructions seemed a possible basis for a suitable exercise test for the elderly. The self-paced nature of such a test might allow an assessment, not only of physical condition, but also of customary rates of performance. They may be as important to the man in the street as musical tempi to a famous conductor.

THE UNSUITABILITY OF STANDARD TESTS

In conventional tests the exercise consists of walking on a treadmill, stepping, or pedalling a bicycle ergometer. All these activities are unfamiliar to untrained subjects and are probably particularly alarming to the elderly. These methods are therefore not likely to be acceptable to elderly people except for those of them who are unusually robust and therefore not representative of their age group. Moreover these methods are not justifiable for use with an unselected group of elderly subjects because of the risk of cardiac or orthopaedic accidents which is higher with this group than with young subjects, particularly when the rate of work is selected by the observer.

In a series of tests using a bicycle ergometer with 64 year-old men 30% of a sample of volunteers from a group of manual workers had to be rejected on grounds of ECG abnormalities or hypertension (see Chap. 11).

CRITERIA FOR MEASUREMENT OF PHYSICAL CONDITION IN ELDERLY SUBJECTS

The assessment of physical condition from the results of a conventional exercise test has already been defined (p3) and described in detail (pps 23-24 in Chap. 2). As explained there the following criteria must be met if an exercise test is to be a useful tool in assessing the physiological response to exercise. The subject must work with large muscle groups at several known levels spaced out over his range. He must maintain each rate of work steadily so that there is negligible variation with time; he must maintain it steadily for a sufficient time for the response of the cardiovascular system to reach a plateau value appropriate to that level of work; and then he must continue to maintain it for a further time sufficient for measuring the cardiovascular response.

Four further criteria were adopted for the special case of exercise tests for elderly subjects. These were that the test must be acceptable to an unselected group of these subjects; that it must not cause anxiety; that it must not jeopardise health; and that there must be no need to learn a new skill.

The two sets of criteria ensure adequate measurement of the cardiovascular response on the one hand, and familiarity of the exercise on the other hand; they are met by the ubiquitous activity of walking.

In conventional tests on a treadmill the exercise is adequate because large muscle groups are used in walking, the work levels can be graded by using a range of speeds and the activity can be maintained for many minutes. However, walking on a treadmill and walking freely on the floor are not the same and it is the differences between them which make the free activity suitable for the elderly where the conventional test is not. Firstly, the treadmill is a noisy and alarming machine, even young subjects need several tests in order to get used to it (Shephard et al, 1968) whereas walking freely is a customary activity. Then, on a treadmill the track rolls towards the subject, whereas in free walking there is a greater need to produce a forward momentum of the body. Therefore in treadmill walking the pattern of action of the muscles differs slightly from that of free walking, postural balance differs and most important of all the observer rather than the subject controls the level of activity. For all these reasons walking freely is preferred for the elderly. Provided the subject is capable of keeping his free walking speed at a steady level then the criteria for an exercise test are met.

SELF-PACED WALKING

Walking uphill was the most energetic exercise possible within the limitations of our criteria. A uniform slope of adequate length would be required so that the level of activity could remain steady for a sufficient time. However, such slopes are most likely to be found out of doors, where the vagaries of British weather would present practical difficulties. Rain, wind and temperature fluctuations would interfere by preventing tests and introducing uncontrolled variables, also outdoor slopes are likely to be public places where the subjects could be disturbed by passers-by.

Walking on an indoor level course was therefore left as the best basis for a self-paced exercise test for the elderly. This is possible in any unfrequented large hall or corridor. The length of the course can be increased by including a sufficient number of laps to ensure that the response of the cardiovascular system reaches a plateau. It remained to be established that the subject could maintain a steady rate of work and an adequate spacing of levels of activity.

Standard Instructions

Exercise performance in a free situation such as this would be initiated by standard instructions given to the subject by the observer verbally or in writing. The general importance of steady performance should be emphasised. Then the specific instructions should be brief, unambiguous, easy to grasp and emotionally neutral. They should apply only to the exercise expected to follow immediately, and care should be taken to ensure that the subject has heard and understood correctly.

In a standard test, on a bicycle ergometer for instance, the subject's rate of work and pedalling frequency are prescribed by the observer and the subject endeavours to maintain the required pedalling frequency with the help of visual information from a speedometer or auditory information from a metronome. These ways of controlling activity are unfamiliar except to trained subjects.

In a walking test the subject is given standard instructions and then determines his own level of activity in accordance with them. The level of activity varies with pace length and stepping frequency. He is asked to perform steadily with no additional feedback and so he will control these two parameters using the sensory information with which he always controls his locomotion.

Measurement of Level of Activity

In the light of the instructions, the subject walks at what he considers to be the appropriate speed and this walking speed is the measure of his level of activity. In conventional tests the level of activity is measured as a rate of work (in Watts or $kg.m.\ min^{-1}$ see p 28) or as the rate of oxygen uptake during the activity. In walking on the level the rate of work cannot be measured in the conventional terms of Newtonian physics. Measurement of oxygen uptake would be possible, but undesirable, for the elderly subjects whom we hoped to study because the bag for collecting expired air with its tap, valved mouthpiece and supporting harness is cumbersome and heavy. It would be possible to design lightweight equipment or use the less accurate Kofranyi-Michaelis portable system for oxygen uptake but this might still reduce the acceptability of the test to elderly subjects.

It was therefore decided to accept walking speed as a reasonable measure of the level of activity. A linear relation between oxygen uptake and the square of the walking speed has been demonstrated (see Table 5.1); it is agreed by several authors to take the following general form:-

where a and b = constants, M = body mass and V = walking speed,

$$\text{the rate of oxygen uptake, } \dot{V}_{O_2} = a\,MV^2 + bM$$

Exercise Performance

If a reproducible walking speed is elicited from a subject by a particular instruction then this is one measure of performance which might reveal differences with age. Older subjects are found to have a lower maximum performance than young subjects even when they do not differ from the young in physical condition (see Chap. 1). It is possible that sub-maximal performance measured in this way might be correlated with maximal performance.

One of the striking differences observed in daily living between the young and the old is that the old do many things at a slower pace than the young. The sub-maximal performance elicited by standard instructions is likely to reflect the way in which the subject performs in daily life and may give a quantitative measure of this difference.

Physical Condition

Physical condition may be assessed by relating the cardiovascular response to the square of the walking speed since that is related to oxygen uptake. In order to make comparisons between one test and another or one subject and another, variation in walking speed must be accommodated. Subjects are likely to be able to walk steadily and consistently in accordance with instructions but they are not likely to be able to walk at a precisely quantified speed of, say, 4 km hr^{-1}. Therefore at least two, and preferably more, different walking speeds should be elicited, so that the results can be used to obtain a regression line and an interpolated value for the response at a standard walking speed.

Physical condition measured in this way should give results which are analogous to those obtained from a conventional method and should rank subjects in the same way.

TABLE 5.1 RELATION BETWEEN OXYGEN UPTAKE AND LEVEL WALKING SPEED ON A TREADMILL

YEAR	AUTHORS	n	SEX	AGE in years	SPEED in km hr^{-1}	EQUATIONS $\dot{V}_{O_2}$ in l min^{-1}; V in km hr^{-1} (unless otherwise stated) M = body weight in kg
1960	Cotes & Meade	10	M	18-19	1.4 - 6.6	$\dot{V}_{O_2} = (2.45 \times 10^{-4}\ MV^2) + (8.0 \times 10^{-3}\ M)$ S.D. = 0.07
1961	Macdonald	330	M	13-65	1.0 - 8.5	$\log_{10}H = (2 \times 10^{-5}V^2) + (2.8 \times 10^{-3}V) + (0.0033M) + 0.072$ S.D. = 0.06 kcal min^{-1} = 0.24 l min^{-1} H in kcal min^{-1} V in m min^{-1}
		58	F	13-54	1.4 - 6.8	$\log_{10}H = (5.3 \times 10^{-3}V) + (6.5 \times 10^{-3}W) - 0.257$ S.D. = 0.04 kcal min^{-1} = 0.23 l min^{-1}
1962	Grimby & Soderholm	36	M	22-46	4.3 - 7.4	$\dot{V}_{O_2} = (3.4 \times 10^{-4}MV^2) + (5.8 \times 10^{-3}M)$ S.D. = 0.19
		11	M	56-64	4.3 - 6.1	$\dot{V}_{O_2} = (3.6 \times 10^{-4}MV^2) + (7.4 \times 10^{-3}M)$ S.D. = 0.16
1973	van der Walt & Wyndham	6	M	20-26	3.2 - 8.0	$\dot{V}_{O_2} = (3.66 \times 10^{-4}MV^2) + (5.99 \times 10^{-3}M)$ S.D. = 0.16

Cardiovascular Response

The heart rate is the best single measure of cardiovascular response for exercise tests of mild intensity with the elderly. It can be measured conveniently by non-invasive methods and it is linearly related to the oxygen uptake. It is generally accepted that for an individual subject the relation between oxygen uptake and heart rate remains similar whatever form the exercise takes, provided large muscle groups are used (Astrand, 1960; Bobbert, 1960; Grimby & Soderholm, 1962).

Since the subjects were walking freely the heart rate had to be recorded by telemetry or by portable tape recorder. The recent availability of Oxford Instrument miniature tape recorders made this our choice of method.

Relations between Oxygen Uptake and Walking Speed

If level walking is to be used as a basis for exercise tests and, if walking speed is therefore to be used as a measure of the level of activity, then the relation between walking speed and oxygen uptake is of crucial importance. There have been a number of studies of this relation and they are listed in Table 5.1 with the numbers of subjects in each study, the range of walking speeds and the equations relating oxygen uptake and walking speed.

In 1960 Cotes & Meade reported a study of army recruits. They give an equation of the following form:-

$$\dot{V}_{O_2} \text{ l min}^{-1} = (2.45 \times 10^{-4}MV^2) + (8 \times 10^{-3}M)$$

This type of equation also appears in two subsequent papers; that of Grimby & Soderholm (1962) and van der Walt & Wyndham (1973). It can be seen from Table 5.1 that the agreement between these last two is fairly good. The discrepancy between them and the equation of Cotes & Meade has been explained by van der Walt & Wyndham as a greater mechanical efficiency of walking in the subjects of

Cotes & Meade who were young (18-19 years) and presumably trained to march. The homogeneity of this group of subjects probably explains the smaller standard deviation found by Cotes & Meade.

In 1962, Grimby & Soderholm studied 47 normal men of various ages who were exposed to exercise tests for the first time. They found that the oldest group had a significantly higher oxygen uptake per body weight than the youngest group which was also attributed to a lower mechanical efficiency of walking in older subjects (Durnin & Mikulicic, 1956). This means that comparisons of heart rate at a standard walking speed, made on the same basis, between old and young groups must be interpreted with caution.

The subjects of Grimby & Soderholm exercised on a bicycle ergometer as well as on a treadmill. The standard deviations of oxygen uptake were similar to those found in walking and amounted to ± 10%. Unfamiliarity with the test procedures would be expected to give rise to greater variation than with trained subjects which probably explains why it is so large, but the lack of difference in this respect between the two types of exercise test was encouraging.

In 1961 Macdonald reviewed the available literature which included papers from 1912 onwards. This amounted to data on 330 male subjects from which he obtained the following equation:-

where $H = \text{kcal min}^{-1}$; $V = \text{m min}^{-1}$; $M = \text{kg body weight}$

$$\log_{10}H = (2.8 \times 10^{-3}V) + (2.0 \times 10^{-5}V^2) + (3.3 \times 10^{-3}M) + 0.072$$

The data from 58 female subjects gave rise to a slightly different equation:-

$$\log_{10}H = (5.3 \times 10^{-3}V) + (6.5 \times 10^{-3}M) - 0.257$$

The lack of a V^2 term was attributed to the smaller range of speeds. This term is numerically very small compared to the others at low and moderate speeds. The greater apparent efficiency was attributed to a lower basal metabolic rate in females. No age difference was found, but that might have been because of the variation in the sample or because of limited numbers in the older age groups.

Van der Walt & Wyndham (1973) favour the quadratic form of the equation for relating oxygen uptake and walking speed, and reject the logarithmic equation on the theoretical grounds that oxygen uptake is more likely to be modified by the terms MV^2 and MV than log. terms because they have the dimensions of energy and momentum. This argument has some appeal but is probably too simple. The forward motion of the body in level walking depends upon complicated rhythmic movements, in both vertical and horizontal planes, of the trunk, arms and legs which result in no net external work done.

Dean (1965) has attempted to calculate the mechanical work done in level walking from first principles by considering vertical motion, sideways and progressional oscillation of the body, and arm and leg swing. He concluded that the net energy expenditure could not be accurately calculated in this way because there are positive and negative components in each movement with transfer of an unknown amount of energy between them. Thus the resultant energy expenditure depends on a small difference between two large factors which cannot be determined with sufficient accuracy. However he found that the energy expenditure attributable to these components varied with the walking velocity raised to a range of power indices. This would give an equation for energy expenditure of a form closer to Macdonald's than that of Cotes & Meade but more complicated than either.

The relative merits of the various equations can only be judged by using them both with the same set of data to see which gives the best fit. Since claims have been made with supporting evidence for both the logarithmic and quadratic equations, it seemed found, but that might have been because of the variation in the sample or because of limited numbers in the older age groups.

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The relative merits of the various equations can only be judged by using them both with the same set of data to see which gives the best fit. Since claims have been made with supporting evidence for both the logarithmic and quadratic equations, it seemed likely that they would give similar predictions for oxygen uptake. It was not possible to convert the equations to a similar form mathematically, so a theoretical range of speeds and weights were substituted and the predictions compared (see Fig. 5.1). When this was done it was found that the predictions were within 10% of each other over the range 70-90 kg body weight and 2-7 km hr^{-1}. The logarithmic equation predicted higher oxygen uptakes at faster speeds especially for lighter subjects. Since the equations agreed, the quadratic form was preferred as it is simpler, at least until both could be tested against some recorded data.

Factors Affecting Walking Performance

The factors which are likely to affect self-paced walking speed are numerous and include the following:- cardiovascular and respiratory function, body composition, mobility of joints, muscle strength and motivation.

Cardiac malfunction may limit walking speed if the cardiac output is reduced to low levels, if there is a right-left shunt across the ventricles or if the subject suffers from symptoms such as angina or palpitations.

Respiratory malfunction may limit walking speed if there is inadequate oxygenation of the pulmonary blood leaving the lungs. This may be due to inequality of ventilation and perfusion, a reduced alveolar surface area or inadequate transfer across the alveolar capillary membrane.

Ischaemic pain in the leg muscles may limit walking speed if the blood flow is reduced by obliterative arterial disease.

These three areas of malfunction are common in the elderly and can all give rise to symptoms of breathlessness. If the muscles receive an inadequate oxygen supply from any cause, they produce

Fig. 5.1

COMPARISON OF TWO DIFFERENT EQUATIONS FOR PREDICTING OXYGEN UPTAKE FROM THEORETICAL VALUES OF WALKING SPEED AND BODY WEIGHT

$\dot{V}_{O_2}$ = oxygen uptake in l min^{-1} V = walking speed in km hr^{-1}

M = body weight in kg

Grimby & Soderholm (1962):- $\dot{V}_{O_2} = (3.4 \times 10^{-4} MV^2) + (5.8 \times 10^{-3} M)$

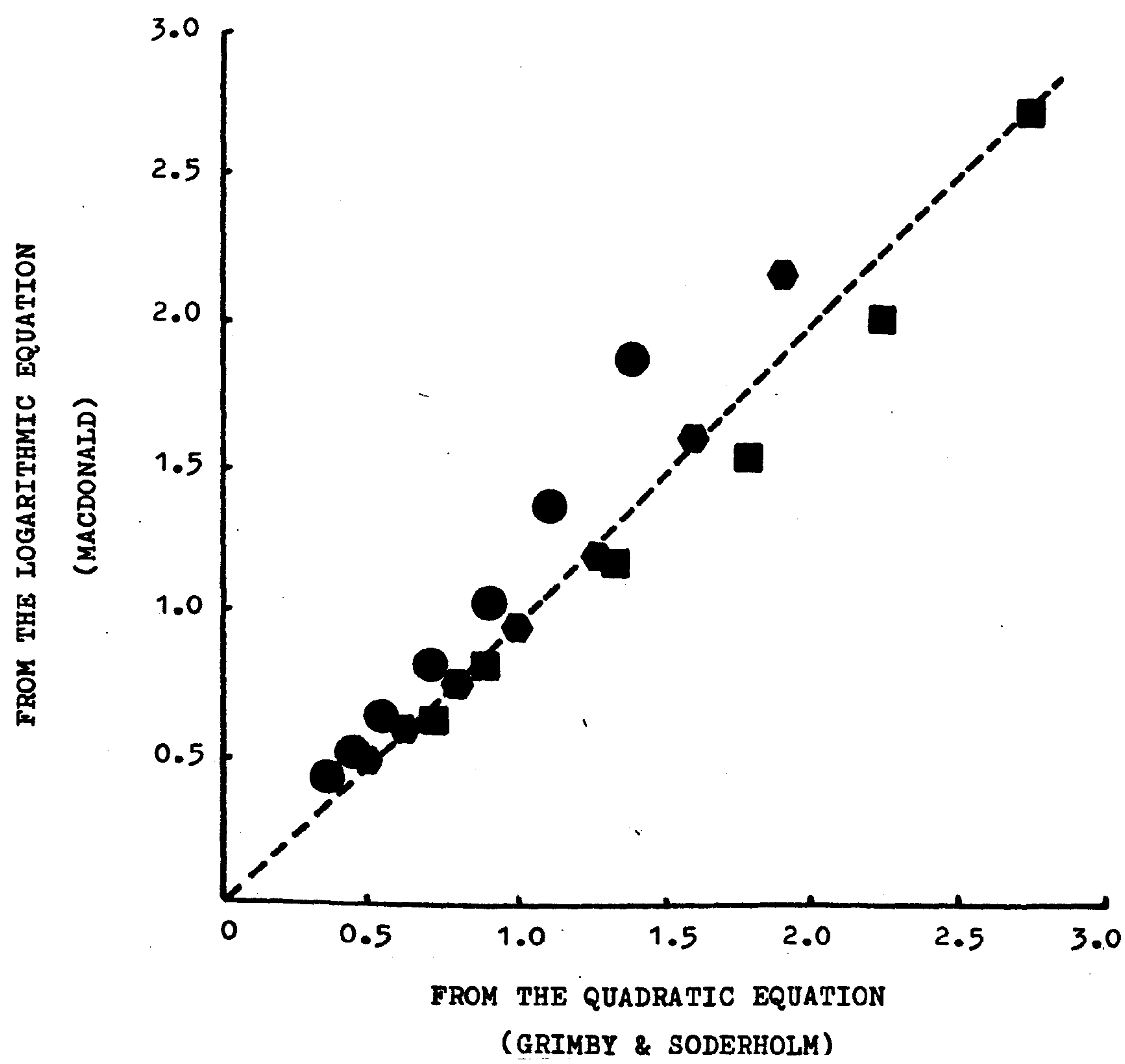
Macdonald (1961):- transformed to the same units, see Table 5.1 for the original form of the equation

$$\log V_{O_2} = (4.1 \times V^2) + (5.8 \times 10^{-4} V) + (6.9 \times 10^{-4} M) + 0.015$$

The graph is a plot of the theoretical values obtained for V_{O_2} from each equation when values for V and M are substituted as follows:-

V = 2, 3, 4, 5, 6, 7 and M = 50 ●; 70 ⬢; 100 ■;

The dotted line is the line of coincidence



increased amounts of lactate which produce correspondingly greater pH changes which will stimulate respiration.

Body size, as such, is not likely to affect performance because a given walking speed costs proportionally more in oxygen uptake for a large man than a small man, due to his greater weight (see Fig. 5.1). However, body composition will affect the situation, the fat man with a small muscle bulk and a proportionately small capacity for oxygen uptake, will be at a disadvantage in that a given walking speed demands a much higher proportion of his maximum capacity. It is possible that such people would perform more slowly than thin muscular people, other factors being equal. Similarly the well-trained might perform faster than those in poor condition.

Leg length also affects walking speed because it affects stride length and the natural frequency of leg swing. A short-legged person walking fast may reach the limit of his stride length, he can then increase his speed further only by increasing his pace frequency more, and departing further from his natural frequency of leg swing. This will decrease his efficiency and cost more in oxygen uptake per increment in walking speed.

If the mobility of joints is limited by arthritic conditions the gait may be altered in numerous ways which are likely to make it less efficient and therefore possibly slower. Pain is particularly likely to limit walking speed in such conditions.

Defective balance and defective vision may also impose limitations.

The final major influence on walking speed is the psychological motivation of the subject. This will depend upon the personality of the subject interacting with the test situation. It cannot be eliminated however careful the observers are to give neutral instructions and avoid a competitive atmosphere (Morgan, 1973).

SUMMARY AND PLANS

Self-paced walking on the level in response to standard instructions seemed a possible basis for a suitable exercise test for the elderly. The familiarity of the activity and its self-paced nature would make the test acceptable to the subject and minimise the risk of cardiac or orthopaedic accidents. The test could be performed by anyone, however old or infirm, provided that he could walk. It may therefore extend the potential range of the study into extreme old age.

In such a test the walking speeds selected may be considered as a measure of performance and the relation between heart rate and walking speed as a measure of physical condition, analogous to the relation between heart rate and oxygen uptake (or work rate) obtained from more conventional tests. There is evidence for a linear relation between oxygen uptake and the square of the walking speed; it was presumed that the relation between heart rate and the square of the walking speed is also linear. This remained to be firmly established (see Chap. 8).

First it was necessary to find out whether the subjects in such a free situation could walk steadily and consistently in response to standard instructions. In order to make a valid assessment of feasibility, the walking test was tried out with subjects from the target population, that is people of over 60 years of age (see Chap. 6).

These results were then compared with those from a group of young people to see if there were age differences in performance (see Chap. 7). Both these groups were women. The trials were then extended to include male subjects, both young and old, and a comparison was made with these subjects between the results of the walking test and those of a standard progressive bicycle test as methods of assessing physical condition. This enabled us to see whether the two tests ranked subjects in the same way and what the relations between the two tests were.

CHAPTER 6

AN INVESTIGATION OF THE FEASIBILITY OF A PRELIMINARY WALKING TEST WITH ELDERLY WOMEN

INTRODUCTION

The aim of the investigation described in this chapter was to find out whether a walking test was feasible. Since the test was intended for use with the elderly, some early trials with that age group were indicated and the first question to be answered was whether these subjects could act on standard instructions in a steady and reproducable manner. Unless they could do this, further development of the test would have been fruitless for our purpose.

In addition to walking, the test for this group of subjects included carrying baskets containing a weight selected by the subject. This made the test a simulation of shopping. Since the subjects were female, it was thought that shopping might be more acceptable than simple walking. The additional burden might increase the rate of work, provided the subjects did not compensate by walking more slowly, and so a larger increase in heart rate might be produced without infringing the criterion that the test should be based on a familiar activity. The chosen weight would also add an extra dimension in which to look for consistency and age differences (see next Chapter).

There was no evidence that the extra weight would distort the results by giving rise to increments in heart rate due to sustained isometric work. Brezina & Reichel (1914) and Consolazio, Pollack, Crowley & Goldstein (1956) have found that a carried load has the same effect as an equal increase in body weight as long as the load is not awkwardly arranged. The subjects of Consolazio _et al_ carried weights of up to 40 kg.

TABLE 6.1

BASIC PHYSICAL CHARACTERISTICS

(mean values ± 1 S.E.)

Subjects who Completed the Test	Age in Years	Body Wt in kg (with shoes)	FVC in l at B.T.P.S.	FEV 1 sec in l at B.T.P.S.	Grip Strength in kg
Keep-Fit Group (n = 11)	69.4 ± 1.3	62.0 ± 4.0	2.20 ± 0.13	1.70 ± 0.15	18.6 ± 1.2
Workshop Group (n = 5)	69.6 ± 2.5	65.7 ± 3.8	2.07 ± 0.30	1.23 ± 0.34	19.8 ± 1.9
Difference	N.S.	N.S.	N.S.	N.S.	N.S.
Whole Group (n = 16)	69.5 ± 1.17	63.1 ± 2.98	2.16 ± 0.13	1.55 ± 0.15	19.0 ± 1.02
	Recorded values for n = 3				
Subjects who did not complete the test	74	86.4	2.0	1.55	20
	75	64.0	1.85	1.25	20
	81	49.2	1.85	1.50	14

METHODS

The Subjects were all female with an age range of 64-81 years. Some of them belonged to a Keep-fit (Music and Movement) Class run by the City of Nottingham Education Committee (n = 13), and the others to a Workroom for the Elderly run by a voluntary committee and affiliated to the Employment Fellowship, (n = 6). They were all accustomed to doing their own shopping and lived independently. They visited the department in small groups. Physical characteristics are given in Table 6.1. No significant differences between the groups were found in these respects. Some of the lung capacities were below the predicted range for age and height (Berglund et al, 1963). This may be an error due to difficulty in eliciting an adequate performance from the subject. Of the 19 subjects who attempted the test, 16 completed it successfully.

Procedure. The tests took place in the University Department of Physiology and consisted of walking the length of a corridor in both directions covering a total course of 170 m. While they walked, the subjects carried two shopping baskets containing tinned goods (see Fig. 7.1 in next Chap.). The weight of goods was selected by the subjects in accordance with the instructions given below. The subjects were asked to read the instructions and then to load the baskets and walk. The instructions were standard; they were displayed on a white board in 1" high black lettering and read as follows:-

> Please take these tins to the other end of the corridor. Please carry them as quickly as you can without making yourself breathless or tired. Please do not carry more than the most you would normally do when shopping. This is not a competition but a test of your good judgement.

The time taken to cover the course and to reach the half-way point was noted from a stop-clock. After each walk the baskets were weighed and emptied. The subject was then asked to read the instructions again and to re-load for another walk. Three walks to the same instructions were required. Those subjects who, despite the instructions, made themselves breathless or otherwise fatigued, rested sitting down until they felt recovered before re-loading. At least 2 minutes elapsed between walks for all the subjects. The first walk was regarded as a warm-up and trial run; it was not used in the analysis.

If subjects were doubtful about the weight to be carried the observer would emphasise that it should be a balanced load and "the right weight for you". No other instructions, encouragement or caution were given. The observer ensured that each subject tested the weight she had chosen by lifting both baskets together. Plenty of time was given for adding or removing tins and testing again. After the first walk a variable small number of tins was left in each basket so that the subject did not count the number of tins. The baskets were made of woven raffia and each weighed 930 g. A flat hard-board base was added so that they stood up on their own, and the handles were padded for a comfortable grip.

Before the test began all the subjects spent at least half an hour sitting down.

The stability of the walking speed was assessed by comparing the time taken to walk out (85 m distance) with the time taken to walk back (also 85 m distance) along the corridor. This assessment was based on the measurements of time taken, rather than the derived speed, for two reasons. The speed is proportional to the reciprocal of the time taken to travel a fixed distance. This is not a linear relation therefore the variation in speed would be slightly different from the variation in time taken. Moreover the assessment made was not of the instantaneous variation in speed but of the difference between the mean speeds in the 1st and 2nd halves of the walk. Therefore strictly speaking variation in speed was not measured, only variation in lap time.

RESULTS

Acceptance of the Test. Three of the 19 subjects declined to complete more than one walk. These subjects are separately listed in the Tables. They are at the older end of the age range but otherwise do not appear to differ from the other subjects. Two belonged to the Keep-fit class and one to the Workshop.

Standard Instructions. All subjects appeared to understand the instructions, at least by the 2nd walk. However more than half of the subjects in each group showed some symptoms of fatigue or admitted to having carried more, or walked faster than they usually would.

Variation in Performance. The results for the 2nd and 3rd walks, treated separately for all subjects are shown in Fig. 6.1 where the times for each half of the walk are plotted against each other. There was no significant difference between them according to Student's t test for paired means, and it can be seen that the points are evenly distributed about the line of coincidence ($n = 26$). The mean difference between the two halves of the walk was 0.5 ($\pm$ 1.36) s in a mean time of 68 s. The S.D. of the differences is $\pm$ 7.1 s giving a variation of $\pm$ 10.3% (expressed as a % of the mean time).

The two slowest subjects slowed down consistently. One subject apparently walked back in 46 s having walked out in 60 s a discrepancy of 25%. This result seemed so unlikely in a subject who was otherwise consistent that it may be due to observer error in

Fig. 6.1

TIME TAKEN IN SECONDS TO WALK 85 m IN EACH HALF OF THE COURSE

Values from the 2nd and 3rd walk included separately for all subjects (n = 26).

The dotted line is the line of coincidence.

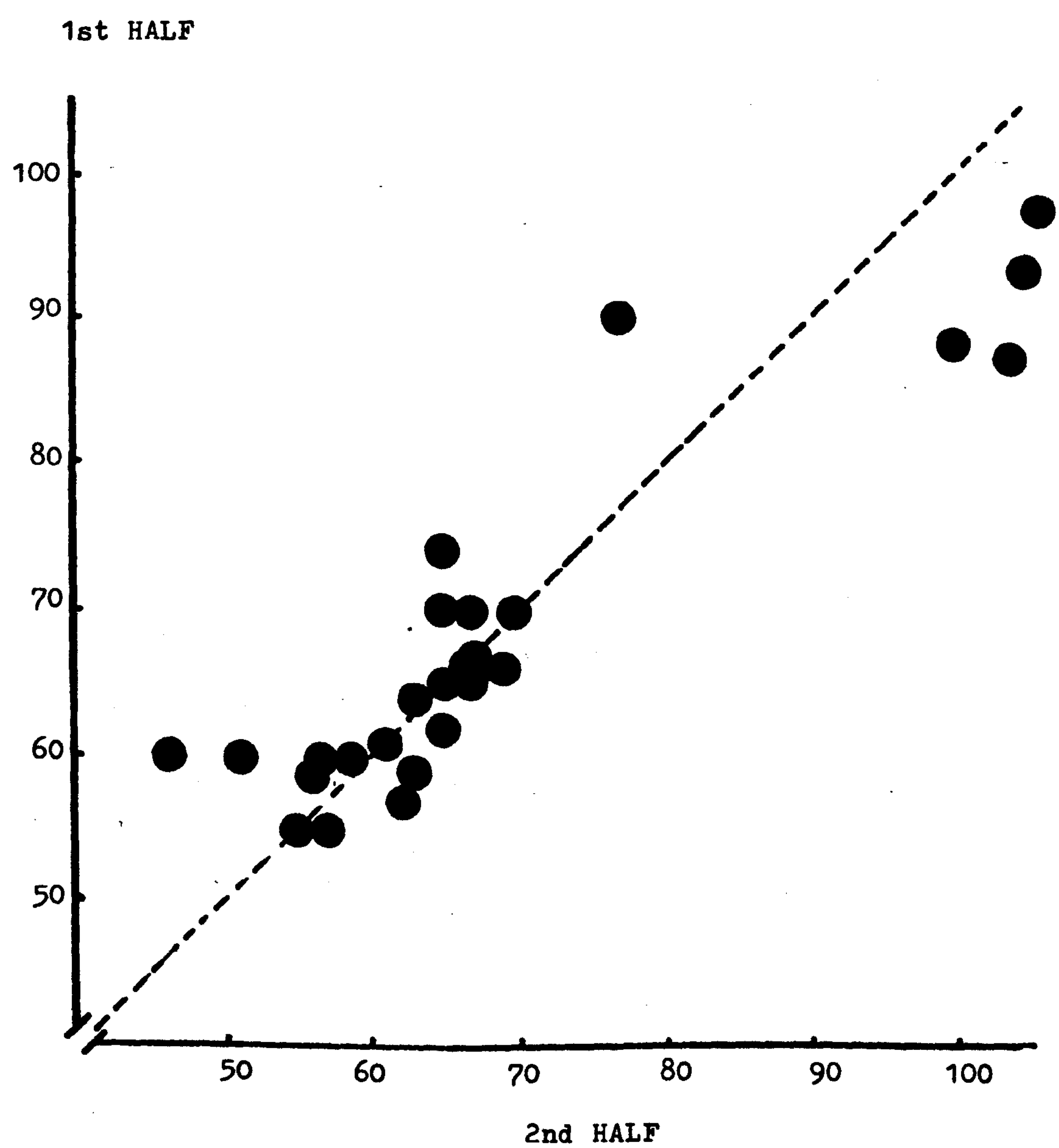


Fig. 6.2

VARIATION ON RE-TEST IN TIME TAKEN IN SECONDS TO WALK THE WHOLE COURSE OF 170 m.

n = 16 subjects

The dotted line is the line of coincidence.

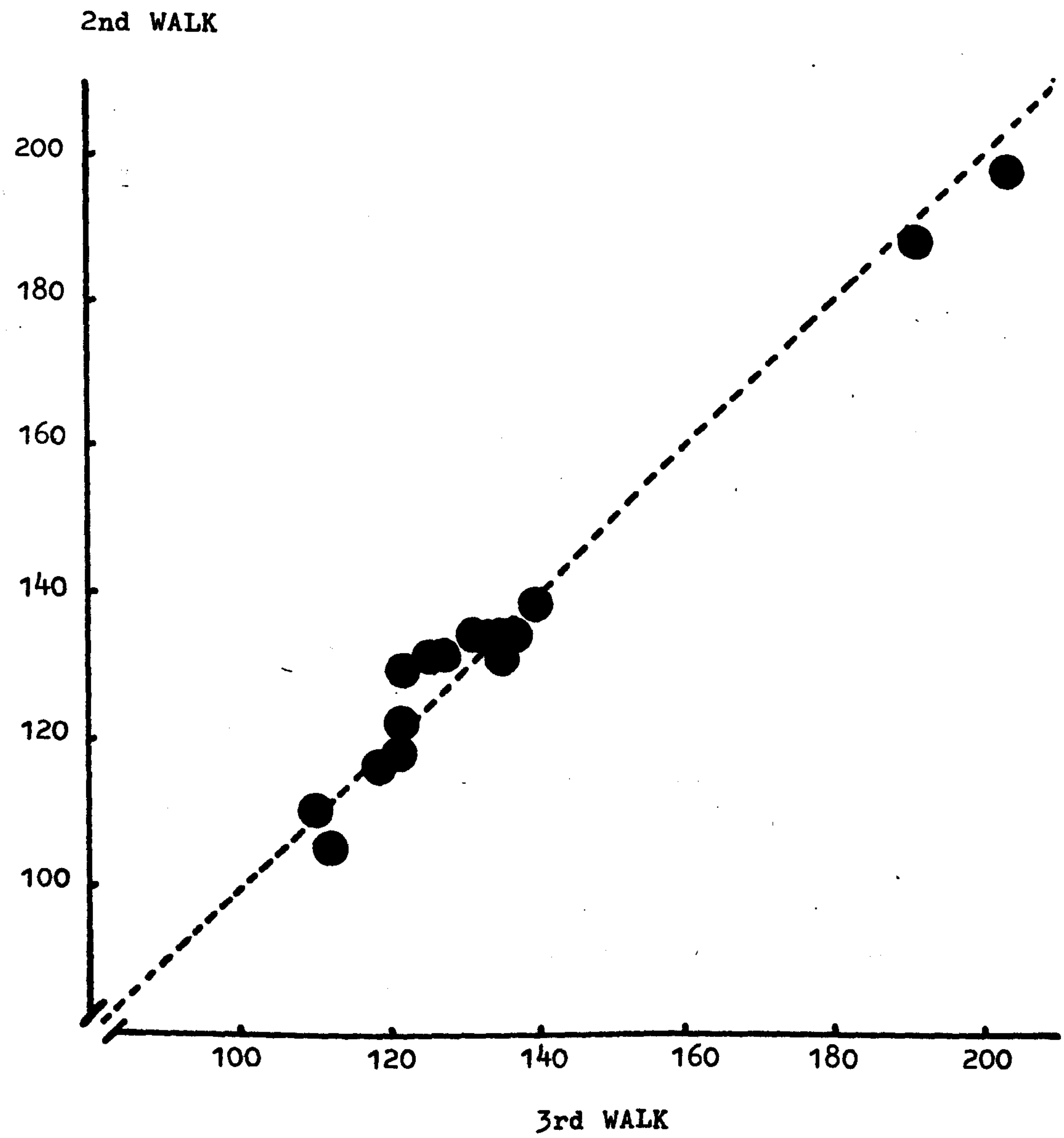
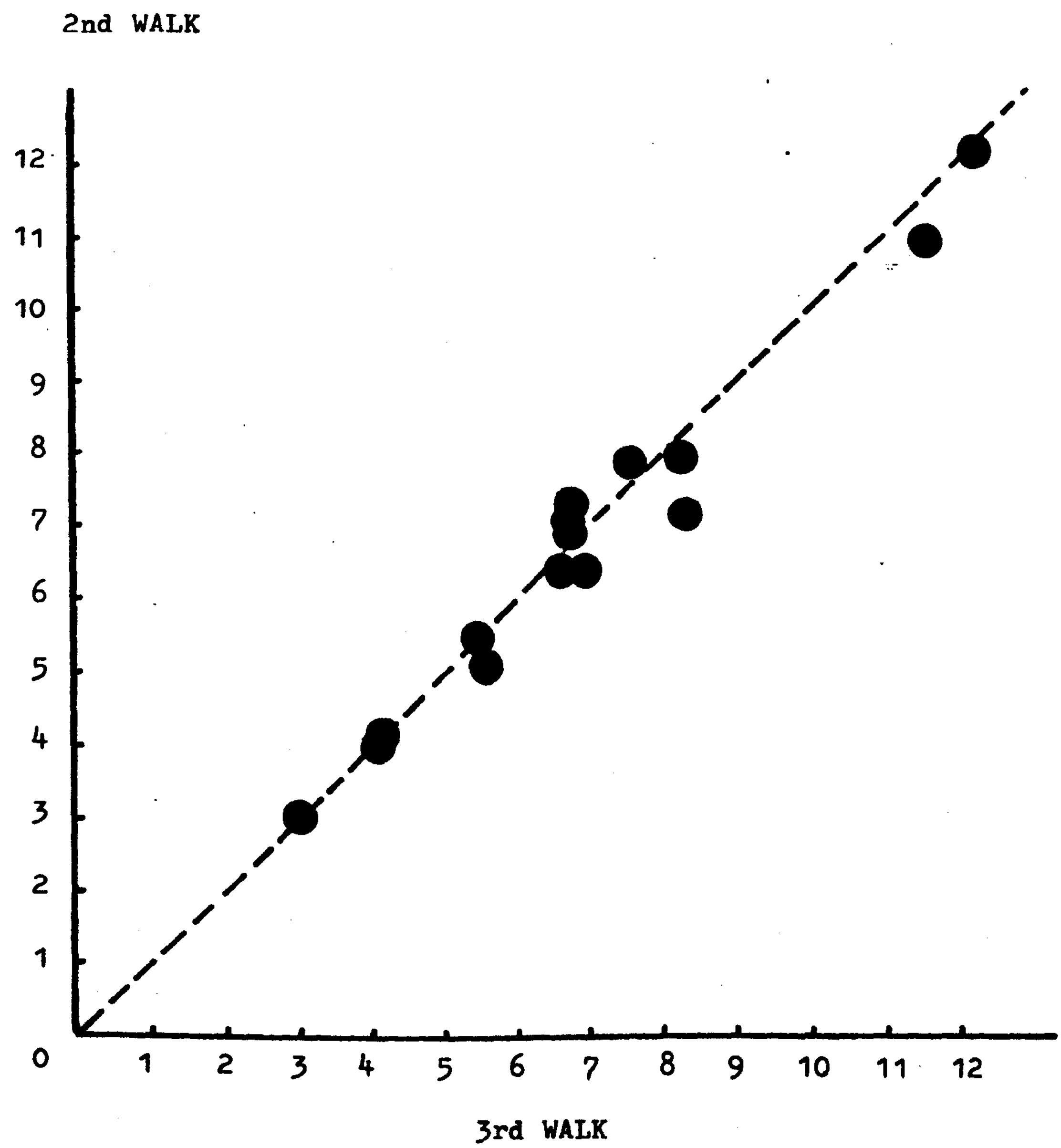


Fig. 6.3

VARIATION ON RE-TEST IN SELECTED LOAD IN KG.

n = 15 subjects

The dotted line is the line of coincidence.



reading the stop-clock. Without these three subjects the variation was reduced to ± 7.1%.

Variation on Re-Test

The Time Taken for the 2nd walk was compared with that for the 3rd walk (see Fig. 6.2). The mean values were 135.5 (± 6.54) s and 135.4 (± 6.85) s respectively and there was no significant difference between them. The S.D. of the differences was 4.15 s (variation = ± 3.1%). The walking speed derived from the mean time is 4.54 km hr^{-1}.

The Load Selected for the 2nd walk was compared with that for the 3rd walk (see Fig. 6.3). The mean values were 6.8 (± 0.63) kg and 6.96 (± 0.65) kg respectively and there was no significant difference between them. The S.D. of the differences was 0.43 kg (variation = ± 6.2%).

Comparisons

The subjects from the Keep-fit Class walked significantly faster than those from the Workroom ($P<0.01$). The mean times were 126 (± 2.4) s and 158 (± 15) s respectively which represent speeds of 4.85 km hr^{-1} and 3.88 km hr^{-1}.

There were no significant differences between the groups in selected load. The mean values were 7.5 (± 0.73) kg and 6.12 (± 1.22) kg, respectively. The mean selected load for all the subjects together was 7.08 (± 0.63) kg.

There was no indication of a relation between chosen speed and chosen load. Those who walked faster did not consistently choose bigger loads (see Fig. 6.4).

The relations between age and the selected speeds and loads were considered separately (see Fig. 6.5). There was no convincing evidence for a relation with age in either case.

Fig. 6.4

SELECTED LOAD AND SPEED FOR EACH SUBJECT

(mean results from 2nd and 3rd walk)

○ Keep-fit Group n = 11

● Workshop Group n = 5

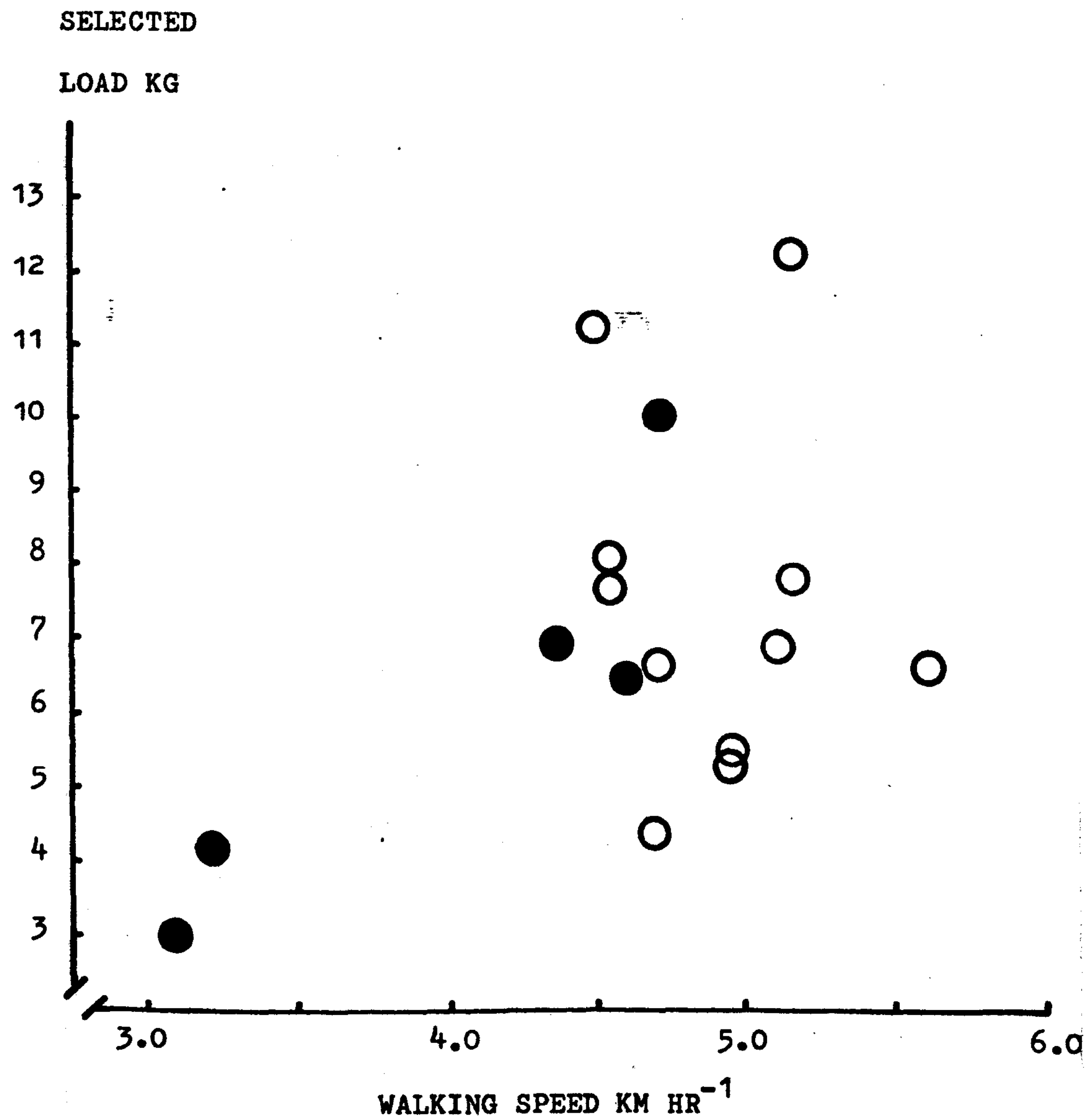


Fig. 6.5

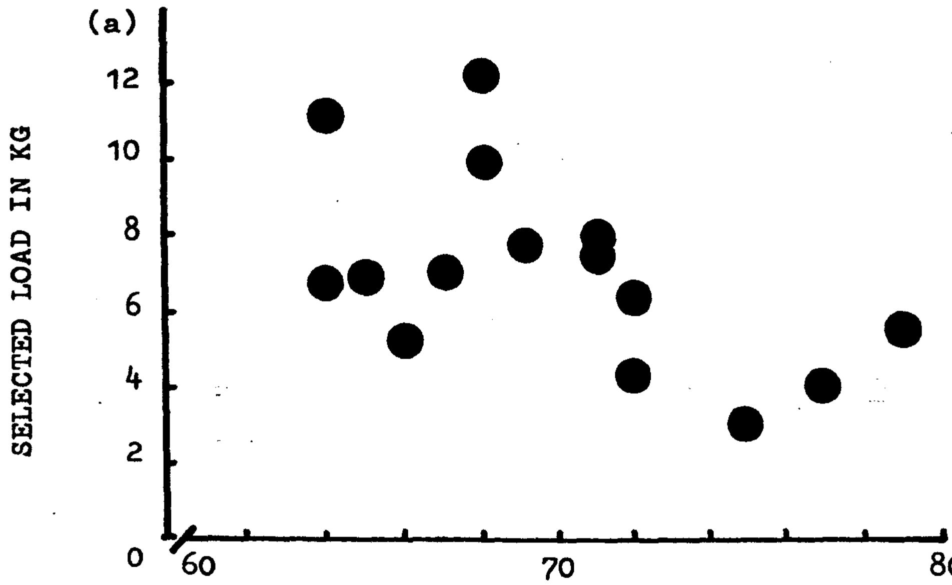
RELATION BETWEEN AGE AND

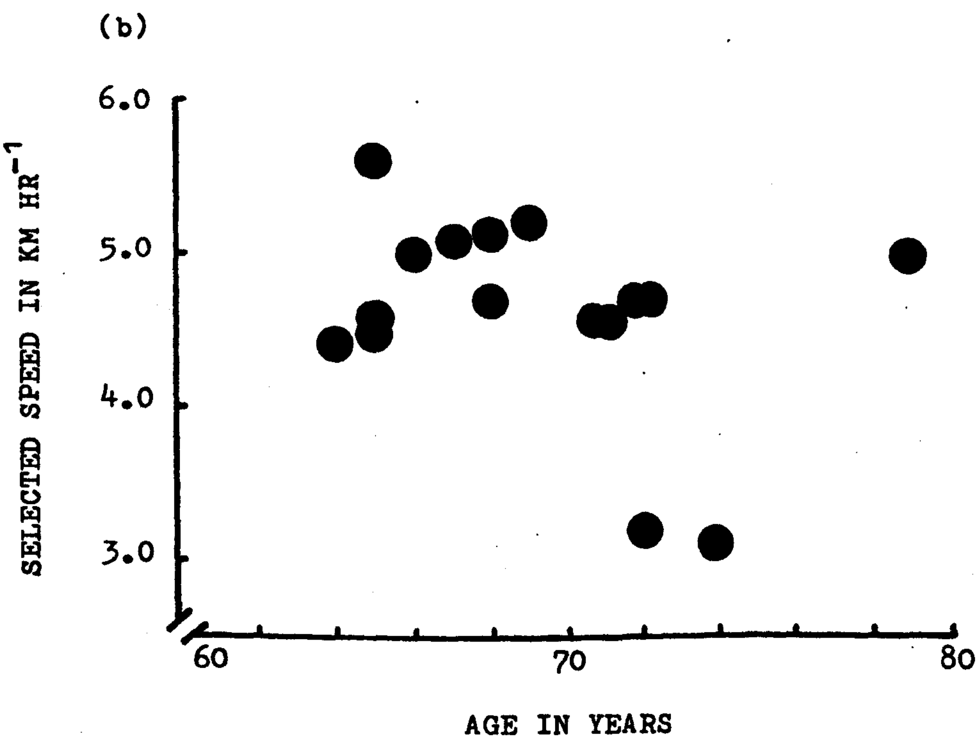
(a) SELECTED LOAD

(b) SELECTED SPEED

n = 16 subjects

(mean results from the 2nd and 3rd walk for each subject)





DISCUSSION

The test was evidently acceptable to over 80% of this sample of elderly women of mean age 71 years, and it was clear that they could perform steadily and reproducibly. A variation of $\pm$ 10% or less compares favourably with that for pedalling in a conventional test on a bicycle ergometer. These results provided encouragement for further trials of self-paced tests since the first requirement, that subjects must be able to perform steadily, was satisfied.

The subjects could also reproduce both their speed and the selected load, after some minutes, with very little variation ($\pm$ 3% and $\pm$ 6%) which suggests that their performance is characteristic and may reflect customary levels of activity.

This was borne out by the difference in walking speed found between the two groups. Subjects from the Keep-fit group walked significantly faster and they probably had higher levels of customary activity than those of the Workroom. The evidence for a difference in customary activity came partly from a questionnaire survey which indicated that subjects from the Keep-fit group had less difficulty with physical tasks than the Workroom subjects and partly from their very membership of the Keep-fit class.

The results suggest that walking speed may be a sensitive indicator of customary activity in the elderly and so of physical condition since this is known to be affected by activity.

The selected load did not provide a way of discriminating between the groups. The variation on re-test was greater than for speed and the mean difference between the groups smaller than for walking speed.

Some criticisms of the design of the test emerged at this stage, which were relevant for development although they did not cast doubt on the general feasibility of self-paced testing.

The three subjects who declined to finish the test may have over-taxed themselves during the first walk. One walked much faster than any other in the group at 6.8 km hr^{-1}. This suspicion combined with the observation that many subjects showed symptoms such as breathlessness indicated that the standard instructions were not satisfactory. Clearly subjects could not judge a weight and speed that was "as much as possible without making yourself breathless or tired", although they could be consistent in their response particularly in their speed. The instructions may have been too complicated or too likely to induce competitive behaviour. A simpler less demanding instruction might have resulted in a 100% acceptance rate, and no symptoms of fatigue.

If the weight-carrying task were left out this would both simplify the test and reduce the demand on the subjects. Unless the weight-carrying could be proved to have some positive value it seemed best omitted in future trials.

There was no correlation between selected load and speed (see Fig. 6.4) so that analysis of the results would be difficult unless an equation relating walking weight and speed to oxygen uptake could be used (see Chap. 5). Variation in efficiency reduces the accuracy of prediction by such equations and older people probably vary as much in this as younger ones, if not more, since they are prone to arthritic diseases.

It was not possible to tell whether simulated shopping was more acceptable than simple walking at this stage. There was no difference in selected load between the two sub-groups although they differed significantly in walking speed so weight-carrying did not add another dimension to the test within this age group. It remained to be seen whether a much younger group would select heavier loads (see Chap. 7).

There was a slight indication of a reduction in selected loads and speeds with increasing age but the variation was large and the relations obviously not significant (see Fig. 6.5). A longitudinal study may be the only method of detecting such changes with age if they exist.

CONCLUSIONS

It was concluded that free walking was a feasible basis for an exercise test for the elderly. The variation in walking time was less than ± 10% when the 1st half of the walk was compared with the 2nd half showing that these female subjects of mean age 70 years could perform steadily in accordance with standard instructions despite their free situation.

The subjects were also able to perform in a reproducible way when asked to repeat the test after some minutes. The variation on re-test in time taken and selected load was ± 3% and ± 6% respectively. It was therefore concluded that the performance might be characteristic for the subject. This conclusion gained some support from the significant differences in walking speed found between the two sub-groups who were also reported to have different levels of activity in daily living.

The inclusion of a carried load in the test had some disadvantages. It gave rise to complicated instructions and difficulties in analysis. Its advantages were not clear at this stage.

CHAPTER 7

A COMPARISON OF THE PERFORMANCE OF ELDERLY AND YOUNG WOMEN IN A PRELIMINARY WALKING TEST

INTRODUCTION

The aim of the investigations described in this chapter was to find out whether the performance of a self-paced walking test would show age differences. A group of young female subjects were given a test exactly as described for the elderly group of women in the last chapter and their performances were then compared.

In addition the heart rate response to the exercise was investigated in both groups. This was done by recording the ECG on portable tape recorders. It gave rise to considerable technical problems initially and was only partly successful with the elderly group, who were studied first.

METHODS

The Subjects were 9 young female students and 9 elderly women. The elderly women were selected from the groups described in the last chapter on the basis of successful ECG recording during the test (see Procedure below). Four of them belonged to the Keep-fit class and 5 to the Workshop. They ranged in age from 64-79 years and did not differ significantly from the others in the whole elderly group in either physical characteristics or performance of the test. The young group were undergraduate students, resident in the University and from Departments other than the Medical School. They were moderately active and not accustomed to regular heavy shopping. They ranged in age from 18-20 years. Physical characteristics for both age groups are given in Table 7.1. There was no significant difference between these two age groups in body weight but the young group had clearly larger lung capacities and significantly greater grip strength.

Procedure. The test was a simulation of shopping and the procedure was exactly as described in Chapter 6. The ECG was recorded using portable tape recorders throughout the test period.

TABLE 7.1

BASIC PHYSICAL CHARACTERISTICS OF THE SUBJECTS

(Mean values ± 1 S.E.M.)

	Age in Years	Body Weight kg	FVC in l (at B.T.P.S.)	FEV 1 s in l (at B.T.P.S.)	Grip Strength in kg
OLDER GROUP n = 9 (range)	70 ± 1.8 (64-79)	65.7 ± 4.4	2.16 ≠ ± 0.17	1.48 ≠ ± 0.23	19.8 ± 1.76
YOUNGER GROUP n = 9	19 (18-20)	58.2 ± 3.7	4.19 ± 0.15	3.67 ± 0.16	31.7 ± 1.92
Significance of Difference		N.S.			$P<0.001$

≠ These values may be too low (see Chapter 6) but it is still likely that the young group had larger lung capacities.

Portable Tape Recorders for ECG. In the first trials with elderly subjects from the Keep-fit Class the Philips (M.E.) Type XM 4600/00 single channel recorders were used.

In these recorders the incoming ECG signal modulates a carrier wave (1400 Hz) and is recorded on standard magnetic tape (speed 4.7 cm s^{-1}). The carrier wave makes it possible to record relatively slow signals (less than 1 Hz) on magnetic tape by pulse width modulation. A varying D.C. input signal is made to alter the width of a carrier pulse in such a way that the pulse width separation after differentiation is directly related to the input voltage. The signals are played back through a dual-purpose modulator-demodulator unit in the recorder for display on any convenient ECG machine. Since the carrier wave has a frequency in the audible range, this can be used for checking recorded signals. A second (pilot) carrier wave is used to cut down interference. The pilot signal goes through the same processes simultaneously with the ECG signal and so picks up the same noise. Finally the pilot signal goes through a phase reversal and is then subtracted from the ECG signal, thus cancelling interference common to both pathways.

These recorders measure 20 x 15.5 x 5.5 cm, and weigh 1.9 kg. They were found to be too heavy to be worn comfortably on a shoulder harness by elderly women so they formed part of the shopping load during the test. This was not satisfactory from several points of view. It might bias the load if the subject chose a small load that approached the weight of the recorder. It gave rise to considerable noise during walking which obscured the ECG signals in 75% of the tests.

Subsequently the much smaller and lighter Oxford Instruments Tape Recorders (Medilog Type 4.24) became available. These weigh only 400 g and measure 11.2 x 8.7 x 3.6 cm. They can therefore be

Fig. 7.1.

AN ELDERLY SUBJECT CARRYING THE TWO BASKETS DURING A WALKING TEST

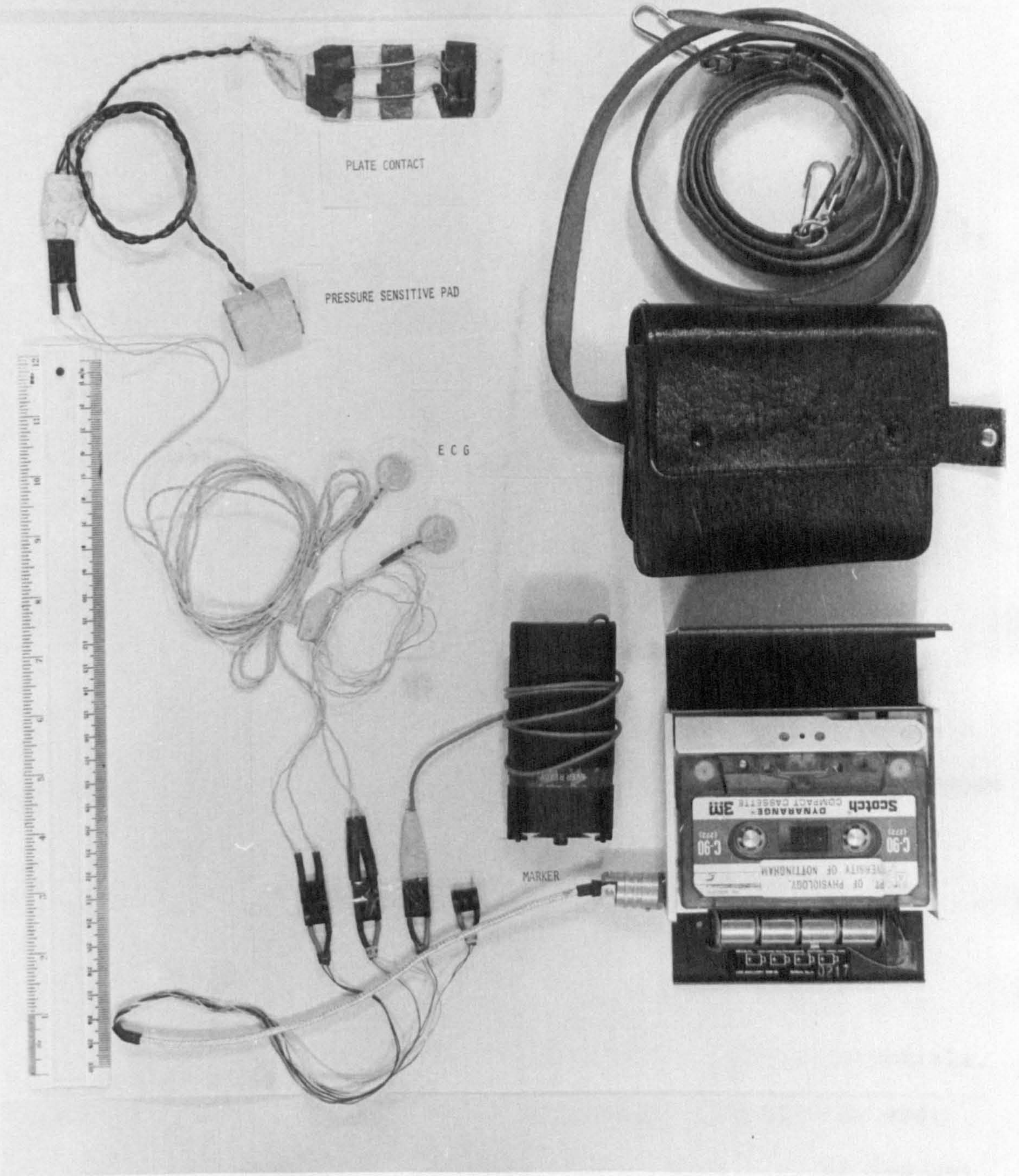


Fig. 7.2.

THE OXFORD INSTRUMENTS MINIATURE TAPE RECORDER (MEDILOG TYPE 4.24) worn on a waist belt and do not impose an unwelcome burden even on frail subjects (see Fig. 7.1 and 7.2).

The recorders are similar to the Philips in that the signals are recorded on carrier waves and stored on magnetic tape. They contain 4 independent channels and record at slow speed (2 mm s^{-1}). There is no pilot wave and no demodulator unit in the recorder. Power is supplied by 4 Mallory RMIN mercury cells (1.35 v) which have a life of 36 hours. The ECG amplifier (Type AD2) has accessible zero and gain controls.

A monitor socket allows the signals going to the recording head to be inspected and the batteries checked for adequate power. The monitor unit demodulates the signals sufficiently for them to be checked and the amplifiers calibrated. The play-back unit replays the tapes at 25 times real time. It demodulates the signals giving an analogue output which can be fed to a computer, oscilloscope or fast-response U.V. recorder.

ECG Electrodes. The ECG was recorded from 2 chest electrodes instead of 3 as in the previous study since an earth lead is not possible with a portable recorder. They were silver, coated with silver chloride, which reduces interference from junction potentials. It is essential with these recorders to obtain an ECG of 1 mv and, to this end, to have a skin impedance of less than 5 KΩ. It was not possible to measure this in the first series of trials because the only available Avometer drew a current which is above the safety limit. A portable ECG machine was used to ensure that the electrodes were picking up a large enough signal, free from interference. The signals on the Philips recorder could be checked by replaying a short recording and listening for the rhythmic changes in the pitch of the carrier wave.

In order to obtain a clear ECG signal from well-corsetted subjects, one electrode was placed on the mid-sternal position and the other over the vertebral column at T 6 or 7. This was found to be an effective alternative to the usual positions (manubrium and "V5").

RESULTS

1. Younger Group

All the subjects completed the test and appeared to understand the instructions. None showed symptoms of fatigue.

1.1 Variation in Performance

Variation in Time Taken Within a Walk. The stability of the walking speed was assessed in the same way as in the last chapter. It was found that these subjects tended to slow down. The time taken for the first half of the walk was significantly shorter than for the second half ($P<0.05$). The mean times were 44 ($\pm$ 1.23) s and 49 ($\pm$ 1.49) s respectively. There were two subjects who slowed down markedly (by 13-27 s) in both the 2nd and 3rd walks. One of them walked out faster than anyone else taking just over 30 s. When these two subjects were omitted from the assessment no significant difference was found. The mean values were then 46 ($\pm$ 0.87) s and 47 ($\pm$ 1.07) s and the S.D. of the differences was 3.6 s (variation $\pm$ 7.8%).

1.2 Variation on Re-Test

The Time Taken for the 2nd walk was compared with the time taken for the 3rd walk. The mean values were 94 ($\pm$ 2.7) s and 93 ($\pm$ 2.65) s respectively. There was no significant difference between them, and the S.D. of the differences was 3.6 s (variation $\pm$ 3.8%).

The Selected Load in the 2nd walk was compared with the load selected in the 3rd walk. The mean values were 8.7 ($\pm$ 0.74) kg and 9.1 ($\pm$ 0.76) kg respectively. There was no significant difference between them and the S.D. of the differences was 0.81 kg (variation $\pm$ 9.0%).

1.3 Heart Rate Response

The heart rates were obtained by counting over the last minute of each walk, less 5 s for deceleration. In order to see whether the heart rate had reached a plateau the counts over the first and second halves of the minute were compared. Three subjects showed a higher heart rate in the 2nd half minute in every walk. For these subjects the half minute count was used to assess the heart rate. (They had the highest heart rates of the group at 164 and 166 b min^{-1}). For the other 7 subjects there was no indication that the rate was still rising over the last minute. The mean difference between the 1st and 2nd half minute counts was 0.86 ($\pm$ 0.43) b min^{-1} which was not significant. The values from the whole minute count were used for these subjects.

The response to the 2nd and 3rd walks was compared and no significant difference was found, the mean values were 135 ($\pm$ 5.77) b min^{-1} and 137 ($\pm$ 6.12) b min^{-1}. A mean of the 2nd and 3rd walk values was therefore used except for one subject who appeared to have a higher response with each successive walk. This subject had an atypically high heart rate response (166 b min^{-1} in the 3rd walk) and the difference between the 2nd and 3rd walk values was 8 b min^{-1}. Her 2nd walk value was used for the comparison between the older and younger groups.

2. Older Group

The assessments of variation and reproducibility of performance for the older subjects have been given in the previous chapter. The 9 subjects forming the group for comparison with the younger subjects in this chapter were not different from the others in these respects.

2.3 Heart Rate Response

Heart rates had levelled by the last minute of the walk for all but one subject who had a high heart rate response compared to the rest of the group (118 b min^{-1} from the 2nd half minute count). For the other 8 subjects there was no indication that the rate was still rising over the last minute. The mean difference between the 1st and 2nd half minute counts was 0.2 ($\pm$ 0.46) b min^{-1} which was not significant. The whole minute counts were therefore used for these subjects.

The response to the 2nd and 3rd walks was compared and no significant differences were found, the mean values were 102 ($\pm$ 5.91) b min^{-1} and 102 ($\pm$ 5.86) b min^{-1} respectively.

3. Comparison between the Two Age Groups (see Table 7.2)

For each subject mean values from the 2nd and 3rd walk for speed, chosen load and heart rate were used for the comparison, except where otherwise noted.

The older group were found to walk significantly more slowly ($P<0.001$). The mean values were 4.48 ($\pm$ 0.27) km hr^{-1} for the older group and 6.58 ($\pm$ 0.18) km hr^{-1} for the younger group.

The difference between the two groups for chosen load was not significant. The mean values were 7.03 ($\pm$ 0.94) kg for the older group and 8.92 ($\pm$ 0.74) kg for the younger group.

The older group had significantly lower heart rates ($P<0.01$). The mean values were 102 ($\pm$ 4.8) b min^{-1} for the older group and 136 ($\pm$ 5.8) b min^{-1} for the younger group. This would be expected since they walked more slowly.

TABLE 7.2

RESULTS OF WALKING TEST FOR BOTH AGE GROUPS

(Mean values ± 1 S.E. derived from the mean results of the 2nd and 3rd walks for each subject).

	Walking Speed km hr^{-1}	Load Carried kg	Heart Rate b min^{-1}
OLDER GROUP n = 9	4.48 ± 0.27	7.03 ± 0.94	102 ± 4.8
YOUNGER GROUP n = 9	6.58 ± 0.18	8.92 ± 0.74	136 ± 5.8
Significance of Differences	$P < 0.001$	N.S.	$P < 0.01$

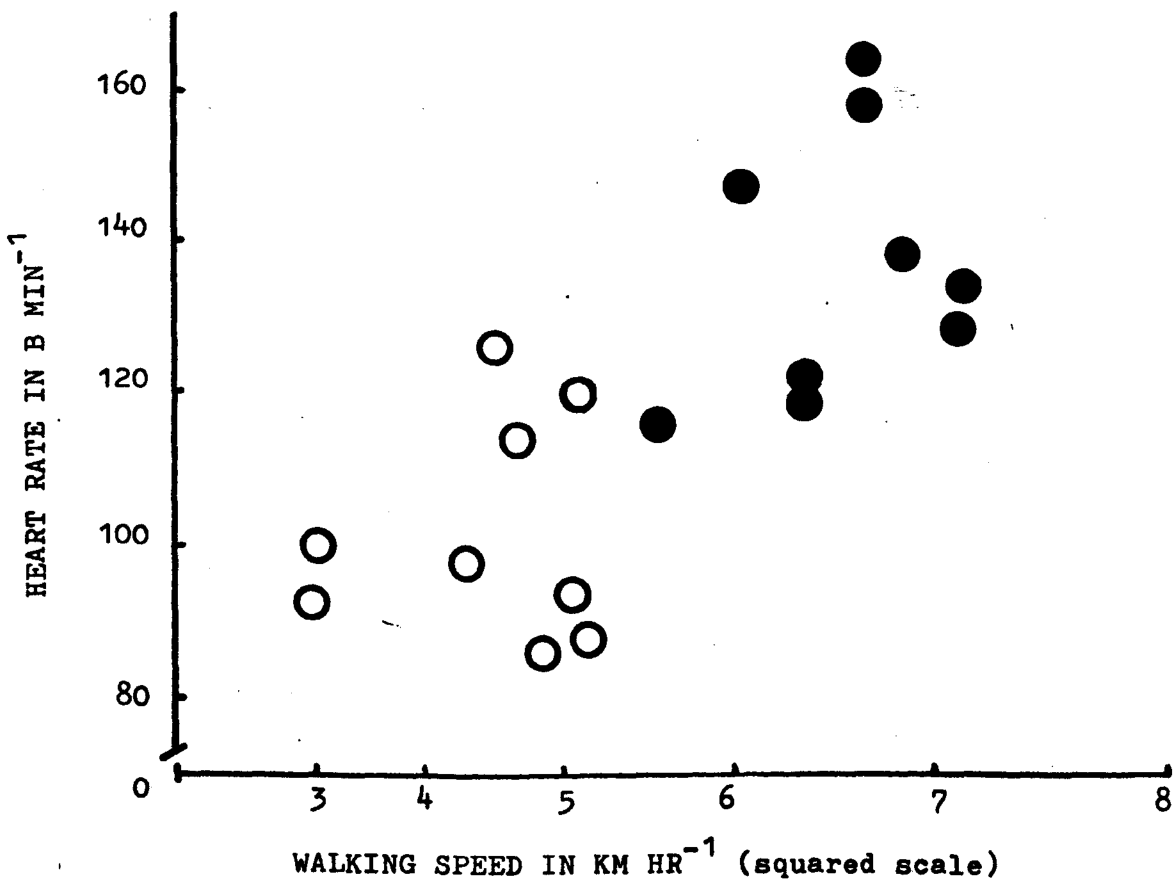
<u>Fig. 7.3</u>

HEART RATE AND WALKING SPEED

Mean values from the 2nd and 3rd walks for each individual.

Younger subjects - closed circles n = 9

Older subjects - open circles n = 9



The heart rates are plotted against the square of the walking speed in Fig. 7.3. It is not possible to deduce from this limited data whether there was a difference in physical condition between the groups. There was no significant difference between them in walking weight but there was a wide variation in this among the individuals from each group, which could explain the scatter of the heart rates.

The variation in walking speed and selected load in the young group were similar to those found for the older group as shown:-

TABLE 7.3

VARIATION IN PERFORMANCE IN BOTH AGE GROUPS

	Walking Time in seconds		Load in kg
	Within Walk	Between Walk	
Older Group n = 9	± 7.1%	± 3.1%	± 6.2%
Younger Group n = 9	± 7.8%	± 3.8%	± 9.0%

DISCUSSION

The young subjects like the older subjects performed steadily and reproducibly, providing further confirmation that the test is feasible. The young subjects also walked significantly faster than the older group. This confirmed our previous findings that walking speed in accordance with standard instructions is an indicator of performance which probably reflects the differing life styles of the two age groups.

There was no significant difference in selected load between the groups and the variation on re-test was greater than for walking speed. Both groups were used to doing a little shopping but they were not accustomed to the regular stocking of a large family larder. Middle-aged women, used to shopping for families of 4 or more people, might select significantly heavier loads. The lack of difference in the groups studied discouraged us further from including weight-carrying in future tests.

It is possible that the carried load slowed the older group down and that without it there would have been no significant difference in walking speed between the groups, but as discussed in Chapter 6 the inclusion of the carried load has other disadvantages. It requires complicated instructions and leads to difficulties in analysis.

In both groups the variation in walking time between walks was about half the variation within walk, this appears to be because the variation <u>within</u> walk is expressed as a % of <u>half</u> the walk time whereas the variation <u>between</u> walks is expressed as a % of the <u>whole</u> walk time. There is no reason why the variation in mean speed from one lap to another should depend upon the duration of the walk, therefore, within limits, the longer the walk the smaller the variation in walking time because the absolute differences are smaller.

It was surprising that additional re-test variation appeared to be negligibly small.

The exercise elicited by the standard instructions was vigorous enough to provoke a mean heart rate of 102 $\pm$ 6 b min^{-1} in the older group. This heart rate implies an oxygen uptake of about 1.0 l min^{-1} (see Chap. 11) which is an accepted level for assessing the response to exercise (Cotes, 1971).

In the younger group the mean heart rate during the exercise was 136 $\pm$ 6 b min^{-1} which reflects their faster walking speed. Moreover this group showed no symptoms of fatigue so their performance represented a smaller stress.

In both groups the heart rate reached a steady level during the walk but, in a few subjects, not until the last half-minute. A longer course would therefore be preferable, allowing a minimum duration of 2 min. This would also reduce the variation in walking time.

The relation between heart rate and the square of the walking speed for all the subjects together appeared to be linear, with no difference in heart rate at a standard speed between the two groups. However, the scatter due to different body weights and carried loads made it impossible to make definite conclusions. In this series of trials the walking test was used as a performance test and was not intended as a test of physical condition. This requires a different design which includes several walking speeds (see Chap. 9).

CONCLUSIONS

It was concluded that free walking in accordance with standard instructions, as a basis for an exercise test, was also valid for young female subjects, since they performed as steadily as the older female group, the variation in time taken being $\pm$ 8%.

The young subjects were also similar to the older group in that they were able to reproduce their performance, after some minutes, with a variation of $\pm$ 4% for time taken and $\pm$ 9% for selected load. This performance appeared to be characteristic at least for each age group since their walking speeds differed, the younger group walking significantly faster. The walking test may therefore provide an indicator of an age-linked reduction in performance.

The selected load did not reveal age-linked differences in performance and with both age groups the variation on re-test was greater than for time taken. The advantages of including the carried load, namely, to increase the psychological acceptability of the test and to increase the intensity of the exercise in the test remained unproven.

It was concluded that the intensity of the exercise produced by the standard instructions was adequate for assessing the response to exercise since the mean heart rates for both groups were over 100 b min^{-1}.

It was concluded that the course should be longer than 170 m in order to ensure "steady state" heart rates, sustained for at least one minute, in all subjects and also to reduce the variation in walking time which appeared to be independent of the length of the walk.

CHAPTER 8

AN INVESTIGATION OF THE RELATIONS BETWEEN HEART RATE, OXYGEN UPTAKE AND WALKING SPEED

INTRODUCTION

The experiments described in this chapter were intended to investigate the relations between heart rate, walking speed and oxygen uptake during free walking. In particular it was necessary to confirm that the relation between heart rate and the square of the walking speed is linear, since it was necessary to standardise heart rate on walking speed in order to use a self-paced walking test as a measure of physical condition.

There is evidence for a linear relation between oxygen uptake and the square of the walking speed during level walking on a treadmill (see Table 5.1), and for the linear relation between heart rate and oxygen uptake which is always found during steady exercise with large muscle groups (see Chap. 5 p149). It is likely therefore that the relation between heart rate and the square of the walking speed is also linear.

METHOD

Subjects. The subjects were 4 male members of the Physiology Department in the Medical School who were all used to exercise test procedures.

Their basic physical characteristics are listed in Table 8.1 and include an estimate of fat-free mass. This was based upon 4 measurements of skinfold thickness (biceps, sub-scapular, supra-iliac and anterior thigh) measured with Harpenden constant pressure calipers. The % body fat was then obtained from the regression equation given by Durnin & Womersley (1974).

Procedure. The ECG was recorded continuously during the test using the body-borne tape recorders made by Oxford Instruments (see Chap. 7). The oxygen uptake was obtained by collecting expired air in a 100 l plastic bag (Plysu) which the subject carried on a shoulder harness. The mouthpiece was supported with a cloth head harness and a spring

TABLE 8.1

BASIC PHYSICAL CHARACTERISTICS

Subject	Age Yr	Height cm	Weight kg	Body Fat %
G.E.	20	168.6	54.1	20
J.P.	35	181.9	84.9	34
I.M.	30	175.8	72.5	28
J.W.	34	178.0	77.0	27

(see Fig. 8.1). Using a stop-watch, the subject himself timed the collection of expired air over a complete number of respiratory cycles, coincident as nearly as possible with the last lap of each walk. The tap to the bag was opened and closed by an observer walking behind and to the side of the subject, at a signal from him. The expired air was analysed afterwards in the usual way (see Chap. 2).

Procedure. The subjects walked along a corridor and back over a course of 129 m for 2 laps at the slower speeds (walks 1 and 2) and for 3 laps at the faster speeds (walks 3-6; see below). This ensured that the subjects walked for at least 2 min at each speed, before collection of expired air began. This was to allow the oxygen uptake to reach a steady value (Astrand & Saltin, 1961). They walked first at a normal speed for 2 laps; this was a trial run in which all the measurements were made but subsequently discarded. They then walked at 6 different speeds in accordance with standard instructions as shown below. The instructions were printed on a card for the subject to look at before he began the test and between walks, in order to help him to space out his walking speeds.

STANDARD INSTRUCTIONS

Walk 1 very slowly

2 a little faster but not as fast as normal

3 normal

4 a little faster than normal but not fast

5 rather fast

6 as fast as possible

The subjects rested for 5 min or longer after walks 3, 4 and 5 in order to allow their heart rates to return to resting levels. The heart rate was monitored during these rest periods using a portable

Fig. 8.1.

Subject J.W. walking. He is wearing the shoulder harness with the collection bag in place, the head harness which is supporting the mouthpiece via a spring, and a tape recorder. The observer is about to open the tap to the bag.

battery operated meter (Childerhouse Cardiac Monitor SER. NO. 131).

RESULTS

Heart Rate and Oxygen Uptake. The values for heart rate and oxygen uptake are plotted with the best fit regression lines for each subject in Fig. 8.2. The relation was linear for all 4 subjects over the whole range of walking speeds ($r > 0.97$ in all cases, for which $P < 0.001$).

Oxygen Uptake and Walking Speed. The values for oxygen uptake and walking speed (squared scale) are plotted for all the subjects in Fig. 8.3. It can be seen that the relation is linearat the lower walking speeds and then becomes curved at levels over 7.2 km hr^{-1} or 1.5 l min^{-1} oxygen uptake. The regressions for each subject were linear if points over 1.5 l min^{-1} were omitted ($r > 0.98$ in all cases, for which $P < 0.001$). These regression equations expressed in oxygen uptake per kg body weight (+ equipment) and km hr^{-1} are shown in Fig. 8.4 and listed in Table 8.1 along with equations given by other authors.

Heart Rate and Walking Speed. The values for heart rate and walking speed (squared scale) are plotted with the best fit regression lines in Fig. 8.5 omitting values over 7.2 km hr^{-1}. The relations were linear ($r > 0.98$ in all cases, for which $P < 0.001$).

Fig. 8.2

HEART RATE AND OXYGEN UPTAKE DURING WALKING

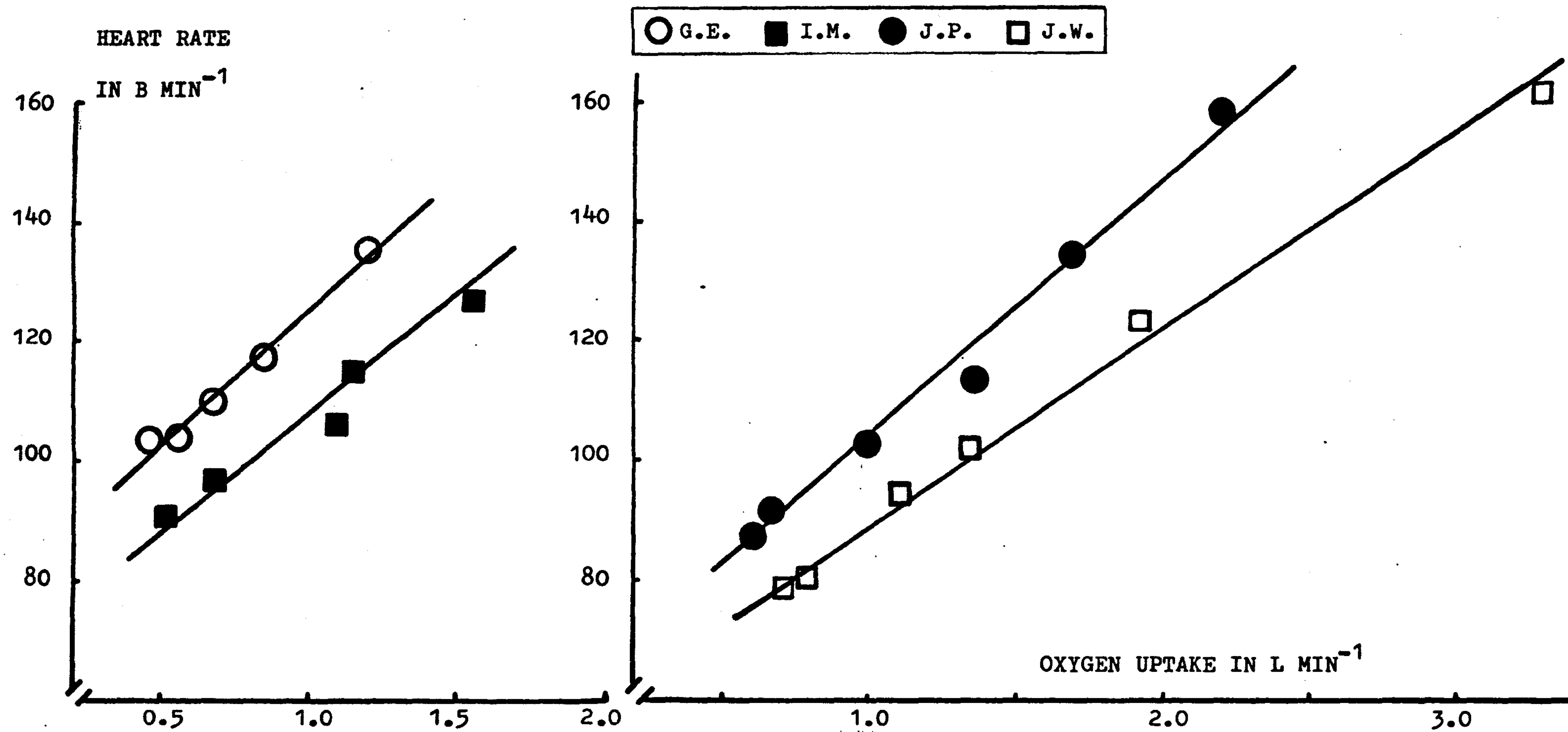


Fig. 8.3 OXYGEN UPTAKE AND WALKING SPEED

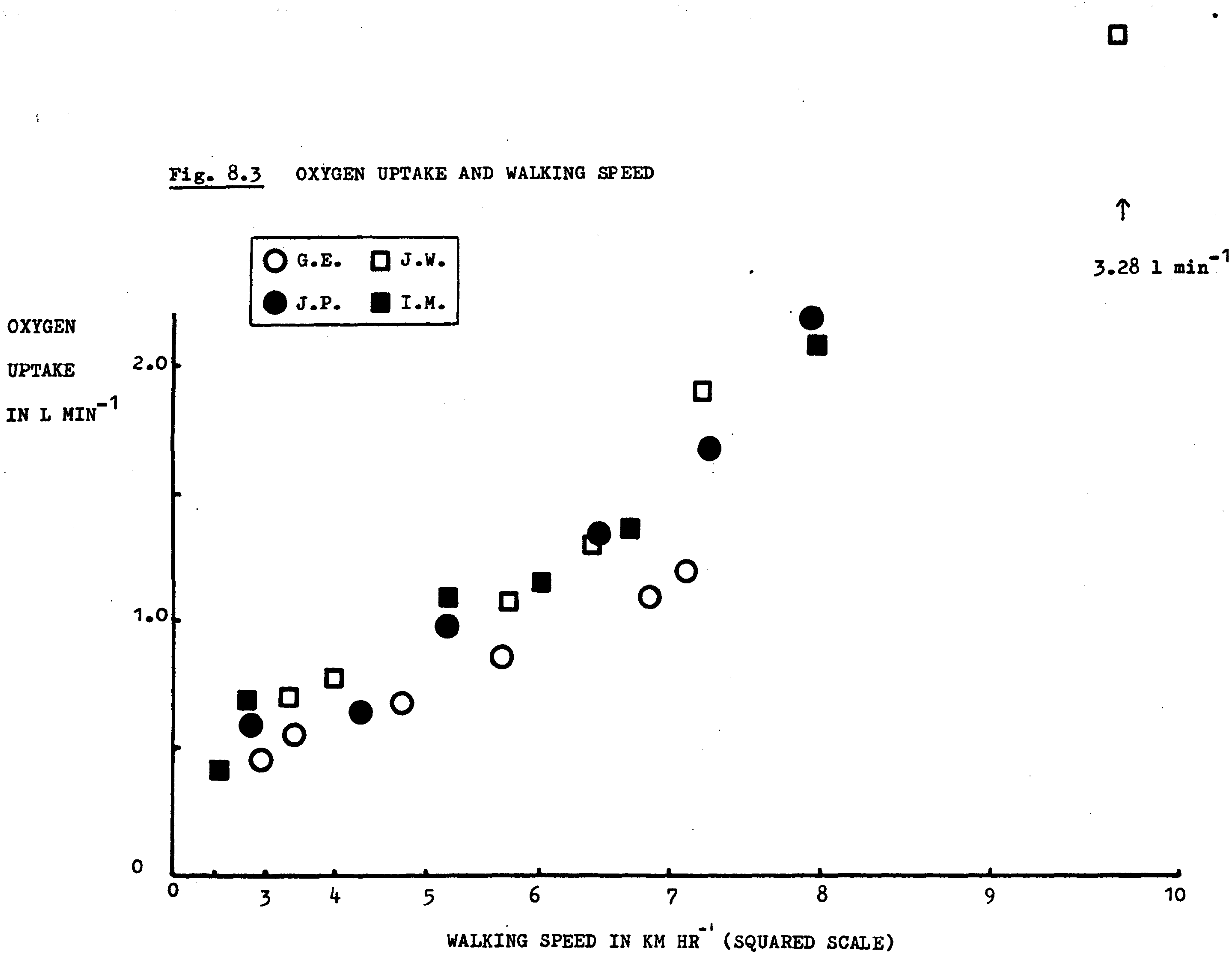


Fig. 8.4

OXYGEN UPTAKE PER KG BODY WEIGHT AND WALKING SPEED

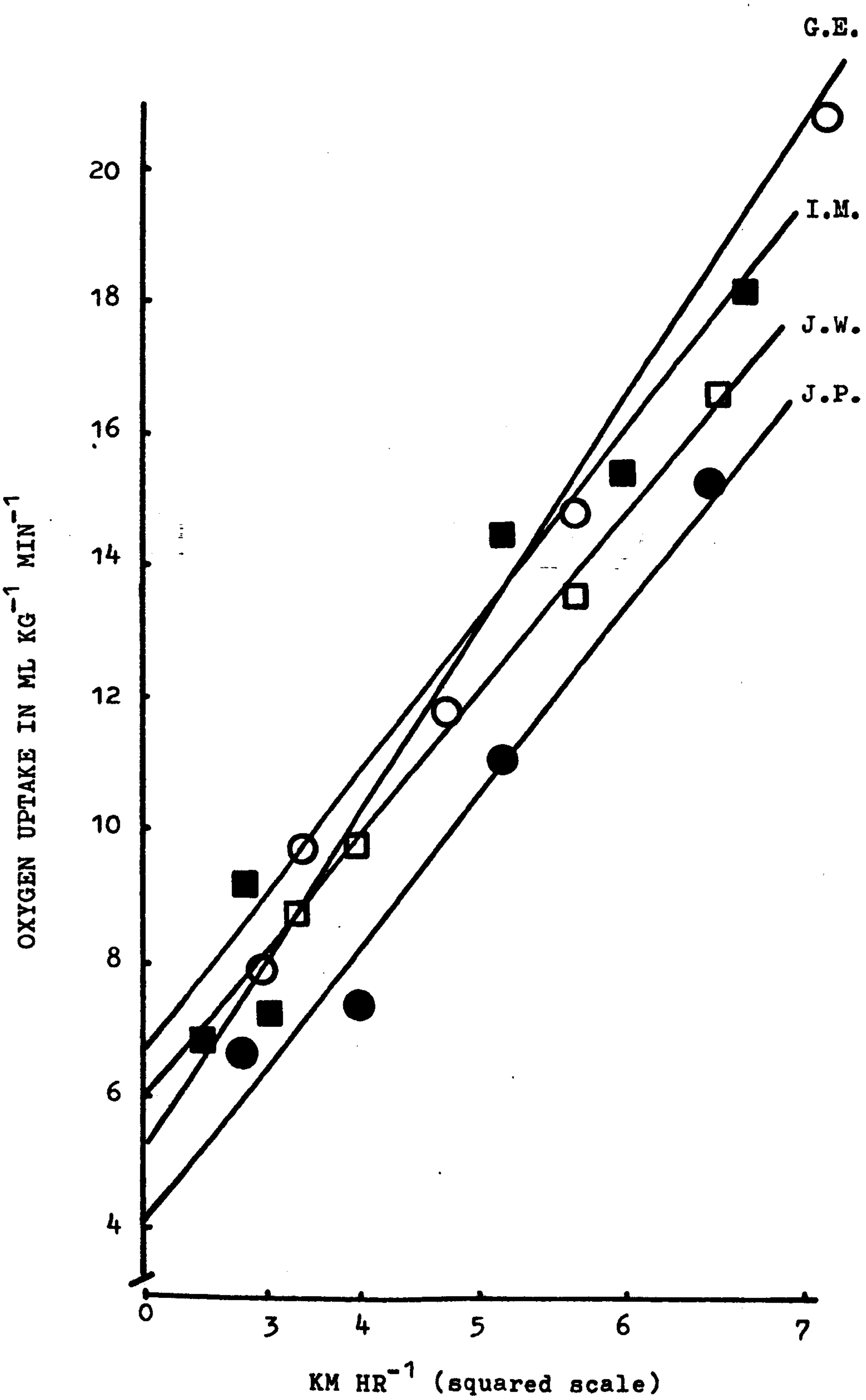


TABLE 8.2

REGRESSION EQUATIONS FOR OXYGEN UPTAKE ON WALKING SPEED

$\dot{V}_{O_2}$ = oxygen uptake in ml kg min^{-1}

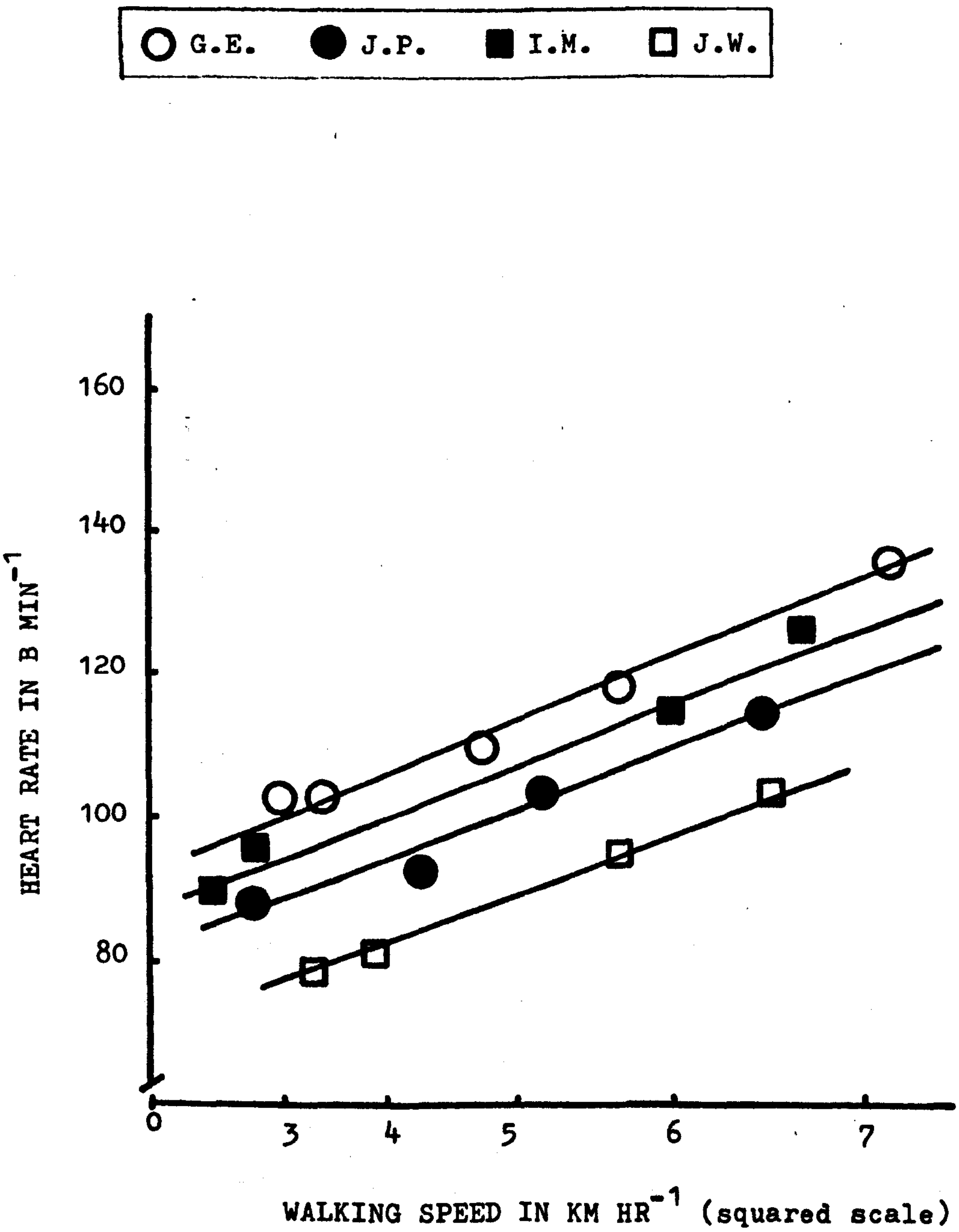
V = walking speed in km hr^{-1}

Present Results	Subject
$\dot{V}_{O_2} = 0.318V^2 + 5.23$	G.E.
$= 0.258V^2 + 4.17$	J.P.
$= 0.257V^2 + 6.67$	I.M.
$= 0.245V^2 + 5.97$	J.W.
Other Authors' Results (see Table 5.1)	**Author**
$\dot{V}_{O_2} = 0.34V^2 + 5.8$	Grimby & Soderholm 1962
$= 0.24V^2 + 8.0$	Cotes & Meade 1960
$= 0.37V^2 + 6.0$	van der Walt & Wyndham 1973

Fig. 8.5

HEART RATE AND WALKING SPEED

(speeds below 7.2 km hr^{-1} only)



DISCUSSION

The subjects were able to walk at 6 different steady speeds for the required distance without difficulty.

The linear relation between heart rate and oxygen uptake during rhythmic exercise was found to hold good in this free walking situation, as expected.

The linear relation between oxygen uptake and the square of the walking speed was also confirmed for free walking speeds up to 7.2 km hr^{-1}. It is not likely that walking speeds higher than that occur in natural situations because at speeds over about 7 km hr^{-1} it is more comfortable and efficient to run (Noble, Metz, Pandolph, 1973). There was no need therefore to consider more complicated relations such as the logarithmic one of Macdonald (see Chap. 5). The regression equations for oxygen uptake in ml kg min^{-1} and walking speed agreed with those of other authors (see Table 8.2). Of the four subjects in the present study, one (J.P.) had a lower oxygen uptake, per kg of weight transported at any given walking speed, than the other three (see Fig. 8.4). The difference was in the intercept and not in the slope indicating a difference in mean basal metabolic rate per kg body weight rather than a difference in walking efficiency. This subject had the highest body fat in proportion to his weight (see Table 8.1) and since fat is a tissue with a low oxygen consumption this might account for the observed difference. Body composition will therefore affect assessments of physical condition based on walking speed. Differences in walking efficiency, which may be marked in the elderly, will also affect the assessment. These two points will be discussed further in the following chapters.

The relation between heart rate and the square of the walking speed was found to be linear as we had expected from other evidence. Provided the higher walking speeds (over 7.2 km hr^{-1}) were omitted the relations were as linear as those between heart rate and oxygen uptake. This means that they are equally suitable for assessing physical condition. The assessment would then be the heart rate response to a given walking speed, rather than at a given oxygen uptake. The two assessments may differ if there are differences in walking efficiency but this would not invalidate the assessment based on walking speed as a relevant measure of physical condition.

CONCLUSIONS

Subjects are able to maintain several clearly different walking speeds in accordance with standard instructions.

The relations between:-

(i) heart rate and oxygen uptake;

(ii) oxygen uptake and walking speed squared;

(iii) heart rate and walking speed squared were found to be linear provided speeds over 7.2 km hr^{-1} were omitted in (ii) and (iii).

There are differences between subjects in the relation between oxygen uptake and walking speed which might affect the assessment of physical condition based on walking speed.

CHAPTER 9

MEASUREMENTS OF PERFORMANCE AND PHYSICAL CONDITION IN MEN USING A WALKING TEST

INTRODUCTION

The results of trials so far had shown that walking freely could be a feasible basis for an exercise test for both young and elderly female subjects. The subjects were able to maintain a steady level of activity despite their free situation and to perform with adequate intensity.

It had also been found in 4 male subjects of varying ages that several distinct grades of steady activity were possible during free walking. The relation between heart rate and walking speed could then be used to assess physical condition in a way that is analogous to assessments based on heart rate and oxygen uptake (see Chap. 8). A walking test was therefore designed to include three walking speeds and used with another group of subjects (elderly men) in order to assess their physical condition.

The carrying of a selected load was omitted. The instructions were no longer simple if it was included and the interpretation of the results was more difficult and perhaps inconclusive (see Chap. 7).

The walking course was increased in length to 256 m; the course was inside a rectangular hall rather than along a corridor and back; and the subjects foot-fall was recorded in addition to heart rate. This enabled further checks to be made on the steadiness of performance and also provided information about the subjects' gait. In particular the contribution of stride length and pace frequency to increments in walking speed could be investigated.

It was apparent from the earlier trials that walking speed, in accordance with particular instructions, was influenced by age and activity (see Chaps. 6 and 7). Therefore a second aim of these experiments was to see whether the walking test could be used as a performance index as well as a test of physical condition.

The inclusion of three speeds provided three separate assessments of performance.

The subjects repeated the test after a lapse of several days, so that the reproducibility of the results for performance and physical condition could be assessed.

This chapter describes the results of these walking tests with 24 elderly male subjects, who formed the first group in a longitudinal study of retirement.

METHODS

The Subjects were 24 men aged 63-65 years. They were industrial workers from Stanton Iron Works (B.S.C.), who were either due to retire within the following month (n = 15) or who had been retired for a year (n = 9). They volunteered as a result of an introduction made by the Personnel Department.

Their basic physical characteristics are given in Table 9.1. The lung volumes were within 2 standard errors of the estimate of the predicted values for age and height (Kory, Callahan, Boren, & Syner, 1961) except for one man who had chronic bronchitis. The values for % body fat were over 15% for all but 2 subjects (see Table 9.2).

TABLE 9.1

BASIC PHYSICAL CHARACTERISTICS (Lung Volumes at B.T.P.S.)

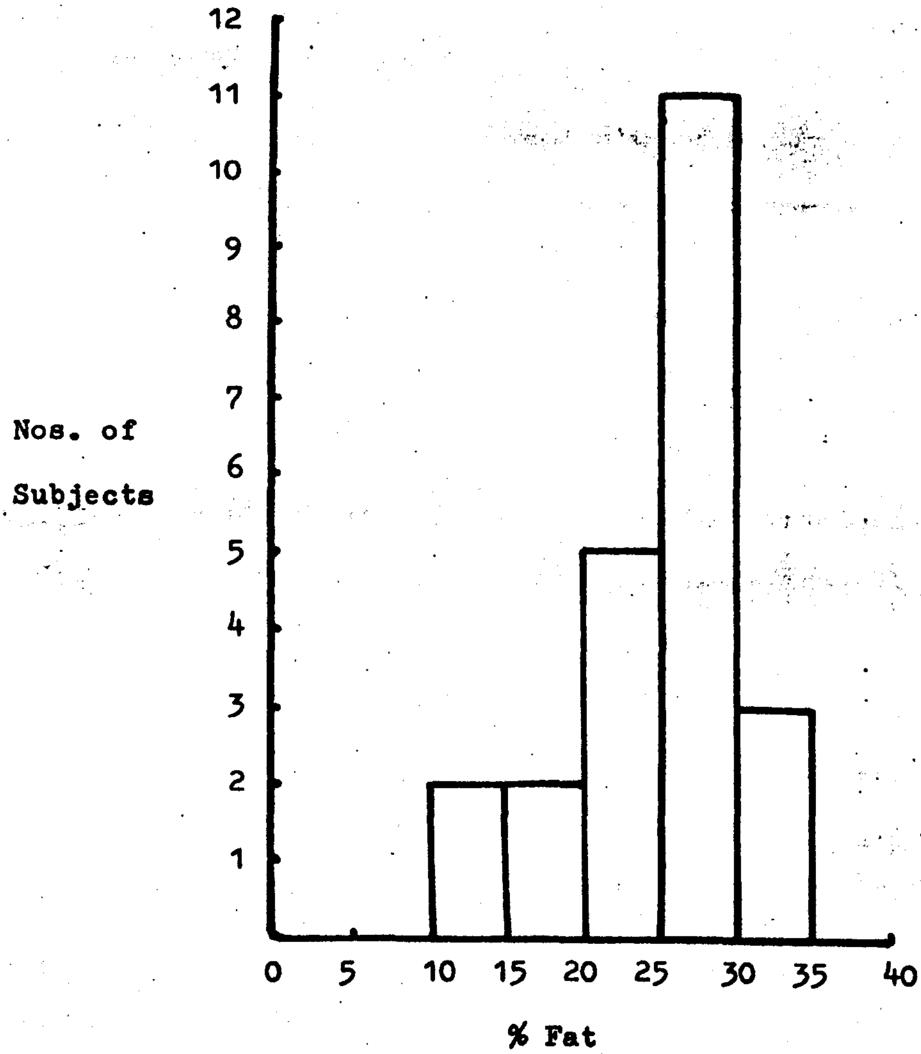
Mean values ± 1 S.E. n = 24

Height cms	Weight kg	Fat-free mass kg	Sub-ischial height cms	Handgrip kg	Forced Vital Capacity l	F.E.V. 1 sec l
168 ± 1.35	73.2 ± 2.37	54.3 ± 1.41	80 ± 1.17	46 ± 1.59	3.83 ± 0.15	2.76 ± 0.14

TABLE 9.2

BODY FAT CONTENT:

DISTRIBUTION OF VALUES IN THE GROUP



<u>Procedure</u>. Two walking tests were performed on separate days with a lapse of 1-7 days between them.

<u>The Walking Test</u> consisted of walking several times around a rectangular course of 128 m in an indoor Sports' Centre. The course was delineated by the perimeters of two adjacent 5-a-side football pitches.

Subjects were asked to complete two circuits (256 m) at each of 3 walking speeds and to rest sitting for 5 min between each walk. The instructions, given below, were similar to those used by Borg, Edgrem & Marklund (1973). It was emphasised that a steady pace was required.

Standard Instructions:-

1st walk - "Please walk rather slowly".

2nd walk - "Please walk at your normal and just right pace, neither fast nor slow".

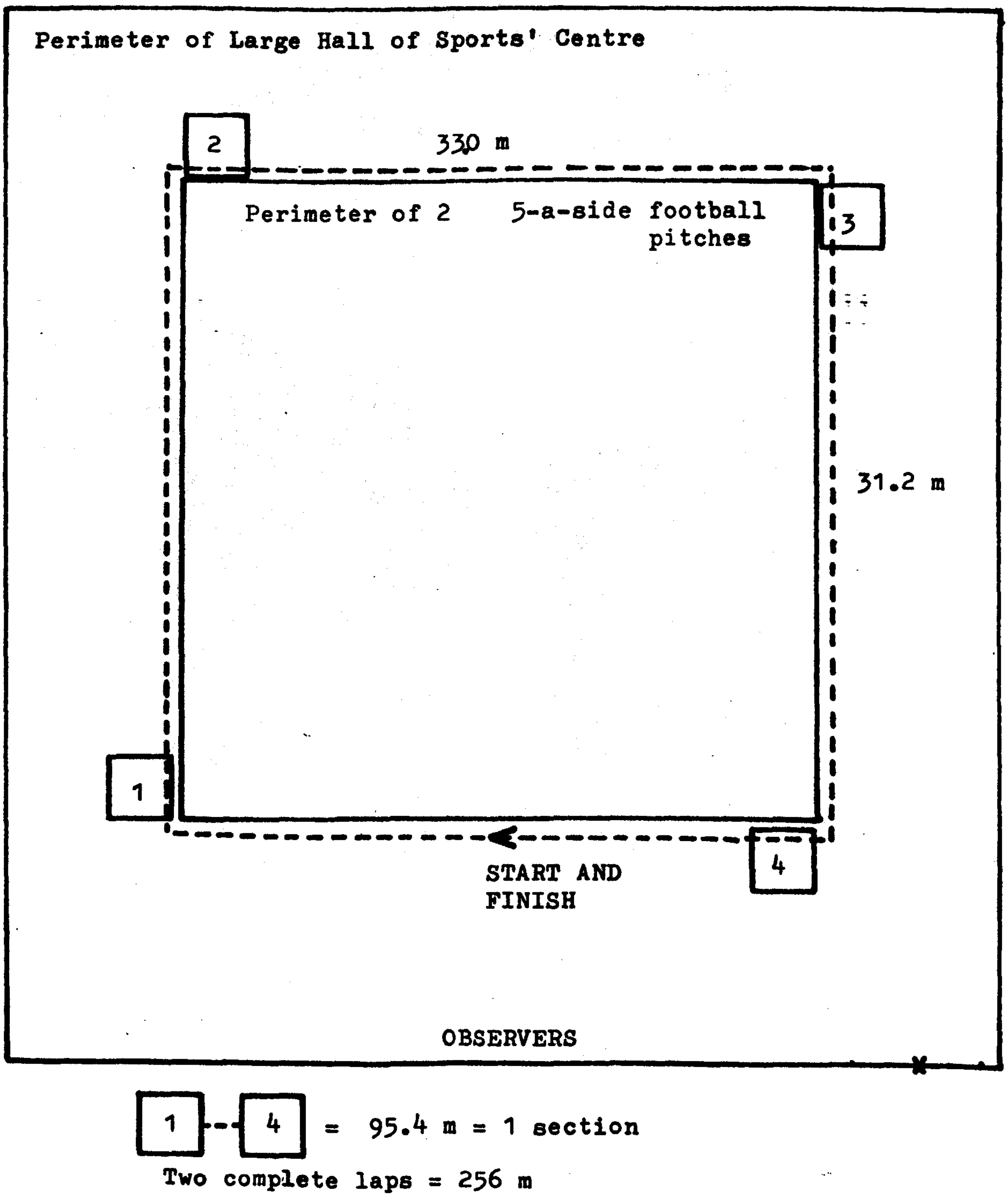
3rd walk - "Please walk rather fast but without over-exerting yourself".

The starting and finishing point, where the observers remained, was at the mid-point of one of the sides of the course (see Figs. 9.1 and 9.2). During each walk, the times were noted when the subject reached each corner of the rectangular course and at the end of each of the two circuits. The representative speed for each circuit was calculated from the time taken to walk round 3 complete sides of the rectangle from corner 1 to corner 4, a distance of 95.4 m, referred to hereafter as one section. The walking speeds for each test were calculated from the time taken to walk this section in the 2nd circuit of each of the 3 walks.

<u>The ECG</u> was recorded continuously over the whole test period using a body-borne Oxford Instruments tape recorder (see Chap. 7). A low current impedance meter (10 μ amps) was used to ensure that

Fig. 9.1

PLAN OF THE WALKING COURSE



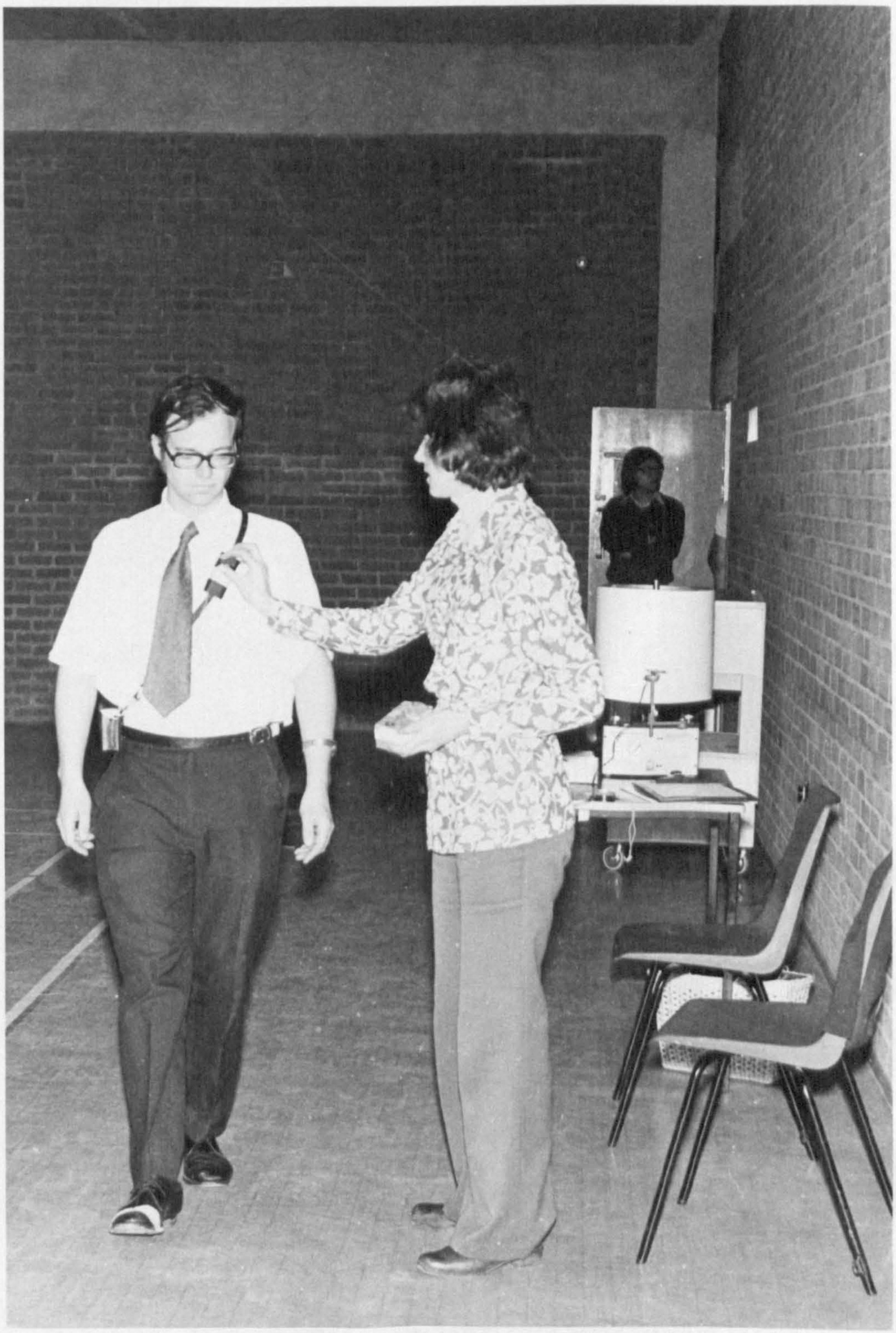


Fig. 9.2.

One of the members of the team acting as a subject for a walking test in the Sports' Centre. The observer is marking the end of a walk on the tape recorder.

the initial impedance between the electrodes was low (Hanish, Neustein, Van Cott & Sanders, 1971). It was possible in most subjects to obtain an impedance of about 1 K ohm, without damaging the dermal layers, by abrading the skin with Scotchbrite. The impedance doubles (approximately) within the first half hour after application of the electrodes, so an initial impedance of 1 K ohm gives a working impedance of 2 K ohm. This usually ensured a favourable signal to noise ratio.

Occasionally, when the humidity was low, there was troublesome interference and some data was lost. The interference was worst during walking and appeared to be due to static electricity generated in layers of clothing. It did not occur sufficiently frequently to warrant asking subjects to wear cotton clothing, nor did we investigate the phenomenon fully.

Heart rates were obtained by counting over a minute during the 2nd section of each walk. In order to obtain a measure of physical condition, the values for the heart rate were plotted against the square of the walking speed, and the best regression line fitted to the three recorded points. A standardised heart rate was then obtained by interpolation (cf Fig. 3.4, p65).

Footfall. During the test a pressure sensitive pad on the heel was used to record footfall on another channel of the tape recorder using a Type AR-1 amplifier (Barber, Wilson, Fentem & Evans, 1973). This channel was also used to mark the moment at which the subject reached each of the four corners of the walking course; metal plates on the floor completed a circuit in parallel with the heel pad provided by two wires fixed to the sole of the shoe. These extra markers allowed further assessment to be made of how steadily the subject was walking. Any acceleration or deceleration at each end of the course was eliminated from the analysis because only the 1-4 section was used.

Symptoms of Fatigue. After each walk, the subject was asked if he had any symptoms of fatigue (including breathlessness, chest pain or leg pain), and he was asked to give a rating of perceived exertion according to the scale devised by Borg (1962):-

RATING OF PERCEIVED EXERTION

3	extremely light	13	rather laborious
5	very light	15	laborious
7	light	17	very laborious
9	rather light	19	extremely laborious
11	neither light nor laborious		

Ambient Conditions. The mean temperature ($\pm$1 S.D.) was 16.5 ($\pm$ 3.6)°C, dry bulb and 14 ($\pm$ 3.8)°C, wet bulb. The subjects wore normal clothing including jerseys, jackets and comfortable outdoor shoes.

Analysis. For reasons explained in Chap. 6 the variation in performance was assessed using the recorded values for time and number of paces taken rather than the derived values for speed, stride length and cadence. The relations between these three derived parameters were then investigated separately.

Informal Performance

After the walking test the subjects were driven back to the Medical School from the Sports Centre by car. They then walked from the car park to the door over a level course. The heart rate during this "free" walk could be identified and compared with that recorded during the formal walk. Care was taken not to pace the subject, and he was not aware that his performance during this part of the proceedings was to be analysed.

The heart rate and number of paces were counted over a minute. The count was started about a minute after the subject got out of the car, provided the heart rate was steady according to the ratemeter. These free walk values were then compared with those recorded in the formal walks.

The subjects were next obliged to walk up 6 flights of stairs (vertical height 11.0 m) to the Physiology Department on the 2nd floor. The time taken to do this was recorded, without the knowledge of the subject, using a stop-watch. The peak heart rate reached during the climb could be identified from the ratemeter record. The subject was always allowed to walk up the stairs ahead of the observer(s) and conversation was avoided as far as possible.

RESULTS

The mean results for walking speed and heart rate are given in Table 9.3. The exercise performance results will be dealt with first and then the heart rate response to the exercise, and finally the analysis of the gait.

The subjects took about 4 min to cover the whole course of 256 m during the slow walk and at least 2 min during the fast walk. The mean walking speeds on the 2nd day were 3.6, 4.6, and 5.4 km hr^{-1}.

1. Variation in Performance within Walk

This was assessed by comparing the performance as time and number of paces taken to cover the test section on the 1st and 2nd time round. The results from each of the three walks and from each day were considered separately (see Figs. 9.3 and 9.4). The variation was found to be $\pm$ 6% or less for both parameters. (As before, the variation is the standard deviation of the differences as a percentage of the mean value).

1.1 Time Taken. On the 1st day there was a tendency to speed up; in the slow walk the time taken was significantly shorter in the 2nd section than the 1st ($P<0.05$); in the normal and fast walks there was no significant difference. On the 2nd day there were no significant differences between the two section times and the

TABLE 9.3

SPEED AND HEART RATE DURING WALKING

Mean values ± 1 S.E. for the 2nd section from each walk.

	WALKING SPEED IN KM HR^{-1}		
	Slow	Normal	Fast
1st Day	3.6 ± 0.12	4.6 ± 0.11	5.6 ± 0.09
2nd Day	3.6 ± 0.11	4.6 ± 0.10	5.4 ± 0.11
Difference	N.S.	N.S.	**
	HEART RATE IN B MIN^{-1}		
1st Day	82 ± 2.3	88 ± 2.0	99 ± 2.0
2nd Day	81 ± 2.4	87 ± 2.1	94 ± 2.0
Difference	N.S.	N.S.	**

variation was small especially in the normal walk. The mean values for the 2nd day are given below:-

TIME TAKEN IN SECONDS TO WALK 95.4 M SECTION (n = 19)

	SECTION 1st	SECTION 2nd	Mean difference ± S.E.		Variation %
Slow	96	96	0.3 ± 1.3	N.S.	6.05
Normal	76	75	0.2 ± 0.6	N.S.	3.3
Fast	64	64	0.1 ± 0.4	N.S.	2.7

1.2 Number of Paces. The number of paces recorded is half the number of paces taken since the pad is on one foot, so all the values given below represent half the true values. The number of paces taken is inversely proportional to the stride length since the distance is fixed.

On the 1st day there were no significant differences in the slow and normal walks, but in the fast walk the number of paces was significantly greater in the 2nd section but by less than 1 pace ($P<0.05$). On the 2nd day there were no significant differences. These values are plotted in Fig. 9.4 and given below :-

NUMBER OF PACES TAKEN TO WALK 95.4 M SECTION

	SECTION 1st	SECTION 2nd	Mean difference ± S.E.		Variation %
Slow n = 16	73	73	0.25 ± 0.33	N.S.	1.8
Normal n = 17	67	67	0.23 ± 0.34	N.S.	2.1
Fast n = 18	62	62	0.28 ± 0.43	N.S.	2.9

Fig. 9.3.

VARIATION WITHIN WALK : COMPARISON OF TIME TAKEN IN SECONDS TO WALK THE 1ST AND 2ND SECTIONS (95.4 m)

Each point represents the results from the 2nd day for one subject walking at one speed.

□ Slow ● Normal ○ Fast

n = 18 19 17

The dotted line is the line of coincidence

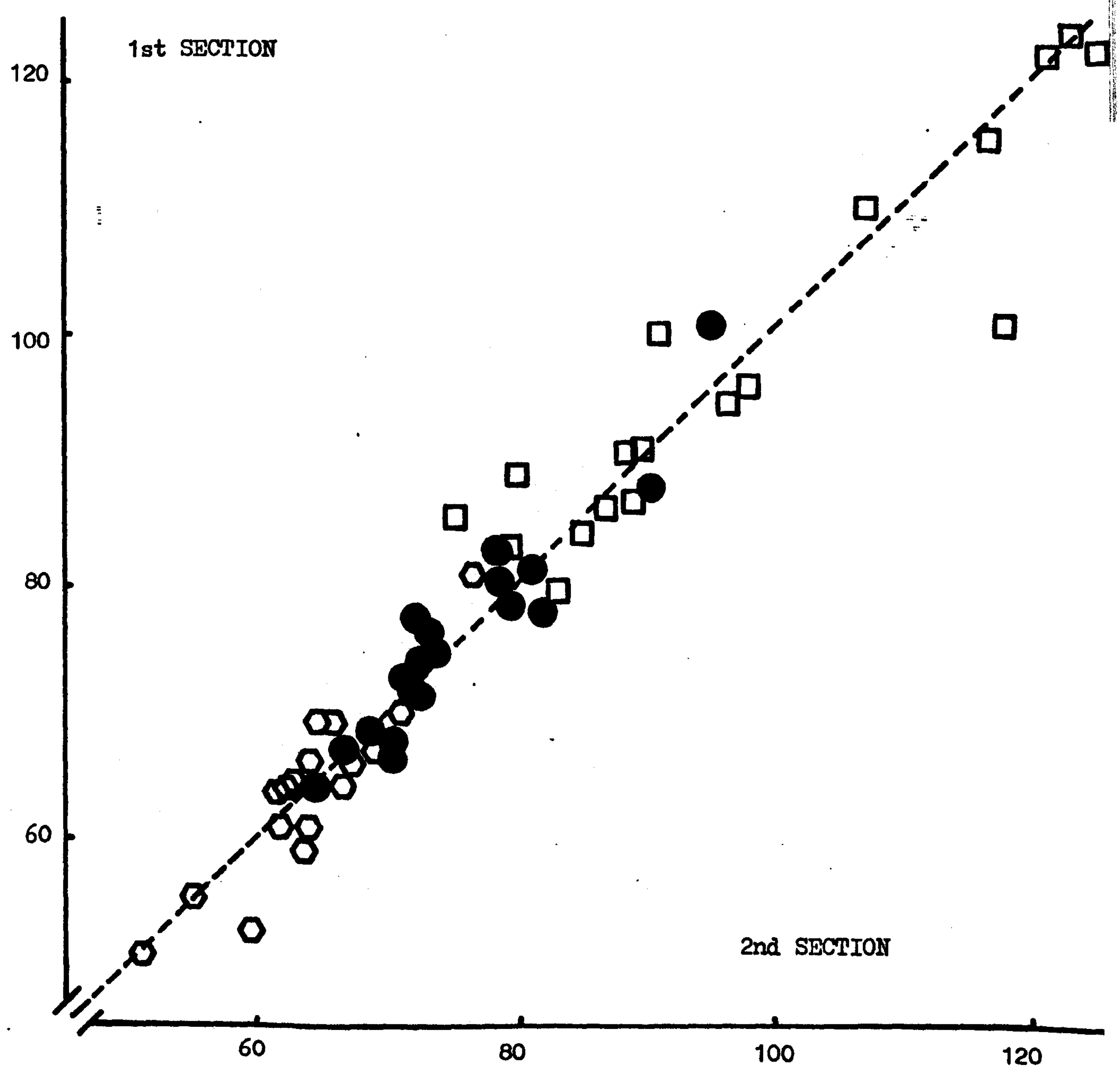


Fig. 9.4

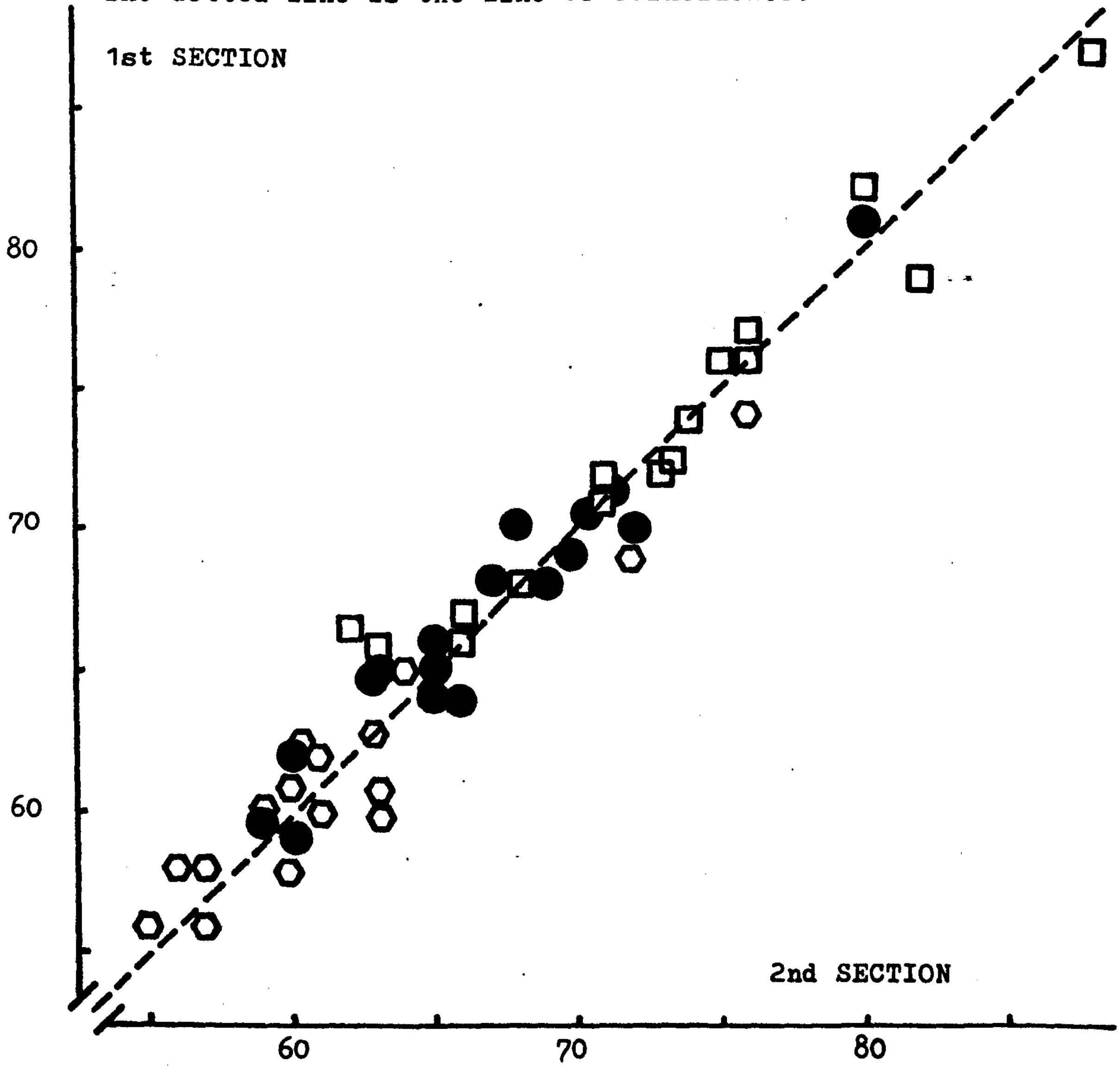
VARIATION WITHIN WALK: COMPARISON OF NUMBER OF PACES TAKEN TO WALK THE 1ST AND 2ND SECTIONS (95.4 m)

Each point represents the results from the 2nd day for one subject walking at one speed.

□ Slow ● Normal ○ Fast

n = 16 17 16 subjects

The dotted line is the line of coincidence.



The steadiness of the walking performance was also checked by considering the number of paces taken to travel the 2 parallel sides of the rectangular course (i.e. corner 1-2 and corner 3-4, each 31.2 m). The difference was never more than one pace in values of 16-20 paces. This is within the experimental error of the measurement, since the metal plates were about 2 m long in order to ensure catching one footfall.

2. Heart Rate Response

2.1 Recorded Heart Rates

The heart rate had reached a steady level in all but one subject, by the 2nd section of each walk, as judged by eye from the ratemeter record. (The one subject was hypertensive at rest, 230/130 mms Hg). This was checked in 12 consecutive subjects by comparing the counts over the 1st and 2nd halves of the last half of the minute of the 1-4 section. There was no significant difference between them and the mean difference was 0.03 $\pm$ 0.17 beats. The values for the 1st and 2nd half-min for each subject for each walk are plotted in Fig. 9.5.

When the results for the 1st and 2nd day were compared there were no significant differences in the slow and normal walks but in the fast walk the heart rate was significantly lower on the 2nd day. The mean values on the 2nd day were 81, 87 and 94 b min^{-1} for the slow, normal and fast walks respectively (see Table 9.3).

The heart rates always returned to a similar baseline level during the 5 min rest after each walk. Resting values were obtained from the ratemeter record; a mean of the three resting values recorded during the 3rd min after each walk was taken for each subject. The mean values for the group were 68 ($\pm$ 2.19) b min^{-1} for the 1st day and 67 ($\pm$ 2.22) b min^{-1} for the 2nd day. There was no significant difference between them.

Fig. 9.5

COMPARISON OF THE NUMBER OF HEART BEATS COUNTED IN THE 1st AND 2nd HALVES OF THE LAST MINUTE OF EACH WALK

Each point represents the results for one subject walking at one speed.

□ Slow; ● Normal; ⬡ Fast; n = 34 points

The dotted line is the line of coincidence.

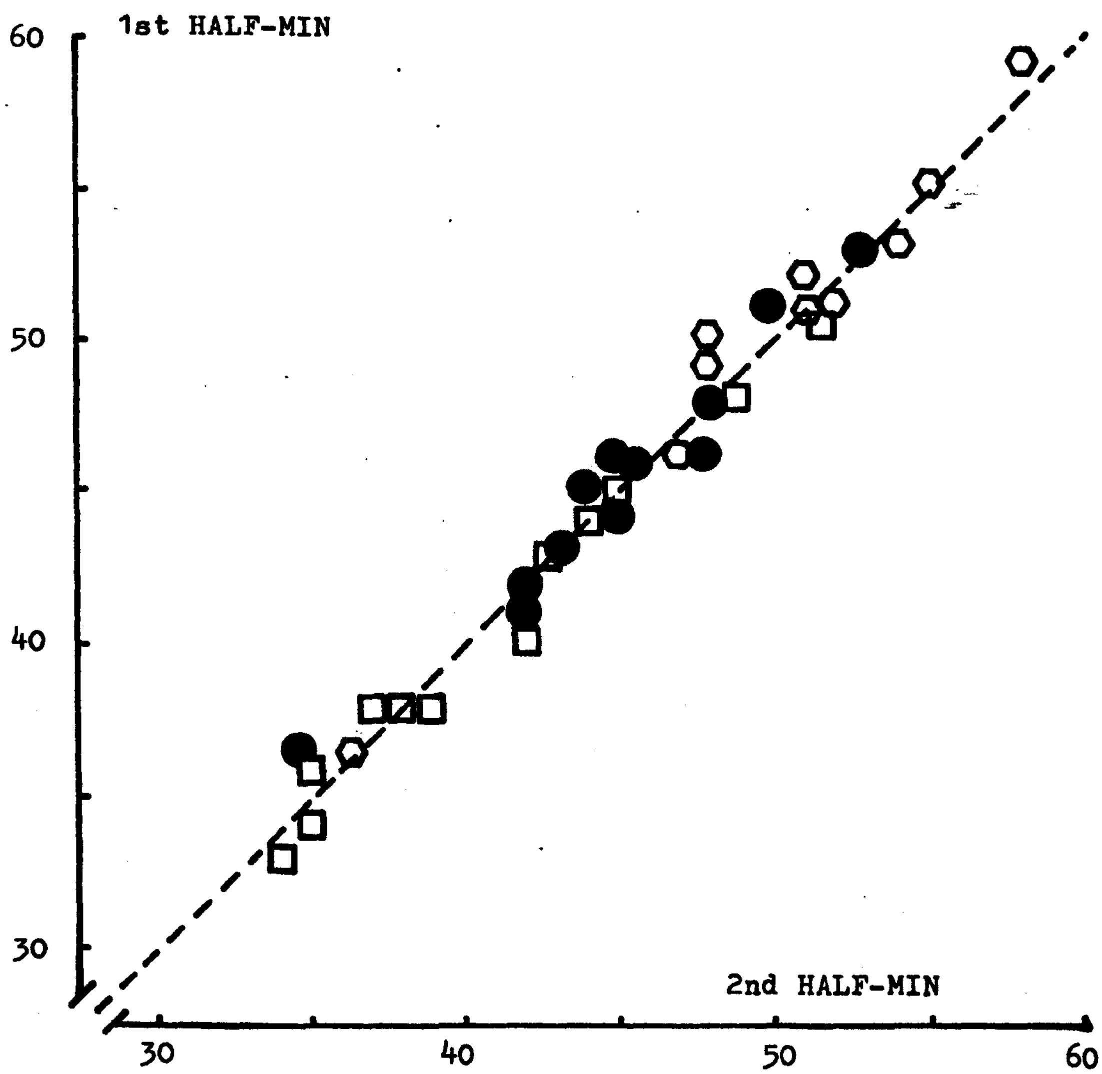
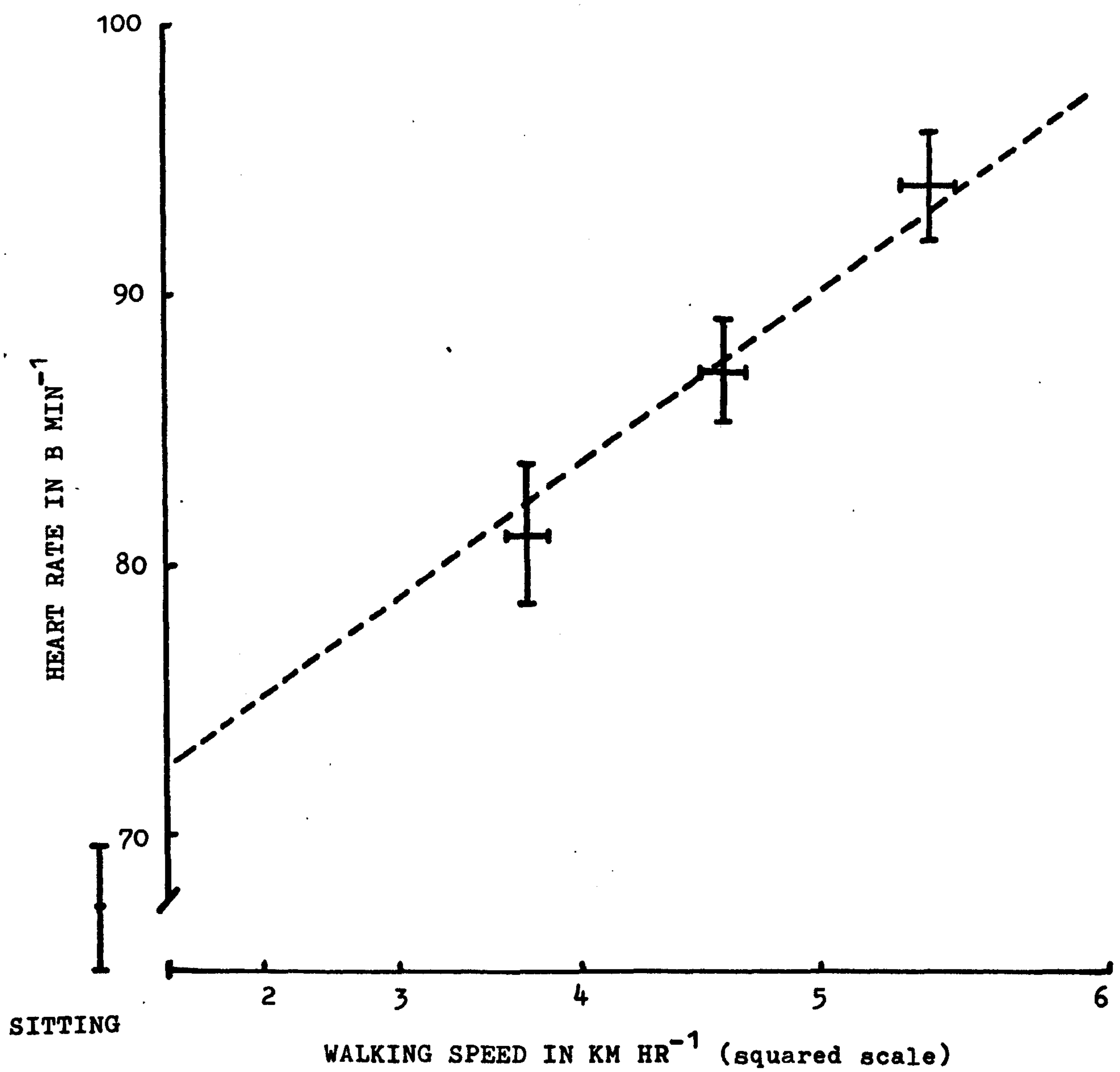


Fig. 9.6

HEART RATE AND WALKING SPEED

(Mean of recorded values ± S.E. on 2nd day, n = 24)

The dotted line is the best fit regression line obtained using all the recorded points separately n = 66



These three mean values for the group are plotted in Fig. 9.6 and give a linear relation with walking speed using a squared scale. If the relation is extrapolated to zero walking speed the intercept on the heart rate axis is appropriately a little above the value recorded during sitting.

2.2 Standardised Heart Rates

The results were standardised for each individual to eliminate variation in walking speed and obtain a measure of physical condition. The standard speed used was 4.8 km hr^{-1} because it fell between the recorded normal and fast walking speeds for 18 of the 24 subjects and within 0.5 km hr^{-1} of the normal speed for 5 of the remainder. An extrapolation of 0.3 km hr^{-1} was required for one subject who suffered from arthritis of the knees.

The standardised results were 91 ($\pm$ 2.03) b min^{-1} on the 1st day and 90 ($\pm$ 2.21) b min^{-1} on the 2nd day. There were no significant differences between them. The values for the 1st day were plotted against those for the 2nd day in Fig. 9.7; the variation on re-test was 5.4%.

2.3 Standardised Heart Rate Response and Performance

There was little indication that those with the lowest standardised heart rates, who could be said to be in the best physical condition, walked the fastest (see Fig. 9.8).

Fig. 9.7

STANDARDISED HEART RATE IN B MIN^{-1}. COMPARISON OF 1st AND 2nd DAY VALUES.

Each point represents the results for one subject at 4.8 km hr^{-1} n = 21

The dotted line is the line of coincidence

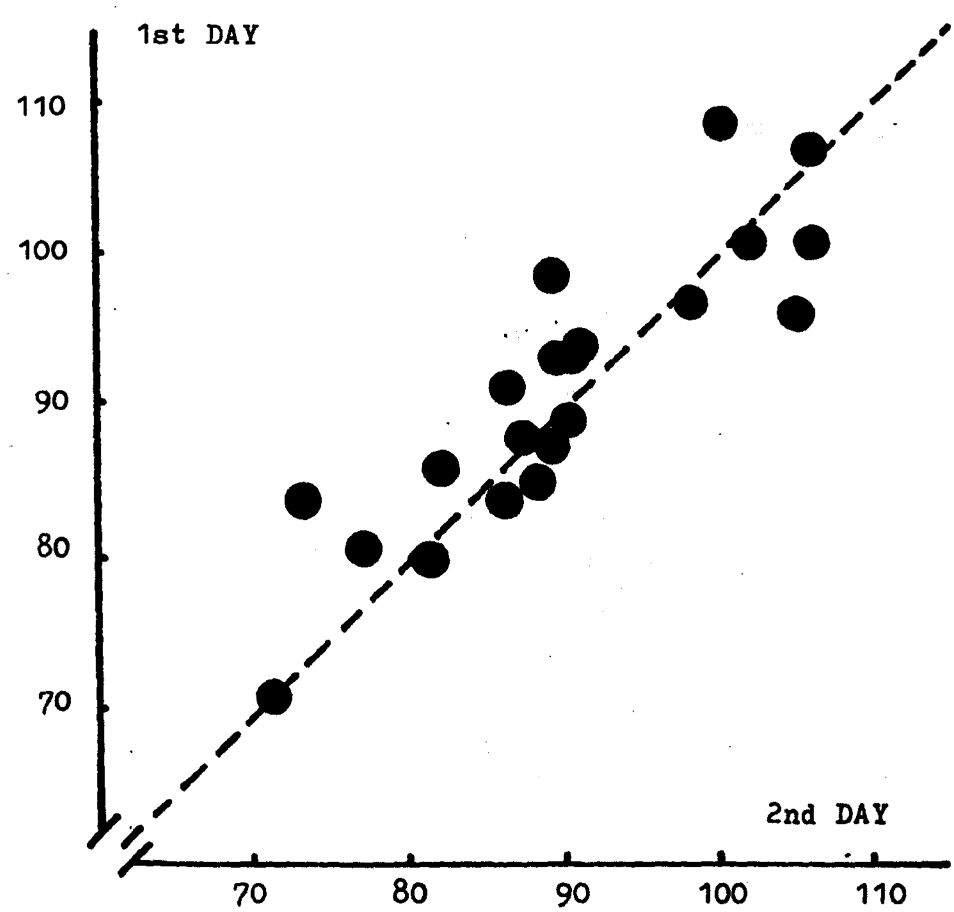
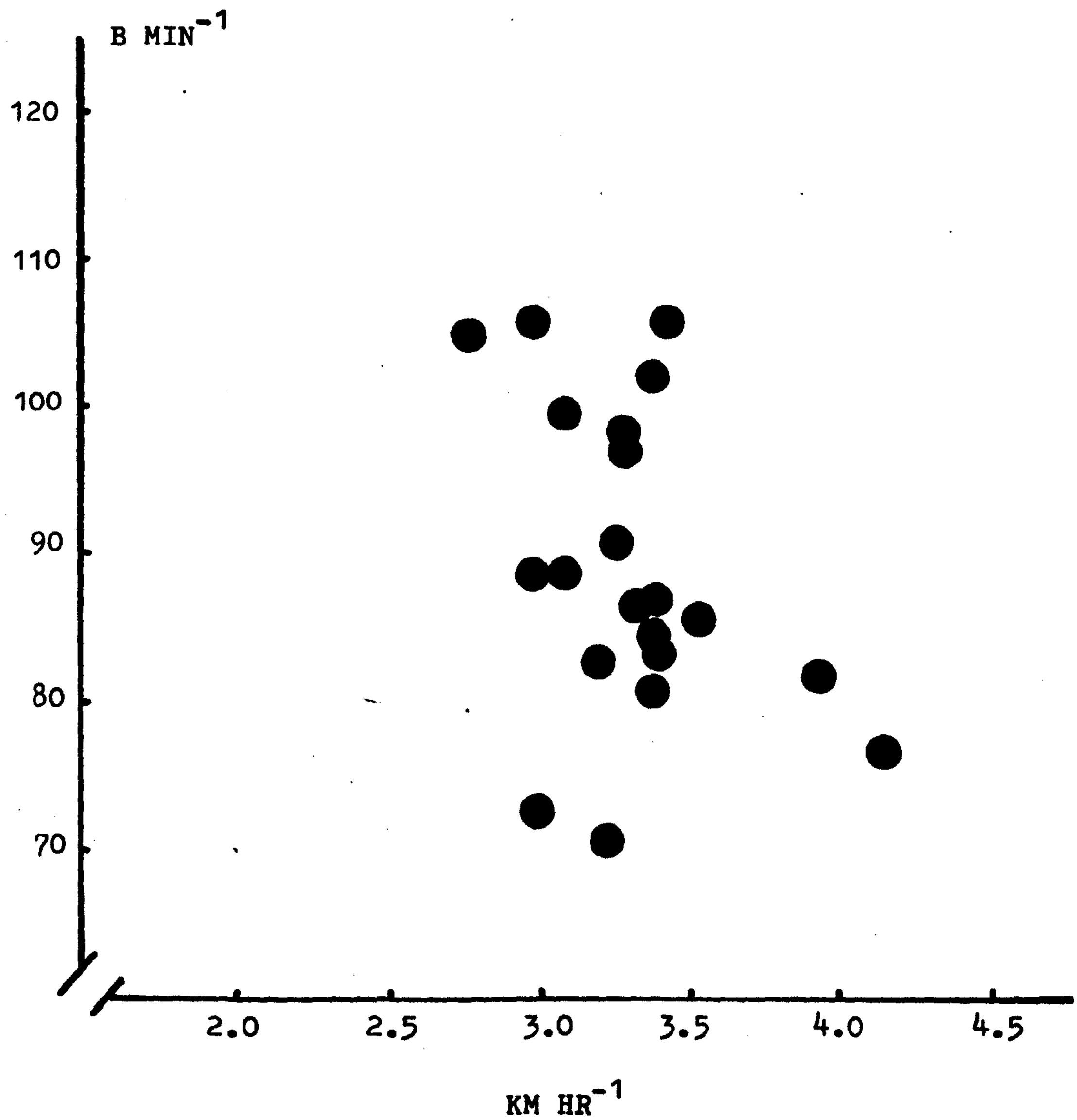


Fig. 9.8

STANDARDISED HEART RATE AND FAST WALKING SPEED

Each point represents the results for one subject on the 2nd Day. n = 21

The heart rate was standardised at 4.8 km hr^{-1}



3. Performance Index

3.1 Variation in Performance on Re-test

This was assessed by comparing the time (and number of paces) taken on the 1st and 2nd days in each of the three walks. Since there were significant differences between the 1st and 2nd section values on the 1st day (see above), the 2nd section results only from each day were used. The variation was a little greater than within each test.

3.1.1. Time Taken. In the slow and normal walks there was no significant difference between the 1st and 2nd days. In the fast walk the mean time taken was significantly longer on the 2nd day. The values are plotted in Fig. 9.9 and are given below:-

TIME TAKEN IN SECONDS TO WALK 95.4 M SECTION (n = 21)

	DAY		Mean difference		Variation
	1st	2nd	± S.E.		%
Slow	98	96	1.65 ± 2.0	N.S.	9.5
Normal	75	75	0.13 ± 0.73	N.S.	4.5
Fast	63	64	1.65 ± 0.65	$P<0.05$	4.7

The speeds calculated from these times for each subject are plotted in Fig. 9.10.

Fig. 9.9

VARIATION ON RE-TEST: COMPARISON OF TIME TAKEN IN SECONDS TO WALK THE 2nd SECTION (95.4 M) ON THE 1st AND 2nd DAY

Each point represents the results for one subject walking at one speed   n = 21 subjects

□ Slow   ● Normal   ○ Fast

The dotted line is the line of coincidence.

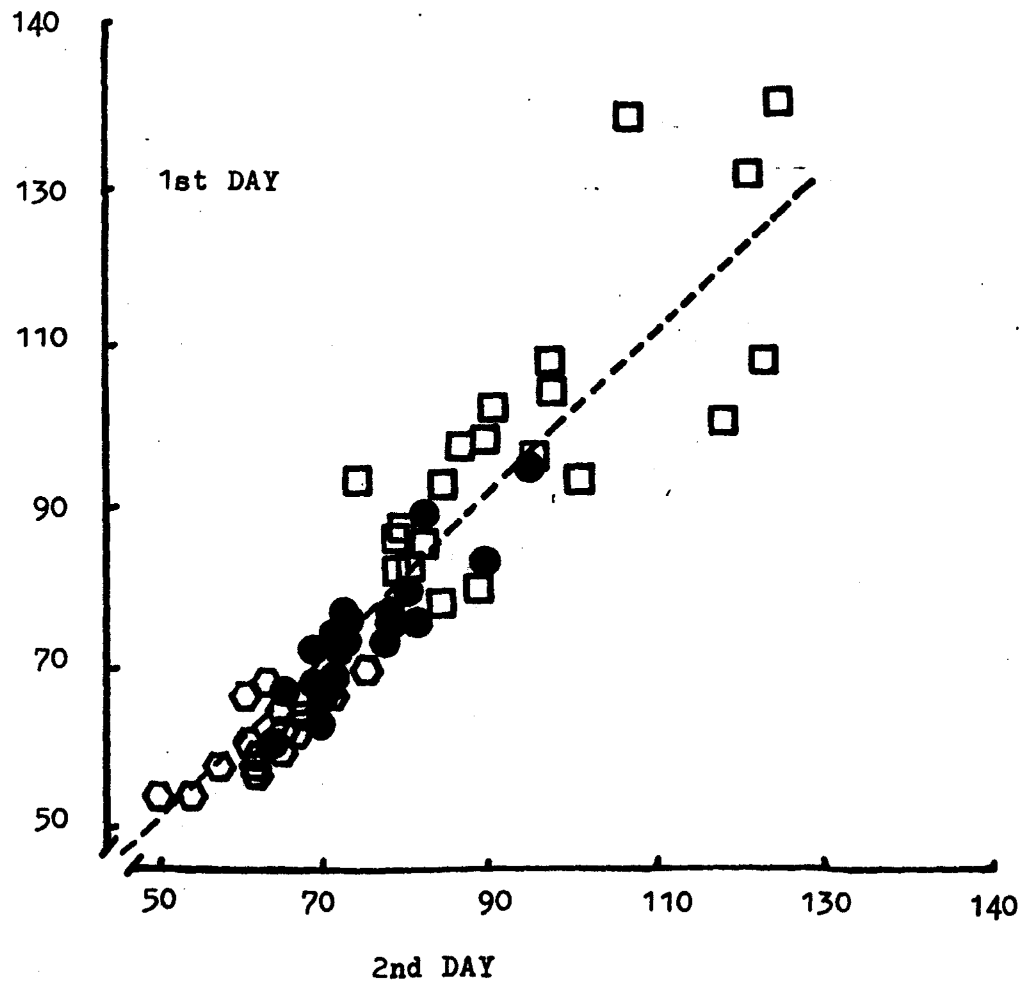
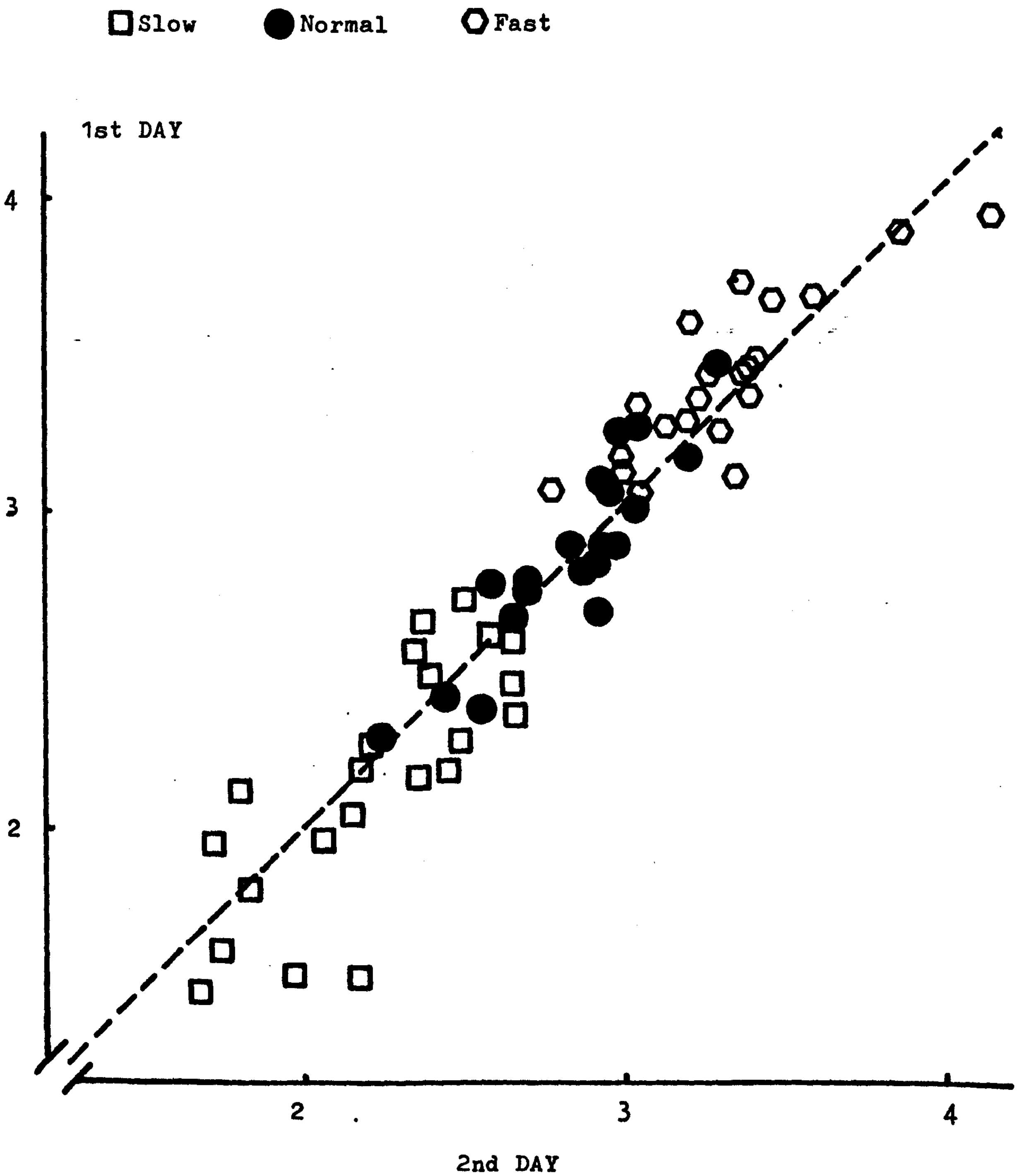


Fig. 9.10

VARIATION ON RE-TEST: COMPARISON OF WALKING SPEEDS IN KM HR^{-1} ON THE 1st AND 2nd DAY

Each point represents the results for one subject walking at one speed, n = 21 subjects



3.1.2. Number of Paces. In the slow and normal walks there were no significant differences between the 1st and 2nd days, but in the fast walk the mean number of paces was significantly greater on the 2nd day. The values are plotted in Fig. 9.11 and given below:-

NUMBER OF PACES TAKEN TO WALK 95.4 m SECTION

	DAY 1st	DAY 2nd	Mean difference ± S.E.		Variation %
Slow n = 9	74	72	1.89 ± 0.79	N.S.	3.2
Normal n = 12	66	67	1.67 ± 1.03	N.S.	5.3
Fast n = 10	60	62	2.0 ± 1.30	$P < 0.05$	6.7

3.2 Symptoms of Fatigue

After slow and normal walking no symptoms of fatigue were reported except by one subject with arthritic knees. After fast walking 13 subjects were slightly breathless and 2 reported aching knees. The other 9 subjects had no symptoms of fatigue.

Perceived exertion (see Methods) was rated over a range from 3-13 for slow and normal walking and from 6-15 for fast walking. Two of the 3 subjects who rated fast walking at 15 also reported aching knees (15 = laborious).

3.3 Informal Performance

3.3.1. Free Walk

The heart rate recorded during the "free" walk from the car-park was compared with the values from each of the formal walks using the 2nd day values. The results from the last 12 consecutive subjects were used because a reliable time base was available from a clock in the recorder, which had not been available for the

Fig. 9.11

VARIATION ON RE-TEST: COMPARISON OF NUMBER OF PACES TAKEN TO WALK THE 2nd SECTION ON THE 1st AND 2nd DAY

Each point represents the results for one subject walking at one speed.

	Slow	Normal	Fast
n =	9	12	10

The dotted line is the line of coincidence.

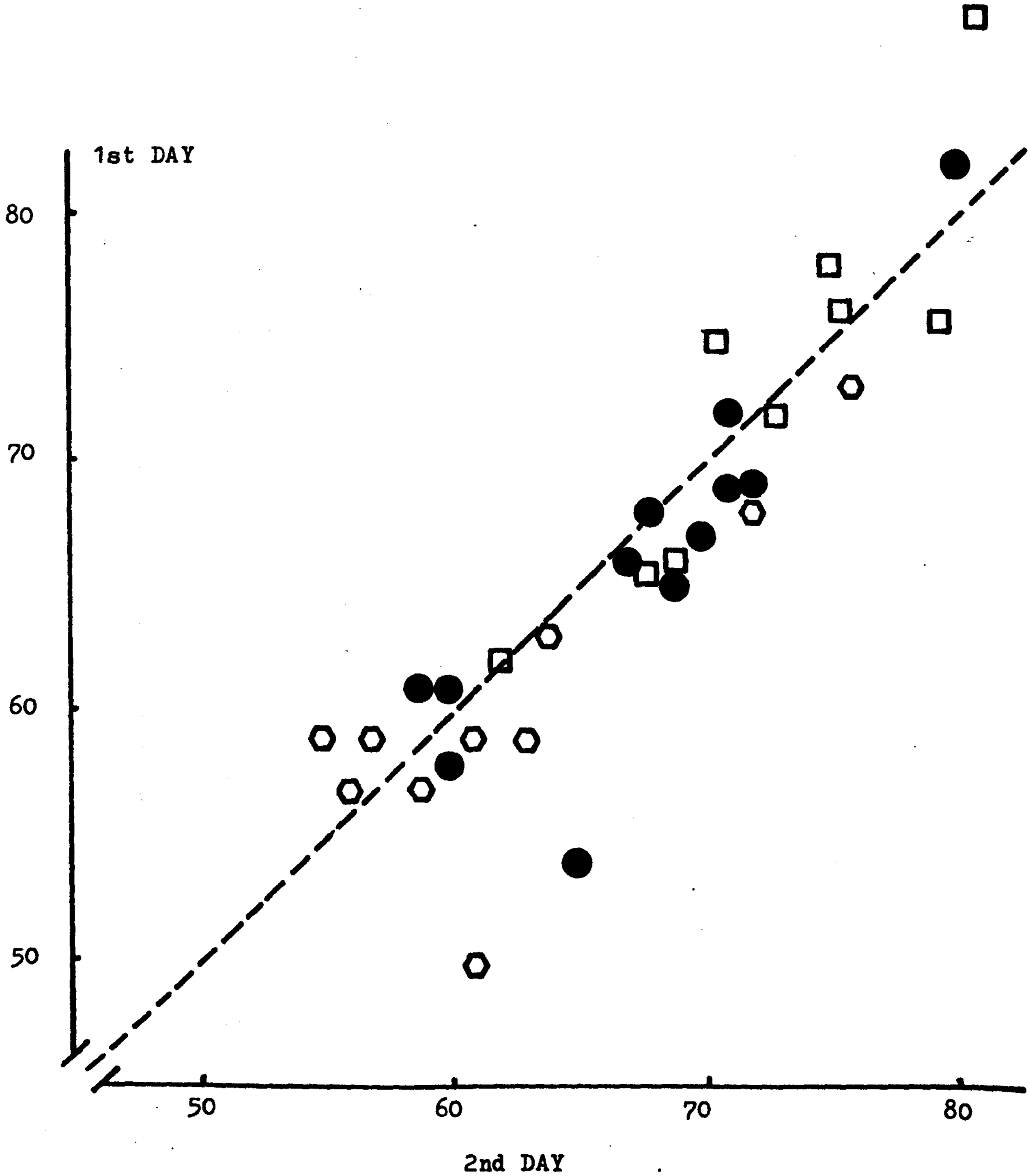


TABLE 9.4

COMPARISON OF MEASUREMENTS MADE DURING FREE AND FORMAL WALKING

Mean values ± S.E. for the group recorded on the 2nd day.

(n = 12)

Walk	HEART RATE B MIN^{-1}	Mean Difference ± S.E.		
Free	84 ± 2.8			
		0 ± 3.1 N.S. (Free vs Slow)		
Slow	84 ± 3.2			
			4 ± 2.7 N.S. (Free vs Normal)	
Normal	88 ± 2.7			
				13 ± 3.0 P<0.001 (Free vs Fast)
Fast	97 ± 2.7			
	NUMBER of PACES (½ cadence)			
Free	55 ± 2.3			
		10 ± 2.8 P<0.05 (Free vs Slow)		
Slow	45 ± 1.8			
			2 ± 3.4 N.S. (Free vs Normal)	
Normal	53 ± 2.3			
				8 ± 3.1 N.S. (Free vs Fast)
Fast	61 ± 1.4			

earlier tests. The heart rate within the counted minute was not as steady during the free walk as in the formal walks.

It was found that the values for the free walk were not significantly different from those recorded during slow or normal walking. The cadence during free walking was not significantly different from that recorded during normal and fast walking (see Table 9.4).

3.3.2. Stair Climbing

The subjects climbed at a steady rate in so far as this could be judged by the observer. Two subjects paused on the landing before the 6th flight. The time taken to climb the stairs was 54 ± 3.79 sec on the 1st day and 53 ± 2.93 sec on the 2nd day. The difference between them was not significant. The rates of work calculated from this and the subjects' weight were therefore 150 ± 14.7 watts on the 1st day and 149 ± 14.2 watts on the 2nd day.

The peak heart rates reached during the climb judged from the ratemeter were 110 ± 2.32 b min^{-1} on the 1st day and 108 ± 3.08 b min^{-1} on the 2nd day, (variation on re-test = 8.4%).

4. Gait Pattern

The number of paces taken to cover the fixed distance of 95.4 m in a known time was used to calculate cadence (pace frequency per minute) and stride length. The mean values for cadence on the 2nd day were 93 ± 2.8, 106 ± 1.6 and 117 ± 2.2; and for stride length in cm 65 ± 1.6, 72 ± 1.3 and 74 ± 1.4 for the 3 speeds.

When the square root of the walking speed was related to the cadence (Dean, 1965), the relation was found to be linear for each subject (see Fig. 9.12) and highly correlated ($r > 0.94$ in all cases, for which $P < 0.001$). Leg length is thought to influence cadence (Bobbert, 1960; Cotes & Meade, 1960) and this is plotted for three standard speeds in Fig. 9.13. The graph suggests that leg length might have a negative influence on cadence but the evidence is not clear.

Fig. 9.12

CADENCE AND WALKING SPEED

Recorded values for one subject

open circles = 1st day; closed circles = 2nd day

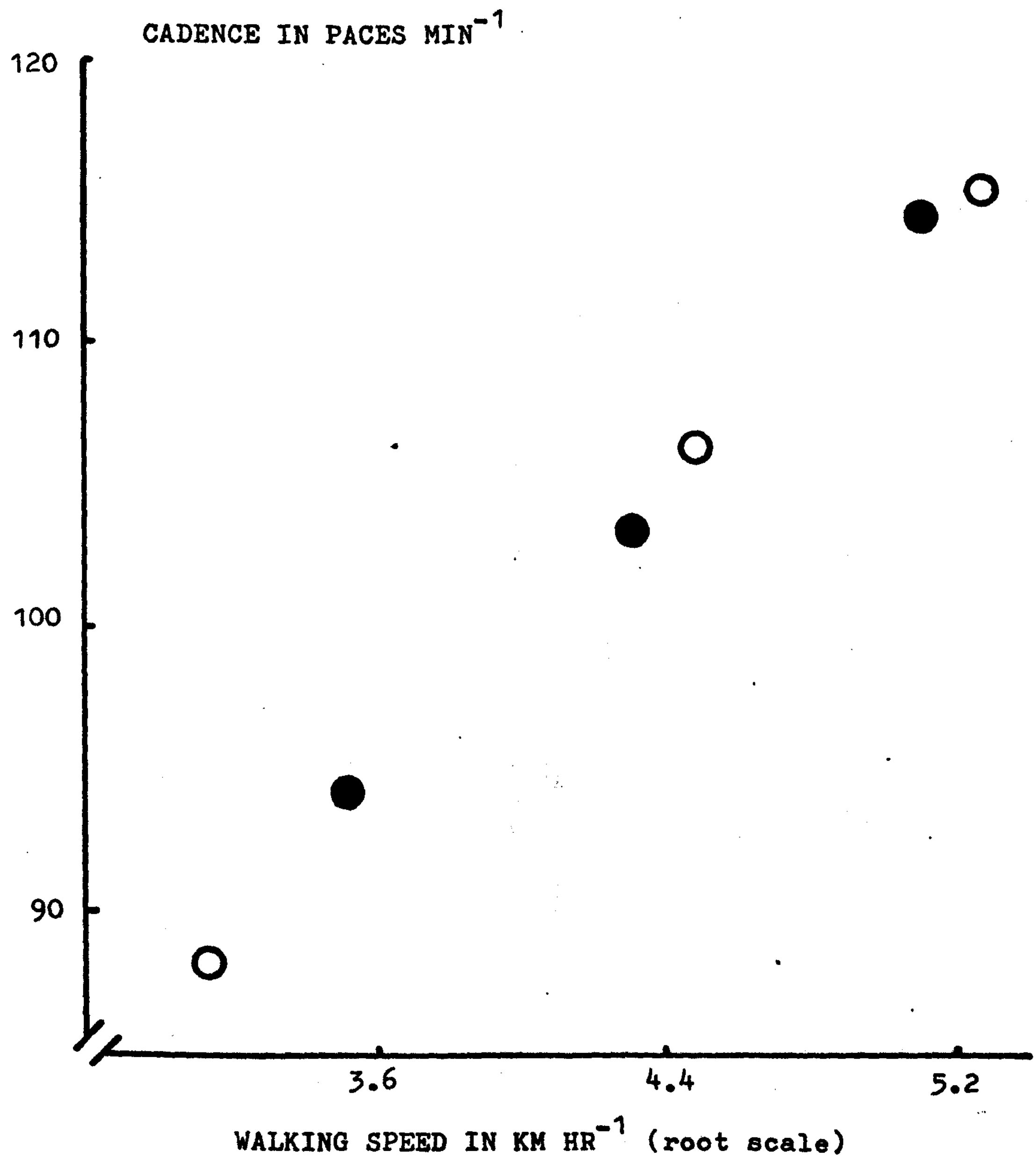
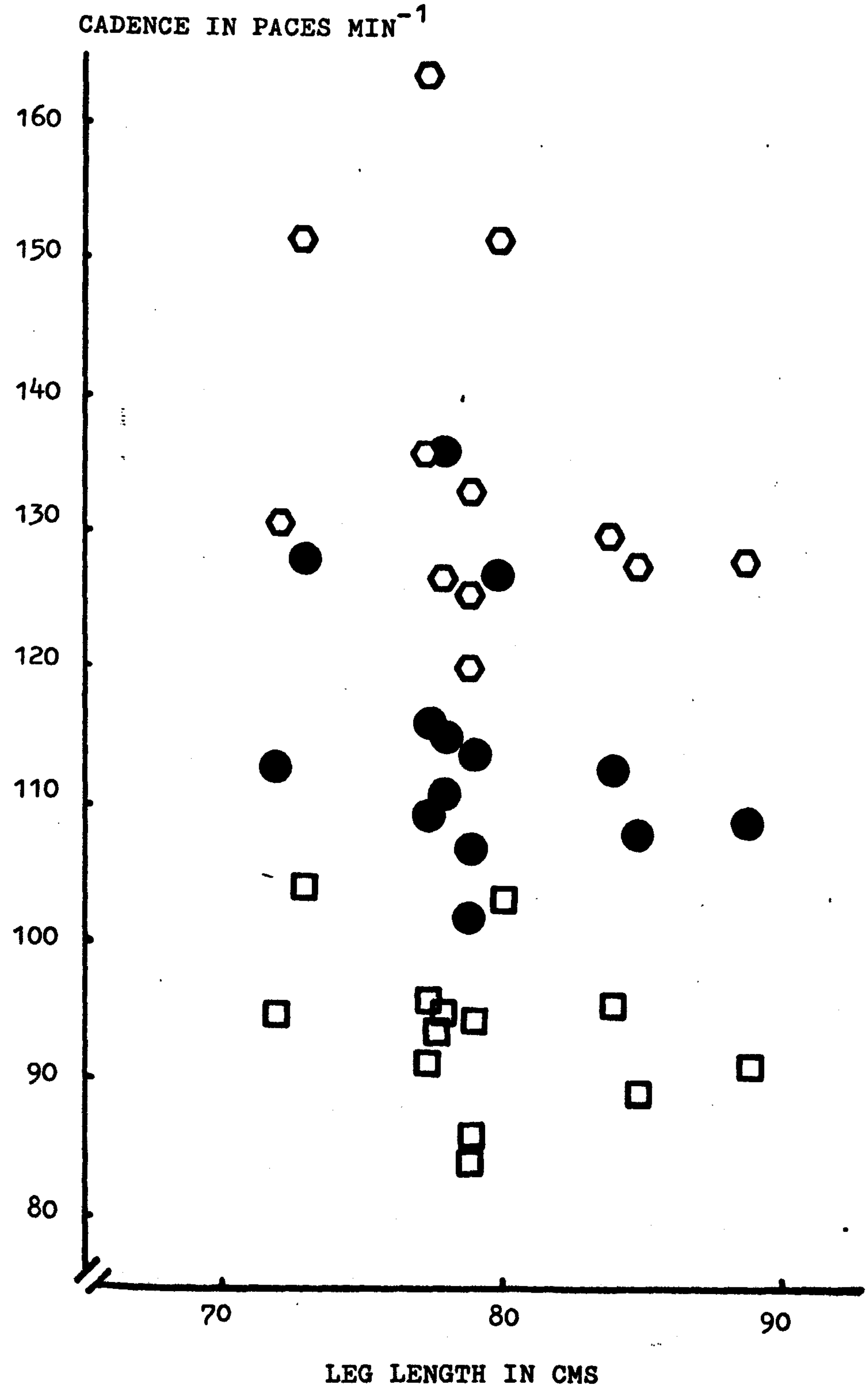


Fig. 9.13

CADENCE AND LEG LENGTH

Each point represents one subject walking at one speed

n = 13 subjects □ slow ● normal ○ fast



DISCUSSION

The results confirmed that elderly men as well as women can perform steadily when walking freely. The instructions were well understood and resulted in three clearly defined speeds. The criteria laid down for an exercise test in Chap. 5 were met in all respects and will be discussed below under the appropriate headings. The criteria were as follows:-

(a) Large muscle groups must be used. This is so in walking.

(b) There must be several known levels of activity. These were the three walking speeds.

(c) The activity levels must be spread over the subjects range (see 2.1).

(d) The activity must be maintained at a steady level (see 1.).

(e) The response of the cardiovascular system must reach an appropriate plateau level value (see 2.2).

1. Variation in Performance within in Each Walk

This was the most crucial question because initially it was doubted whether subjects in such a free situation would be able to walk steadily. It has therefore been considered at some length.

The variation in performance was low and compares favourably with that found in other forms of exercise test. Variation in time taken for the two sections within each walk was about ± 3% except in the slow walk when it was ± 6%. In this series of tests the number of paces taken to cover the distance could be used to assess the variation in walking performance and this also was found to be ± 3% or less. This is an acceptably small amount of variation in performance intensity and means that walking freely meets the first essential requirement of an exercise test. The variation in pedalling speed on a friction-braked ergometer may be as much as ± 10% (see Fig. 4.4 p95) and an electrically-braked ergometer which is compensated for variation in pedalling speed (Lannooy) has an accuracy of ± 5% (manufacturers claim).

Variation in cadence within a walk was not detectable by eye from the footfall records except during the acceleration and deceleration at each end of the walk. This source of error was eliminated by using the floor plates as markers. This is evidently worth doing and it may explain why the variation in this series of tests was less than in the previous tests when it was ± 8% and ± 7% in time taken for a similar distance. The corners were not usually detectable from the footfall record alone and so presumably did not alter the rhythm of walking significantly. A rectangular or round course is probably preferable to a straight there-and-back course for this reason.

The use of the floor plates was a crude method since their length produced a maximum error of ± 2m in the 94.5 m section which contributed to the variation in performance. A more sensitive detector such as the interruption of a light beam by the passing subject could be used. The disadvantage of this would be the need for a power source which might rule out otherwise suitable locations for the test.

2. Physical Condition

2.1 Range of Activity Levels

The variation in walking performance at each speed was small enough not to obscure the differences between each of the three walking speeds which were about 20% (taking the normal speed as 100%). This was necessary for assessing physical condition which depends upon defining the relation between heart rate and walking speed and then obtaining a standard heart rate by interpolation. Three points spread out over a range of activity levels is a minimum requirement for defining this relationship because there is some variation in the heart rate which is independent of the activity level (due to respiratory, thermoregulatory, metabolic and hormonal influences).

The spread of activity levels obtained should be judged by the recorded heart rates as well as the walking speeds. During slow walking, the mean heart rates were 15 b min^{-1} above the values recorded whilst sitting resting; during normal walking they were about 22 b min^{-1} above; and during fast walking about 30 b min^{-1} above the resting values. This last is an increase of about 50% over resting levels which is sufficient for making an assessment of the response to moderate exercise.

2.2 Steady Heart Rate Response. The length of the course was adequate for the heart rate response to reach a plateau appropriate to the concurrent level of activity. The one subject who did not reach a plateau had an unusually slow heart rate transient perhaps because he was hypertensive. This one anomaly did not provide sufficient justification for increasing the length of the course and making the test more tedious.

2.3 Standardised Heart Rate. The mean standardised heart rate was 90 b min^{-1} with a range from 70-110 b min^{-1}. There was no indication of a decrease on the 2nd day as is often found with conventional tests.

2.4 Variation in Physical Condition. The variation on re-test was ± 5% which compares favourably with re-test variation in much more strenuous tests on a bicycle ergometer. Davies et al (1968) give a variation of ± 8% and in the tests described in Chap. 4 (p92) it was ± 9%. Therefore as a method for assessing the response to exercise the walking test appears to be at least as sensitive as the bicycle test, despite the low levels of work.

2.5 Physical Condition and Performance. It is possible that physical condition as we have measured it influences fast walking speed, but the evidence for this was inconclusive (see Fig. 9.8).

3. Performance Index

3.1 Variation in Performance on Re-test. The second aim of these tests was to see whether the walking test could be used as a performance index. This would be possible if the subjects always produced a similar performance when given the same standard instructions. It would be of further interest if the performance matched their daily activity levels. The variation in performance after a lapse of several days was not much greater than that found within walk. This means that the performance level itself could be used as a measurement of the subject apart from its contribution to the assessment of his physical condition.

The slow walk was the most variable (± 10%) as was found when assessing variation within walk. This reflects the greater subjective difficulty of maintaining and reproducing a slow speed. The normal walk was performed with little variation, either within walk or on re-test (± 5%). This confirmed our belief that people have a characteristic normal walking speed which could be used as a performance index. The subjects did not have such an accurate sense of their capability for fast walking. On the 1st day they must have either over-estimated their abilities or behaved more competitively than on the 2nd day, since they walked slightly more slowly on the 2nd day. A more accurate assessment of a person's fast walking speed might be obtained by further testing or by using a longer walk. This was found to be so by Borg, et al (1973) who studied 14 military conscripts walking in the open air over a longer course (1,000 m in 5 laps of 200 m). They found that subjects could reproduce their walking speeds after a lapse of 4 weeks with significant correlations in most cases, and the correlations were higher for walking very fast than for normal speed.

3.2 Symptoms of Fatigue

There were no symptoms of fatigue reported after the normal walk and the perceived exertion was rated no higher than 11 (neither light nor laborious) except by one subject with arthritic knees. This is consistent with the performance being a true reflection of the subjects' normal walking speed. The perceived exertion scale has not been validated in a free walking situation and it was therefore used only as a check and not as data. It was useful as a check since two subjects who reported painful knees after the fast walk also rated the walk much higher than the other subjects at 15 (laborious). The ambient temperature remained within a subjectively comfortable range for the normal clothing worn.

3.3 Informal Performance

The assessment of the "free" walk and the stair-climbing were made because they formed an inevitable part of the procedure and seemed likely to yield useful information. The "free" walk should reflect the "normal" walk if subjects really are walking at their normal speed. The stair-climbing was another form of self-paced exercise of a more strenuous kind but still within the scope of customary activity for many elderly people. Therefore the opportunity was taken to investigate the variation in performance in these two situations and to see whether there were age differences when the comparison was made with a younger group (see Chap. 10).

The comparison between the free walk and the formal walks indicated that the free walk fell between the slow and normal walks and nearer to the normal according to the cadence measurements. Since cadence was found to be closely related to walking speed, this is confirmation that the subjects "normal" performance in the test situation was normal for him. When the comparison was made using the heart rate values the free walk was closest to the slow walk. This may indicate that the heart rates during the formal walks were slightly elevated because the subjects knew that they were being tested. On the other hand the walk from the car-park was to some extent a sight-seeing trip and would therefore be expected to produce speeds slightly below the normal perhaps due to a decreased stride length. Both these possible sources of error would reduce the free walk heart rate relative to the formal walk heart rate. The agreement found between them is therefore encouraging, and provides support for our belief that the formal walk is a valid reflection of the subject's normal behaviour.

The stair-climbing provided an opportunity for more strenuous self-paced exertion than the walking test, as was evident from the higher heart rates recorded (110 compared with 95 b min^{-1}). However it was less satisfactory than walking in various ways. The time taken was not long enough for the heart rate to reach a steady state, although most subjects climbed steadily. It is not clear how adjustments for different rates of climbing could be made. The rate of stair-climbing varied considerably from one day to the next and was therefore not as characteristic of an individual as walking speed. There is also much greater risk of accident in stair-climbing. Unless stair-climbing is sensitive to age differences it seemed unlikely to prove a useful addition to self-paced walking.

4. Gait Patterns

The measurements of cadence obtained from the recording of footfall revealed surprisingly constant relations with walking speed. It might therefore be possible to predict walking speed from the footfall records alone provided the subject was walking steadily on level ground.

The results were consistent with those of Dean (1965) who found a linear relation between cadence (adjusted for body height) and the square root of the walking speed, for a heterogeneous group of subjects.

We were able to use the more appropriate adjustment of leg length but found that in this group the variation in leg length was small and that its influence on cadence was not clear (see Fig. 9.13). This may be because the subjects were older than those of other authors who found a negative correlation between the leg length and cadence. (Bobbert, 1960; Cotes & Meade, 1960). Older subjects are thought to suppress the normal gait patterns, which are influenced by the natural frequency of swing of the leg, in order to obtain greater stability (Finley, Cody and Finizie, 1969). The need for this may arise because of diminished muscular power or a deteriorated sense of balance. Possible age differences in gait were of interest and comparisons are made in the next chapter with results from a group of young male subjects.

CONCLUSIONS

The elderly men were able to perform steadily whilst walking freely, confirming the results of the previous studies with young and elderly women. In addition the men were able to discriminate clearly between the three verbal instructions (i.e. to walk at a slow, normal and fast pace), and to spread their 3 performances out evenly over a range of walking speeds. The variation in time taken was $\pm$ 3% for the men in this walking test whereas for the women it was $\pm$ 10% in the previous walking test . The reduction in variation was due at least in part to improvements in the design of the test.

The results were suitable for assessing the response to exercise as the heart rate at a standard walking speed. The intensity of the exercise was adequate; the mean heart rate reached 94 b min^{-1}

in the fast walk which was 50% over resting levels. The heart rate reached a plateau appropriate to each of the 3 steady walking speeds; these heart rates appeared to be linearly related to the square of the walking speed and the heart rate results standardised at 4.8 km hr^{-1} were reproducable on re-test (variation $\pm$ 5%). It was therefore concluded that the design of the test was satisfactory and that the results could be used to assess the response to exercise in a way that is analogous to conventional tests.

The men were able to reproduce their normal and fast walking speeds reliably after a lapse of several days (variation $\pm$ 5% in walking time). These performances therefore appear to be characteristic for the subject.

The analysis of gait showed that the relations between the square root of the walking speed and cadence were linear. This would allow prediction of walking speed from the footfall record.

CHAPTER 10

A COMPARISON OF THE PERFORMANCE OF ELDERLY AND YOUNG MEN IN A WALKING TEST

INTRODUCTION

This chapter contains a further study of the walking test in which comparisons were made between the results from the 24 men of retiring age described in the last chapter, and the results from 10 young men.

Cross-sectional studies of different age groups made by other authors have not revealed differences in physical condition (see Chap. 1), therefore a walking test is not likely to do so. However, if the test is considered as a measure of performance, then there might be differences between the older and younger men as were found between the older and younger women in Chap. 7. There are marked differences with age in voluntary maximum exercise performance (Shephard, 1966, p.11); there may also be differences with age in sub-maximal performance.

METHOD

The Subjects were 10 students aged 19-21 years from departments of the University other than the Medical School. They were active rather than sedentary as a group, 7 of the 10 played football regularly, but they were not athletes. They volunteered after an introduction from fellow students. Their results were compared with those from the 24 older men described in the last chapter.

Basic physical characteristics are listed in Table 10.1 along with those of the older subjects (cf Chap. 9). The young subjects were significantly taller but there was no significant difference in subischial height (= leg length). There was no significant difference in body weight but the younger subjects had a significantly greater fat-free mass. The mean value for % fat in the younger group was 15 $\pm$ 1.4% and only 4 of the subjects had a body fat of over 15%. They were therefore less burdened with fat than the older subjects (see Table 10.2). The younger subjects also had a significantly

TABLE 10.1

BASIC PHYSICAL CHARACTERISTICS

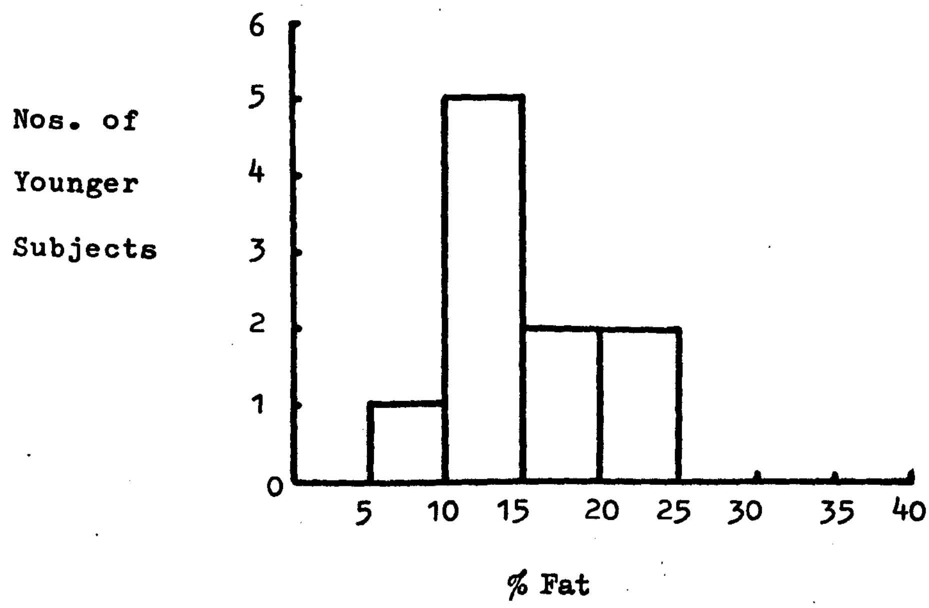
	n	Height cm	Sub-ischial height cm	Weight kg	Fat-free mass kg #	Handgrip kg	F. Vital Capacity l B.T.P.S.	$F.E.V._{1\ sec}$ l B.T.P.S.
Older Group 63-65 yr	24	168 ± 1.35	80 ± 1.17	73.2 ± 2.37	54.3 ± 1.41	46 ± 1.59	3.83 ± 0.15	2.76 ± 0.14
Younger Group 19-21 yr	10	179 ± 1.73	82 ± 1.93	75.7 ± 2.97	64.5 ± 2.25	54 ± 2.63	5.43 ± 0.18	4.54 ± 0.20
Difference		$P < 0.001$	N.S.	N.S.	$P < 0.001$	$P < 0.05$	$P < 0.001$	$P < 0.001$

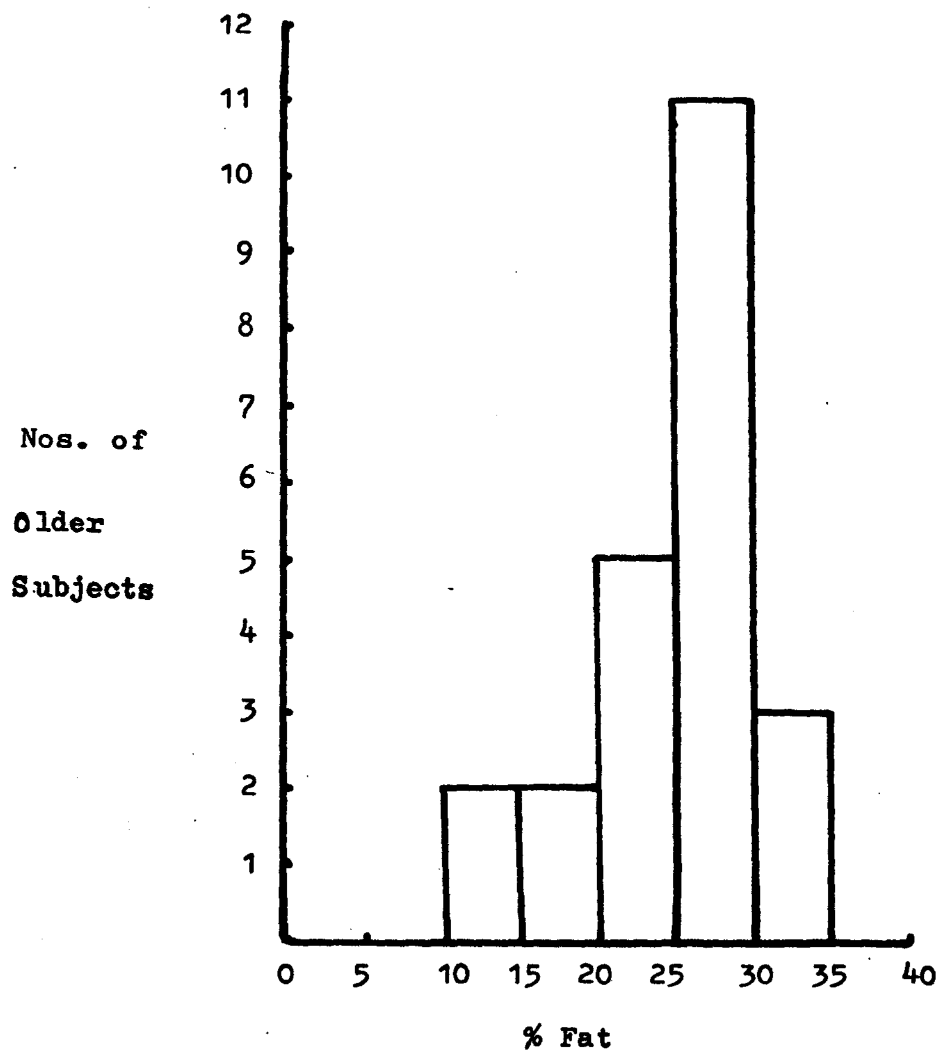
(from 4 skinfolds. Durnin & Womersley, 1974)

TABLE 10.2

BODY FAT CONTENT:

DISTRIBUTION OF VALUES IN THE OLDER AND YOUNGER GROUPS





greater grip strength and significantly larger lung volumes.

Procedure. This was exactly as described in Chapter 9. The mean ambient temperatures $\pm$ 1 S.D. were 16.1 $\pm$ 1.28°C, dry bulb and 13.5 $\pm$ 3.1°C, wet bulb.

RESULTS

The mean results for walking speed and heart rate are given in Table 10. 3 along with the results from the previous tests on the elderly men.

The walking speeds for the young group were 3.7; 5.0 ; and 6.6 km hr^{-1}. The young subjects walked faster than the elderly men in the fast and normal walks, the difference being significant for fast walking and almost so for normal walking.

1. Variation in Performance within Walk

This was assessed as before by comparing 1st and 2nd section results for time taken and number of paces in each of the three walks. The variation was $\pm$ 5% or less and similar to that found in the older group which is given in the tables for comparison.

1.1 Time Taken. There wereno significant differences on either day in any of the three walking speeds. The mean values for the 2nd day are given below:-

TIME TAKEN IN SECONDS TO WALK 95.4 m SECTION (n = 10)

	SECTION 1st	SECTION 2nd	Mean difference $\pm$ S.E.	Variation %	Older Group Variation %
Slow	93	94	1.9 $\pm$ 1.37	4.4	6.0
Normal	68	69	1.1 $\pm$ 1.02	4.5	3.3
Fast	54	53	0.7 $\pm$ 0.94	5.5	2.7

TABLE 10. 3

RESULTS of WALKING TEST

(on the 2nd Day)

	Walking Speed in km hr^{-1}			Heart Rate in b min^{-1}			Standardised heart rate b min^{-1}
	Slow	Normal	Fast	Slow	Normal	Fast	at 4.8 (km hr^{-1})
Younger Group n = 10	3.7 ± 0.20	5.0 ± 0.22	6.6 ± 0.28	87 ± 3.5	91 ± 3.9	102 ± 4.8	91 ± 2.2
Older Group n = 21	3.6 ± 0.11	4.6 ± 0.10	5.4 ± 0.11	81 ± 2.4	87 ± 2.1	94 ± 2.0	90 ± 2.2
Difference	N.S.	N.S.	P<0.001	N.S.	N.S.	N.S.	N.S.

1.1.2. Number of Paces. There was no significant difference on the 1st or 2nd day at any of the three walking speeds. The mean values from the 2nd day are given below:-

NUMBER OF PACES TAKEN TO WALK 95.4 m SECTION (n = 10)

	SECTION 1st	SECTION 2nd	Mean difference ± S.E.	Variation %	Older Group Variation %
Slow	70	70	0.0 ± 0.62	2.7	1.8
Normal	60	60	0.37 ± 0.37	1.8	2.1
Fast	53	53	0.5 ± 0.57	3.0	2.9

2. Heart Rate Response

2.1 Recorded Heart Rates

The heart rate had reached a steady level in all subjects on both days by the 2nd section. In some subjects the rate dropped over the 1st section in the slow walk. When the results for the 1st and 2nd days were compared there were no significant differences in the mean heart rates during slow and normal walking, but during fast walking the mean heart rate was significantly lower on the 2nd day (110 ± 3.67 and 102 ± 4.86 b min^{-1}). The 2nd day values during slow and normal walking were 87 ± 3.53 and 91 ± 3.91 b min^{-1} respectively (see Table 10.3). The regression lines for each age group based on all the individual values for heart rate and walking speed squared (from the 2nd day) were compared using analysis of co-variance (Snedecor & Cochran, 1967). There was no significant difference in slope or intercept between the two age groups (see Fig. 10.1). The mean heart rates at zero walking speed obtained by extrapolation were 75 b min^{-1} for the younger group and 73 b min^{-1} for the older group. These values were compatible with the recorded values for mean heart rate during sitting (see below and p211).

The heart rates always returned to a similar level during sitting after each walk. The mean values were 68 ± 3.41 b min^{-1} on the 1st day and 64 ± 2.76 b min^{-1} on the 2nd day. There was no significant difference between them.

2.2 Standardised Heart Rates

The results were standardised at 4.8 km hr^{-1} as for the older group; this was also close to the normal walking speed for the younger group. One subject was omitted because his heart rate dropped with increased walking speed. The standardised results were 94 ± 2.48 b min^{-1} on the 1st day and 91 ± 2.16 b min^{-1} on the 2nd day. There was no significant difference between them and the variation on re-test was ± 8.2%.

The comparison between 1st and 2nd day results was also made at the higher walking speed of 5.6 km hr^{-1} which fell between the normal and fast walking speeds for this group. The values were then 100 ± 2.61 b min^{-1} on the 1st day and 97 ± 3.24 b min^{-1} on the 2nd day. There was still no significant difference between them and the variation was similar at ± 8.4%.

As with the older group there was no correlation between physical condition, measured as standardised heart rate, and the fast walking speed.

When the older and younger subjects were compared no significant differences were found in any of the heart rate results either recorded or standardised (see Table 10.3).

3. Performance Index

3.1 Variation on Re-test

When the 1st and 2nd day results were compared the young subjects were found to be rather more variable than the old.

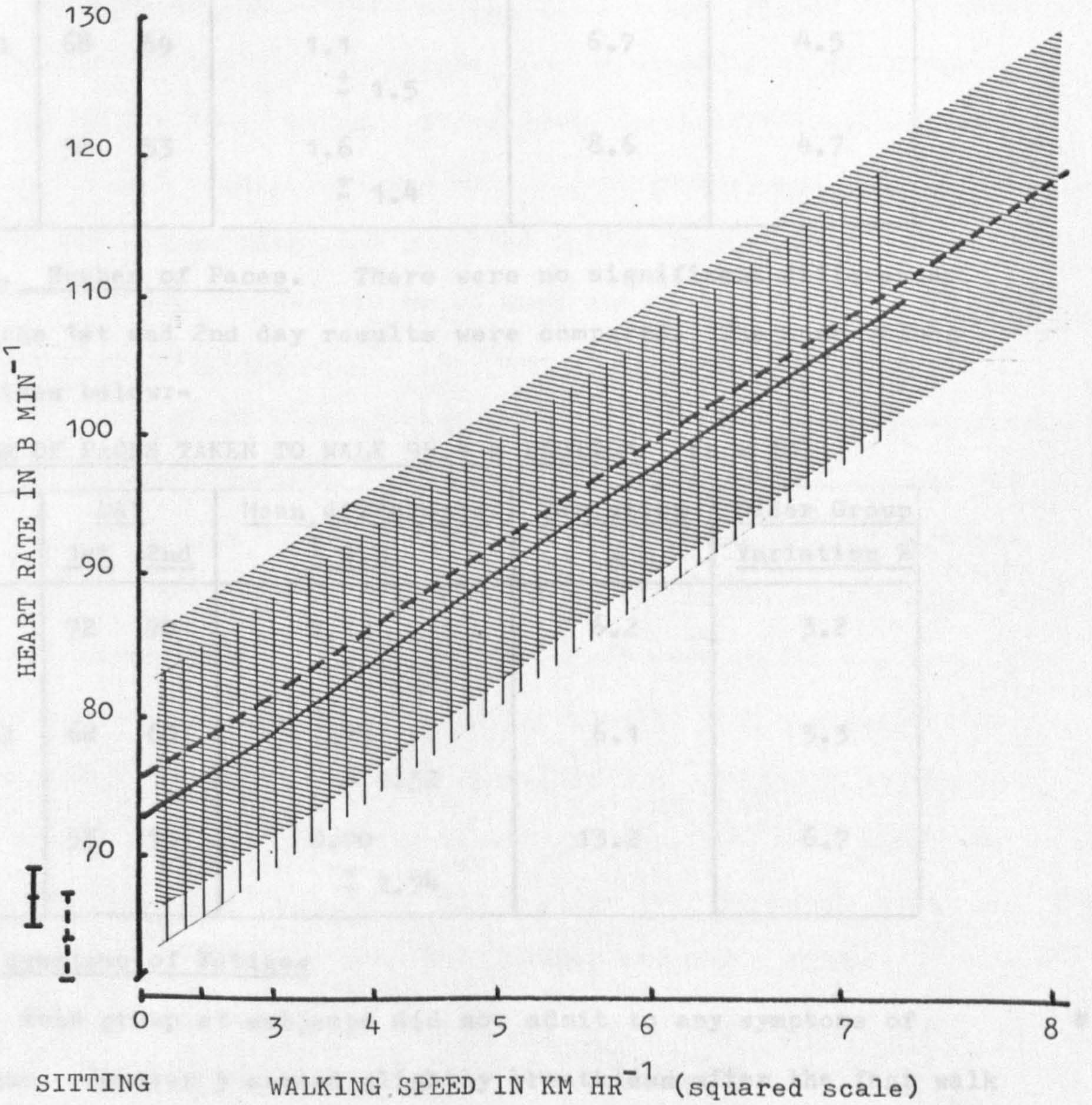
Fig. 10.1

REGRESSIONS OF HEART RATE ON WALKING SPEED (2nd Day)

Older group n = 66 recorded values for 24 subjects

Younger group n = 30 recorded values for 9 subjects

Best fit regression lines ± 1 S.E.



3.1.1. Time Taken. There were no significant differences at any of the three walking speeds, and the mean values are given below:-

TIME TAKEN IN SECONDS TO WALK 95.4 m SECTION (n = 10)

	DAY 1st	DAY 2nd	Mean difference ± S.E.	Variation %	Older Group Variation %
Slow	93	94	1.55 ± 2.7	8.6	9.5
Normal	68	69	1.1 ± 1.5	6.7	4.5
Fast	52	53	1.6 ± 1.4	8.6	4.7

3.1.2. Number of Paces. There were no significant differences when the 1st and 2nd day results were compared. The mean values are given below:-

NUMBER OF PACES TAKEN TO WALK 95.4 m SECTION (n = 10)

	DAY 1st	DAY 2nd	Mean difference ± S.E.	Variation %	Older Group Variation %
Slow	72	70	2.12 ± 1.55	6.2	3.2
Normal	62	60	1.75 ± 1.32	6.1	5.3
Fast	55	55	0.00 ± 2.74	13.2	6.7

3.2 Symptoms of Fatigue

This group of subjects did not admit to any symptoms of fatigue. However 5 seemed slightly breathless after the fast walk and agreed that their ventilation was increased. Perceived exertion for normal walking (see p205) was rated at 11 or less by all the young subjects. This was the same as for the elderly group. For fast walking the young subjects ranged widely in their ratings (4-16), but the one subject who rated it at 16 (>laborious) was walking faster than the others at 8.4 km hr^{-1}.

3.3 Informal Performance

3.3.1. Free Walk

The heart rate and cadence recorded during the free walk were counted and compared with those recorded during the formal walks as before. The mean heart rates during free walking were closest to those recorded during normal walking but the S.D. of the differences was large ($\pm$ 17 b min^{-1}) and there were no significant differences with any of the three walks. The cadence during free walking was closest to that recorded during slow formal walking and was significantly less than that recorded during fast walking. These results were too variable to be of much use.

3.3.2. Stair Climbing

The peak heart rates during the stair climb were assessed from the rate meter deflection. They were 124 $\pm$ 2.42 b min^{-1} in the 1st test and 115 $\pm$ 2.83 b min^{-1} in the 2nd test. These values were not significantly different. The time for ascent of the stairs was 47 $\pm$ 2.77 secs on the 1st day and 48 $\pm$ 2.85 secs on the 2nd day. The mean rates of work calculated individually from the subject's weight and speed of ascent were therefore 179 $\pm$ 14 Watts on the 1st day (n = 8) and 180 $\pm$ 12 Watts on the 2nd day (n = 10). There was no significant difference when the results for the 2 days were compared (n = 8), nor between the younger and older groups.

4. Gait Patterns

In the younger group the recorded values for cadence were similar to those for the older group but the younger subjects walked with a significantly longer stride at all three speeds.

STRIDE LENGTH IN CM AT EACH WALKING SPEED (2nd day)

	Slow	Normal	Fast
Younger Group n = 9	69 ± 3.2	80 ± 3.5	87 ± 3.6
Older Group n = 13	65 ± 2.1	71 ± 1.7	77 ± 1.9
Difference	$P<0.05$	$P<0.05$	$P<0.01$

As with the older group the relation between root walking speed and both stride length and cadence respectively were found to be linear and similar on both days. The effect of leg length on cadence was more pronounced than for the older group (see Fig. 10.2) and showed an inverse relation.

DISCUSSION

Performance. The performance of the young group differed from that of the older group in that they walked faster. The difference was significant in the fast walk and almost so in the normal walk. There were also differences in gait. The younger subjects walked with a longer stride than the older group although they did not differ in leg length.

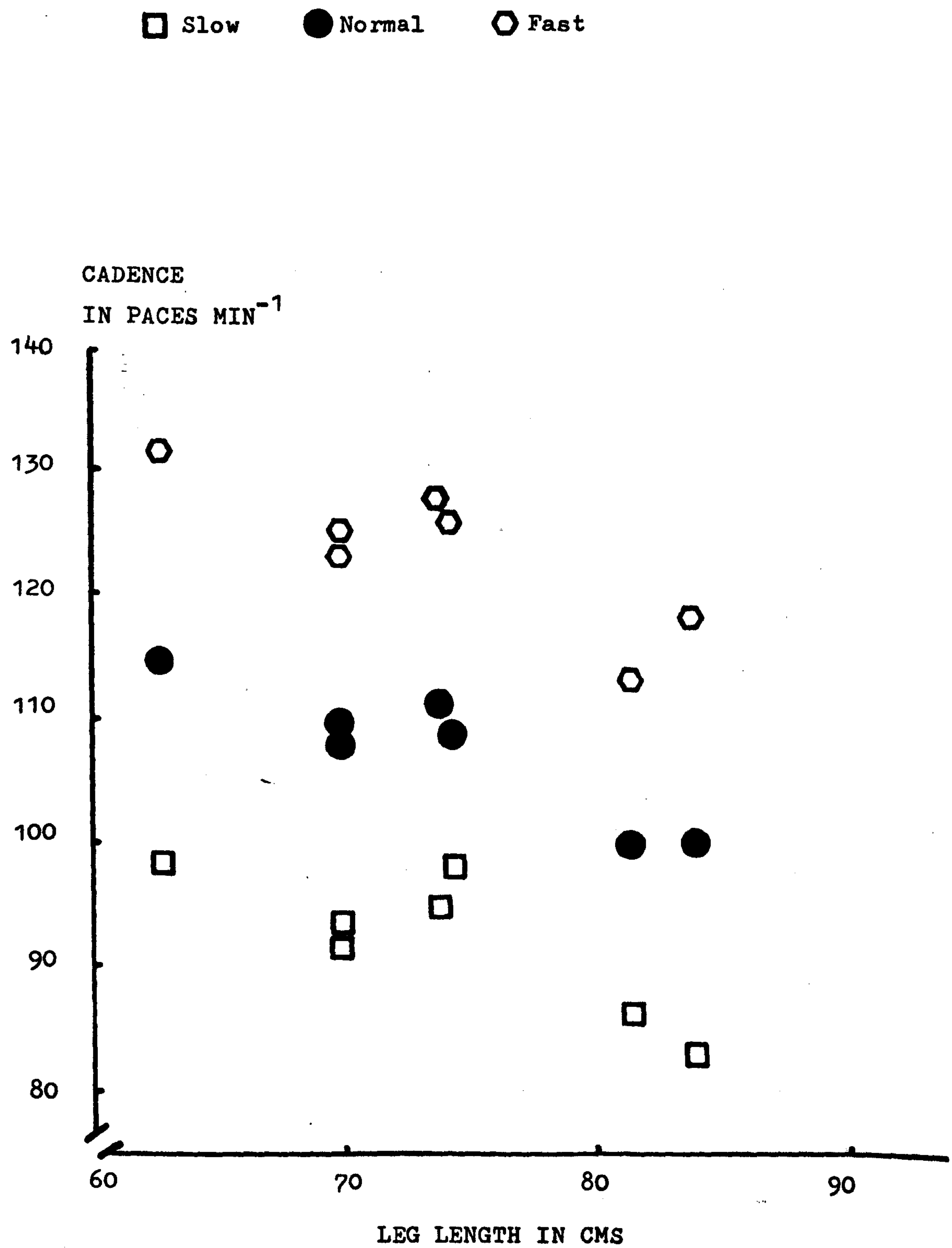
These two observations, of a reduced walking speed and a modified gait, in the older group may be related. The shorter stride is likely to be associated with a reduced efficiency and higher oxygen cost of walking, it may therefore lead to a reduction in fast walking speed.

Optimum walking speeds (resulting in minimum oxygen uptake per distance travelled) range from 3.6-6.0 km hr^{-1} (Macdonald, 1961). The normal walking speeds of the present group of subjects all fell within this range. However Ralston (1958) found the optima for individuals to have a much narrower range. He also found that

Fig. 10.2

CADENCE AND LEG LENGTH IN THE YOUNGER GROUP

Each point represents one subject walking at one speed n = 7 subjects



individuals walk at a speed at or close to their own optimum when asked to walk at a "natural or comfortable" speed. If the difference in normal walking speeds is a real one, it may be that elderly subjects have lower optimum speeds or that they prefer to walk at speeds below their optimum for reasons peculiar to this age group. This requires further investigation.

Further possible reasons for the difference in fast walking speed were sought in the answers to questions and from the measurements of basic characteristics.

Cardiovascular or respiratory impairment could give rise to increased breathlessness for the same work since the supply of oxygen to the muscles might be reduced. Half of the group of elderly men (n = 13) admitted to breathlessness after the fast walk; half of the young (n = 5) to "breathing more". The difference between these two symptoms is one of subjective discomfort which may be a function of the smaller maximum capacities of the older group. It cannot be concluded that the old men had significant cardio-respiratory impairment.

Muscle bulk and strength are known to decline with age, and the old group in this study had a significantly lower fat-free mass than the young group although their body weights were similar. This could have been a contributory reason for the slower performance and the modified gait.

Half of the subjects in the older group had some degree of arthritis or pain in the legs which could reduce walking speeds, and limit stride length.

Neuronal degeneration in either motor, sensory or central systems could contribute to diminished performance. The modification of gait patterns is compatible with this view, since walking requires the nice co-ordination of many muscle groups and depends upon sensory information of several kinds. An increased cadence at a given walking speed has been found by others in the elderly (Finley, Cody & Finizie, 1969), and has been attributed to a need for increased stability. This need could arise because of neuronal degeneration or because of a change in the ratio of leg muscle strength to body weight.

Finally a difference in motivation between the two groups cannot be ruled out, although the observers were aware of this problem and treated the two groups in the same way.

It is likely that there is some social pressure on those whose optimum or preferred walking speed is at the extreme ends of the population range to conform to the population norm. It may be that many men of 65 years of age who are still at work can respond to such pressure and maintain their walking speed, whereas older people who have retired feel released from this pressure and allow their activity levels and walking speeds to fall. This remains to be elucidated in a longitudinal study.

In summary the difference in performance observed between the older and younger groups could have had 5 contributory causes:- some degree of cardiovascular or respiratory impairment; reduced muscle bulk in proportion to body weight; lack of joint mobility; neuronal degeneration; and psychological factors.

Performance as a Reflection of Daily Living

All these factors affect both the test situation and the subjects' daily living, and so in no way invalidate the test as a measure of performance which characterises a person and may influence his physical condition. The test was found to be more reliable in the older group than the younger group as a performance index in that the re-test variation was lower, this was encouraging since we were primarily interested in studying the elderly.

Stair-Climbing as a Performance Test. The lack of difference between young and old in performance of stair-climbing was a surprise. Edwards (1971) found a difference in rate of ascent between those with respiratory disease and normals, but these subjects reduced their mean rate of ascent by intermittent rests as well as by reducing their rate of climbing. It is likely that climbing rates have a narrow range for optimum efficiency and that as the rate slows the efficiency falls off sharply. Whatever the reason, stair-climbing does not seem a promising avenue to pursue as a test of performance in the elderly (see Chap. 9).

Physical Condition

The three walking speeds were included in this series of tests so that a standardised heart rate could be obtained and used as a measure of physical condition. The three speeds produced satisfactory results for all but one young subject, who may have been anxious at the beginning of the test.

There were no significant differences between the two age groups in standardised heart rate. This is in keeping with the findings of most authors in cross-sectional studies (see Table I, p7). Customary activity is a more important determinant of physical condition than age as such and both the groups in this study were active rather than sedentary.

In the next chapter a further assessment of physical condition is described. This was made using a conventional exercise test with a bicycle ergometer, and the test included the measurement of oxygen uptake. The two methods of assessing physical condition could then be compared.

The younger group differed from the older in being more variable in physical condition on re-test, and unlike the older group they evidently needed to become habituated to the walking test as with conventional exercise tests (Davies et al, 1968).

The evidence for habituation comes from studies of young people who possibly have a more labile autonomic nervous system. This was illustrated in some of the young subjects by the initial increase in heart rate in the slow walk which then dropped to a lower plateau. It might also explain the greater re-test variation seen in the younger group.

There was no correlation between physical condition measured in this way and the sub-maximal performance test measured as fast walking speed. Those who walked fastest were not found to have the lowest standardised heart rates. The many factors which might limit walking speed independently of the cardiovascular system have been discussed.

Gait Patterns

The relations between root walking speed and both cadence and stride length were linear in the younger group as well as in the older group which gave further support to the possibility that these could be used to predict speed. The relation between root walking speed and cadence even in the young group was somewhat different from that found by Dean (1965). The reasons for this require further investigation. The differences found between the younger and older group have already been discussed in terms of the implications for walking performance.

Design of the Test

The length of the course in a walking test, the standard instructions, and the number of different walking speeds requested were determined by decisions which were to some extent arbitrary. The protocol was then tested. If a particular protocol proves successful in practice this does not preclude the success of other designs. However, there are a number of obvious constraints. The walk must be long enough to allow steady-state measurement of heart rate during the last minute. The faster the walking speed, the higher the heart rate and the longer is the time needed to reach a plateau. A minimum of about 2 min is required. This would have been adequate even for a young subject who reached 160 b min^{-1} (see p 177). Since the walking speed is not expected to be above 7 km hr^{-1}, a minimum distance of 250 m is long enough to provide 2 min of walking.

If the distance is increased, this may affect the performance. It is particularly likely to reduce fast performance and make it more sensitive in detecting subjects whose capacity is low. Normal walk performance should remain on a plateau with increasing distance, at least until the walking time approaches hours rather than minutes. Further tests are required to confirm this. If the normal walk does remain on a plateau then nothing is gained by further increase in the length of the walk. A slow walk over a long distance would become very tedious and unacceptable to both subjects and observers.

Borg et al (1973) have made a study of self-paced walking in the open air over 1,000 m (see Chap. 9); the mean walking speeds are given below with those from the young subjects in the present study. Their subjects were military conscripts who might be expected to walk faster and this was so for the normal walking speed, but the other two speeds differed from the normal much less than in our study. This may be a consequence of the design of the study; the longer walk (four times as long) and the addition of a very fast walk. Their slow speed might be faster so as to avoid excessive tedium and their rather fast walk might be slower in order to allow for further increase.

COMPARISON OF WALKING SPEEDS from BORG et al (1973) AND PRESENT STUDY

	n	Walking Speeds in km hr^{-1}			
		Slow	Normal	Rather Fast	Very Fast
Borg *et al*	14	5.0 ± 0.14	5.8 ± 0.10	6.1 ± 0.14	6.8 ± 0.14
Present Young Group	10	3.7 ± 0.20	5.0 ± 0.22	6.6 ± 0.28	

The format of the standard instructions is open to alteration, but it is necessary that the words are easily understood and relate to the subject's everyday experience. The format used in these tests was translated from Borg *et al*, (1973) who had found it satisfactory with younger subjects, both male and female.

Borg *et al* used 4 different instructions and found that subjects could differentiate between them. The 4th instruction, to "walk as fast as possible" was excluded from our study on grounds that it might elicit speeds which would be prejudicial to the older subject's health.

Increasing the number of instructions in other ways is possible. It would be an advantage in a test of physical condition to have 4 points rather than 3 for a regression line but the risk is that the subjects might become confused.

It is possible that the format and design of the test will affect the subjects' performance but it is not likely to influence the assessment of response to the exercise.

CONCLUSIONS

Young male subjects, walking freely, like the elderly men, were able to perform at three different speeds which spanned an adequate range, were evenly spread and steadily maintained (variation ± 5%

within walk). As in the case of the elderly men, the exercise was adequate in intensity and the results suitable for assessing the response to exercise, as heart rate at a standard walking speed. The design of the test remained satisfactory for young as well as elderly subjects.

As was expected the younger group did not differ significantly from the older in standardised heart rate (physical condition) except that they were more variable on re-test ($\pm$ 8.2% for the young group and $\pm$ 5% for the older group).

However there were differences with age in performance. The young subjects walked faster than the older subjects in the normal and fast walks, the difference being significant for the fast walk and nearly so for the normal walk. They were also more variable in their walking speed on re-test. The reasons for the differences in walking speed could not be resolved without further investigation.

The younger subjects differed from the older subjects in gait; they walked with a longer stride and had a lower cadence for a given walking speed.

CHAPTER 11

THE WALKING TEST COMPARED WITH A BICYCLE ERGOMETER TEST IN BOTH YOUNG AND ELDERLY MEN

INTRODUCTION

The studies described in the last 5 chapters showed that free walking could be used as a basis for an exercise test with male and female subjects of various ages both young and old. The results could be used to assess the heart rate response to exercise in a way that is analogous to the assessment made by a conventional test. The two assessments are not identical but it is likely that they would rank subjects in the same way. It was therefore of interest to see how the walking test (in which the exercise intensity is measured as speed) compared with a conventional test based upon pedalling a bicycle ergometer (in which the exercise intensity is measured as oxygen uptake).

The 24 elderly men who took part in the tests described in the last 2 chapters also performed progressive exercise tests on a bicycle ergometer. The young male subjects were asked to do so as well so that comparisons could be made between the two kinds of test.

METHODS

Subjects. The subjects were the two groups described in the last two chapters, namely 24 elderly men and 10 young men.

Procedure. The tests using a bicycle ergometer described in this chapter differed from those described in Part A in several ways. The ergometer was electrically rather than mechanically braked and the test was progressive rather than graded (see pps 23-44 for previous method). The ergometer was a Lannooy/Lode which has a free wheel and is designed for rates of work ranging from 0-400 W. The manufacturers claim an accuracy of ± 5%, or better, provided the pedalling speed remains within 45-65 rpm; it was not possible to check this. The subject's rate of work is maintained constant over a range of pedalling speeds by automatic adjustment of the force against which the subject has to pedal. It was therefore unnecessary to count the pedal revolutions, but the subject was still encouraged to maintain a pedalling speed of 50 rpm for maximum efficiency.

The procedure was based upon that used by Cotes, Allsop & Sardi (1969) and Bennett & Morgan; it is depicted in Fig. 11.1. It differed from that of the graded test in that the subject pedalled for a shorter time at each load and that more load increments were included. The subject pedalled at 25 W for 1½ min, then the rate of work was increased in increments of 25 W every 1 min 20 s up to 150 W (6 increments in 8 min). Each increment was made with the proviso that the subject was willing and that there were no untoward indications such as ectopic beats. Expired air was collected for analysis during the last minute at each load and the ECG was continuously monitored as in the graded tests.

In addition to the precautions mentioned in Chapter 2 maximum limits of 150 b min^{-1} heart rate and 200 mm systolic blood pressure were set for the old group.

Preliminary screening excluded 6 of the 24 old subjects from the test because of ventricular ectopic beats recorded at rest or during the previous walking tests, because of hypertension, or treatment for hypertension. A further subject could not complete the test because of unco-ordinated pedalling and discomfort from the saddle and the mouthpiece. Another two subjects were precluded from a 2nd test because of ECG abnormalities (signs of ischaemia and runs of ventricular ectopic beats during the 1st test).

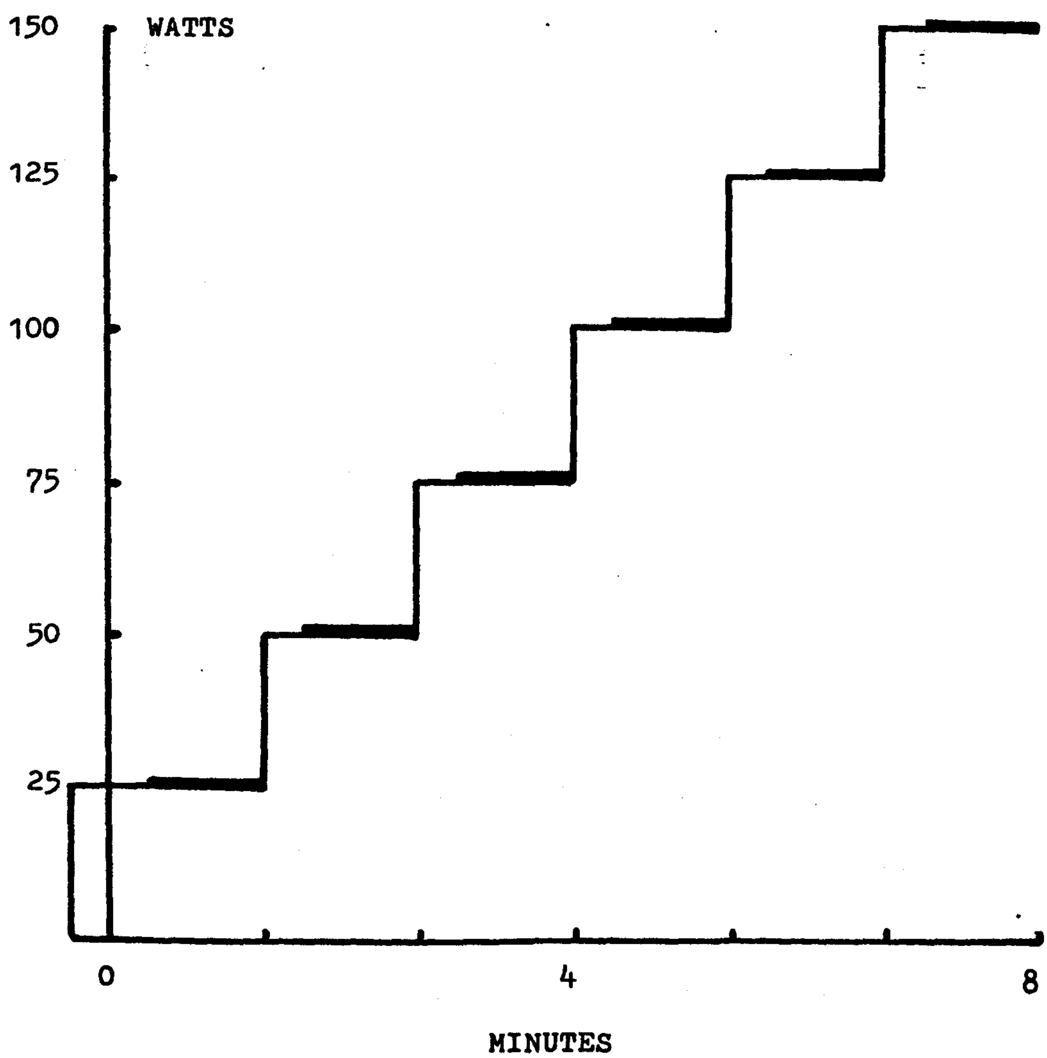
In all other respects the bicycle tests were run in the way previously described (see Chap. 2).

Ambient temperatures in the laboratory during the tests were 22.0 $\pm$ 2.6°C (dry bulb) and 16.0 $\pm$ 4.2°C (wet bulb).

Fig. 11.1

DESIGN OF PROGRESSIVE BICYCLE ERGOMETER TEST

The heavy line indicates the 1 m collection time within each 1 m 20 s of work.



The heart rates were standardised in three ways. Firstly, at an oxygen uptake of 1.0 l min^{-1} to give a measure of the response to demands of exercise in general and for comparison with other groups in the literature. Secondly, at an oxygen uptake of 18 ml per kg fat-free body mass min^{-1} as the best measure of the economy of the oxygen transporting system, regardless of the subject's size (Cotes, Berry, Burkinshaw, Davies, Hall Jones & Knibbs, 1973). Thirdly, at an oxygen uptake of 15 ml per kg gross body mass min^{-1} for comparison with the walking test results.

The adjustment for gross body mass is the most appropriate if the results of the two kinds of tests are to be compared because during walking the oxygen uptake at any given speed is affected by the body mass which is being carried. Thus in both tests the fatter man, with a smaller lean body mass, will have a higher standardised heart rate due to the effect of the weight of his fat on the assessment. In the walking test it will give rise to a higher recorded oxygen uptake for any given speed and in the bicycle test to a higher calculated oxygen uptake for standardisation, and therefore to higher heart rates in both situations. The level of 15 ml was chosen because it gave heart rates in a similar range to those found during walking at 4.8 km hr^{-1}.

RESULTS

1. Bicycle Test

1.1 Performance. The young subjects all completed the whole test of 6 increments in work rate reaching 150 W. Their mean heart rate at 150 W was 137 ($\pm$ 13.8) b min^{-1} and the oxygen uptake was 2.04 ($\pm$ 0.22) l min^{-1}.

Only three of the older subjects who performed the test completed the whole of it. The others stopped earlier because of fatigue or were stopped by the observers because of cardiovascular signs. The final work rates achieved by the older group are shown in Table 11.1.

TABLE 11.1

ACHIEVED WORK RATES FOR THE OLDER GROUP

The subjects are grouped according to their work rate during the last minute of the bicycle test, mean achieved heart rates are given for each group.

No. of subjects	Final work rate W	Mean achieved heart rate $b\ min^{-1}$
4	75	108
6	120	122
4	125	123
3	150	142
17 = Total		

1.2 Standardised Heart Rate. The results for heart rate, standardised on oxygen uptake, in the 3 ways described are given in Table 11.2. It was necessary to extrapolate from the recorded values for two of the old subjects. No significant differences were found between the 1st and 2nd day values nor between the 2 age groups for any of the three comparisons.

There was no correlation between the achieved work rates and the standardised heart rates.

TABLE 11.2

HEART RATE IN B MIN^{-1} STANDARDISED ON OXYGEN UPTAKE

	DAY	AT 1.0 l min^{-1}	15 ml kg^{-1} min^{-1}	18 ml kg F.F.M.$^{-1}$ min^{-1}
Young n = 10	1	96 ± 2.8	100 ± 2.0	100 ± 3.5
	2	94 ± 3.3	98 ± 3.1	93 ± 2.2
Older n = 15	1	94 ± 2.3	99 ± 2.4	99 ± 3.4
	2	96 ± 2.6	99 ± 2.8	95 ± 2.3

1.3 Standardised Respiratory Parameters. The minute ventilation was standardised at an oxygen uptake of 1.0 l min^{-1} and the tidal volume at a minute ventilation of 30 l. The mean values are given in Table 11.3 below. Two of the older subjects did not reach a minute ventilation of 30 l, so their results were extrapolated.

The 1st and 2nd day values for both these standardised parameters were compared and no significant differences were found.

When the two age groups were compared no significant differences were found.

TABLE 11.3

		STANDARDISED MINUTE VENTILATION in l at an OXYGEN UPTAKE of 1.0 l min^{-1}	STANDARDISED TIDAL VOLUME in l at a MINUTE VENTILATION of 30 l
	DAY		
YOUNG n = 10	1	23.8 ± 0.99	1.32 ± 0.06
	2	23.2 ± 0.91	1.32 ± 0.07
OLD n = 15	1	24.1 ± 1.00	1.46 ± 0.09
	2	24.3 ± 0.67	1.43 ± 0.09

Reliability on Re-test

The individual values for the heart rate standardised at an oxygen uptake of 15 ml kg^{-1} min^{-1} for the 1st and 2nd day are plotted against each other in Fig. 11.2 (b) which shows the dispersion about the line of coincidence. There was no significant difference between the values for the 2 days in either group.

Of the young subjects, 2 showed a drop of nearly 20 b min^{-1} on the 2nd day, 7 subjects showed little change (1-4 b min^{-1}) and one subject showed a rise of 18 b min^{-1} on the 2nd day. This last subject was the only one who had followed a different protocol. Unlike the others, he did not perform the bicycle test on the same day as the walking test and he performed the bicycle test at 13.00 hrs instead of 11.00 hrs. This subject was omitted from subsequent comparisons of the two kinds of test.

The variation on re-test was ± 7.7% for the younger group (without the anomalous results from the subject mentioned above).

Fig. 11.2 — STANDARDISED HEART RATES in b min^{-1}

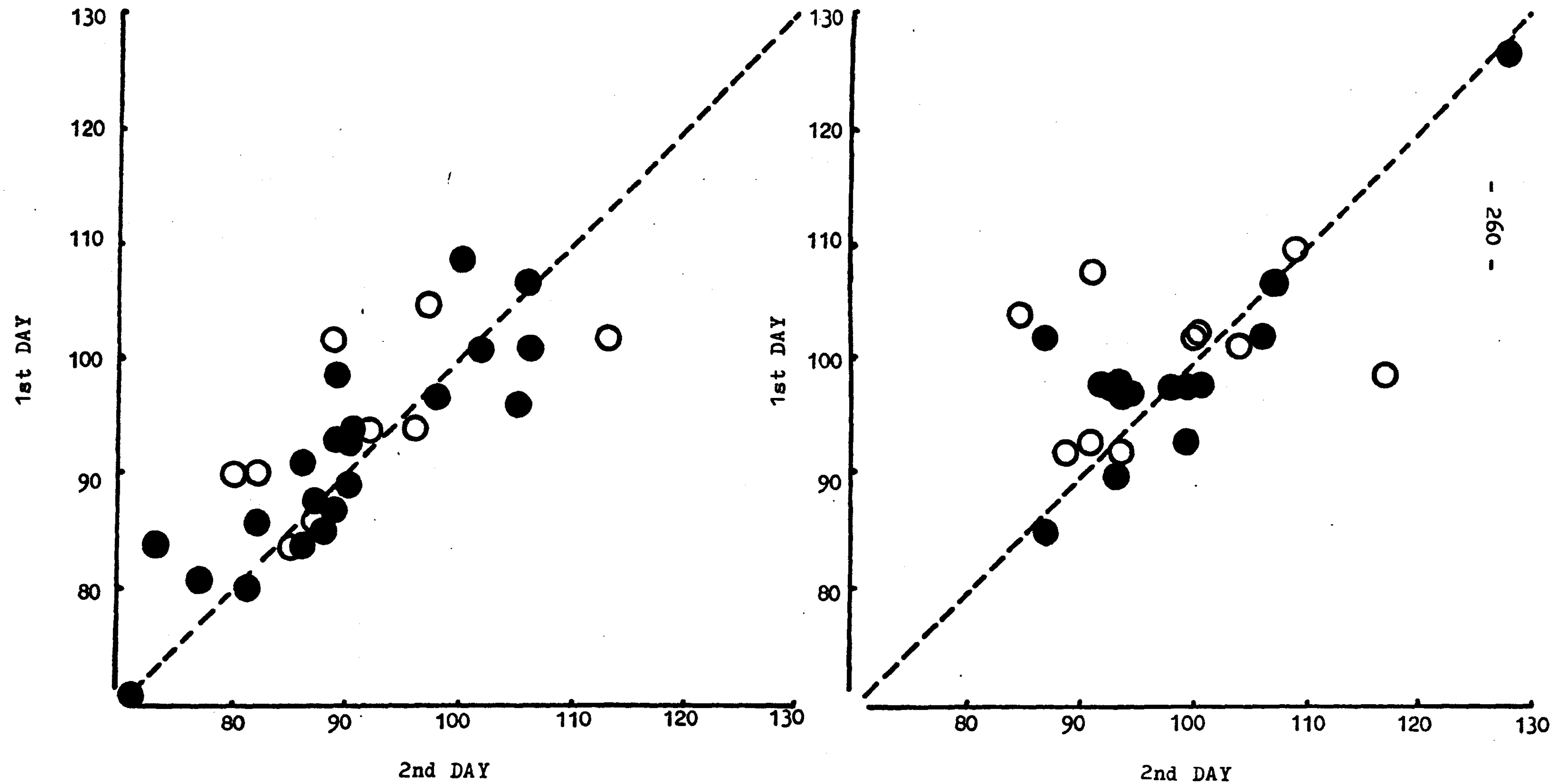
a) WALKING TEST at 4.8 km hr^{-1}

Filled circles - older group n = 21

Open circles - younger group n = 9

b) BICYCLE TEST at 15 ml kg^{-1} min^{-1} oxygen uptake

Older group n = 14; younger group n = 10



The older subjects were more consistent. The variation in standardised heart rate, at the same oxygen uptake of 15 ml kg^{-1} min^{-1}, was $\pm$ 5.4%. In order to find out what the re-test variation in the bicycle test results would be if the work range was restricted to that of the walking test, the standardisations were made on the 3 lowest recorded points only. The re-test variation at 15 ml kg^{-1} min^{-1} was then found to be $\pm$ 9.7% in the older group.

2. Walking Test

The results for both groups have been given in the last two chapters.

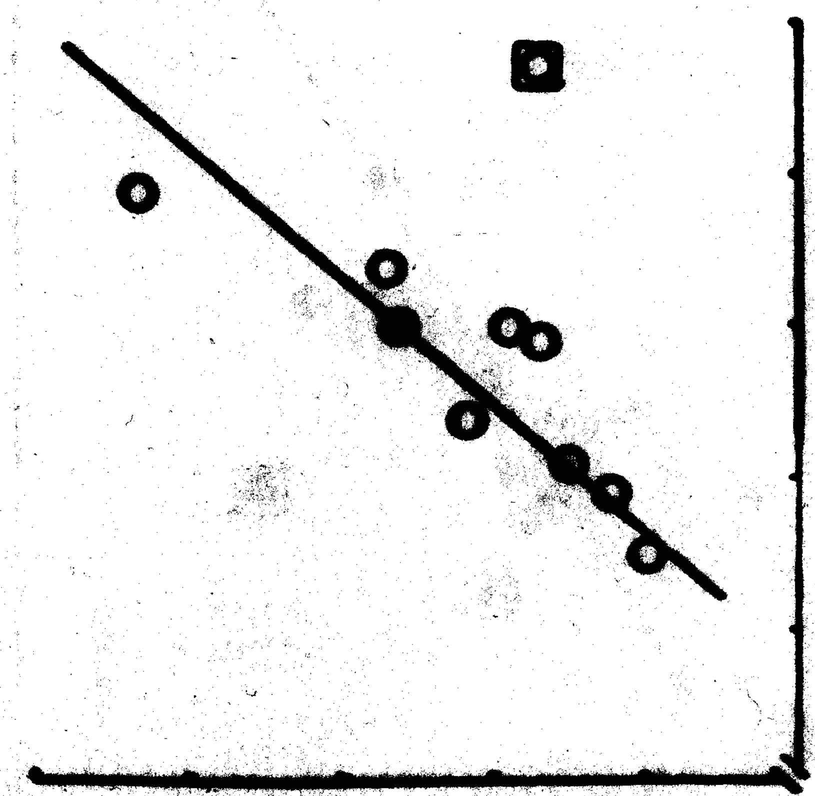
3. Comparison between Bicycle Test and Walking Test Results

The standardised heart rate results from the two kinds of test were compared in two ways. The values for each individual were plotted against each other (see Fig. 11.3) and then ranked in order to obtain Spearman's correlation coefficient r.

Since most of the subjects had performed both tests on the same day the 1st day results and the 2nd day results were compared separately. The two age groups were considered separately and then together since there were no significant differences between them.

The results for the two groups considered separately are given in the table below. For the younger group the correlation was highest on the 2nd day ($P < 0.001$), but on the 1st day it was not significant. For the older group the situation was reversed and the correlation was highest on the 1st day. On the 2nd day the correlation was not significant unless the two subjects known to suffer from arthritis were omitted.

There was no evidence of a difference between the two test groups in the slope of the relation between the two tests (analysis of co-variance).



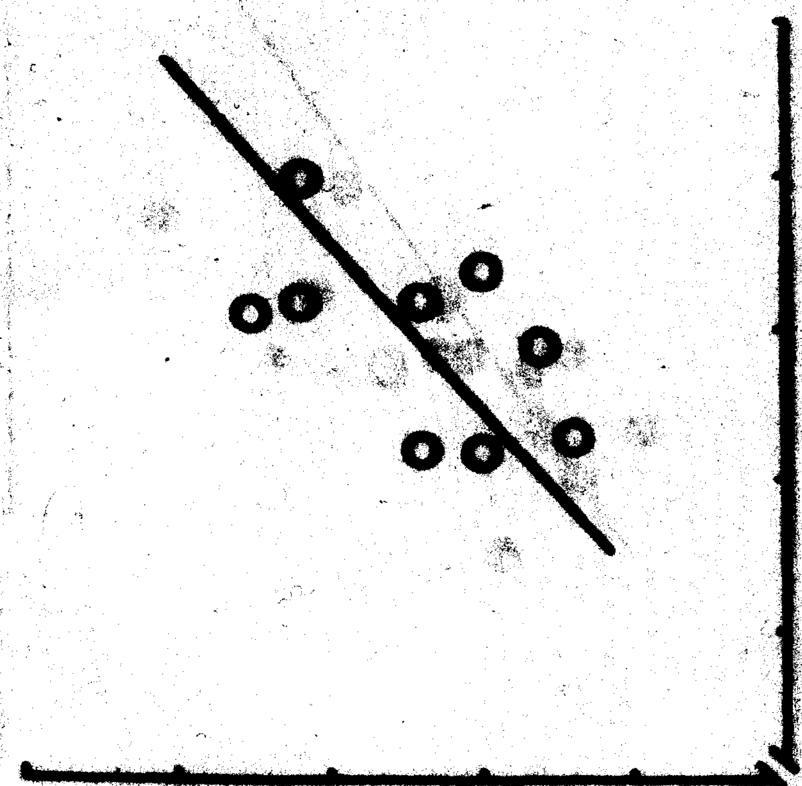


Fig. 11.3

COMPARISON OF STANDARDISED HEART RATE IN B MIN^{-1} FROM WALKING TEST AND BICYCLE TEST

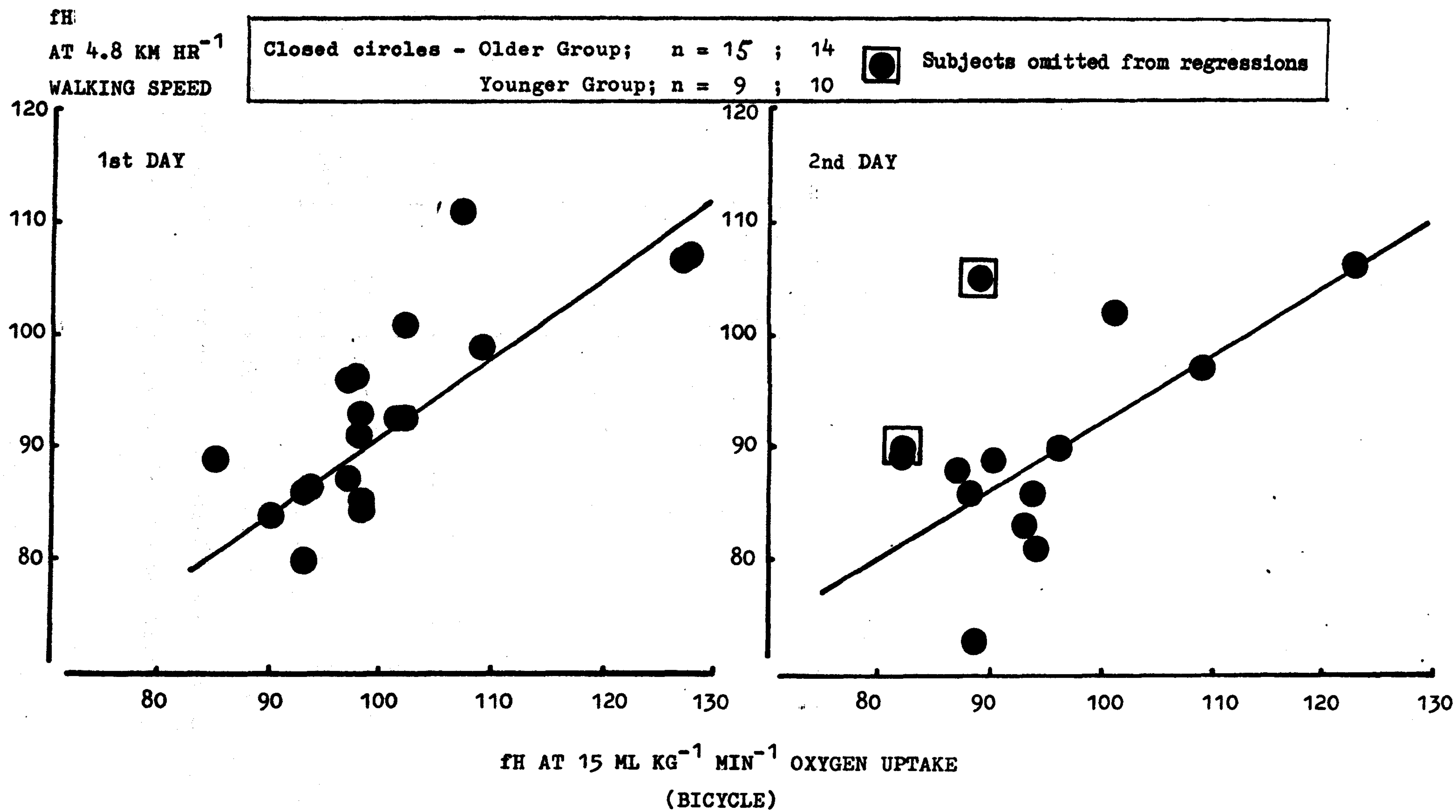
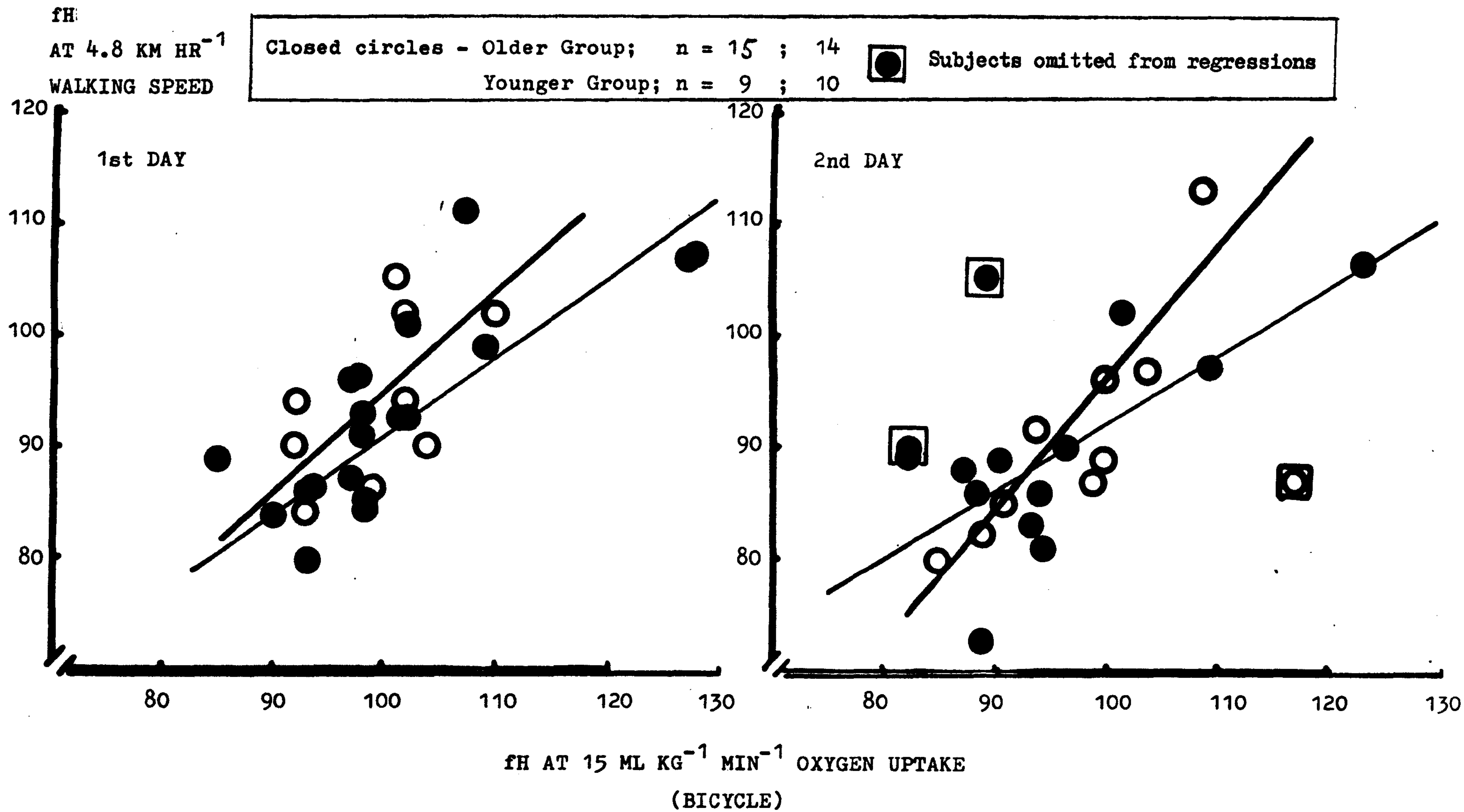


Fig. 11.3

COMPARISON OF STANDARDISED HEART RATE IN B MIN^{-1} FROM WALKING TEST AND BICYCLE TEST



Comparisons made at various different levels (10 ml kg^{-1} min^{-1} oxygen uptake and 4.8 km hr^{-1}; 15 ml kg^{-1} min^{-1} and 5.2 km hr^{-1}; 18 ml kg^{-1} min^{-1} and 5.6 km hr^{-1}) gave similar results for the young group. Extrapolation beyond the recorded results was not considered justified for the older group.

When the two groups were considered together the results were similar. There was a significant correlation between the two tests on both days. On the 1st day $P<0.001$ for the regression and $P<0.01$ for Spearman's ranking (n = 24); and on the 2nd day $P<0.01$ for both regression and ranking (n = 22) (see Table 11.4).

TABLE 11.4

COMPARISON BETWEEN STANDARDISED HEART RATES FOR THE TWO TESTS (BICYCLE AND WALK) FOR SEPARATE AGE GROUPS

	Correlation coefficient			Spearman's Rank correlation	
	r	P	S.E.	r	P
Older Group					
1st day; n = 15	0.74	0.01	6.2	0.74	<0.01
2nd day; n = 14	0.56	0.05	8.1	0.37	N.S.
without the arthritics n = 12	0.75	0.01	6.3	0.57	<0.05
Younger Group					
1st day; n = 9	0.65	N.S.	6.6	0.36	N.S.
2nd day; n = 8	0.92	0.001	4.4	0.96	<0.01

The S.E. in b min^{-1} is given for the results of the walking test regressed on the results of the bicycle test. Significance levels of 5% and 1% only are identified for Spearman's ranking (Snedecor, 1956).

COMPARISON BETWEEN STANDARDISED HEART RATES FOR THE TWO TESTS (BICYCLE AND WALK) FOR ALL SUBJECTS

	Correlation coefficient			Spearman's Rank correlation	
	r	P	S.E.	r	P
1st Day n = 24	0.6828	<0.001	$\pm$ 6.1	0.6772	<0.01
2nd Day n = 22	0.6417	<0.01	$\pm$ 7.5	0.693	<0.01

DISCUSSION

Comparison between the Tests

The results of the 2 tests were moderately well correlated as can be seen from Fig. 11.3 and the correlation was especially good for the young subjects on the 2nd day. In general these subjects who had relatively high heart rates in the bicycle test also had relatively high heart rates in the walking test and vice versa.

The more bunched results for the younger group on the 1st day may be due to the vagaries of variation on re-test or to habituation affecting one test more than the other in some subjects. The older subjects may be more scattered because of differences in efficiency.

For both groups the re-test variation in standardised heart rate, which is found in any exercise test, is bound to produce some scatter. Differences in the room temperature in the two test situations may have contributed to this. The correlation between the two kinds of test is surprisingly not much worse than the correlation found on re-test within one kind of test (cf Fig. 11.2).

The regression coefficients were calculated on the erroneous assumption that the x values, in this case the standardised heart rates from the bicycle test, are independent and not variable. The statistic must therefore be interpreted in that knowledge. The Spearman's correlation does not have this limitation as it is calculated from the paired differences in rank order and not upon the difference from the regression line along the y axis. However it has another limitation in that it is non-parametric being based only on rank order and therefore loses quantitative discrimination. It was encouraging that, despite these limitations, the r values from both methods of analysis were over 0.9 for the young group. The lower values of 0.6 or 0.7 for the old group can be explained by re-test variation and differences in efficiency.

The problems of quantifying the comparison between the two tests could be elucidated by further studies which included the measurement of oxygen uptake in both tests.

The reason why a correlation between the tests is expected is because there is a simple linear relation between the two parameters on which the heart rate was standardised as shown by van der Walt & Wyndham (1973) and others, viz:-

$$\frac{\dot{V}_{O_2}}{M} = a\,V^2 + c \qquad \text{where } M = \text{body weight},\ V = \text{walking speed} \quad \ldots \quad \text{Equation 1}$$

The scatter in the group correlation may be explained by variation between individuals in the values of the constants, especially in (a) the oxygen cost of unit increment in speed (or walking efficiency). The second constant (c) is a measure of the metabolic rate while standing.

The theoretical links between heart rate, oxygen uptake and walking speed are as follows:-

During any rhythmic exercise with large muscle groups

$$f_H = b \frac{\dot{V}_{O_2}}{M} + d \quad \ldots \quad \ldots \quad \ldots \quad \text{Equation 2}$$

During walking

$$f_H = p\, V^2 + q \quad \ldots \quad \ldots \quad \ldots \quad \text{Equation 3}$$

Substituting in Equation 2 from Equation 1

$$f_H = b\,(aV^2 + c) + d \quad \ldots \quad \ldots \quad \text{Equation 4}$$

$$= abV^2 + bc + d$$

therefore

from Equations 3 and 4 $p = ab$ and $q = bc + d$

it follows that $a = \frac{p}{b}$ and $c = \frac{q - d}{b}$

Only if these ratios are similar for all subjects will there be a close correlation between the standardised heart rates from the two kinds of test.

It is clear that the relation between heart rate and walking speed is influenced by the slope of both the heart rate/oxygen uptake relation (b) and the oxygen uptake/walking speed (a) relation. This means that those subjects for whom the oxygen cost of walking is high compared to the group will have higher standardised heart rates during walking than would be expected from the results of the bicycle test. They will have a high p constant and therefore a higher p/b ratio (= a) than the group mean. The discrepancy will become more marked the higher the walking speed since it is the slope of the relation which is affected and not the intercept. Two subjects who had unexpectedly high standardised heart rates during walking suffered from arthritis of the knees and complained of discomfort during walking (see Fig. 11.3).

Variations in basal metabolic rate will also affect the comparison between the two tests. Women are known to have a lower basal metabolic rate and so will have lower values for the c constant than men (see Chap. 5). Moreover one of the male subjects studied in Chap. 8 was predicted to have a lower metabolic rate per kg at zero walking speed than the 3 others (low c constant). This was thought to be due to his greater % body fat. If this is so then variations in body fat might produce some of the scatter in the comparisons between the tests. This has implications for a longitudinal study since changes in body fat with time may affect the assessment of physical condition in a walking test independently from changes in body weight. However the considerably greater % body fat of the older group (see Table 10.2) was not sufficient to reduce the standardised heart rates from the walking test relative to those of the younger group. The effect must therefore be small unless it is masked by reduced efficiency of walking in the older group. This requires further investigation.

Because of the variations in efficiency the correlation between the two tests was not close enough to permit prediction from one to the other in elderly subjects. It might become possible for young subjects if it could be shown that the efficiency of walking is fairly uniform in this group. For the time being the two tests are best considered as complementary rather than alternative.

Advantages of the Walking Test

Free walking was found to have several advantages over the bicycle ergometer as a method for testing elderly subjects. Nine of the 24 elderly subjects could not be asked to complete the tests using the bicycle ergometer because of cardiovascular abnormalities, whereas they were all able and willing to walk. In a group that is older or more debilitated than this group (aged 65 years), the reduction in numbers fit to ride a bicycle ergometer might be much greater.

Another advantage of free walking is that the re-test variation was found to be small. Variation in the response to exercise on re-test is considered to be less the more severe the exercise (Davies, 1968b). Despite the low levels of work, the variation in standardised heart rate in the walking test was as low or lower than in the bicycle test for both age groups (5.2 and 5.4% for the older group; 8.2 and 10% for the younger group). Moreover when the standardised heart rates from the bicycle test were derived from only the 3 lowest recorded points the re-test variation in the older group was $\pm$ 9.7%. Therefore as a method for assessing the response to exercise the walking test appears to be as accurate as the bicycle test and more so for elderly subjects who are unable to complete many increments of work. The lower the re-test variation the more sensitive the test will be to changes occurring with increasing age, for example a decrease in the levels of daily activity.

Theoretically the use of the bicycle provides many more grades of activity than a test based on walking. This was true for the young subjects, but only 3 of the old subjects completed all 6 increments, (see Table 11.1), and 4 subjects managed only 3 increments to 75 W, which is a similar level of exertion to that of fast walking.

The bicycle test therefore loses much of its advantage for the older group. The reduction in sample size and the possible bias produced by the exclusion of one third of the group has to be balanced against the advantage of more grades and higher levels of exertion for some of the subjects. The higher levels of exertion are desirable in a bicycle test for reducing the re-test variation, but that appears to be small in the walking test despite the low levels of work. The only remaining advantage is that there are more grades of work in each test for some of the subjects. Again with a group that was older and more debilitated than the one studied, this advantage would be reduced if fewer of the subjects were able to complete more than 3 grades of work.

Physical Condition

No significant differences in physical condition, assessed by the bicycle test, were found between the old and young group, whether or not adjustments for body mass and fat mass were made (see Table 11.2). The mean values for standardised heart rate for the two groups were close (within 4 b min^{-1}) and the range was similar (standard deviations about $\pm$ 10 b min^{-1}). The similarity between the groups was surprising and was presumably due to the balance of genetic endowment and physical activity being similar for both groups.

There was a difference between the 2 age groups in the re-test variation in standardised heart rate. In both bicycle and walking test the older group were less variable. This is probably because the younger group have a more labile sympathetic nervous system than the older group. This was manifest in the signs of habituation in the younger group in both tests.

These values for physical condition compare favourably with those of other authors. The mean heart rates at an oxygen uptake of 1.0 l min^{-1} in this study were 94 ($\pm$ 3.6) and 96 ($\pm$ 2.8) b min^{-1} whereas comparable values found by Spiro et al (1973) for normal male subjects, aged over 40 years and not in athletic training, were 106 ($\pm$ 3.1) b min^{-1} and those found by Cotes et al (1973) for young men, also not in athletic training but used to exercise, were 102 b min^{-1}. This indicates that the subjects in this study were typical of those used to physical exercise, with a relatively low heart rate response to exercise. They would therefore be considered to be in good physical condition compared to the general population. This was expected since most of the young men took part in sports activity and most of the older men had been used to fairly strenuous manual work in the steel industry.

Limitations of Performance

Although neither bicycle test nor walking test revealed any significant differences in physical condition between the two age groups, differences in performance were apparent in both tests. The older subjects were not all able to complete the whole bicycle test and they did not walk as fast. It was not possible to make individual comparisons between the achieved walking speed and achieved work rate on the bicycle because the limiting criteria were different.

The bicycle test was terminated either by the subject, due to fatigue of the thigh muscles or breathlessness; or by the observer if there were any ECG abnormalities such as S-T segment depression or if the systolic pressure rose over 200 mms of mercury. The latter do not lead to subjective symptoms unless there is angina or a reduced cardiac output. Whereas in the walking test the performance depended upon the subject's interpretation of "rather fast without over-exerting yourself". It was therefore not surprising that there was no individual correlation between fast walking speed and achieved work rate on the bicycle.

However the group differences were of interest because they reflect the dissociation between maximum performance capacity and physical condition found in cross-sectional studies of age differences. The maximum performance capacity declines markedly with increasing age although physical condition does not (see Chap. 1). It may be that the walking test will provide a more sensitive indicator of changes associated with increasing age if it is used as a measure of performance than as a measure of physical condition.

The possible reasons for the reduced performance of the older subjects have been discussed in the last chapter but the additional measurements of oxygen uptake in the bicycle tests provide some further evidence.

The lack of difference in standardised minute ventilation between the two groups indicates that the older group could achieve as good a blood supply to the working muscles as the younger subjects and that therefore cardiovascular or respiratory impairment were not responsible for their reduced performance in either bicycle or walking test. This was a possibility considered in the last chapter. The only exception to this was one older subject who had a standard minute ventilation of 28 l min^{-1} which was about 2 S.D.s higher than the mean for the group (23 l min^{-1}). He also had the smallest standard tidal volume and vital capacity and a history of bronchitis. It seemed likely that this subject was limited by respiratory impairment. In the bicycle test he was only able to complete 2 increments on one day and 3 on the other, but his fast walking speed was above the meanvalue for the group.

Some subjects complained of shortness of breath in both tests which might have been because their maximum ventilatory capacity was lower than for the younger group (higher dyspnoeic index, Cotes 1965), although there was no difference in their minute ventilation at 1.0 l min^{-1} oxygen uptake.

Body size may limit performance due to subjective fatigue in both tests. In the bicycle test small thigh muscles will begin to fatigue at a lower rate of work than large thigh muscles, and the older group had a significantly smaller fat-free mass than the younger group (mean difference 9 kg). In the walking test as already mentioned (see p146) the ratio of leg muscle mass to the total body mass which those leg muscles must carry seems likely to influence walking speed. The ratio of fat-free mass to total body mass was lower in the older group and could therefore have contributed to their lower speeds.

Arthritic pain also limited at least one older subject during bicycling and several during walking. As has been mentioned (p246) reduced joint mobility and smaller stride length may have affected walking speeds in the older group.

Finally both tests may be influenced by age-linked differences in motivation, tolerance of minor discomfort and fear of over-exertion.

The reasons for the lower performance in the elderly could therefore be due to the following:-

bicycle only	ECG abnormalities high systolic blood pressure smaller fat-free mass
both tests	higher dyspneoic index arthritic pain psychological motivation
walking only	lack of joint mobility neuronal degeneration smaller ratio of fat-free mass to body mass smaller stride length

Further tests would be required to determine the contribution of all these factors but it is clear that the limitations to performance in the bicycle test are different from those in the walking test in many respects.

The achieved performance in the bicycle test would be less suitable as a performance index than the achieved walking speed, because the work rate is controlled by the observer in fixed increments whereas in walking the speed is continuously variable and controlled by the subject. Moreover bicycling is not a natural activity for many elderly people and may be limited by fatigue of the quadriceps muscles whereas walking is a habitual activity in which the burden of the work is distributed more evenly over a larger number of muscle groups.

So whether used as a test of performance or physical condition the walking test is a realistic one since the demands of daily living include walking rather than bicycling. It provides a way of measuring the stress of a habitual activity and of assessing submaximal performance in a wide range of elderly people, including many for whom the conventional tests are unsuitable. It can be usefully applied to the investigation of changes induced in the elderly by changes in activity patterns, illness, diet or neuromuscular degeneration.

CONCLUSIONS

It was concluded that there was a reasonable correlation between the results of the walking test and the bicycle test (between heart rate standardised on walking speed and on oxygen uptake per kg body weight respectively). The scatter in the correlation could be explained on grounds of re-test variation and differences in efficiency. The correlation was not good enough to be used for prediction.

The bicycle test was considered too strenuous for one third of the group of older subjects. The two thirds who undertook the test did not all complete it. The re-test variation in the standardised heart rate results from the bicycle test was found to be greater than from the walking test. For these two reasons it was concluded that the walking test is preferable to the bicycle test for elderly subjects.

The reasons for the reduced performance in the older group could not be attributable to reduced lung function or a compromised blood flow to the working muscles. Other possible reasons are discussed.

The re-test variation in the standardised heart rate was found to be less for the older subjects than the younger subjects in both tests. There were no significant differences between the two age groups in physical condition measured in this way in either test. These findings are in keeping with the literature. Both groups of subjects were in good physical condition compared to the general population.

It was concluded that the walking test is a realistic test of the stress of a habitual activity especially in the elderly.

CHAPTER 12

GENERAL SUMMARY AND DISCUSSION

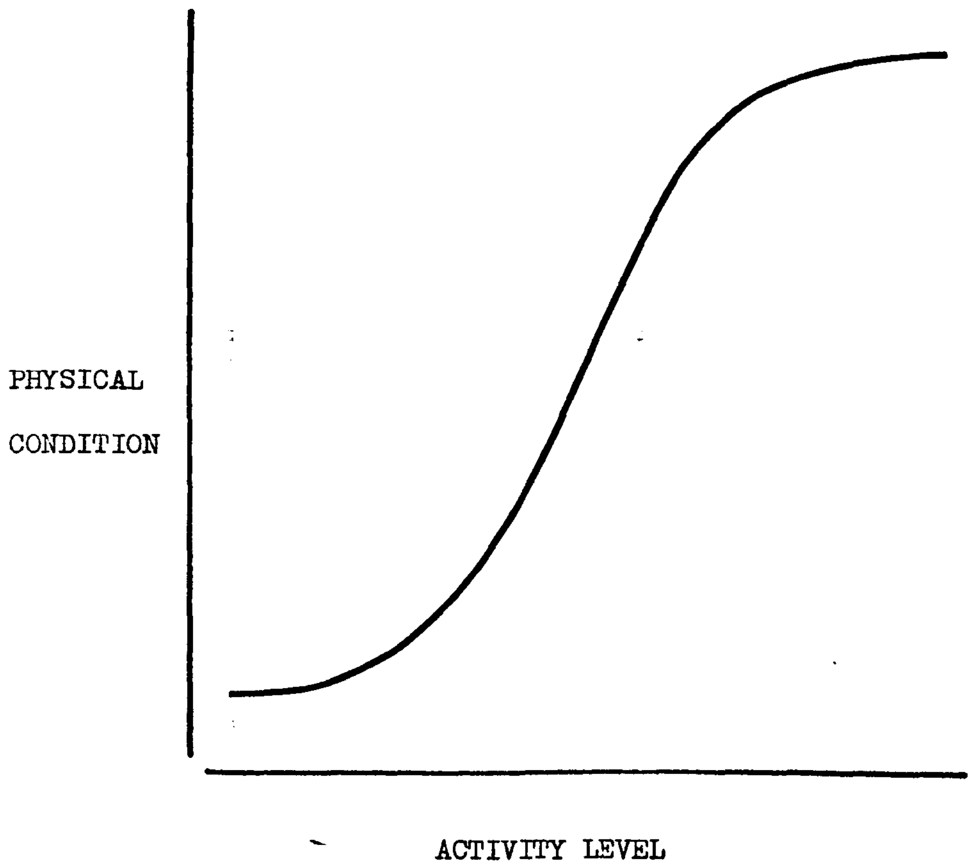
GENERAL SUMMARY AND DISCUSSION

Our thesis at the outset was that inactivity contributes to the physical deterioration which is sometimes seen with increasing age. This is not yet established but a technique has been developed which should make it possible to decide whether this happens to any great extent,

The first study (Part A) showed that bedrest as a model of inactivity caused a deterioration in the cardiovascular response to exercise. It also showed that the deterioration was greater in those who were initially in the better condition. The older subjects deteriorated less and this appeared to be because their initial physical condition was the poorest. These findings were consistent with our thesis, but showed that the complete inactivity of enforced bedrest would not cause a drastic deterioration in those already used to low levels of activity. Although this might produce deterioration in other systems the heart rate response to exercise would not be expected to change to any great extent.

Taking this finding and the known effects of training into consideration it seems likely that the relation between physical condition and activity levels is an S-shaped curve, with the maximum rate of change of physical condition occurring over the middle ranges of activity. At the low end of the curve when physical condition has reached a minimum there is very little change when activity levels drop even further, conversely at the high end of the curve physical condition will reach a maximum and further increase in activity will produce no further improvement. This is where an athlete reaches his peak.

THEORETICAL DOSE - RESPONSE CURVE



According to Saltin et al (1968) changes in physical condition, measured as a standardised heart rate, encompass a range of about 40 b min^{-1}. The range of effective activity levels remains to be determined. This will need to be worked out in terms of both intensity and duration of exercise and tailored to each individual. The body-borne tape recorders which were used in the studies described in Part B to record heart rate and footfall can be used over a whole day and promise to provide a method of approaching this problem. The footfall record is a guide to the duration of many forms of exercise and it is more reliable and practical than other available methods (questionnaire or observer). The heart rate record taken in conjunction with the footfall record gives a measure of the intensity of the exercise. Both records can be interpreted more fully if the subject has also performed a walking test, so that the relations between heart rate, cadence and walking speed are known. Then in a longitudinal study changes in physical condition due to changes in activity would not obscure the measurement of that activity.

The second study (Part B) was mainly concerned with developing a method of assessing the physical condition of elderly subjects. The use of self-paced walking in a free situation combined with the tape recording of heart rate and footfall proved successful for this with subjects of both sexes and ages ranging up to 70 years and more. This assessment of physical condition is influenced by walking efficiency and it is therefore a realistic measure of the stress of an activity which is habitual and necessary for independent living.

So far this method has not revealed age differences in the heart rate response to exercise which is in keeping with the literature. Cotes, Hall, Johnson, Jones & Knibbs (1974) have recently shown that there is a slight drop in standardised heart rate with increasing age in subjects with similar activity levels.

He attributes this to diminishing sympathetic nervous stimulation. Thus there may be two processes occurring with increasing age, a reduction in heart rate due to reduced sympathetic tone which is masked by an increase in heart rate caused by reduced physical activity.

This raises again the unsolved problem of the control of heart rate during exercise. The centrally initiated drive through the sympathetic nerves might be expected to increase rather than decrease as muscles grow weaker with age or inactivity (Hartley et al, 1972). It would be of interest to know whether the reflex drive from ischaemic muscles decreases with age (Lind, Taylor et al, 1964), and whether there are changes in baroreceptor activity due to age-linked changes in the arterial walls, or a diminished blood volume in those who are elderly and also inactive (Strandell, 1964).

The changes with age which were observed in Part B were a decreased rate of performance in the older groups. This was seen in two comparisons of walking speeds made between older and younger groups. The walking performance had a sufficiently high re-test reliability to assume that it reflected daily activity levels at least in intensity. There was further evidence of this in the differing performance of two elderly groups of women who were similar in age but reported to differ in daily activity levels. Therefore there was some evidence in this study of a decline in activity with age. This is in keeping with the results of tests of psychomotor function and observations from daily life which also indicate that the old slow down.

The difference in walking speeds was associated with a difference in gait. The older men walked with shorter strides and a higher cadence. This may be a sign of neuromuscular rather than cardiovascular degeneration and may be an explanation for the slower walking speeds.

If this is so our hypothesis, that many elderly people suffer a deterioration which is due to decreased activity and therefore remediable, must be modified. Neuronal degeneration cannot be reversed but it might be possible to compensate partly for it on the efferent side of the locomotor system by training the remaining motor units.

If, on the other hand, the changes in gait and walking speed occur for psychological reasons, because older people are afraid that their ability to walk with a free-swinging gait has diminished, then a change in over-protective social attitudes to the elderly might be the necessary antidote.

Further studies must be concerned with the unravelling of the reasons underlying changes in exercise performance and levels of activity in the elderly.

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APPENDIX

GAS EXCHANGE

Data Collected on Proformata during a Work Test

Wt = body weight of subject without shoes

P_B = barometric pressure in mms Hg

Load = in kg from bicycle ergometer dial

Revs = revolutions of flywheel from counter

Time t = in % min from stop-watch

Pulse = in beats min^{-1} from ECG trace, counted for ½ min. x 2

Resp Tr = respiration rate from thermistor trace, counted as time in secs. for 10 complete breaths

Ex. O_2% = percentage of oxygen in expired air, from oxygen meter

Ex. CO_2% = percentage of carbon dioxide in expired air, from carbon dioxide meter

Gasmeter start) finish) = readings in litres from gasmeter = G_S G_F

Aliquot volume in litres, drawn off for gas analysis = A_V

Temp. of gas in °C as the expired air passes through the gasmeter = T

Water vapour pressure in mms from Temp. of gas and tables of saturated water vapour pressure = P_W

Calculations of Gas Exchange based on work test data.

Work rate in kg m min^{-1} = Load x Revs. x $\frac{100}{t}$

Frequency of respiration in breaths min^{-1} = $\frac{10 \times 60}{Tr}$

Minute ventilation in litres min^{-1}

$$\dot{V}_{E_{BTPS}} = \frac{(P_B - P_W) \times (G_F - G_S + A_V)}{P_B - 47.035} \times \frac{310}{T + 273} \times \frac{100}{t}$$

$$\dot{V}_{E_{STPD}} = \frac{(P_B - P_W) \times (G_F - G_S + A_V)}{760} \times \frac{273}{T + 273} \times \frac{100}{t}$$

Vol. of O_2 used = vol. inspired - vol. expired

Vol. of O_2 inspired = $\frac{20.95}{100} \times \frac{N_E}{N_I} \times \dot{V}_{E_{STPD}}$

where N_E is the % nitrogen in expired air = (100 - Ex.O_2 - Ex.CO_2)%

N_I is the % nitrogen in inspired air = 79.04%

vol. O_2 expired = $\frac{Ex.O_2 \times \dot{V}_{E_{STPD}}}{100}$

Oxygen uptake in litres min^{-1}

$$\dot{V}_{O_{2STPD}} = \dot{V}_{E_{STPD}} \left[\frac{20.95\ (100 - Ex.O_2 - Ex.CO_2)}{100 \times 79.04} - \frac{Ex.O_2}{100} \right]$$

Oxygen uptake in ml kg^{-1} min^{-1} (adjusted for body weight)

$$= \frac{\dot{V}_{O_2} \times 1000}{Wt}$$

Carbon dioxide production in litres min^{-1}

$$\dot{V}_{CO_2} = \dot{V}_{E_{STPD}} \left[\frac{Ex.CO_2}{100} - \frac{0.03}{100} \times \frac{(100 - Ex.O_2 - Ex.CO_2)}{79.04} \right]$$

Respiratory Quotient = $\frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}}$

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Spring, 1971

The Nuffield Foundation, realising the increasing problems associated with an ageing population has given us a grant for research into the best methods of maintaining fitness, and of regaining it after an operation. We want to find out, using a series of simple tests, how well the body adapts to exercise at various ages, and whether this adaptability changes when people undergo enforced rest followed by convalescence and returning activity.

This kind of project is entirely dependent on the good will of people like you who take part in the tests.

If you are willing to help us we will ask you to let us decide how fit you are before the operation and at intervals until you leave hospital. For this one of the doctors will examine you and will record your electrocardiogram. Afterwards we shall ask some of you to take two sorts of exercise; we will ask you to pedal a stationary bicycle using your good leg only; and later to grip two bars with one hand.

The bicycle test will take place in our mobile unit (outside Ward 8) and consists of pedalling a stationary bicycle, with your good leg for two or three periods each of about five minutes duration. (The effort involved is something like walking briskly upstairs). During the test we record your blood pressure, your pulse and also how much, and how fast you breathe. You will be asked to breathe through a mouthpiece into a large plastic bag. The whole procedure takes about half an hour including the 10-15 minutes exercise and it will be repeated once a day on the three days preceeding operation and then, if you are willing, at about fortnightly intervals until you are discharged.

The hand-grip test, during which we measure blood pressure and pulse rate, you can do in bed. First of all we will want to know how hard you can squeeze two bars together; this is your maximum hand-grip. Then, after we have made resting measurements of your blood pressure and pulse, we will ask you to hold the bars at a quarter of your maximum grip for four minutes. This will feel something like holding a lump of coal with a pair of tongs. While you are doing this four minutes of exercise we will continue to make measurements of blood pressure and pulse rate at minute intervals. The whole test takes about half an hour. It will be repeated three times before your operation and at weekly intervals afterwards.

The purpose of this note is to outline the nature of the tests and to ask you whether you would like to take part, on the understanding that you can change your mind at any stage if you do not wish to go on.

This project has been undertaken with the full knowledge and approval of the medical staff of this hospital, who have given us all the facilities we need.

A.T.B.
18.2.71.

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PROFORMA FOR CLINICAL EXAMINATION

Series: . . . .   Name: . . . .

Examiner: . . . .   Date: . . . .

Damaged leg:. . . . .

B.P. Systolic. . . . .

Diastolic. . . . .

Pulse rate . . . .

	No	Yes
Pallor conjunctivae		
Mucous membranes		
JVP. raised		
Ankle swelling		
Apex beat displaced		
Abnormality of heart sounds		
Murmur		

Specify . . . .

Pulses	Present Right	Present Left	Absent Right	Absent Left
Radial				
Carotid				
Femoral				
Popliteal				
Post Tibial				
Dorsalis Pedis				

Bruits	Absent Right	Absent Left	Present Right	Present Left
Carotid				
Femoral				
Popliteal				

PROFORMA FOR CLINICAL EXAMINATION (contd.)

	No		Yes	
Chest deformity	☐		☐	
Specify				
	Yes		No	
Chest movements Equal	☐		☐	
	Yes		No	
	Right	Left	Right	Left
Good air entry	☐	☐	☐	☐
	No		Yes	
Adventitious sounds	☐		☐	
Specify				
	No		Yes	
	Right	Left	Right	Left
Legs Trophic changes	☐	☐	☐	☐
	Right	Left	Right	Left
Muscle wasting	☐	☐	☐	☐
	Right	Left	Right	Left
Knee swelling	☐	☐	☐	☐
	Right	Left	Right	Left
Range of movement limited	☐	☐	☐	☐
	Right	Left	Right	Left
Movement painful	☐	☐	☐	☐

COMMENTS:

HEALTH AND ACTIVITY QUESTIONNAIRE FOR SCREENING

HOSPITAL PATIENTS

UNIVERSITY OF NOTTINGHAM MEDICAL SCHOOL

Date

FULL NAME ....

ADDRESS ....
....
....

TELEPHONE ....

SURVEY NO. ....

HOSPITAL NO. ....

WARD ....

CONSULTANT ....

1. What is your occupation?
....

2. How long have you had this occupation?
....

3. What were your previous occupations?
....
....

4. What is your date of birth?
....

5. How many cigarettes do you smoke per day?
....

6. How old were you when you began to smoke?
....

7. When did you stop smoking? (give year)
....

8. Do you have diabetes? No ☐ Yes ☐

9. Have you ever been in hospital? No ☐ Yes ☐

If YES, please give the following information for each hospital admission -

	Year	Nature of illness
(1)	....	....
(2)	....	....
(3)	....	....
(4)	....	....

10. Do you take any medicines? No ☐ Yes ☐

If YES, please state

Medicine	Reason for taking
....	....
....	....

Do you have Blackouts No ☐ Yes ☐

How often do they occur?
....

11. Do you usually bring up any phlegm from your chest first thing in the morning in the winter? No ☐ Yes ☐

If YES, do you bring up phlegm like this on most days for as much as three months in the winter each year? No ☐ Yes ☐

12. In the past three years, have you had a period of increased cough and phlegm lasting for 3 weeks or more? No ☐ Yes ☐

If YES, - 1 period ☐
2 or more periods ☐

13. Do you get short of breath walking with people of your own age on level ground? No ☐ Yes ☐

14. Does your chest sound wheezy or whistling on most days (or nights)? No ☐ Yes ☐

15. Does the weather affect your breathing? No ☐ Yes ☐

If YES, specify type of weather
....

16. Have you ever had a severe pain across the front of your chest lasting for half an hour or more? No ☐ Yes ☐

17. Have you ever seen a doctor because of pain or discomfort in your chest? No ☐ Yes ☐

If YES, what did he say it was?
....

HEALTH AND ACTIVITY QUESTIONNAIRE FOR SCREENING

HOSPITAL PATIENTS (contd.)

(a) Do you get this pain or discomfort when you walk uphill or hurry? No ☐ Yes ☐

(b) Do you get it when you walk at an ordinary pace on the level? No ☐ Yes ☐

(c) When you get any pain or discomfort in your chest what do you do?

Stop ☐

Slow down ☐

Continue at the same pace ☐

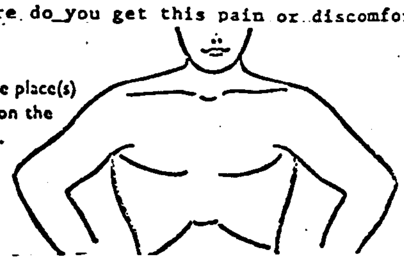
(d) Does it go away when you stand still? No ☐ Yes ☐

(e) How soon?

10 min or less ☐

More than 10 min ☐

(f) Where do you get this pain or discomfort



18. Do you get a pain in either leg on walking? No ☐ Yes ☐

If YES

(a) Does this pain ever begin when you are standing still or sitting? No ☐ Yes ☐

(b) Do you get the pain in your calf (or calves)? No ☐ Yes ☐

(c) Do you get it when you walk uphill or hurry? No ☐ Yes ☐

(d) Do you get it when you walk at an ordinary pace on the level? No ☐ Yes ☐

(e) Does the pain ever disappear while you are still walking? No ☐ Yes ☐

(f) What do you do if you get it when you are walking?

Stop ☐

Slow down ☐

Continue at the same pace ☐

(g) What happens to it if you stand still?

Usually continues more than 10 minutes

Usually disappears in 10 minutes or less

19. Do you own a car? ☐

Motor cycle? ☐

Bicycle? ☐

20. How do you regularly get to work?

By walking? a) ☐

By bicycle b) ☐

By motorcycle c) ☐

By 'bus d) ☐

by car e) ☐

If (a) Do you walk for more than

15 mins daily ☐

30 mins daily ☐

If (b) Do you cycle for more than

15 mins daily ☐

30 mins daily ☐

21. At work do you spend all your time indoors? No ☐ Yes ☐

If NO., how long do your regularly spend outdoors?

....

22. At work how long do you on average

Sit? ....

Stand? ....

Walk? ....

23. Do you pursue any other activities at work and if so for how long?

....

....

24. How long has your knee been troublesome?

....

HEALTH AND ACTIVITY QUESTIONNAIRE FOR SCREENING
HOSPITAL PATIENTS (contd.)

25. Before your knee injury what were your active leisure activities?

Activity	Frequency	Hours/Week
....	....	....
....	....	....
....	....	....
....	....	....

26. What are your activities since injuring your knee?

Activity	Frequency	Hours/Week
....	....	....
....	....	....
....	....	....
....	....	....

27. Between the ages of 15 and 25 were you

Very active ☐
Active ☐
Sedentary ☐
Very sedentary ☐

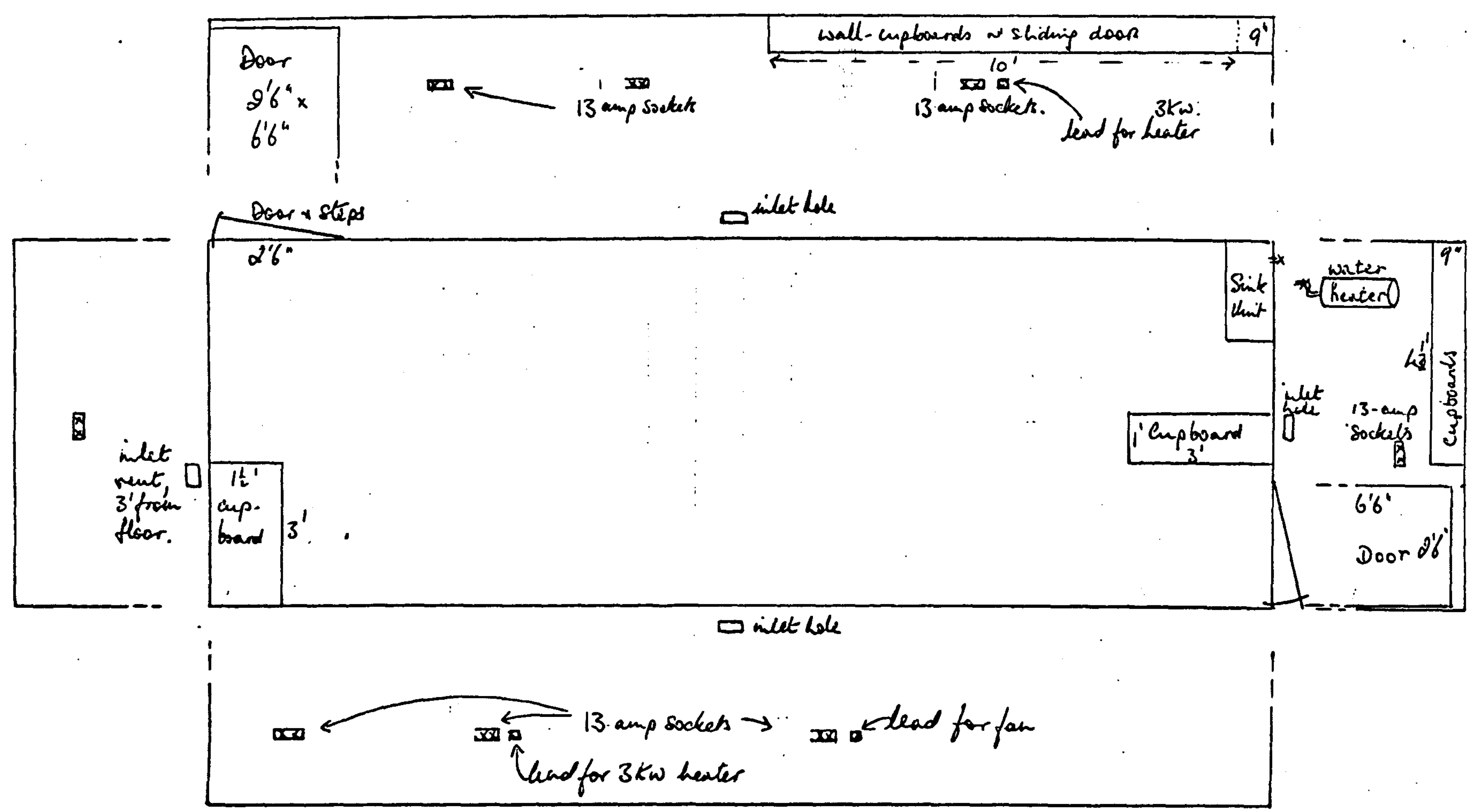
28. Do you regard yourself now as

Very active ☐
Active ☐
Sedentary ☐
Very sedentary ☐

Interviewer's initials .....

Exploded Plan of Floor & Walls of Mobile Unit.

Scale:- $\frac{3}{4}$cm : 1 ft.



SPECIFICATIONS FOR A TOWABLE MOBILE SHELL

Internal Dimensions:-

	Length	Width	All over height
Minimum	21' 6"	7'	7'
Preferable	22' 6"	7' 9"	7' 6"

Load ratings:-

Static Load 16 cwt.
Towing Load 10 cwt.

Van-Frame Strength:-

The frame must be strong enough to carry a weight of up to 30 lbs (one item).

Fittings - inside:-

One double door 4' x 6' 6" or
One single door 3' x 6'6"
One single door (see plan) 2' 6" x 6' 6"
Steps to fit doorways
Two roof window/ventilators 5' x 6' (or whatever available).
Two built in cupboards (see plan) 3' x 1' 6" x 2' 6"
3' x 1' x 3'
Built in wall cupboards at roof level - 2' (9" x 9'k 14') (or whatever available).
Built in small sink unit with single cold tap and electric water-heater. (Pipes to be connected to mains water and drains).
1" Dexian fixed to framing (on both side walls). (4' lengths fixed vertically at 1' above floor level at intervals of about 4' according to the framing intervals). 32' in all.
Expanded aluminium grid covering the ceiling and 1" below it, with cut out panels for lighting tubes and access to window handles.

Electricity:-

One 60-amp ring main carrying,
2 heaters @ 3 kw.
1 water-heater (see above)
1 fan
These to be permanently wired in, and the heaters and fan on long leads.

Three 5' fluorescent tubes.

One ring main carrying 16 13-amp sockets in groups of 2 sockets (see plan) and recessed into the wall, 6' from the floor.

Fittings - outside:-

Sockets for mains electricity (see above). Recessed wall compartment for cables.
Bracket(s) on towing bar for 2 x 150 lb. gas cylinders.
4 Apertures for gas cylinder inlets, with lids, one in each side, 3' from floor.
Over-run brakes.