INVESTIGATING THE WAYS IN WHICH VIRTUAL ENVIRONMENTS COULD INFLUENCE AIRCRAFT PASSENGERS' COMFORT AND EXPERIENCES

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ABSTRACT

The experience of comfort is an important factor in passengers' acceptance of transport systems. Comfortable cabin environments can be used as a means to differentiate between aircraft manufacturers and airlines and therefore, may be a key marketing feature. In 2010 and 2011, the European Commission presented its vision for aviation in the year 2050, highlighting the importance of enhancing passengers' experiences. They also envisaged the use of virtual reality (VR) to provide aircraft passengers with entertainment and a means of 'escaping from the fast pace of society'. The VR-HYPERSPACE project addressed this vision by examining the use of virtual and mixed reality technologies to enhance passenger comfort on aircraft in the year 2050. This approach to increasing comfort would be comparatively cheaper than changing the physical parameters of an aircraft.

This thesis presents a series of studies which investigated the ways in which two virtual environments (VEs) that were developed for the VR-HYPERSPACE project (one depicting a tropical island and one depicting the view outside of a low-flying aircraft, referred to as the 'invisible aircraft VE') could influence potential aircraft passengers' comfort and experiences. The findings from these studies provide insight into the prospect of using VR to enhance passengers' comfort and experiences in future flight from a user-centred perspective.

An initial user study was carried out to gain an understanding of the ways in which the two VEs, with various combinations of motion tracking, affected people's comfort and experiences. The results of this study showed that the VEs have the potential to enhance people's experiences, for example, by giving them an enhanced perception of space and time. They also might provide people with unique opportunities if used in flight, for example to augment or escape the flight experience. The study identified that motion tracking enhanced the experience of the invisible aircraft VE but detracted from the relaxing nature of the tropical island VE. The findings of this study were used to select combinations of VEs and motion tracking configurations to be taken forward for further investigation.

The initial study also identified that it was difficult to determine the extent to which VEs could enhance comfort when the participants were not exposed to discomfort. Consequently, a new approach to measuring the effect of interventions on discomfort was developed. This involved a workshop and a user study which were carried out to select and test sources of discomfort. Two common sources of discomfort were selected: the sound of a crying baby and restricted legroom. These were used subsequently to induce discomfort in participants in later studies.

The final series of studies aimed to determine the extent to which VEs could distract people from sources of discomfort. The findings indicated that passive VEs could be used to either fully distract people from sources of discomfort or minimise their negative responses. However, the VE used was more effective at distracting people from the discomfort associated with restricted legroom than the sound of a crying baby. The findings indicated that VEs become more distracting when they are interesting and that when exposed to stressful stimuli, relaxing distractors may be beneficial. The findings also indicated that VEs can be used to support existing strategies which people might use to overcome sources of discomfort in present-day flight situations.

This research considered existing research in both the comfort and the pain domains to develop a novel approach to enhancing passenger comfort through the use of VEs. The research showed that VEs have the potential to distract people from sources of discomfort which are commonly experienced in-flight and to enhance potential passengers' flight experiences. Further investigation is required to understand whether VEs remain effective distractors over longer periods of time, when subject to multiple sources of discomfort and in real-world contexts.

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Acronyms and abbreviations

Acronym/abbreviation	Definition
BPD	Body Part Discomfort Scale
DVT	Deep vein thrombosis
EC	European Commission
EMG	Electromyography
EU	European Union
FhG	Fraunhofer IAO
FP7	Seventh Framework Programme
HCI	Human-computer interaction
HMD	Head-mounted display
IFE	In-flight entertainment
LMD	Localised Musculoskeletal Discomfort
MPG	Max Planck Institute for Biological Cybernetics
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
UX	User experience
VE	Virtual environment
VR	Virtual reality
VR-HYPERSPACE	the innovative use of Virtual Reality to increase Human comfort bY changing the PERception of Self and sPACE

1. INTRODUCTION

1.1. **Background**

Air travel currently plays an important role in our lives. The number of aircraft passengers has increased over time (with an average increase of 8% per annum in the UK from 1950-2013) (Brand & Weekes, 2014) and forecasts suggest that this trend will continue in the future (Buck et al., 2013). The emphasis on aircraft passengers' comfort and experiences has also changed over time (Figure 1-1 shows a timeline of milestones affecting aircraft passengers' comfort). In the early days of passenger air travel, flight was viewed as a means of moving between two locations and was something to be endured. In the mid-1930s, efforts were made to improve passenger comfort through the provision of improved seats, food and in-flight entertainment systems (IFE) (Budd, 2011). At this time, passenger air travel was seen to be glamorous. There were no tiered cabin classes as only the wealthy could afford to fly (Lovegrove, 2000). The emphasis on the passenger experience in the design of cabin interiors continued until the introduction of low-cost airlines in the 1990s. These airlines made air travel more affordable but also led many passengers to be prepared to endure discomfort in order to save money (Patel et al., 2012). However, other airlines currently offer varying levels of design, services and prices in order to compete for different types of passengers (Ahmadpour et al., 2014a).

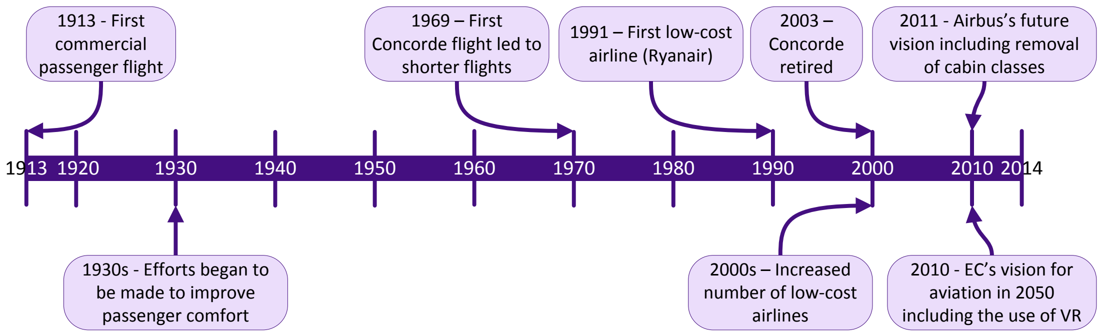

Figure 1-1 Timeline of milestones affecting passenger comfort in-flight

Richards (1980) highlighted that comfort is an important factor in passengers' acceptance of transport systems and therefore willingness to fly again (Richards & Jacobson, 1975; Richards et al., 1978). Nevertheless, people are still willing to endure the discomfort of low cost airlines for the sake of cost. A study of over 1500 aircraft passengers identified legroom as one of the main elements of the overall journey that people worry about before taking a flight (APEX, 2014). As comfort plays such an important role in passenger acceptance, improved cabin comfort can be used as a means of marketing for aircraft manufacturers and airlines (Richards & Jacobson, 1975). This was demonstrated by Airbus in 2013 when they launched an advertising campaign for their wider seats (see Figure 1-2). Therefore, enhancing the flight experience for passengers is an important element of encouraging repeat business.

Figure 1-2 Example from an Airbus advertising campaign focussing on passenger comfort (permission obtained from Airbus) (Airbus, 2013)

The European Commission (EC) set out its vision for aviation in the year 2050 in which it highlighted the importance of the passenger experience (European Commission, 2011). In a previous report, they also envisaged the use of virtual reality (VR) technologies to enable personalised experiences, to enable passengers to 'escape from the fast pace of society' and to provide entertaining and friendly experiences (European Commission, 2010). This is something which has also been referred to in both Airbus's future vision and Skyscanner's future travel report (Airbus, ND; Skyscanner, 2014).

It is known that changing the physical parameters of an aircraft is not economically viable as this approach to enhancing comfort would incur costs as a result of redesign as well as a reduction in passenger capacity. An alternative approach which would be comparatively cheaper would be to introduce VR into aircraft in order to provide novel experiences and enhance passenger comfort. As well as being cheaper, this approach addresses the EC vision for air travel in the year 2050. This PhD research aims to explore the potential of using virtual environments (VEs) to enhance passengers' comfort and experiences.

1.1.1. Research context: the VR-HYPERSPACE project

The research presented in this thesis was carried out within the context of the EU FP7 funded project, VR-HYPERSPACE (the innovative use of virtual reality to increase human comfort by changing the perception of self and space) (AAT-2011-RTD-1-285681). VR-HYPERSPACE was a three year (2011-2014) project which aimed to examine the use of virtual and mixed reality technologies to enhance passenger comfort on aircraft in the year 2050. The project involved researchers from nine organisations across Europe. An overview of the structure of the project can be found in Figure 1-3. The dark purple box shows where this PhD research fit within the overall project.

During the early stages of the VR-HYPERSPACE project, air travellers participated in workshops in order to determine the factors which currently affect their comfort or discomfort when travelling by aircraft (Patel et al., 2012). They were also asked how virtual and mixed reality technologies could be used to enhance their comfort and experiences in future flight (Tedone et al., 2012). From these workshops, a number of current and future scenarios and use cases were developed. This background work was used to inform the development of a number of demonstrators. These demonstrators made use of various hardware including head-mounted displays (HMDs), large-scale displays and 3D multi-viewer telepresence technology. These demonstrators were used to test various concepts including: changing perception of the cabin environment, changing perception of others, positive illusions of self and positive illusions of space. These concepts and demonstrators are described in more detail in appendix 1 and in D'Cruz et al. (2014).

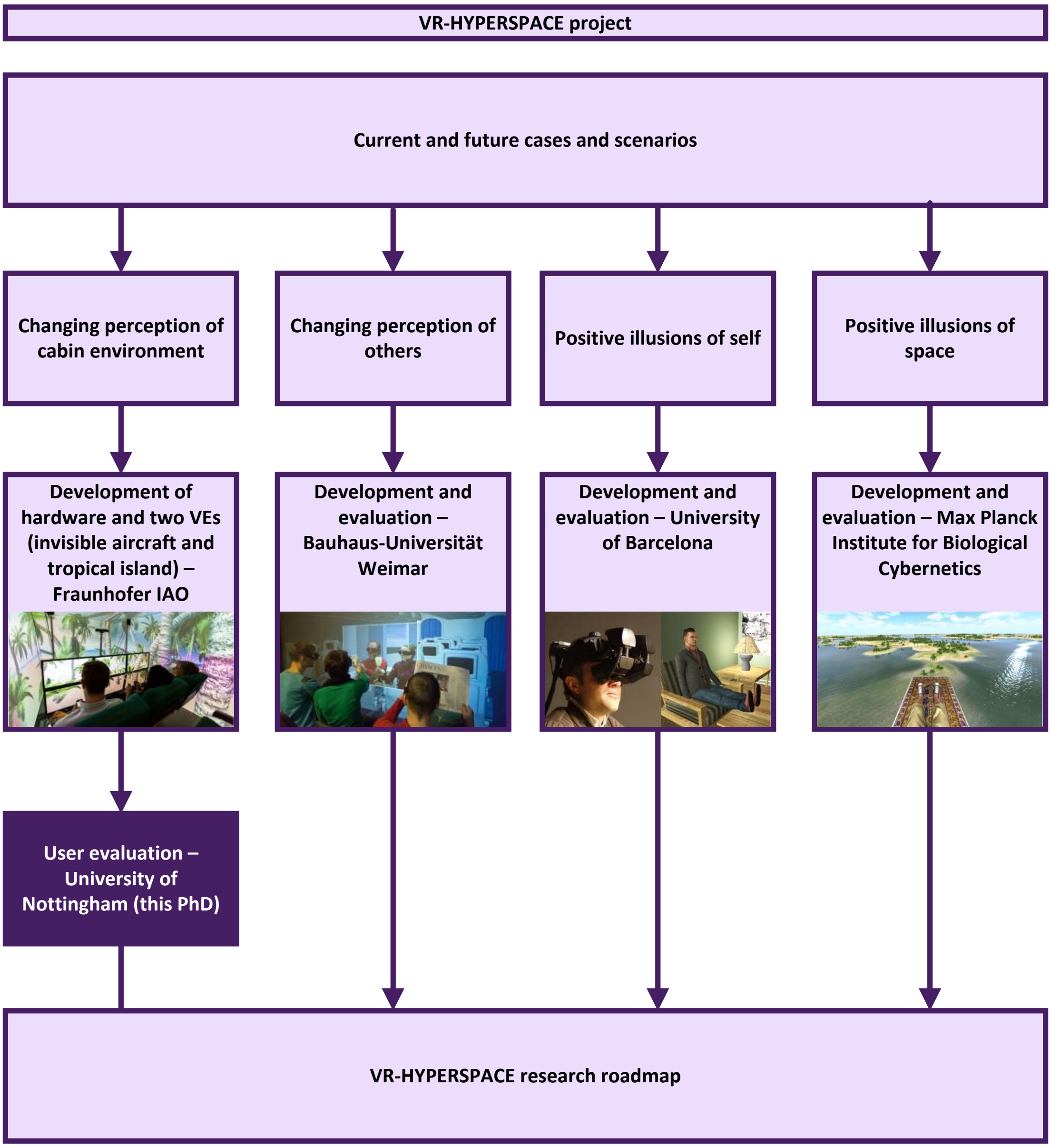

Figure 1-3 Summary of the VR-HYPERSPACE project. The dark purple box shows where this PhD research fit into the overall project.

This PhD focussed on evaluating the two VEs developed by Fraunhofer IAO depicting either a tropical island or the landscape beneath an aircraft (referred to in this thesis as the 'invisible aircraft VE'). Where possible, the studies were carried out in their mock-up which comprised a system of displays surrounding a user, designed to replicate the future concept of all the interior cabin surfaces being displays. The evaluation was conducted to determine the impact of the VEs on future aircraft passengers' experiences and comfort. The VEs and the hardware used in this research are described in detail in chapter 3 of this thesis.

1.2. **Aims and objectives**

The overall aim of this PhD was to investigate the ways in which VEs could be used to enhance passenger comfort and experience on future aircraft. The following objectives address the overall aim.

1. Develop an understanding of the ways in which VEs may influence aircraft passengers' comfort and experiences. This included developing an understanding of approaches to measure comfort and selecting an appropriate method for this research.
2. Investigate the ways in which two different VEs could affect aircraft passengers' comfort and experiences.
3. Investigate the extent to which VEs could distract passengers from sources of discomfort.

The structure of the thesis is illustrated in Figure 1-4, showing the ways in which the individual chapters correspond to the research objectives. Summaries of each of the chapters of this thesis can be found in section 1.3. The research objectives are described further in the following sections.

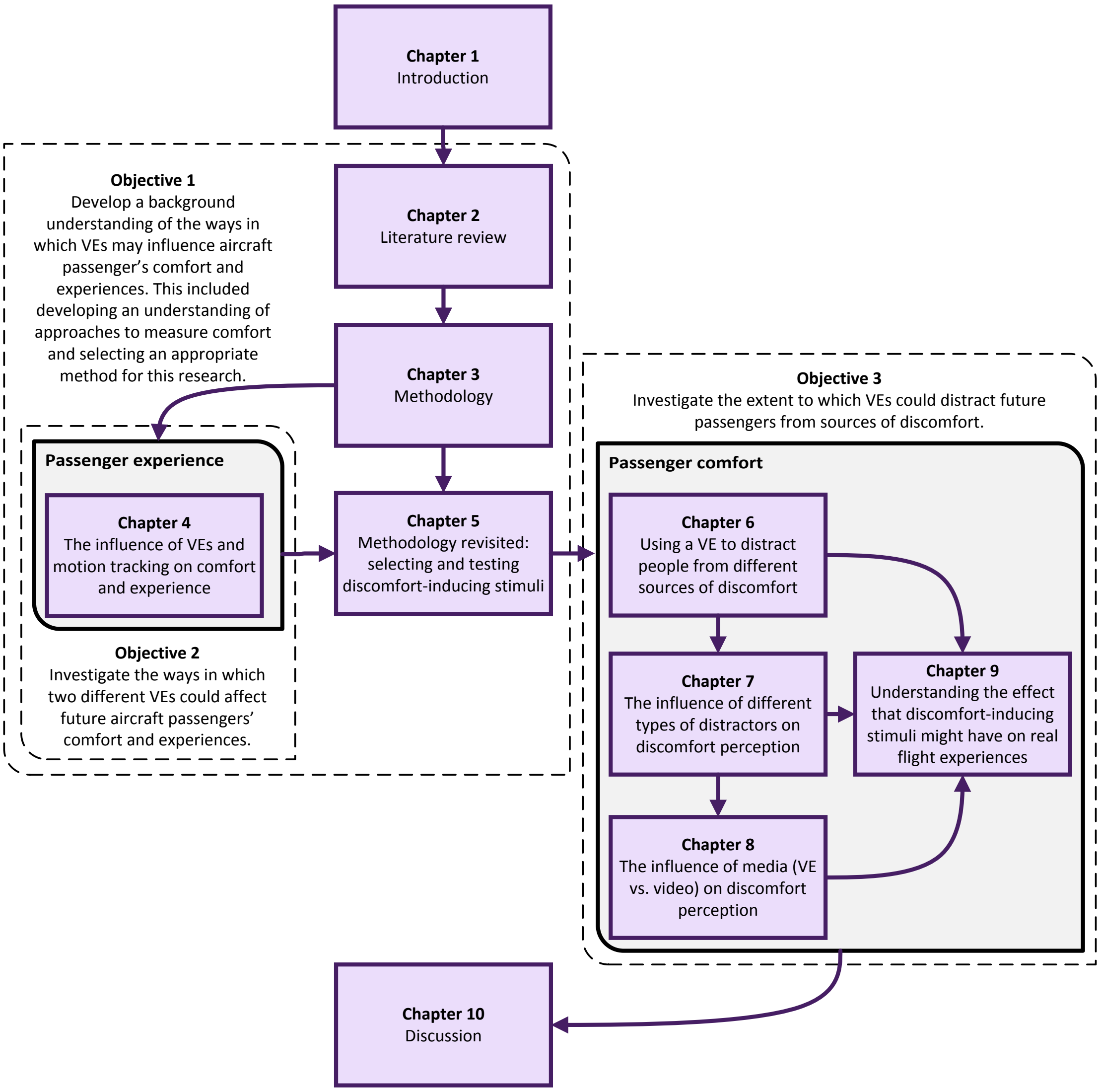

Figure 1-4 Thesis structure

1.2.1. Develop a background understanding of the ways in which VEs might influence aircraft passengers' comfort and experiences and understanding approaches to measuring comfort

The scope of this objective was to obtain background knowledge which could be used to inform the research carried out. This involved a critical review of the literature surrounding user experience, comfort and discomfort, passenger comfort and the use of VEs to distract people from pain (see chapter 2) and a review of approaches taken to measuring comfort (see chapter 3).

This objective also included refining the methodological approach taken in the research following the first studies (see chapter 4). This involved conducting a series of studies which aimed to select and test ecologically valid approaches to inducing discomfort in an experimental context (see chapter 5).

1.2.2. Investigate the ways in which two different VEs could affect future aircraft passengers' comfort and experiences.

This objective aimed to develop an understanding of the ways in which the two VEs developed by Fraunhofer IAO (a tropical island VE and an invisible aircraft VE) could influence the comfort and experiences of potential aircraft passengers (see chapter 4). The first study presented in chapter 4 was a user study where participants experienced both of the VEs with various configurations of motion tracking and were interviewed to obtain a rich understanding of the influence of the VEs on their comfort and experiences. The second study in chapter 4 investigated whether behaviours (which could negatively impact on neighbouring people) which were exhibited by some participants in the first study remained present when the set-up was occupied by more than one person.

These studies were used to select the appropriate configurations of motion tracking for each VE for use in subsequent studies. Consideration was given to the value that motion tracking added to the user experience of the individual VEs and its effect on users' comfort.

1.2.3. Investigate the extent to which VEs could distract future passengers from sources of discomfort.

The final objective of this research was to determine the extent to which VEs could distract participants from sources of discomfort. The sources of discomfort which were selected in chapter 5 were used in the studies presented in chapters 6-8. The study presented in chapter 6 investigated the extent to which the invisible aircraft VE could be used to distract participants from two different sources of discomfort: the sound of a crying baby or restricted legroom. The study presented in chapter 7 investigated the extent to which stimuli which were perceived through different senses could distract participants from the discomfort caused by the sound of a crying baby. Three different distraction stimuli were compared: the tropical island VE only, the sounds associated with this VE (waves and birds) only and the combination of the VE and the sound of waves and birds.

In order to understand how VE interventions compare to the activities which air passengers currently engage in to distract themselves from any discomfort (such as using IFE), the tropical island VE was also compared to videos which depicted similar scenery (see chapter 8). Finally, the effect of the two sources of discomfort (restricted legroom or the sound of a crying baby) on typical present day air passengers was investigated in chapter 9 in order to understand the benefit of introducing VEs into future aircraft.

1.3. **Thesis overview**

The following sections describe each of the individual chapters in turn.

1.3.1. Chapter 2 – Literature review

This chapter presents a critical review of three main bodies of literature which informed the research reported in this thesis. The chapter begins by defining the term ‘experience’ and discussing the relevance of the terms ‘passenger experience’ and ‘user experience’ to this research. A discussion on comfort and discomfort is then presented, including models and theories as well as the factors which affect passenger comfort. The chapter concludes with a review of the literature relating to the use of VEs to distract people from pain. This includes both the theoretical basis for why VEs may be an effective means of distraction from pain as well as examples from both clinical and experimental studies.

1.3.2. Chapter 3 – Methodology

The methodology chapter starts by presenting a review of methods and approaches to measuring comfort and discomfort. It then goes on to describe the methodological approach taken in the research presented in this thesis, including both the approaches to data collection and data analysis. The chapter concludes with descriptions of the hardware and VEs used in the studies presented in chapters 4 and 6-8.

1.3.3. Chapter 4 – Influence of VEs and motion tracking on comfort and experience

This chapter presents a study which was designed to investigate the ways in which two VEs developed by Fraunhofer IAO (a tropical island VE and an invisible aircraft VE) could enhance passenger comfort and experience. The study also investigated the effect of motion tracking on the experience of using these VEs. Twelve people individually participated in the study which involved participants being exposed to seven experimental conditions and being asked about their experiences after each condition (through both questionnaires and interviews). The findings of this study were used to select the optimum configurations of VEs and motion tracking to be used in subsequent studies.

This chapter also presents a small study which aimed to determine whether behaviours (observed in the previous study) which could negatively affect the comfort of other nearby participants were present when multiple people were sitting in the set-up.

1.3.4. Chapter 5 – Methodology revisited: selecting and testing discomfort-inducing stimuli

The first study presented in chapter 4 revealed that it was difficult to measure the effect a VE had on participants' comfort levels when they did not start the study in a state of discomfort. As a result, this chapter presents a series of studies which aimed to select two sources of discomfort to be used in subsequent studies and to test the extent to which these stimuli caused discomfort. Two sources of discomfort which differed in terms of the sensory modalities through which they were perceived were selected and tested. These were ecologically valid for an aircraft environment. A workshop was carried out with five human factors researchers to select an auditory source of discomfort (sound of a crying baby). A tactile source of discomfort (restricted legroom) was selected based on the factors which were identified in chapter 2 as impacting on aircraft passengers' comfort/discomfort. These were tested under controlled experimental conditions with 21 participants and were both found to reduce the participants' comfort levels.

This chapter concludes with a plan for the following studies, including key decisions which resulted from the earlier chapters of this thesis.

1.3.5. Chapter 6 – Using a VE to distract people from different sources of discomfort

The study presented in this chapter aimed to determine the extent to which the invisible aircraft VE could distract participants from the two sources of discomfort which were selected and tested in chapter 5 of this thesis. Forty-three participants were exposed to one of four experimental conditions (no VE with the sound of a crying baby, no VE with restricted legroom, invisible aircraft VE with the sound of a crying baby or invisible aircraft VE with restricted legroom) and their comfort experiences were measured using questionnaires and interviews.

The findings indicated that the VE was an effective distractor from the discomfort caused by restricted legroom but was less effective at distracting people from the discomfort caused by the sound of a crying baby. The findings also indicated that when the VE was interesting, it reduced the participants' awareness of the discomfort-inducing stimuli compared to when it was less interesting.

1.3.6. Chapter 7 – The influence of different types of distraction on discomfort perception

The study presented in this chapter aimed to determine the extent to which the tropical island VE and/or its associated sounds (waves and birds) could distract participants from the discomfort caused by the sound of a crying baby. Forty participants experienced one of four distractor conditions (no distractor, VE only, sounds of waves and birds only, or VE with the sounds of waves and birds) and their comfort was measured using both questionnaires and interviews.

The findings indicated that an auditory element of a distractor is particularly important when experiencing an auditory source of discomfort but this becomes more effective when used in combination with a visual distractor. Although none of the distractors provided were compelling enough to fully distract the participants from the discomfort caused by the sound of a crying baby, the relaxing nature of the distractors did help.

1.3.7. Chapter 8 – The influence of media (VE vs. video) on discomfort perception

This chapter presents a study which aimed to compare the extent to which the tropical island VE could distract participants from the discomfort caused by the sound of a crying baby with the present day scenario of passengers watching a video as a distraction. Thirty people participated in this study, experiencing one of three distractor conditions (no distractor, tropical island VE and associated sounds, or a video depicting similar scenery to the VE). The participants' comfort was measured using both questionnaires and interviews.

The findings of this study revealed that although neither the VE nor the video fully distracted the participants from the discomfort caused by the sound of a crying baby, the relaxing nature of these stimuli helped the participants. The findings also raised a question about the optimum amount of attentional resources that a distractor should demand in order to be effective.

1.3.8. Chapter 9 – Understanding the effect that discomfort-inducing stimuli might have on real flight experiences

During the post-study interviews which were carried out as part of the studies presented in chapters 6-8 of this thesis, the participants were asked how the discomfort-inducing stimuli (restricted legroom or the sound of a crying baby) would affect their real flight experiences. They were also asked about the strategies that they would use to overcome these sources of discomfort on a real flight. This chapter details the analysis of the participants' responses to these questions in order to understand the benefit of introducing VR into future aircraft designs.

1.3.9. Chapter 10 – Discussion

This chapter presents a discussion of the novel contributions of this research and the key findings arising from it, with a view to understanding the benefit that VR might have in terms of enhancing aircraft passengers' comfort in future flights. The findings of the studies are also considered with respect to the debate surrounding the definition of the terms 'comfort' and 'discomfort'. The limitations of the research conducted are discussed and recommendations for areas which should be further researched are also identified.

2. LITERATURE REVIEW

2.1. Introduction

This chapter presents a critical review of the literature which has formed the basis for the research presented in this thesis. This research draws from three main bodies of literature: user experience, comfort/discomfort and distraction from pain. Figure 2-1 illustrates how this literature relates to the studies conducted.

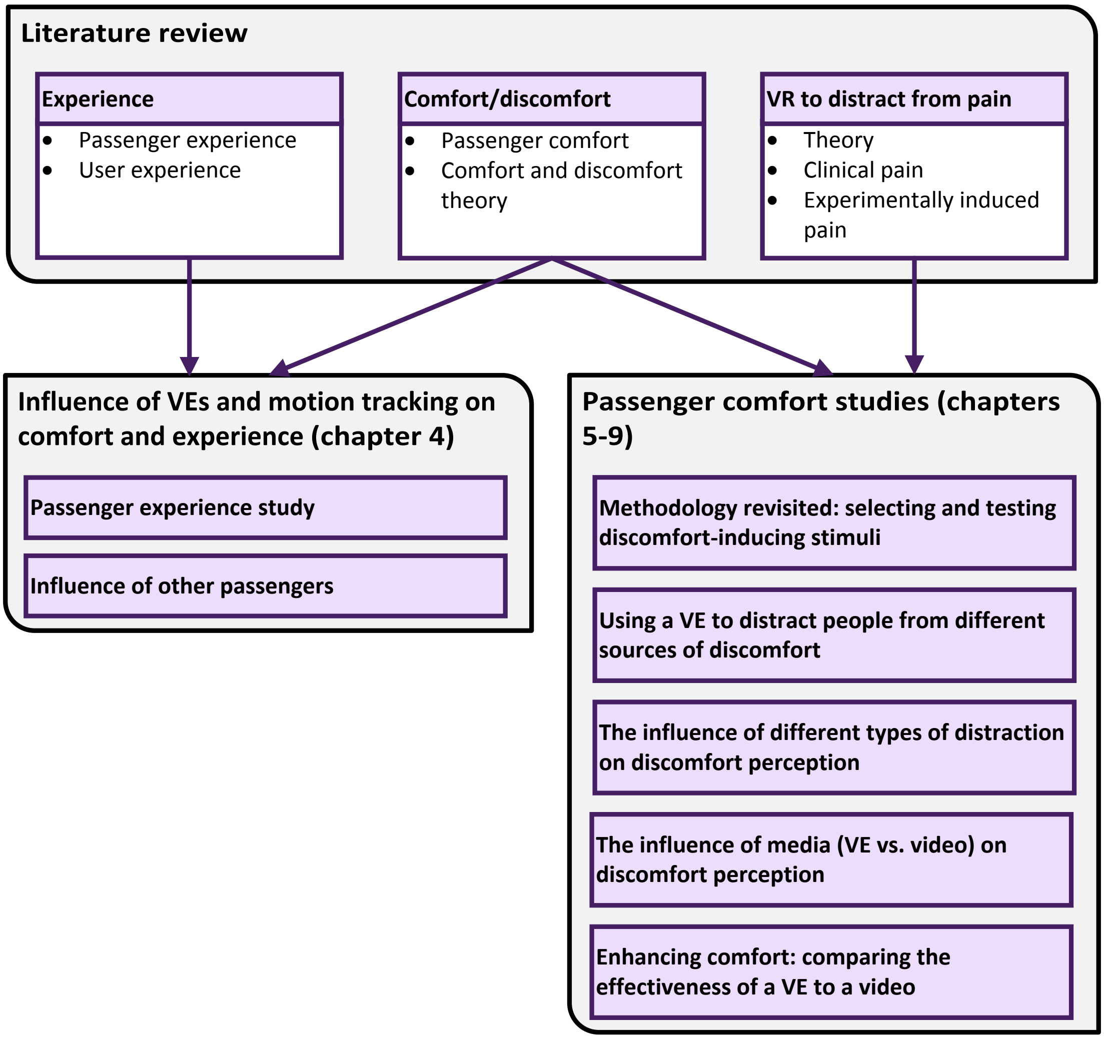

Figure 2-1 Relationship between literature review and studies conducted

This chapter is divided into three main sections. Section 2.2 reviews the literature on user experience, mainly focussing on models of user experience with a view to selecting a framework to use in subsequent data analysis. Section 2.3 presents literature relating to the concepts of comfort and discomfort. This includes definitions and theoretical models of comfort and discomfort, ways in which comfort and discomfort have been measured and factors affecting passenger comfort. Section 2.4 reviews literature surrounding the use of VEs to distract people from pain and theories which may explain the effectiveness of VEs to reduce pain. This body of literature was reviewed as, to the author's knowledge, there has not been any work investigating the use of VEs to distract from discomfort specifically.

2.2. **Experience**

The Oxford English Dictionary defines the word 'experience' as:

> *'The fact of being consciously the subject of a state or condition, or of being consciously affected by an event. Also an instance of this; a state or condition viewed subjectively; an event by which one is affected.' (Oxford English Dictionary, 2014).*

This definition is broad but highlights the importance of a conscious element to an experience (i.e. that something can only be an experience if a person is aware of it). The definition also highlights subjectivity which in turn would lead to variability between individuals. It is reasonable to assume that comfort and discomfort as concepts lie within this broad definition of experience.

'Passenger experience' is a term which is frequently used within the transport domain. However, there is no unified understanding of what the term encompasses. Within the context of aviation, 'passenger experience' often refers to the whole journey experience, including aspects such as purchasing tickets, travel to and from airports, time spent at airports and time spent on an aircraft (e.g. Jabalpurwala (2011b) and Myant and Abraham (2009)). However, some publications exclude the in-flight element from their analyses of the passenger experience (e.g. Civil Aviation Authority (2009)).

In-flight passenger experience can be influenced by the on-time performance, cabin crew, condition and cleanliness of the cabin, temperature, allocated space, seating comfort, IFE, ability to carry out desired activities and safety (Jabalpurwala, 2011b;

Myant & Abraham, 2009). These findings are similar to the findings of studies carried out by Patel et al. (2012) and Ahmadpour et al. (2014a) which aimed to determine factors affecting aircraft passenger comfort or discomfort.

It is evident that the factors which traditionally affect in-flight passenger experience are intrinsically linked with those affecting comfort or discomfort (these will be discussed in section 2.3.4). As the 'experience' element of this research is concerned with the application of VEs within an aviation context, it is strongly associated with user experience of technology. Therefore the definition of user experience (UX) is further explored in the following section with a view to forming a basis for the assessment and analysis of the VEs used in subsequent studies.

2.2.1. User experience

Within the Human-Computer Interaction (HCI) community, the term 'user experience' is widely used and accepted (Law et al., 2009). The term 'user experience' is defined in BS EN ISO 9241-210:2010 as relating to the users' perceptions of and responses to the use of, or anticipated use of, a product, service or system. This standard, and associated literature, suggest that user experience (UX) is affected by the product/system being used, the user and the context of use (British Standards Institution, 2010; Law et al., 2009). Both Law et al. (2009) and Nielsen and Norman (2013) emphasise that UX is a result of a person interacting with such a product/system. Law et al. (2009) also state that UX is a dynamic and subjective concept and that this experience is individual (rather than social), with the social experience forming one aspect of the contextual factors. Factors which are intrinsic to the user include their emotions, preferences, physical and psychological responses and behaviours (British Standards Institution, 2010). These factors are summarised in Figure 2-2.

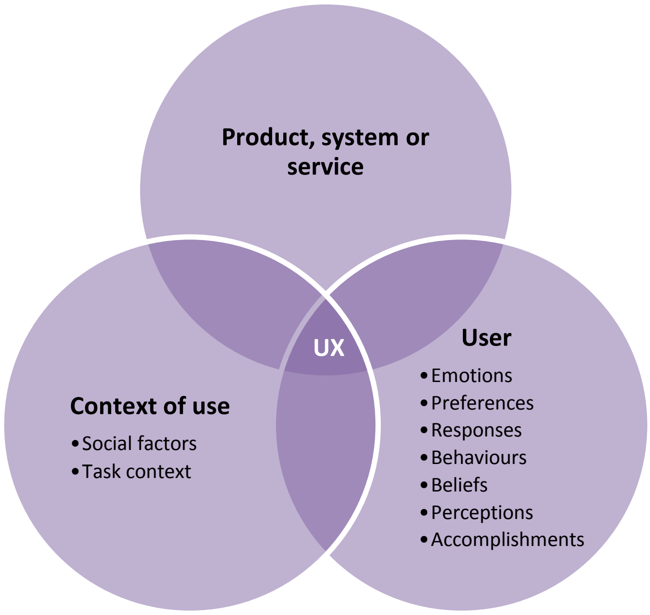

Figure 2-2 Summary of factors affecting user experience drawn from the British Standards Institution (2010) and Law et al. (2009)

Law et al. (2009) also argue that UX encompasses brand experience, product experience and service experience. However, these are narrower in scope than UX and can only be subsets of UX if a user interacts with a product, system, service or object via an interface.

Hassenzahl and Tractinsky (2006) take a different approach to modelling UX (see Figure 2-3), breaking it down into three facets: 'beyond the instrumental', 'emotion and affect' and 'the experiential'. The 'beyond the instrumental' component takes the approach that HCI research should not be solely focussed on task performance. Rather, the authors discuss the value of designing pleasurable products which link products' attributes with the needs and values of the users. This corresponds with Mahlke (2007) who made the case for 'instrumental' and 'non-instrumental' system characteristics (i.e. usability and aesthetic characteristics respectively). The 'emotion and affect' facet of Hassenzahl and Tractinsky's approach is concerned with products' affective consequences on users and is focussed on engendering positive feelings. 'The experiential' aspect of UX is consistent with Figure 2-2 and considers the combination and interconnectedness of the product, the intrinsic state of the user and the time and context in which the experience occurs.

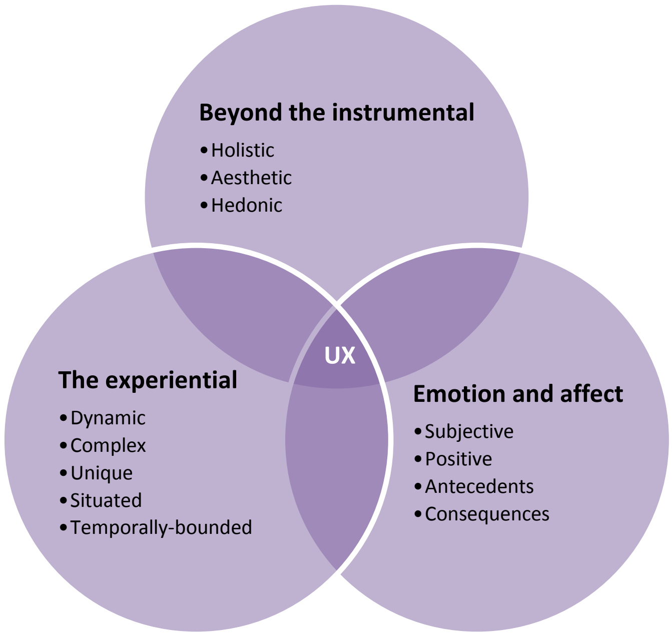

Figure 2-3 Facets of UX (Hassenzahl & Tractinsky, 2006)

Another framework for UX, proposed by Wright, McCarthy and Meekison (2004) and McCarthy & Wright (2004), was designed to analyse user experience (see Figure 2-4). This framework comprised four threads: compositional, sensual, emotional and spatio-temporal. The compositional thread is concerned with the way in which the elements of an experience combine to form a cohesive whole. This includes the overall narrative of the experience, its plausibility and the consequences and explanations of actions. The sensual thread relates to the user's sensory engagement with a situation. This is specific to the sensations experienced immediately in a given situation. The emotional thread refers to the sensations experienced which are ascribed to a situation as a result of the users' individual values, ambitions or desires and, unlike the sensual thread, involves understanding or a sense-making process. The spatio-temporal thread is concerned with the context in which a situation occurs in terms of the place and time. It also refers to the effect that the situation has on a user's experience of space and time.

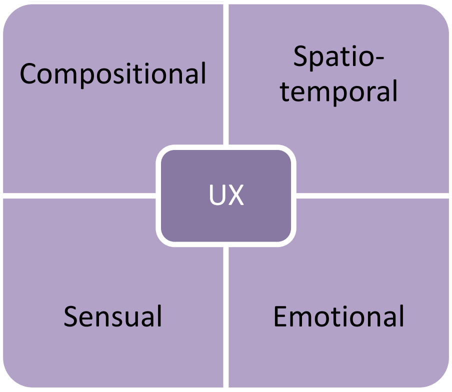

Figure 2-4 The four threads of experience (McCarthy & Wright, 2004; Wright et al., 2004)

Whilst all of these models differ in the way in which they explain user experience, there are also several commonalities. The most evident of these is the emphasis on subjectivity. Although all of these models do consider the functionalities of the systems themselves, they place emphasis on the ways in which users perceive, feel about and interact with systems within a specific context of use.

The ways in which two VEs affect passengers' experiences are investigated in the study reported in chapter 4 of this thesis. Consideration was given to the models described in this section when designing and conducting this evaluation. The research was carried out with a view to optimising the VEs for further evaluation with respect to passenger comfort.

2.3. **Comfort and discomfort**

Although the words 'comfort' and 'discomfort' are commonly used in everyday language, there is much discussion and debate in literature as to the exact definition of these terms and their relationships with one another. This debate includes deliberation as to whether comfort and discomfort are two ends of a single continuum (Richards, 1980; Shackel et al., 1969) or, are in fact, separate constructs with different underlying factors affecting them (De Looze et al., 2003; Vink & Brauer, 2011; Vink et al., 2005a; Vink & Hallbeck, 2012; Zhang et al., 1996). Some authors, suggest that comfort is simply the absence of discomfort (Branton, 1993).

Kolcaba and Kolcaba (1991) suggest that both comfort and discomfort can be experienced simultaneously and to be in a state of comfort does not assume a complete lack of discomfort. Zhang et al. (1996) and Helander and Zhang (1997) proposed that a lack of discomfort does not necessarily lead to comfort as there are different underlying factors which would also need to be present for comfort to occur. They also suggest that a reduction in discomfort could lead to the perception of comfort, therefore implying agreement with Kuijt-Evers et al. (2005) who stated that discomfort will dominate comfort. In addition to this, Helander and Zhang (1997) suggest that high levels of discomfort can only be experienced if comfort levels are low and vice versa therefore indicating that the two constructs are not completely independent of each other. Figure 2-5 summarises these theories and definitions.

Some authors have associated comfort with unexpected positive experiences (Vink & Brauer, 2011) , a sense of well-being (Kolcaba, 1991; Kolcaba & Kolcaba, 1991; Oborne & Clarke, 1973; Richards, 1980; Tutton & Seers, 2003), satisfaction, ease, relief (Kolcaba, 1991; Kolcaba & Kolcaba, 1991; Tutton & Seers, 2003), pleasure (Kolcaba & Kolcaba, 1991) and relaxation (Zhang et al., 1996). Whereas discomfort has been associated with a lack of ease (Tutton & Seers, 2003) pain, soreness and fatigue (Zhang et al., 1996). It is worth noting that the domains in which these authors examined comfort and discomfort varied and therefore may impact on their definitions. For example, Kolcaba (1991) and Kolcaba and Kolcaba (1991) did work in the healthcare domain whereas Richards (1980) and Oborne and Clarke (1973) worked in the transport domain and Zhang et al. (1996) worked within the context of seating in office environments.

Those authors who suggest that comfort is a lack of discomfort (Branton, 1993; Hertzberg, 1958) imply that comfort is a state of neutral or no awareness of any positive or negative feelings. Kolcaba and Kolcaba (1991) suggest that whilst the relief from discomfort can be a definition of the word ‘comfort’, this does not equate to a state of comfort as it only implies a partial or temporary relief of discomfort.

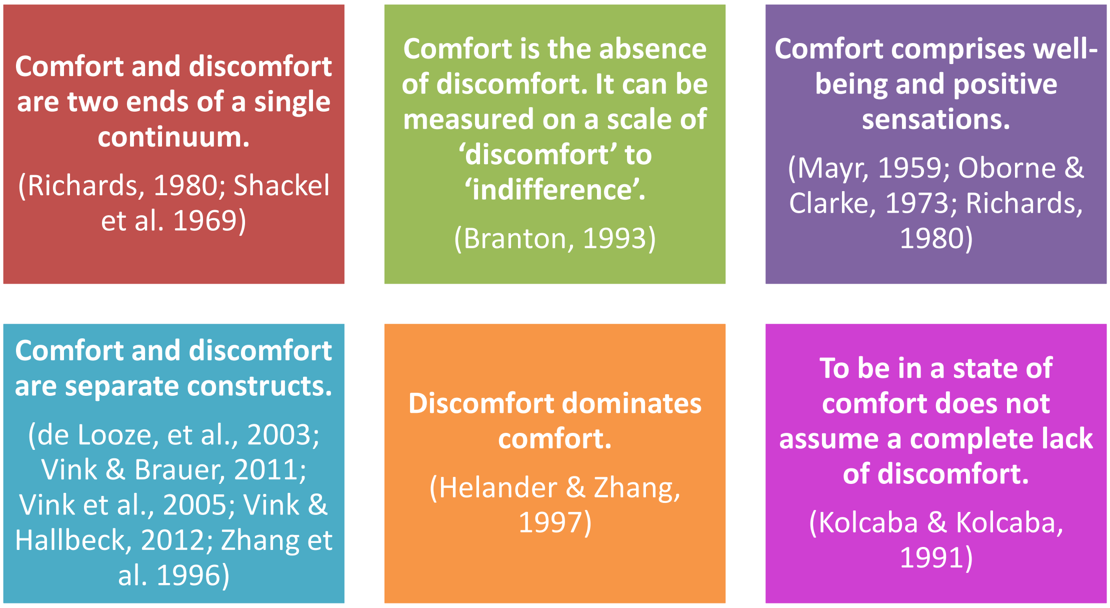

Figure 2-5 Summary of theories and definitions of 'comfort' and 'discomfort'

Whatever the definition of comfort and discomfort, there are always certain commonalities. Both comfort and discomfort are subjective concepts (De Looze et al., 2003). Comfort is always seen to be a positive and desirable state whereas discomfort is always viewed as an undesirable, negative state. Comfort and discomfort will always be an individual's affective reaction to a situation or environment (De Looze et al., 2003; Richards et al., 1978) and therefore can be affected by a number of different factors of varying natures (e.g. physical, physiological or psychological) (De Looze et al., 2003). Therefore it could be said that an environment or product, in itself, is not comfortable or uncomfortable but becomes comfortable or uncomfortable when used and sensed by a user (Vink et al., 2012; Vink et al., 2005a).

It should be noted that in this section, the words 'comfort' and 'discomfort' have been used with reference to a state, i.e. an effect of certain factors on a person. Kolcaba and Kolcaba (1991) suggest that comfort can be considered in terms of cause and effect. The causes could be defined as the factors which lead to this state. These factors are discussed with reference to passenger comfort specifically in section 2.3.4 of this chapter.

2.3.1. Factors affecting the experience of comfort and discomfort

A number of different models of comfort and discomfort have been developed. These are described and discussed in this section.

Figure 2-6 shows a model of comfort and discomfort which was proposed by De Looze et al. (2003). Consistent with Zhang et al. (1996) and Helander and Zhang (1997), this model differentiates between the underlying factors affecting comfort and discomfort as well as the ways in which these states manifest in a person. This model, views discomfort as a physical construct, affected by physical factors and manifesting in physiological or biomechanical responses. Conversely, it views comfort as an emotional state which is influenced by both physical and psycho-social factors.

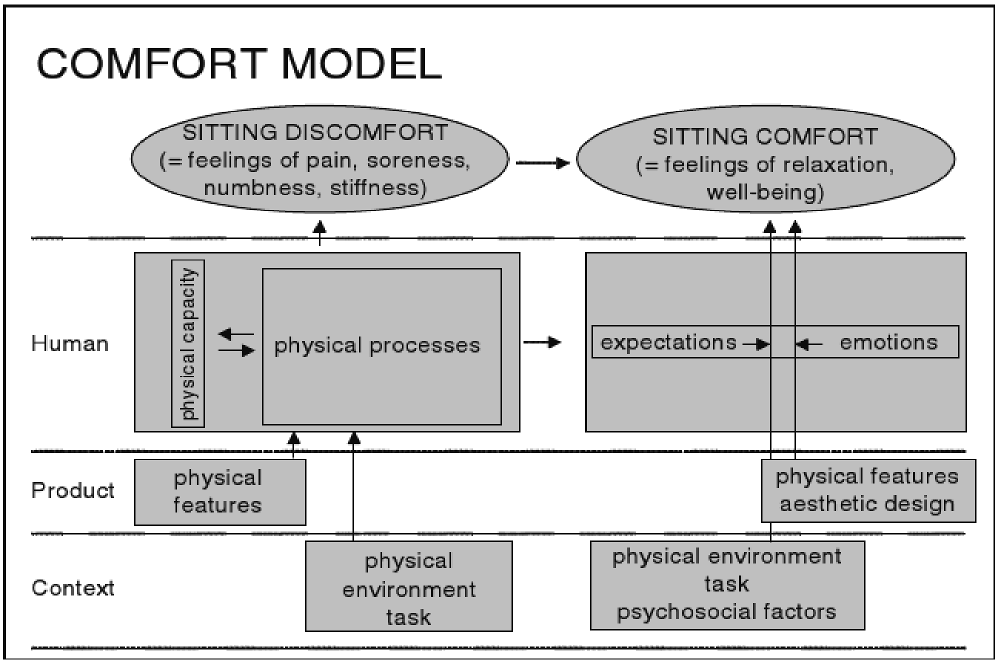

Figure 2-6 Theoretical model of comfort and discomfort taken from De Looze et al. (2003)

Vink et al. (2005a) and Vink and Brauer (2011) produced a simplified input/output version of the model produced by De Looze et al. (2003) (see Figure 2-7). It shows that within a certain environment, external stimuli are perceived as sensory inputs. These interact with a person's state (e.g. feelings or mood) or history (e.g.

expectations or past experiences) and produce an output which can either be discomfort (which is said to be due to physical factors), comfort or no discomfort (which is defined as a neutral state where a person is unaware of either comfort or discomfort).

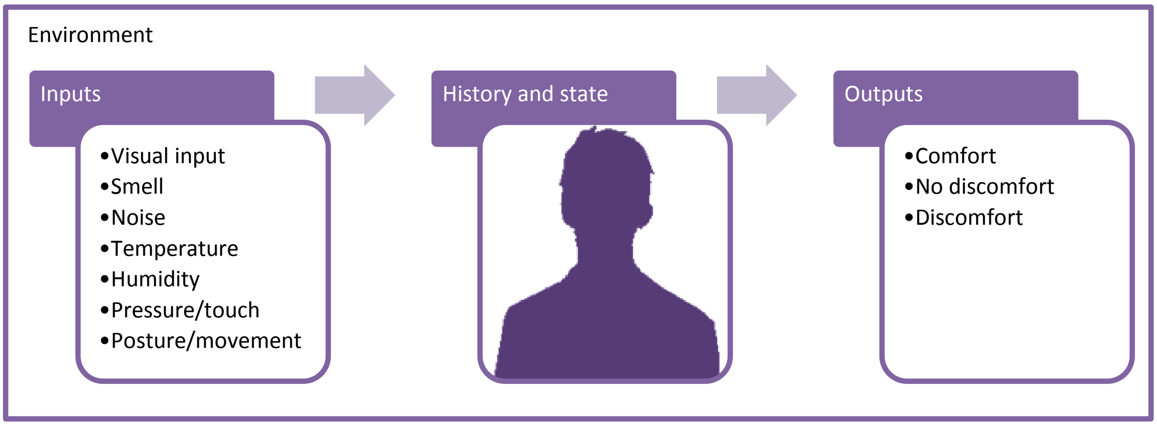

Figure 2-7 Model of comfort redrawn from Vink et al. (2005a) and Vink and Brauer (2011)

Moes (2005) developed a model based on pre-existing literature which can be used to explain the experience of sitting discomfort (see Figure 2-8). It states that in order for discomfort to be experienced a number of phases must occur. A person must interact (I) with something. This interaction will result in a physical effect on the body (E) which will then be perceived (P) and interpreted (e.g. as pain). If the outcome of this perception is not welcome (A), discomfort (D) will occur.

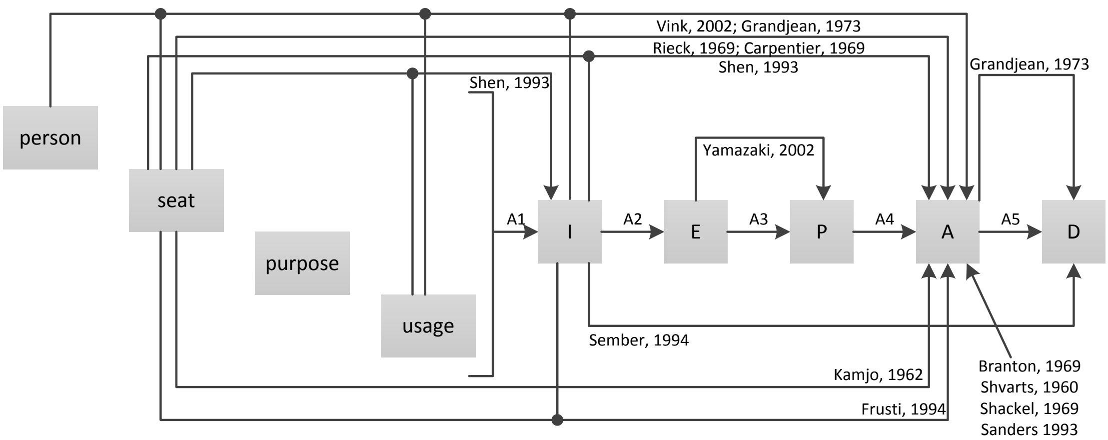

Figure 2-8 Comfort model redrawn from Moes (2005)

Vink and Hallbeck (2012) developed a model of comfort and discomfort (see Figure 2-9) which was published in a special section on product comfort in Applied

Ergonomics. This model drew inspiration from those of De Looze et al. (2003) and Moes (2005) along with other papers in the same special section. This model shows that interaction (I) with a product, which can be physical or non-physical in nature, can result in effects on the human body (H). The perceived effects (P) are influenced by the effects on the human body and also by expectations (E). These perceived effects are interpreted as comfortable (C), a neutral feeling (N) or uncomfortable (D). Discomfort may lead to musculoskeletal issues (M). The circle around expectations and comfort denotes a belief that these two elements of the model are linked to one another. Vink and Hallbeck (2012) note that comfort and discomfort are broad states and that these feelings can range from slight to extreme. They also suggest that people can feel both comfort and discomfort simultaneously.

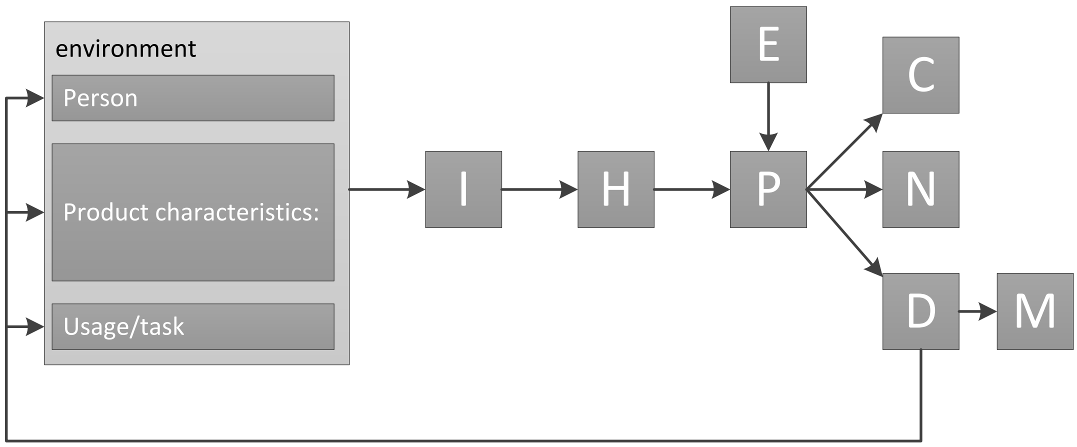

Figure 2-9 Model of comfort redrawn from Vink and Hallbeck (2012)

Whilst these models all differ in the way in which they explain comfort and discomfort, a commonality is that they all consider a person's interaction with their environment/a product which is then interpreted and has a resultant effect of comfort or discomfort. Therefore, considering the interaction between a person (and all intrinsic factors associated with them) and their environment is imperative when designing for comfort.

It is clear that comfort and discomfort are complicated concepts which are widely debated in terms of their definitions. The experience of comfort and discomfort is highly variable between different individuals and the interplay between the factors affecting such an experience is complicated and undefined. For the purposes of this research, it is useful to categorise both the experience of comfort and discomfort and the factors influencing these states. One such way of doing this is to consider comfort and discomfort in terms of their physical, social, psychological and environmental attributes as summarised in Figure 2-10.

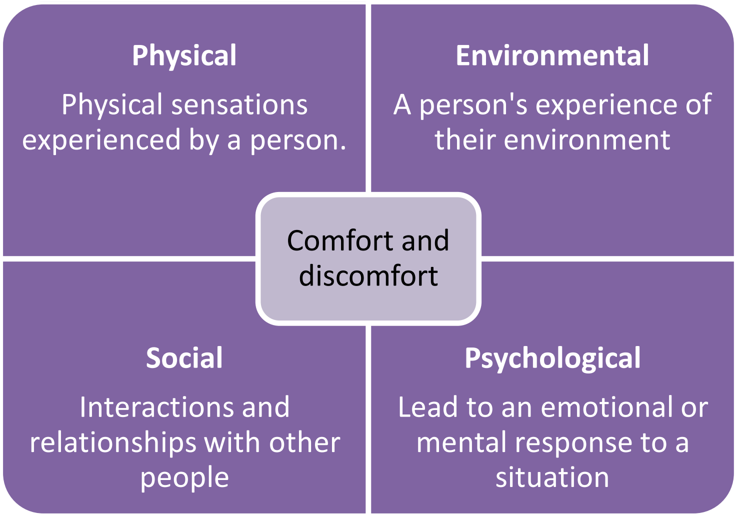

Figure 2-10 Facets of comfort and discomfort

Physical comfort and discomfort relates to bodily sensations (Kolcaba, 1992; Kolcaba, 1991). Within the aircraft context, this may be related to seating comfort (Richards & Jacobson, 1975), legroom and potential for movement (Vink et al., 2005c). Physical discomfort within the aircraft context may induce stress or ill health (Hinninghofen & Enck, 2006) such as leading to deep vein thrombosis (DVT) (Vink et al., 2005c).

Environmental comfort relates to the experience of the surrounding environment and may include lighting, noise levels, colours, temperature (Kolcaba, 1992; Kolcaba, 1991), air quality and vibrations (Mellert et al., 2008; Quehl, 2001). This is closely linked with physical comfort as environmental factors could lead to changes in bodily sensations and therefore changes in physical comfort.

Social comfort relates to relationships and interactions with other people (Cole et al., 2008; Kolcaba, 1992; Kolcaba, 1991). This also includes a shared understanding between the inhabitants of spaces as to what constitutes comfort. This understanding may lead to people compromising their comfort for the sake of collective comfort (Cole et al., 2008). Social comfort within the context of air travel may also relate to personal space, presence of travel companions or cabin crew service (Patel et al., 2012).

Psychological factors are those which lead to an emotional or cognitive response to a situation. They may include expectations, fears, perceived pleasantness or unpleasantness or establishing a memory of prior experiences which may affect subsequent experiences. In the context of air travel, this may also include attitudes towards flying (Richards & Jacobson, 1975; Richards et al., 1978).

2.3.2. The challenge of designing for comfort in flight

There are a number of reasons why it may be challenging to design comfortable experiences in an aircraft. The subjectivity of comfort contributes to this challenge, as it will lead to individuals having different interpretations of what constitutes a comfortable experience (Vink et al., 2005c) as well as placing different levels of importance on the factors which affect comfort and discomfort (Vink et al., 2012; Vink et al., 2005a; Vink et al., 2005c).

Comfort is dependent on both factors relating to the flight environment and those which are intrinsic to the passenger (Richards & Jacobson, 1975; Richards et al., 1978). Comfort is also benchmarked against a person's previous experiences (Vink et al., 2005a). The factors which are intrinsic to passengers and their previous experiences are both difficult to predict and change. A product or environment, in itself, cannot be comfortable or uncomfortable. This is something that results from using the product or environment (Vink et al., 2012) and an individual's subjective experience of it.

The complex interplay between the factors which affect comfort and discomfort and the way in which they are weighted is not yet understood. Therefore it is not possible to know how any given person will react to a product or environment with respect to comfort or discomfort (Vink et al., 2012; Vink et al., 2005a). The exact causes of comfort and discomfort are also not known and there is not a defined design process in order to ensure user comfort (Vink et al., 2005c). In addition, the factors which affect comfort or discomfort may not act independently of each other. Therefore, the attenuation of one discomfort inducing factor may highlight another. For example, attenuation of noise levels may highlight vehicle motion (Oborne, 1978a). This may present challenges in designing for comfort, though it is not impossible to design experiences which are perceived as comfortable by a large proportion of people is not possible.

2.3.3. Passenger comfort

There are very few published reports in the public domain regarding aircraft passenger comfort and much of this research was published in the 1960s and 1970s. It is likely that data is collected by both airlines and aircraft manufacturers but that this information is not in the public domain due to industry competition and commercial sensitivity (Vink & Brauer, 2011). As a result this section does not focus solely on aircraft passenger comfort but rather, the comfort of passengers on various modes of public transport. It is acknowledged that there may be differences in the nature of journeys taken and the attitudes of passengers travelling on differing modes of public transport. It is also acknowledged that there are some contextual factors which are specific to flight, including being subject to confined spaces, potentially for prolonged periods of time with a limited opportunity to escape from uncomfortable situations due to there being a finite number of seats available. These contextual factors may lead to differences in the comfort experiences of passengers using other modes of public transport.

It has been suggested that passenger comfort plays an important role in the acceptance of transport systems (Richards, 1980; Richards & Jacobson, 1975). Similarly, studies have shown strong positive correlations between comfort and intention to fly again (Richards & Jacobson, 1975; Vink et al., 2012). Vink and Brauer (2011) also suggest that efforts to enhance passenger comfort is one strategy adopted by airlines to increase ticket sales. Therefore, acceptance of transport systems is important in order to achieve passenger satisfaction and repeat business.

Enhancing passenger comfort can also add value in terms of enabling passengers to not only move between locations but use their transit time to their benefit (e.g. to relax or work) (Mayr, 1959). Therefore using the cabin design to support activities may enhance comfort. The influence that activities have on comfort and that comfort has on performance of activities is discussed in section 2.3.4. of this chapter.

The comfort experience for passengers can be categorised in a number of ways. Mayr (1959) divides passenger comfort into three constituent parts: riding comfort (experienced inside a vehicle – see Figure 2-11), local comfort (experienced at transport interchanges) and organisational comfort (e.g. reliability, frequency and connections). The research presented in this thesis was only focussed on enhancing riding comfort but it is acknowledged that local and organisational comfort can also affect riding comfort. Oborne (1978b) views passenger comfort in two ways: a holistic view of the journey from departure to arrival or separate reactions to different elements of the environment. Vink and Brauer (2011) suggest four phases of the passenger experience: establishing expectations, comfort at first-sight, short term comfort and long term comfort. They suggest that consideration of all of these phases of comfort and discomfort are important and each require different approaches. For example, if focus is given to long-term comfort without considering comfort at first-sight, the improvements will not effectively influence sales. Similarly, focussing on comfort at first-sight only may lead to disappointment resulting from high expectations.

Mayr (1959) developed a model of riding comfort (see Figure 2-11), representing the relationship between a passenger and the vehicle in which they are travelling. It contains factors which are intrinsic to a passenger such as fears, attitudes and physiological functions (e.g. eyesight or hearing) and those which are related to the vehicle such as aesthetics, lighting, noise and temperature. Whilst some of these factors (such as those which are intrinsic to passengers) are difficult to change, others (such as those related to the cabin environment) can be changed more easily in order to enhance comfort.

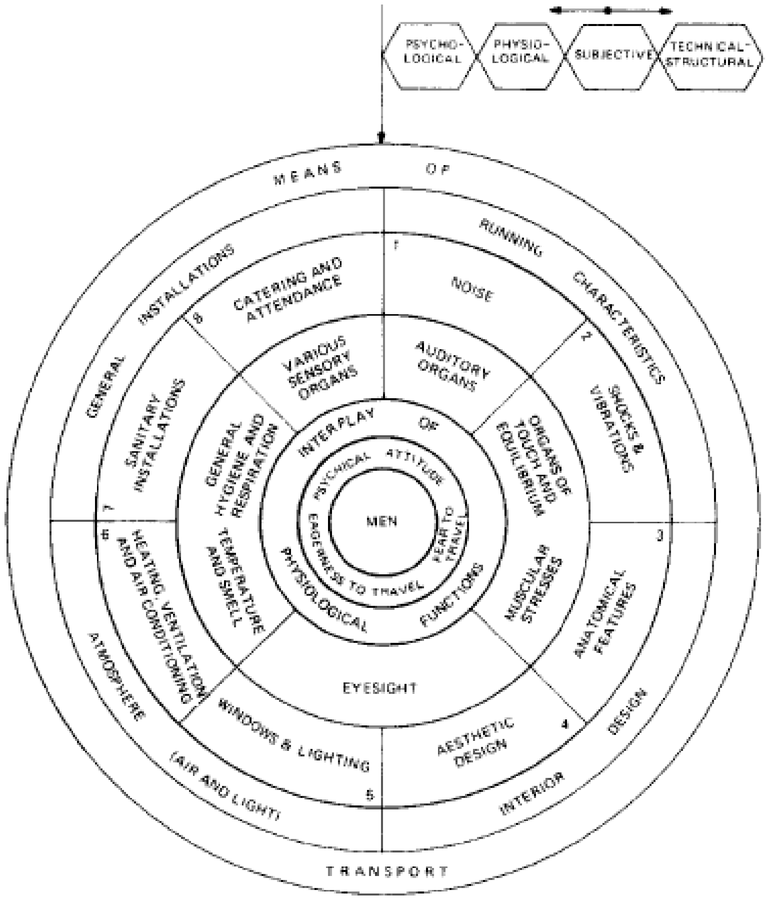

Figure 2-11 Circle of riding comfort taken from Mayr (1959)

An alternative model developed by Patel et al. (2012) (see Figure 2-12) categorises the factors which may affect an aircraft passenger’s experience of comfort or discomfort to include those which are intrinsic to the passenger and those which relate to the aircraft. It also considers passengers’ activities, the effect of other passengers, perception of control and adaptive behaviours.

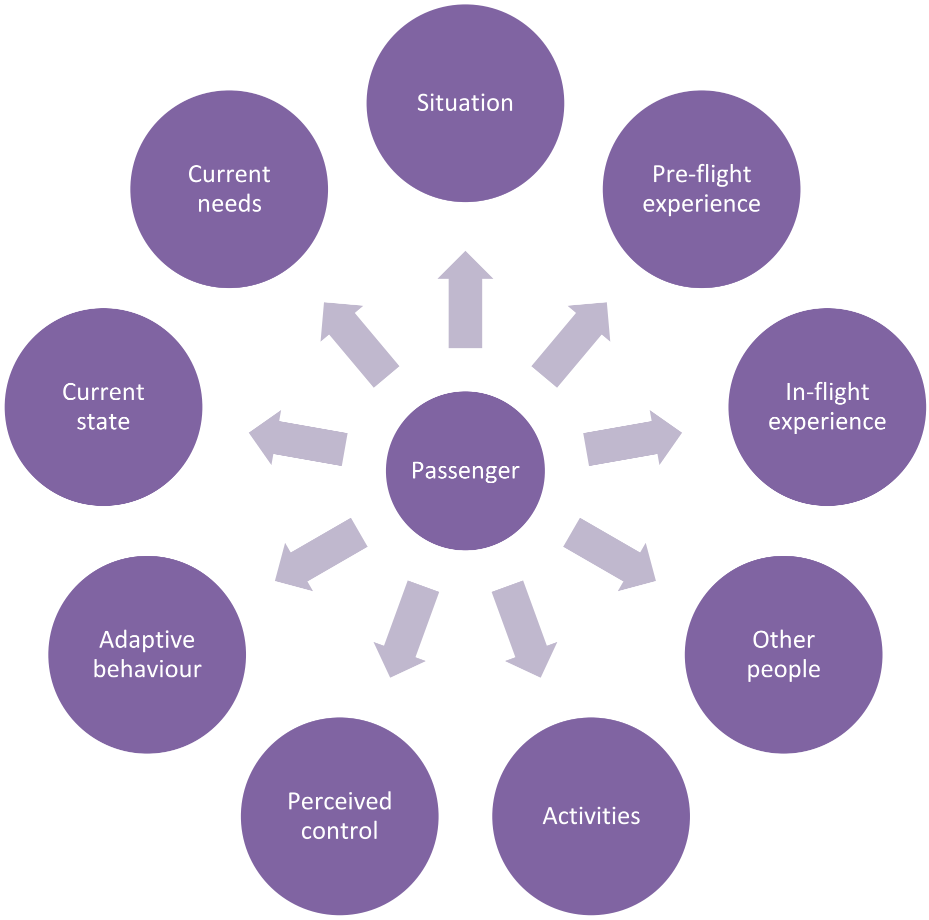

Figure 2-12 Model of aircraft passenger comfort redrawn from (Patel et al., 2012)

Ahmadpour et al. (2014a) put forward another model of passenger comfort which illustrates the relationship between the contextual factors of the cabin interior (such as spatial elements, other people and environmental factors) and the passengers' perceptions of these factors (see Figure 2-13). Due to the dynamic nature of flight, the contextual factors are constantly changing, which in turn changes the passengers' perceptions, emotions, comfort and expectations for future flights (Ahmadpour et al., 2014a).

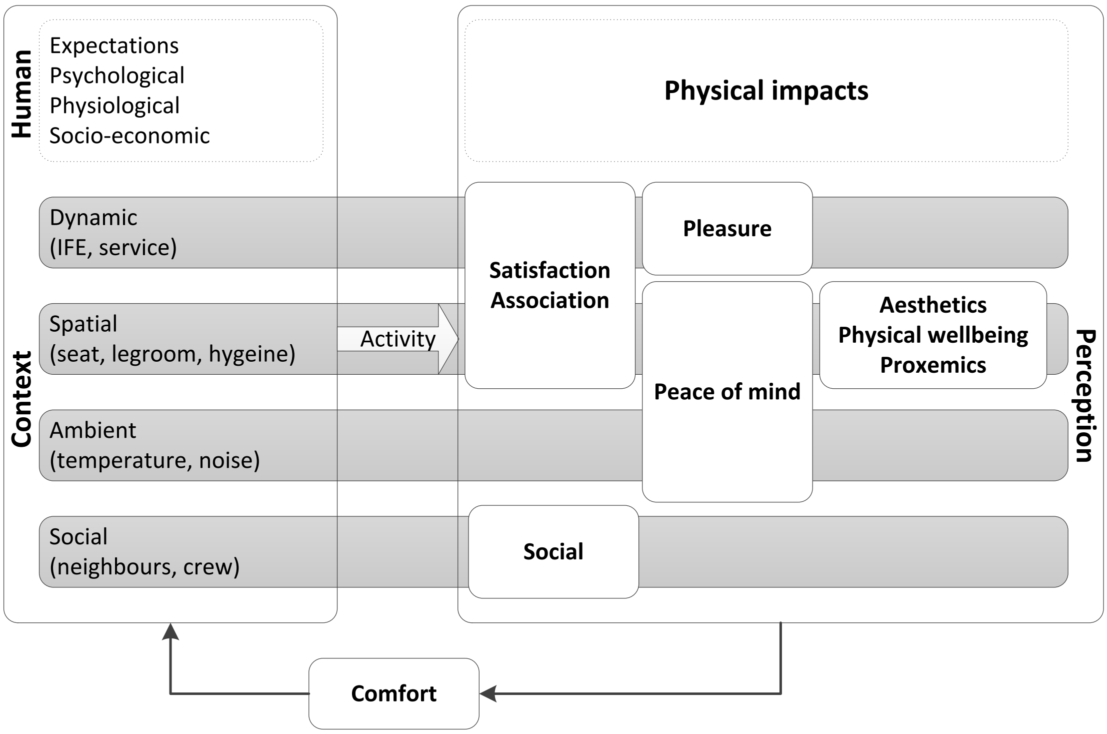

Figure 2-13 Passenger comfort experience model redrawn from (Ahmadpour et al., 2014a)

Drawing on these models, the factors which may affect in-flight passenger comfort are discussed in section 2.3.4. The influence of pre-flight experience on in-flight experience is not discussed in this section as the current research is focussed only on enhancing the in-flight experience through the use of VR in-flight. Therefore, making changes to the pre-flight experience is out of the scope of this research. However, it is acknowledged that a good or a bad pre-flight experience can affect passengers' comfort or discomfort experiences in-flight (Bor, 2007; Konieczny, 2001).

2.3.4. Factors affecting passenger comfort and discomfort

Some of the factors which contribute to passenger comfort are intrinsic to the passengers themselves. This may include factors relating to their demographic, physical factors, physiological factors, their health and well-being, psychological factors, attitudes or expectations (Bor, 2007; Patel et al., 2012). Factors such as gender, anthropometry, susceptibility to motion sickness, expectations and attitudes towards flying have all been found to affect an individual's perception of comfort or discomfort (Richards et al., 1978). Whilst there are many elements which contribute to an overall experience of comfort or discomfort, many of the factors which are intrinsic to passengers cannot be changed (Vink & Brauer, 2011). Unlike the factors relating to the transport system, these intrinsic factors can be difficult to elicit (Oborne & Clarke, 1973). Different people will experience identical environments in different ways due to these factors and may therefore experience different subjective levels of comfort or discomfort. This presents a challenge when designing for comfort and highlights the importance of considering individual differences.

Comfort during flight has been found to be related to attitudes towards flying. For example, in studies by Richards and Jacobson (1975) and Richards et al. (1978), findings indicated that people who like flying are more likely to rate their comfort as higher than those who do not like flying, those who are indifferent to it or those who fly because they 'have to'. Passengers who do not like flying may be more likely to notice the negative aspects of their flight experiences than people who do like flying. Therefore distracting people from the knowing that they are taking a flight may be a method of increasing passenger comfort for those who do not enjoy flying. This is one of the concepts which is explored in the research presented in this thesis.

Expectation is also thought to play a part in the experience of passenger comfort (Oborne, 1978a). Vink and Brauer (2011) discuss the impact of first impressions on comfort as these lead to expectations which may or may not be satisfied. An example of this is a study which found that two car seats which were identical apart from the colour of the fabric used were rated differently in terms of their comfort (Bubb 2008, cited by Vink & Brauer, 2011). Similarly, Vink and Brauer (2011) found no differences between comfort associated with economy class seats and the comfort associated with business class seats. This could be attributed to the expectations of the passengers flying in these cabin classes, i.e. that business class passengers may have had higher expectations of the seating comfort than economy class passengers. Fazlollahtabar (2010) speculated that selling the same seats at different prices would also result in different comfort ratings as this would change people's expectations. Therefore designing for comfort at first sight may have a positive influence as long as these expectations are fulfilled in the long term.

Also linked to expectation are past experiences. Vink (2014) highlighted the relativity of comfort and discomfort as constructs, noting that comfort is related to a person's feelings during the period of time leading up to the present. He went on to speculate on how designing travel experiences which are less comfortable at times could lead to heightened awareness of comfort during more comfortable moments. This could, in turn, lead to a greater overall level of comfort.

It has also been suggested that emotions may influence perceived comfort. Ahmadpour et al. (2014b) identified four emotion groups which may do this: prospect-based (e.g. disappointment, satisfaction or relief), wellbeing (e.g. joy, pleasure or feeling good or bad), wellbeing/attribution compound (e.g. anger or gratitude) and attraction (e.g. love/like). These emotion groups were then associated with elements of the flight context including seating, legroom, service, IFE and neighbouring passengers. The findings indicated that passengers' emotions are influenced by elements of the flight experience, in particular, seating and services, and that the cabin design can be manipulated in order to induce positive emotions.

Another group of factors which may affect passenger comfort are those which relate to the flight situation, for example, the purpose for travel, the flight time and duration, the presence or lack of travel companions, the cost of the trip, who has paid for the trip, the type of airline and aircraft, cabin class, the airports travelled through etc. (Patel et al., 2012). Like many of the intrinsic factors, these factors are often unique to individuals and can be variable in terms of the way that they affect a passenger's level of comfort. For example, journey time can affect passenger comfort. Oborne (1978a) speculated that on long haul flights, more discomfort may be experienced than on shorter flights. Mayr (1959) suggested that the desirable level of comfort will change as a function of the journey time. That is, for a long journey, a greater level of comfort will be required than a short journey. Extending this further, Oborne (1978b) proposed that alongside journey time, the desirable level of comfort is also determined by the reason for travel and the passenger's expectations of journey comfort. The match or mismatch between the desired level of comfort and the actual situation could impact on how a passenger perceives their overall comfort on a given flight.

Also investigating the intrinsic factor of expectation, Gilbert and Wong (2003) found that people travelling for business often had varying levels of expectations for different aspects of the flying experience. For example, business travellers have low expectations for punctuality, quality of food/drinks and IFE but high expectations for convenient timetabling and frequency of flights. Conversely, holidaymakers have high expectations of food/drink quality and IFE amongst other factors. These expectations could be linked to their planned activities (which are discussed later in this section) but could also emerge as a result of their attitudes and expectations which are influenced by situational factors such as their purpose for travel or the cost of the flight.

Environmental factors can also affect passenger comfort or discomfort. These may include noise, lighting, temperature, humidity, air quality, pressure changes, motion or smells (Ahmadpour et al., 2014a; Hinninghofen & Enck, 2006; Huang & Griffin, 2014; Richards & Jacobson, 1975; Richards et al., 1978; Vink & Brauer, 2011; Vink et al., 2005a). Hygiene and cleanliness of the cabin can also affect levels of comfort (Vink et al., 2012).

Factors relating to seating and the space surrounding a person often impact on comfort. This may include the seat itself or the legroom provided (Ahmadpour et al., 2014a; Bor, 2007; Hinninghofen & Enck, 2006; Richards & Jacobson, 1975; Richards et al., 1978; Vink et al., 2012). Factors such as adjustable headrests, armrests and seat upholstery all contribute to seat comfort (Vink et al., 2012). Groenesteijn et al. (2014) suggest that the design of seating should support the activities that passengers wish to carry out during their journeys. The position of seat-back pockets, reclined seats and having an emergency exit seat contribute to the amount of available legroom (Vink et al., 2012). Seat position, in particular with respect to toilets or the aisle, can also influence comfort or discomfort (Budd, 2011). Moreover, the space associated with the cabin as a whole can influence comfort. For example, Vink et al. (2012) found that wide-bodied aircraft are perceived to be more comfortable than narrower-bodied aircraft. It has also been speculated that comfort ratings for seats will increase when placed within more roomy surrounding environments and decrease when placed in smaller spaces (Fazlollahtabar, 2010).

Related to seating and space is the presence of other passengers and how they affect the comfort of others. For example, if the seat in front is reclined, this will have a negative impact on the passenger behind due to a reduction in space. In contrast, being positioned next to an empty seat will have a positive impact due to the increased amount of space surrounding the passenger (Vink et al., 2012). Passengers who do not stay within the boundaries of their own seat (i.e. breach the personal space of other passengers) can also cause discomfort to others (Patel et al., 2012). In relation to this, studies in the rail domain have found that people would choose to stand up rather than take a seat next to another passenger (Evans & Wener, 2007). In addition, proximity to other passengers, the inconsiderate behaviours of other passengers, their hygiene, their inappropriate responses to social cues (Bor, 2007; Budd, 2011; Patel et al., 2012) and undesired conversation (Bor, 2007) can have a negative impact on passenger comfort. In addition, a passenger’s feelings of control can be affected by other passengers which can, in turn, affect their comfort. For example, control over being able to walk away from their designated seat without disturbing other passengers (Ahmadpour et al., 2014a).

As well as proximity to, and interaction with, other passengers, interaction with the cabin crew can influence a passenger’s comfort experience (Ahmadpour et al., 2014a; Bor, 2007). Vink et al. (2012) found a positive correlation between passenger comfort and positive experiences with the cabin crew. Factors associated with the cabin crew may include helpfulness, friendliness and the information provided by them.

The provision and quality of the IFE can also impact on in-flight comfort (Ahmadpour et al., 2014a; Bor, 2007; Budd, 2011). In addition, the activities that a person is trying to perform whilst travelling can both influence and be influenced by comfort. A study by Richards et al. (1978) found that sleeping and writing are more difficult activities to carry out in-flight than reading or concentrating. They also found that comfort is correlated with an ability to carry out these activities. Therefore, frustration or discomfort could result if a passenger's ability to carry out an activity is impaired (Oborne, 1978a) and comfort levels can also determine the ease of performing activities in-flight (Richards & Jacobson, 1975). In contrast, a passenger may be so immersed in an activity that they do not attend to their discomfort (Richards et al., 1978).

This section has provided an overview of the factors which may affect in-flight passenger comfort which are summarised in Figure 2-14. The darker circles show the areas which will be investigated in the research presented in this thesis. The factors which affect passenger comfort vary in their nature, the sensory modalities through which they are perceived and their persistence or ability to change over the course of a flight. At any given point in a flight, a number of factors may be having an influence on an individual passenger's comfort. As already discussed, the way in which these factors interact with each other is not known. The experience of comfort or discomfort is an individual and subjective one. Therefore the emphasis that each passenger places on the factors affecting their comfort or discomfort is variable and changeable even within the individual. This presents a challenge in terms of enhancing passenger comfort and distracting from discomfort.

Figure 2-14 Factors affecting passenger comfort

2.4. **Virtual environments to distract people from pain**

There have not been any studies which have investigated the way in which common sources of discomfort which may be experienced in an aircraft environment can be alleviated by using or viewing VEs. However, a number of studies have investigated how pain (which could be viewed as an extreme type of discomfort) perception can be influenced by VEs. Many of these studies have been carried out in clinical settings with patients undergoing painful medical procedures such as treatment for burns (e.g. Hoffman et al., 2000; Hoffman et al., 2001b; Konstantatos et al., 2009; Sharar et al., 2007), dental treatment (e.g. Aminabadi et al., 2012; Hoffman et al., 2001a) or cancer care (e.g. Gershon et al., 2004; Nilsson et al., 2009). Other studies have been carried out in controlled experimental settings, inducing pain through means such as a cold pressor (e.g. Dahlquist et al., 2010; Dahlquist et al., 2007; Dahlquist et al., 2009; Jameson et al., 2011; Law et al., 2011; Loreto-Quijada et al., 2011; Raudenbush et al., 2011; Weiss et al., 2011). These controlled studies have tended to focus on specific elements of the distractors such as levels of interaction (e.g. Dahlquist et al., 2007; Law et al., 2011; Raudenbush et al., 2011; Weiss et al., 2011), levels of immersion in the VE (e.g. Dahlquist et al., 2009; Hoffman et al., 2004) or differences between first and third person visual perspectives (e.g. Dahlquist et al., 2010).

It should be noted that the interpretation of the term 'VR' is varied within the studies which are reviewed in this section. Some studies have made use of interactive VR whereas others have used passive VR. Some participants have played video games whilst wearing an HMD and some have watched films through an HMD. As a result, the review highlights the media which participants were exposed to in these studies.

The following sections will discuss the theories which may explain why VEs can be an effective distractor from pain. They also discuss studies which have used VEs to distract people from pain in both clinical and experimental settings.

2.4.1. Theoretical basis for understanding distraction from pain

Various theories have been put forward which may explain why distraction may be an effective means of reducing pain. One such theory is the Gate Control Theory which suggests that level of attention to the pain, emotion associated with the pain and previous experiences of the pain will affect a person's perception of the pain (Melzack & Wall, 1965). This was later extended, to acknowledge that in order for a stimulus to be perceived as painful, an individual must attend to it. As attentional capacity is limited, if another attentionally demanding stimulus is provided, this will divert attention away from the painful stimulus. The greater the need for attentional capacity, the more effective this stimulus will be in terms of distracting from the painful stimulus (McCaul & Malott, 1984). This is consistent with Kahneman's (1973) capacity model of attention which proposed that an individual has a limit on their attentional capacity and when the total attentional capacity is not large enough to meet the demands, task performance will decline.

Another theory which may explain why VEs can be effective at reducing pain is Multiple Resources Theory (Wickens, 2008). This proposes that a person has multiple resources which can be used to process information. These resources vary in terms of their sensory nature. Therefore, two stimuli which use the same sensory resource will interfere more with each other than two tasks which differ in sensory nature (Wickens, 2002). Therefore a distractor which uses the same sensory resource as the pain stimulus may alleviate pain more effectively than a distractor which uses different sensory resources. Drawing on this theory, Dahlquist et al. (2007) suggest that visual or auditory stimuli would be ineffective at distracting from pain due to its kinaesthetic and tactile nature.

Eccleston (1995) and Eccleston and Crombez (1999) argued that the capacity and resource models of attention do not fully explain the way in which attention can be diverted from pain. Eccleston and Crombez (1999) proposed a cognitive-affective model which suggested that people are evolutionarily predisposed to attend to pain as a mechanism for noticing and escaping from harm. Eccleston (1995) argued that as pain processing demands central attentional resources, stimuli which are designed to distract from pain should also make use of central attentional resources. Therefore these stimuli should be complex and should not be mundane or repetitive.

2.4.2. VEs to treat clinical pain

Although not directly applicable to the research presented in this thesis, it is worth noting some examples from the literature in which VEs were used to treat clinical pain. Malloy and Milling (2010), Wiederhold and Wiederhold (2007) and Li et al. (2011) have all carried out extensive reviews of this body of literature. The research in this area could be viewed as more generalizable than experimentally induced pain due to participants having varied experiences in terms of types or levels of pain (Malloy & Milling, 2010) and medication provided. This is also true of the aircraft context where each individual passenger would have very different comfort or discomfort experiences as a result of being exposed to different comfort altering stimuli. Therefore the findings of literature relating to clinical pain are interesting within other real-world, uncontrolled contexts.

The findings of a study by Hoffman et al. (2000) indicated that when adolescent burns patients underwent treatment, 3D interactive VR presented through an HMD was more effective at distracting from pain than a video game. However, the novelty of VR compared to video games may have had some impact on the results of this study. One explanation for this is that users experienced a greater degree of presence in immersive VR than when playing video games and therefore their attention was drawn to the distracting stimulus. The effect of presence and immersion in VR on distraction from pain is further discussed in section 2.4.3.

Subsequent studies with burns patients have shown that VEs presented through an HMD is effective at reducing pain compared to no distractor (Hoffman et al., 2001b; Sharar et al., 2007) and remained effective during repeated use (Hoffman et al., 2001b) therefore indicating that novelty of VR technology is not a reason for its effectiveness at distracting from pain. Contrary to these studies, Konstantatos et al. (2009) found that VR increased pain intensity. The main difference between this study and those reported in Hoffman et al. (2001b) and Sharar et al. (2007) was that rather than providing a VE which aimed to distract participants, this study provided a VE which aimed to relax participants. Therefore, VR distraction may be a more effective approach than VR relaxation when aiming to minimise subjective experience of pain. This finding is consistent with that of Simmonds and Shahrbanian (2008) who discovered a positive correlation between ratings of engagement and pain threshold in stroke patients who were exposed to experimentally induced pain using a thermode. The findings of Simmonds and Shahrbanian (2008) and Hoffman et al. (2001b) imply that engaging or distracting VEs will demand greater attentional resources therefore leaving less capacity available to attend to painful stimuli.

VR has also been investigated as a means of reducing pain during cancer treatments, in particular for patients who are children (e.g. Gershon et al., 2004; Nilsson et al., 2009). Gershon et al. (2004) compared the effectiveness of a game played through an HMD, the same game played on a computer monitor and no distractor on the experience of pain. Their findings revealed that the HMD condition led to a significantly reduced pulse rate compared to the no distraction condition. However, no differences were found between the computer monitor condition and the other two conditions. There were also no differences found in self-reported ratings of pain. This indicates that the ability of an HMD to occlude the environment does not influence pain perception. Similarly, Nilsson et al. (2009) also did not find any differences in self-reported pain between conditions where children either had no distractor or played a video game which was displayed on a computer monitor.

Studies have also been carried out with dental patients (e.g. Aminabadi et al., 2012; Hoffman et al., 2001a). VEs presented on an HMD were found to be more effective than a film or no distraction at reducing subjective pain ratings during dental treatment (Hoffman et al., 2001a). However, research has also shown that videos alone are enough to lead to a reduction in subjective ratings of pain (Aminabadi et al., 2012).

2.4.3. VR to alleviate experimentally induced pain

As stated in section 2.4, studies aiming to distract from experimentally induced pain have tended to focus on specific elements of the distractor such as levels of immersion, interactivity or visual perspective.

Dahlquist et al. (2010) conducted a study which involved playing a video game from a first and a third-person perspective with an HMD whilst carrying out a cold pressor task. The findings revealed that although the participants felt more present in the first-person perspective condition, there were no differences in pain tolerance. Both game conditions did improve pain tolerance compared to a baseline of no distractor, therefore questioning the degree to which presence is necessary in order to reduce pain. In contrast, Hoffman et al. (2004) used pain applied by a thermode to compare 'high tech' and 'low tech' VR (which varied in terms of immersiveness, interactivity, resolution, sensory inputs and head tracking) and demonstrated that there was a positive correlation between levels of presence and pain reduction. A cold pressor study with children investigating the effect of a VE displayed on a computer screen compared to a VE displayed on an HMD and a no distraction condition found that VEs in general had a positive effect on pain tolerance and threshold. For older children, the HMD had a greater effect than the computer screen whereas for younger children, the effect of these two conditions was the same (Dahlquist et al., 2009).

Studies have revealed that both interactive and passive distraction (playing a video game through an HMD compared to watching the same video game with no interaction) can increase pain tolerance during a cold pressor task compared to a baseline of no distraction. In addition, this effect is greater for interactive distraction (Dahlquist et al., 2007; Law et al., 2011). A similar study was also carried out but using a video game which was displayed on a television. The findings of this study were consistent with those of Dahlquist et al. (2007) and Law et al. (2011), revealing that pain tolerance was higher for both interactive and passive distractors compared to a no distraction condition (Weiss et al., 2011).

Another study was carried out comparing playing a Nintendo Wii game (active distractor), watching television (passive distractor) and no distractor during a cold pressor task (Jameson et al., 2011). It was found that the active distractor increased pain tolerance and reduced subjective pain intensity compared to the other two conditions. Similarly, Raudenbush et al. (2011) found that subjective ratings of pain decreased and pain tolerance increased when playing a Nintendo Wii game during a cold pressor task compared to a no distractor condition. It is possible that differences in the findings between the study by Jameson et al. (2011) and those by Dahlquist et al. (2007) and Law et al. (2011) are due to confounding variables caused by different stimuli being used as distractors in the active and passive conditions. The passive distractor may also have been less effective if the participants were less interested in the television programme selected.

Dahlquist et al. (2007) speculated that the difference in effectiveness between interactive and passive distraction could be due to the additional modalities of sensory input (i.e. tactile and kinaesthetic) when using a physical controller. Another proposed reason for the increased effectiveness of interactive distraction compared to passive distraction is the addition of an active cognitive processing element of decision making (Dahlquist et al., 2007; Law et al., 2011).

2.5. **Chapter summary**

This chapter has reviewed literature from three distinct areas of research: user experience, comfort and distraction from pain. To the author's knowledge, the concept of using VEs to enhance passenger comfort and experience in aircraft is new. In addition, the use of VEs to distract people from common sources of discomfort has not been investigated. However the use of VEs to distract people from pain has been extensively researched as have the factors which contribute to passenger comfort. This literature review has identified that the use of VEs can be an effective means of distracting people from pain which is either clinical or experimentally induced and therefore may also be an effective way of distracting people from discomfort. It is known that for many aircraft passengers, flying can be uncomfortable but changing the physical parameters of an aircraft to improve comfort can be expensive. There is an obvious gap in the research for determining whether VEs can be used to distract passengers from commonly experienced sources of discomfort such as those caused by environmental factors, other people or the physical parameters of the space surrounding a person. The aircraft environment is extreme in terms of there being limited opportunities to escape from uncomfortable situations and being exposed to such situations for prolonged periods of time. Therefore this environment would be a good test bed from which to investigate the effect of VEs on passenger comfort.

The research presented in this thesis will draw from research in the fields of UX, comfort and distraction from pain in order to investigate the ways in which VEs can be used to enhance passenger comfort and experience and distract people from common sources of discomfort which may be experienced in aircraft environments.

3. METHODOLOGY

3.1. Introduction

This chapter presents the methodology used in the research presented in this thesis. The chapter begins with a review of methods and tools which have been used in previous studies to measure comfort and discomfort. It then describes the methods used in this research, relating these to the research objectives. The chapter concludes with descriptions of the equipment used to carry out this research.

3.2. Measuring comfort and discomfort

This section reviews the approaches taken in the literature to measuring comfort and discomfort (in general rather than specifically with respect to transport), including both subjective and objective measures (e.g. physiological or performance measures). Oborne (1978b) noted that when selecting methods, consideration should be given as to whether the aim is to measure overall journey comfort or the comfort associated with individual aspects of the environment.

As discussed in chapter 2, there is some debate about whether the experience of comfort and discomfort are based on the same underlying factors. As a result, some existing measures assess only comfort or only discomfort whilst others measure both simultaneously. These measures are described in the following sections.

3.2.1. Subjective measures

Due to the subjective nature of comfort, Richards et al. (1978) argued that the best way to measure comfort is to ask people to report how comfortable they are. Subjective measures for comfort and discomfort can be broken down into the categories of physical, social, psychological and environmental comfort/discomfort (see Lewis et al., 2012 for examples of these). This section looks more generally at the design of these scales, rather than measures of comfort or discomfort which are specific in their nature (e.g. environmental comfort, social comfort etc.).

A commonly used group of tools designed to subjectively evaluate physical discomfort are body maps. Two examples of these are the Body Part Discomfort (BPD) Scale (Corlett, 2005; Corlett & Bishop, 1976) and the Localised Musculoskeletal Discomfort (LMD) scale (Van der Grinten & Smitt, 1992). These tools provide respondents with a schematic of the human body which is divided into segments. Participants are asked to mark where they feel discomfort. When using the BPD, participants are also asked to provide an overall comfort/discomfort rating on a seven-point scale with the anchors ‘extremely comfortable’ and ‘extremely uncomfortable’ (Corlett & Bishop, 1976). In the LMD scale, participants used an 11-point scale with the anchors ‘no discomfort’ to ‘extreme discomfort’ (Van der Grinten & Smitt, 1992). The research presented in this thesis is not only concerned with comfort and discomfort which is physical in nature but is more generally related to the perceived experience of comfort and discomfort. As a result, body maps were felt to be too specific in nature to be used as a means of measuring comfort/discomfort in this research.

Another scale designed to measure comfort/discomfort was the General Comfort Rating scale shown in Figure 3-1 (Shackel et al., 1969). However, the validity of this scale was brought into question by Oborne and Clarke (1975) due to the inappropriate or inaccurate ordering of the points on the scale.

I feel completely relaxed
I feel perfectly comfortable
I feel quite comfortable
I feel barely comfortable
I feel uncomfortable
I feel restless and fidgety
I feel cramped
I feel stiff
I feel numb (or pins and needles)
I feel sore and tender
I feel unbearable pain

Figure 3-1 The General Comfort Rating scale (Shackel et al., 1969)

Numerous studies have simply asked participants to rate their levels of comfort and/or discomfort on scales which make reference to extreme levels of comfort or discomfort. Some studies have used scales which measure both comfort and discomfort on a single scale with anchors which refer to extreme levels of comfort and discomfort (e.g. Corlett & Bishop, 1976; Richards, 1978; Richards & Jacobson, 1975). Others authors, such as Vink et al. (2012) and Van der Grinten and Smitt (1992), used scales which measured either comfort or discomfort.

Cascioli et al. (2011) asked all of their participants to rate both their overall comfort and their discomfort (broken down by body regions) on separate scales. Helander and Zhang (1997) (who view comfort and discomfort as separate constructs) recognised that asking people to rate both comfort and discomfort at the same time but on separate scales could lead to bias and people simply providing opposite answers. They evaluated whether there were differences in ratings of comfort only, discomfort only or both comfort and discomfort (on separate scales). They did not find any differences in ratings across conditions and they therefore concluded that comfort and discomfort can be rated at the same time on separate scales.

3.2.2. Observational methods

Observational approaches to the assessment of comfort/discomfort have been taken by some authors, for example, to identify postures which minimise discomfort in railway seating (Branton & Grayson, 1967; Groenesteijn et al., 2014). Other tools which may provide indications of comfort or discomfort through postural observations include the Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993) and the Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000; McAtamney & Hignett, 2005).

The usefulness of observational approaches to assessing comfort or discomfort could be questioned due to their subjective nature (Richards et al., 1978) and reliance on observer interpretation of a situation. Such approaches could produce results which indicate potential for comfort or discomfort as a result of good or poor postures but would not provide information about the degree of comfort or discomfort experienced. In addition, these approaches would not provide information regarding the causes of comfort or discomfort, in particular those relating to any factors other than those which cause people to assume certain postures (e.g. physical surroundings).

In this research, observation was only used to detect behaviours which could cause discomfort to other nearby passengers. This is further described in section 3.3.1.

3.2.3. Objective measures

Some authors have used objective measures of comfort and/or discomfort. Hertzberg (1958) proposed that the discomfort resulting from a seat should be measured by determining the length of time that participants are willing to endure given postures. This is similar to many of the approaches taken in pain research where participants' pain thresholds or tolerances are often timed (see chapter 2). However, it is likely that participants would be able to endure discomfort for prolonged periods of time whereas people would likely have lower tolerances to painful experiences. Therefore, this measure would be unlikely to yield useful results at lower levels of discomfort but may be useful in painful or extremely uncomfortable situations. In addition, this experimental protocol would draw attention to discomfort which may bias the results.

Studies have also shown that comfort and discomfort can be inferred through a variety of physiological or biomechanical measures. For example, in seating studies, relationships have been found between pressure distribution and discomfort (De Looze et al., 2003; Shen & Galer, 1993). Fazlollahtabar (2010) summarises other physiological and biomechanical measures which have been found to be indicators of seating comfort or discomfort. These include temperature or humidity measured at the surface of the skin and electromyography (EMG) as an indicator of fatigue. It should be noted that these approaches do not directly measure comfort or discomfort but rather, provide indicators and possible explanations for why comfort or discomfort is being experienced. It is possible that using these measures will affect the results that they provide due to the hardware required to take the measurements, being a possible source of discomfort.

3.3. **Research methodology**

Figure 3-2 illustrates the methods used to achieve each of the research objectives set out in chapter 1 of this thesis. The research objectives are presented on the left hand side of the diagram and the specific methods and associated chapters are presented on the right hand side. Further detail about the specific methods used to achieve each objective is provided in sections 3.3.2 - 3.3.4. Section 3.3.1 details the overall approach taken to data collection and analysis.

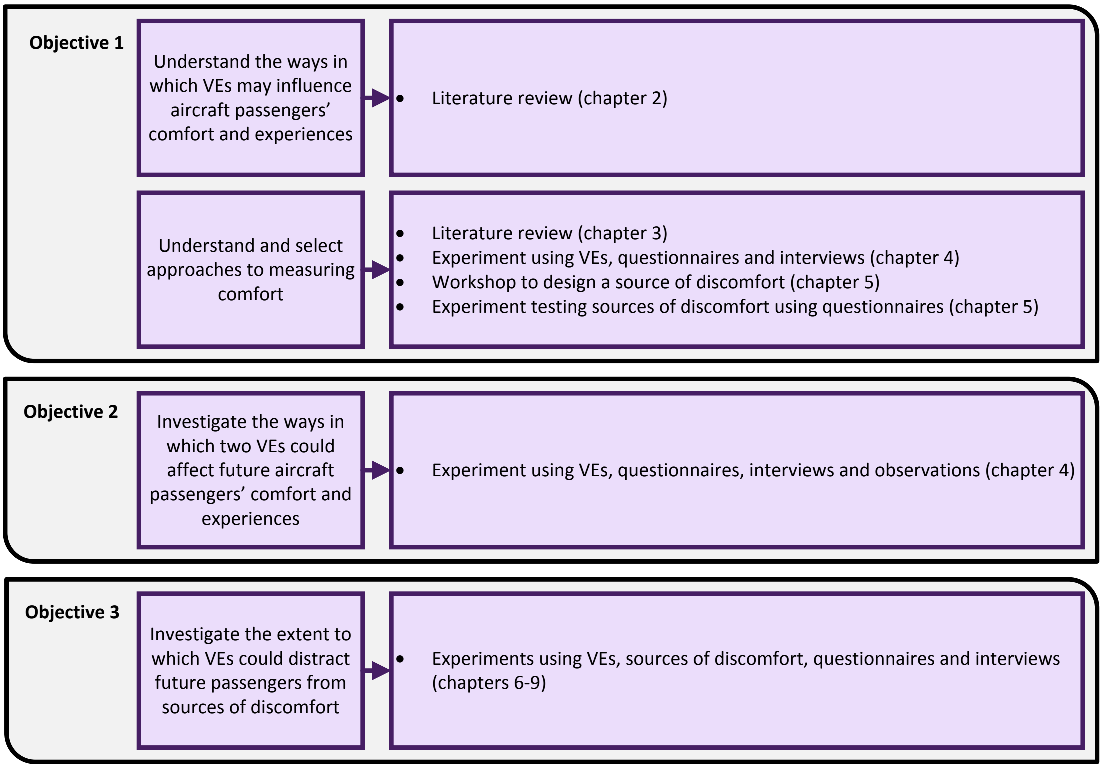

Figure 3-2 Summary of methods used to achieve the research objectives

3.3.1. Approach to data collection and analysis

Most of the studies conducted during this research took a mixed methods approach, collecting both qualitative data through the use of interviews and quantitative data in the form of questionnaires responses. Examples of the questionnaires and interviews used can be found in appendices 2 and 3. The qualitative data collected during this research were analysed using theme based content analysis (Neale & Nichols, 2001). This method was selected as it allows for data to be summarised into broader themes while retaining raw data in the form of direct quotes. The quantitative data were analysed using the appropriate statistical tests.

The framework proposed by Wright, McCarthy and Meekison (2004) and McCarthy & Wright (2004) (see chapter 2) was used as a basis for the analysis of data collected relating to the user or passenger experience (see chapter 4). This framework was selected as it considers both the stimuli presented to the users and the effect of these stimuli on the users' feelings. It was used to ensure that the data collected encompassed all of the facets of the user experience (compositional, spatio-temporal, sensual and emotional) and was also used to structure the data analysis. For the purposes of data analysis, the sensual and emotional threads were combined as these are intrinsically interlinked.

Although many people argue that comfort and discomfort are separate constructs, a decision was made to quantitatively measure comfort and discomfort on a single scale. The distinction between comfort and discomfort was made when qualitatively collecting data (i.e. during interviews). A single questionnaire scale was selected in order to avoid the issue suggested by Helander and Zhang (1997) of participants providing opposite answers when separate scales are used simultaneously. Where comfort and discomfort were measured qualitatively, a seven-point scale was used with anchors 'extremely uncomfortable' (-3), 'neither comfortable nor uncomfortable' (0) and 'extremely comfortable' (3). This number of scale points was selected as this would provide enough points for discrimination and would account for participants who tend to not use extreme points on scales. Although seven-point scales were used for rating comfort/discomfort, when rating agreement with statements, standard five-point scales were used.

In the studies presented in chapters 6-8 of this thesis, the participants were asked to rate their overall comfort and not the comfort or discomfort associated with the restricted legroom or the sound of a crying baby. This decision was made as rating only the discomfort inducing stimuli would not allow for pre- and during condition comparisons. Asking the participants specifically about the discomfort-inducing stimuli would also draw their attention to their discomfort and would also not have encompassed the effect of the distractors.

Interview data relating to comfort and discomfort were collected separately as this would allow for clear identification of the factors having a positive and negative influence on the participants. This would also allow for discussion regarding how the results of the studies carried out relate to the debate surrounding comfort and discomfort as constructs.

In addition to interview and questionnaire data, observable behaviours were recorded in the studies presented in chapter 4. These behaviours were specifically ones which might impact on the comfort, discomfort or experience of other passengers. They were identified using direct observation during the studies and analysed in more detail retrospectively using video analysis.

3.3.2. Objective 1: Develop a background understanding of the ways in which VEs might influence aircraft passengers' comfort and experiences and understanding approaches to measuring comfort

This research objective was divided into two smaller objectives. The first of these was to develop a background understanding of the ways in which VR can influence passengers' comfort and experiences. This was achieved by reviewing literature from three bodies of research: user experience, comfort/discomfort and using VR as a means of distracting people from pain. This review can be found in chapter 2 of this thesis.

The second objective was to understand and select an approach to measuring comfort. This objective was achieved through multiple stages as shown in Figure 3-3. The first step was to review the approaches that had been taken to measuring comfort in previous studies (see section 3.2) with the knowledge acquired from the literature review (chapter 2) regarding the debate surrounding the definitions of the terms ‘comfort’ and ‘discomfort’. From this, quantitative scales were selected and a decision was also made to collect data using interviews in order to gain a rich understanding of the participants’ comfort/discomfort experiences (the approach taken is described in section 3.3.1). These approaches to data collection were used in the first study described in chapter 4. From this study, it was identified that it is difficult to determine the extent to which VR can enhance comfort if the participants are not exposed to a source of discomfort. As a result, literature relating to the use of VR to distract participants from pain was considered (see chapter 2) and the approaches taken were used to influence the methodology. A decision was taken to experimentally induce discomfort and to then measure the extent to which VR could distract participants from the discomfort experienced. Sources of discomfort were selected and tested in chapter 5. These were subsequently used in chapters 6-8 to start all experiments with consistent sources of discomfort and to measure the extent to which interventions distracted the participants from this discomfort.

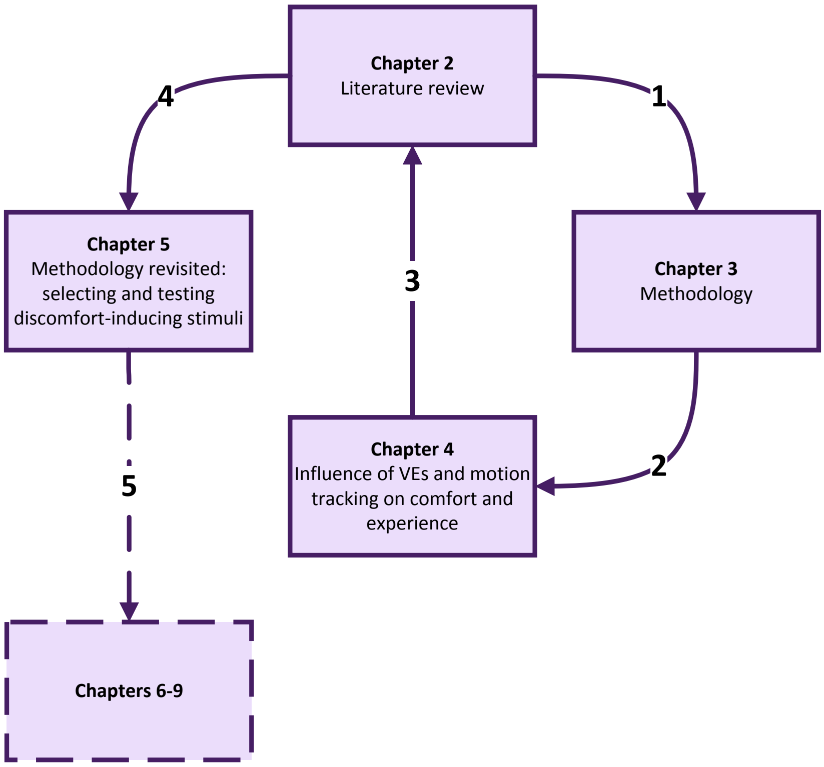

Figure 3-3 Steps taken to develop an approach to measuring comfort

3.3.3. Objective 2: Investigate the ways in which two different VEs could affect future aircraft passengers' comfort and experiences.

This research objective was achieved through conducting an experiment (see chapter 4) which involved 12 participants individually experiencing two different VEs (a tropical island VE and an invisible aircraft VE) with various configurations of motion tracking and answering both questionnaire and interview questions about their experiences. These questions related to the participants' experiences of the VEs, the factors affecting their comfort and discomfort and the circumstances under which they would or would not use these VEs when taking real flights. In this study, behaviours which might negatively impact on the comfort of other passengers were observed. These were coded and structured video observations were carried out to determine the prevalence of these behaviours. A short second study was carried out to determine the extent to which these behaviours were exhibited when other people were sitting in the set-up and, if present, their effect on the adjacent passengers. This study also used interviews and structured video observations.

3.3.4. Objective 3: Investigate the extent to which VEs could distract future passengers from sources of discomfort.

A series of three experiments were carried out in order to achieve this research objective (see chapters 6-9). All of these experiments used the same experimental protocol which comprised participants experiencing a source of discomfort, usually in combination with a distractor, and answering both questionnaire and interview questions about their comfort and discomfort experiences. Table 3-1 summarises the sources of discomfort and the distractors provided in the studies presented in chapters 6-8 of this thesis.

Table 3-1 Summary of sources of discomfort and distractors used in the studies presented in chapters 6-8

	Discomfort-inducing stimuli	
Distractors	**Restricted legroom**	**Sound of a crying baby**
No distractor	Chapter 6	Chapters 6, 7 and 8
Invisible aircraft VE	Chapter 6	Chapter 6
Tropical island VE with sound of waves and birds		Chapters 7 and 8
Tropical island VE without sounds of waves and birds		Chapter 7
Sounds of waves and birds		Chapter 7
Videos of tropical islands		Chapter 8

3.4. Equipment used during experiment

This section describes the hardware and VEs used in the experiments described in chapters 4 and 6-8. There was substantial overlap in the equipment used in these studies and therefore the apparatus is described in this chapter in order to avoid unnecessary duplication in the specific experimental chapters. Reference is made to this chapter in the experimental chapters when describing the hardware and VEs used.

3.4.1. Fraunhofer IAO cabin mock-up

The studies presented in chapters 4, 5 and 6 of this thesis made use of the Fraunhofer IAO physical cabin mock-up in Stuttgart (see Figure 3-4 and Figure 3-5). This comprised two rows of three airline seats. A bank of six 24” monitors was positioned in front of the front row of seats to replicate seat-back displays. The seat pitches were similar to that of a typical economy aircraft cabin (approximately 32”). The dimensions of the seats (in mm) and their positions with respect to each other and the seat-back displays can be found in Figure 3-6. Two 46” televisions were also set into the footwell of the front row of seats. All of this equipment was placed inside a four-sided CAVE which made use of 14 projectors. The VEs were displayed on the CAVE walls as well as the seat-back and floor displays. Speakers were positioned outside the CAVE on the left and right hand sides of the front row of seats to provide stereo sound. During some studies, a video camera was placed behind the seat-back displays to capture the participants’ behaviours.

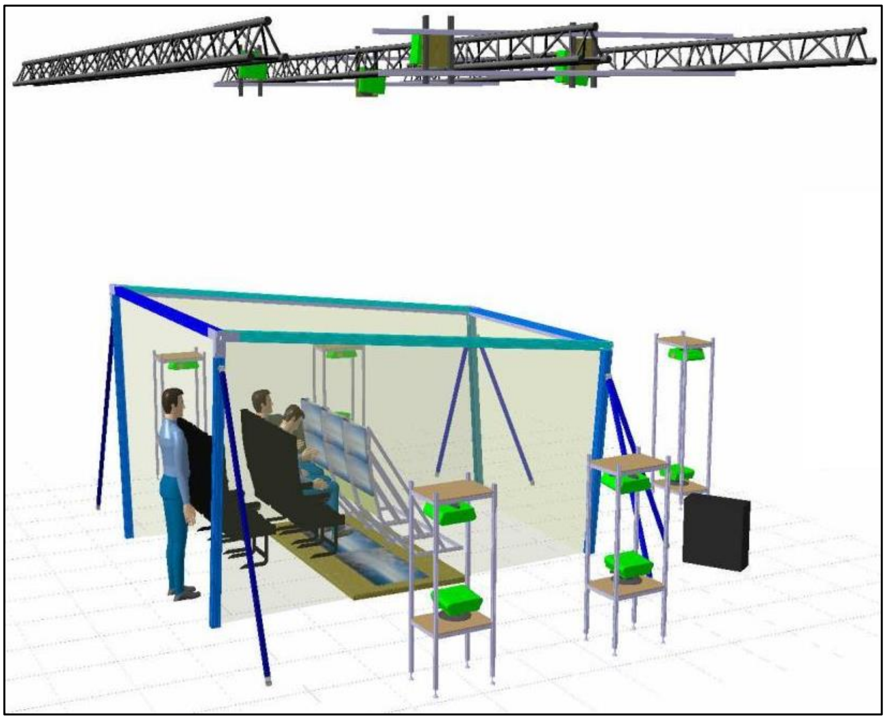

Figure 3-4 Fraunhofer IAO physical cabin mock-up (image produced by Fraunhofer IAO)

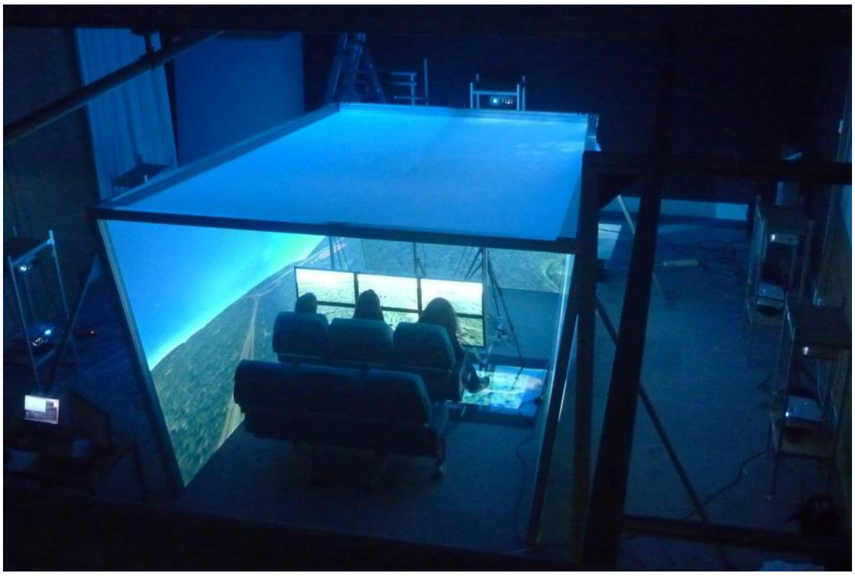

Figure 3-5 Fraunhofer IAO physical cabin mock-up

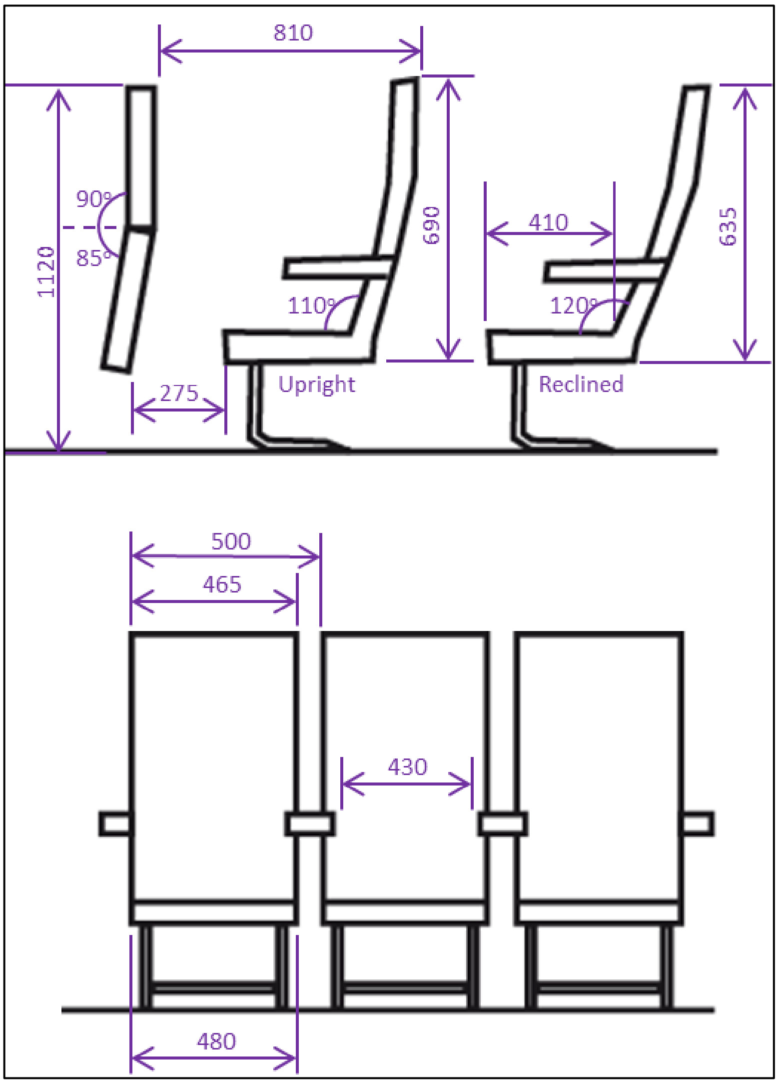

Figure 3-6 Seat dimensions in mm (not to scale)

Motion tracking was provided in this mock-up using an Advanced Realtime Tracking (ART) D-Track optical tracking system. This comprised two AR-TRACK 2 cameras which were positioned behind the seat-back displays. These were used in combination with a pair of glasses without lenses but with markers attached (see Figure 3-7). This technology could be used to provide motion parallax and therefore a true, first person perspective. It could also be used to simply calibrate the VE such that the VEs appeared at the correct eye-height for individual participants.

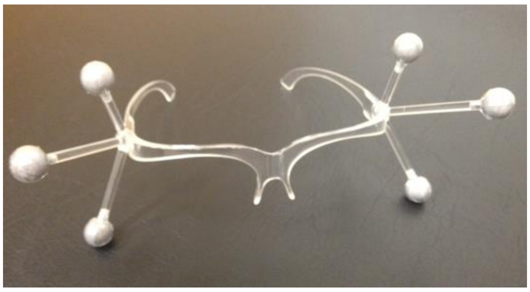

Figure 3-7 Motion tracking glasses

3.4.2. Max Planck Institute for Biological Cybernetics large screen display

The studies presented in chapters 7 and 8 of this thesis used a 2.2m x 1.6m back-projected display at the Max Planck Institute for Biological Cybernetics in Tübingen. Audio was provided in this set-up with stereo speakers which were positioned behind the display. A chair was positioned in front of the display in a position providing an amount of legroom which is typical in economy class cabins (pitch of approximately 32”).

This set-up was used due to a need for a new pool of participants who had not experienced the VEs or experimental protocols which had been used in previous studies. It is acknowledged that this set-up was likely to lead to a less immersive experience for participants. However, it is likely that this would have less of an effect than using participants who were already familiar with the study aims and VEs.

3.4.3. Virtual environments

Two virtual environments (a tropical island VE and an invisible aircraft VE) were used in the research presented in this thesis. These were selected based on ideas which emerged from early studies in VR-HYPERSPACE (see Tedone et al., 2012) and also because of suggestions that natural or outdoor environments may enhance comfort, increase tolerance to discomfort (Cole et al., 2008; Nikolopoulou, 2004; Nikolopoulou & Steemers, 2003) or have positive health effects (Beute & de Kort, 2013). These were also selected because they fit within two different scenarios of use within an aviation context, the enhancement of the aircraft environment or the displacement of passengers from the aircraft environment (White, 2011). Within the VR-HYPERSPACE project, these concepts were named 'super here' and 'super there' and are described as follows:

1. Super here - The 'super here' concept used virtual reality to augment the flight experience. It provided passengers with an enhanced view of what would be around them in the real world. It also provided passengers with an experience which is unique to flight and could not be experienced in the same way on the ground. The example of this which was used in this research is an invisible aircraft VE. This depicted a surround view of the environment outside of the aircraft when taking a low-level flight (see Figure 3-5 and Figure 3-8). The environment displayed was a flight over the area surrounding the Fraunhofer IAO campus and was therefore familiar to all participants (this VE was only used in the studies carried out at FhG). The sound of an aircraft (engine noise and muffled conversation) was played in conjunction with this VE to enhance the ecological validity of the set-up.
2. Super there – The 'super there' concept used virtual reality to enable passengers to perceptually transport themselves to a different location. This concept could encompass any VE which represented a location which was unrelated to the aircraft context and geographic location of the aircraft. The example used in this research was a tropical island VE (see Figure 3-9). This VE had an associated sound of waves and birds.

The VEs were designed to be ambient environments and therefore, the only user-initiated interactivity which was present in some studies was motion tracking.

Figure 3-8 Invisible aircraft (low level flight) VE

Figure 3-9 Tropical island VE

3.4.4. Discomfort-inducing stimuli

The studies presented in chapters 6-8 of this thesis exposed participants to sources of discomfort. This was done in order to determine the extent to which various stimuli could distract the participants from their discomfort. The sources of discomfort used (restricted legroom or the sound of a crying baby) were designed and tested in the studies presented in chapter 5 of this thesis. These stimuli are also described in chapter 5.

3.5. Chapter summary

This chapter has presented the approach taken to conducting this doctoral research along with rationales for the selected methods. Approaches to measuring comfort and discomfort were reviewed. The selected methods were then described and related to the research objectives. The chapter concludes with descriptions of the hardware and VEs used to carry out this research.

4. Influence of VEs and motion tracking on comfort and experience

4.1. **Introduction**

Chapter 2 of this thesis reviewed the literature surrounding passenger and user experience as well as literature relating to comfort/discomfort and the use of VR to distract people from pain. It was identified that there is no consistent definition of the term 'passenger experience' and variability with regards to what this encompasses (e.g. whether this is the whole journey experience or the in-transit element of a journey). The literature review also identified that some of the factors which were identified by Myant and Abraham (2009) and Jabalpurwala (2011a) as affecting in-flight passenger experience overlap with factors which affect passenger comfort (e.g. those identified by Ahmadpour et al., 2014a; Patel et al., 2012; Richards et al., 1978; Vink et al., 2012; Vink & Brauer, 2011; Vink et al., 2005a). These factors include the cabin crew, allocated space, temperature, seating, IFE and cleanliness.

As the research in this thesis is concerned with the ways in which VR can affect passengers' experiences, it is also linked with the user experience of technology. Chapter 2 also presents a review of the literature surrounding user experience, identifying that the user experience is subjective and is concerned with the ways in which users feel about, interact with and perceive systems within a specific context of use. The framework of user experience proposed by McCarthy and Wright (2004) and Wright et al. (2004) was selected to evaluate the effect of VR on passengers' experiences as it considers both the users' feelings and the stimuli presented to the users.

This chapter presents a study which aimed to evaluate the ways in which VEs could influence people's comfort and experience along with issues surrounding passenger acceptance. Two VEs (a tropical island VE and an invisible aircraft VE) were evaluated in conjunction with various configurations of motion tracking in order to determine their effect on passenger comfort and experience. The optimum configurations would subsequently be taken forward for further evaluation.

Motion tracking configurations were evaluated as it is known that motion parallax can enhance depth perception (Bowman et al., 2005) as well as enabling users to view VEs from a first-person perspective (Foxlin, 2002) and therefore may enhance passengers' experiences. Motion parallax causes closer objects to move more quickly across the field of view than distant objects (Blade & Padgett, 2002; Bruce et al., 1996; May & Badcock, 2002) and works by using the tracked position of a user's head to change the position of a virtual camera (Foxlin, 2002).

This chapter concludes with a short study which aimed to determine whether any participant behaviours observed in the first (individual) study were also present when multiple participants were sitting in the set-up. If these behaviours were present, the study also aimed to determine their effect on the other participants' comfort and experiences.

4.2. **Passenger experience study**

4.2.1. Method

Participants

Twelve participants, six male and six female, were recruited from Fraunhofer IAO and Stuttgart University. One participant was from the USA and the remaining 11 were German. They had a mean age of 28.83 (SD=7.42). Recruitment criteria included the ability to speak English and having taken a flight in the past three years. People who had any conditions which are known to be indicators of susceptibility to virtual reality induced symptoms and effects (VRISE) (e.g. those in Ramsey (1999)) were excluded from participation. Criteria included susceptibility to motion sickness, migraines, epilepsy (photosensitive or otherwise), recurring headaches, back pain or back problems, neck or shoulder pain, asthma, problems with depth perception, heart conditions or any other serious injury or illness as well as those who were pregnant.

Participants were asked to complete a short background questionnaire which included measures of how much they liked flying, were scared of flying and their experience using VR using 11 point scales. Descriptive statistics for this data can be found in Table 4-1.

Table 4-1 Descriptive statistics for background data

	Median (IQR)	Anchors
Like flying	7.5 (2.25)	0 = I hate flying 10 = I love flying
Scared of flying	0.5 (1)	0 = Not at all scared 10 = Extremely scared
VR experience	4 (4.5)	0 = No experience 10 = Extremely experienced

<u>Equipment</u>

The Fraunhofer IAO physical cabin mock-up was used in this study. It should be noted that the ceiling display was not functioning at the time of running this study and it was therefore switched off. This set-up was used for displaying both the tropical island VE and the invisible aircraft VE. During all conditions, the sound of an aircraft cabin (engine noise and muffled conversation) was played. In the tropical island VE condition, the sound of waves and birds was overlaid onto the aircraft cabin sound. Full details of the hardware and VEs used can be found in chapter 3.

In this study, motion tracking was used in some conditions, whilst in others it was only used for initial calibration in order to ensure that the VEs were presented at the correct viewing height for each individual. A video camera was placed behind the seat-back displays to capture the participants' behaviours. A voice recorder was used to record the interviews and all questionnaires were paper-based.

Piloting and study refinements

The questionnaires for this study were piloted with four native German speakers. Some questions were rephrased in order to ease understanding. The time taken to complete the questionnaires was measured and as a result, a number of questions were removed. A decision was made to carry out interviews in order to ensure rich qualitative data which would complement the questionnaire responses. As the study was carried out in English but located in Germany, a decision was made for a German speaker to be present during the study to assist with translation if necessary.

The design of the baseline condition was considered. A VE depicting a cabin environment was one option as this would simulate a real current aircraft. However, due to this being a VE, there could still be issues of sickness which would not occur in the real world. Therefore, it was decided that a second identical row of aircraft seats should be installed behind those which were already in the mock-up. This would provide the potential to take baseline measures which pertained only to the seat and amount of physical space available to a participant. It would also, to some extent, simulate a current aircraft cabin. It was decided that the sound of an aircraft would be present in all conditions (including the baseline) in order to maintain consistency. It is acknowledged that technical developments in engine design are leading to quieter engines. Therefore in the future, it is possible that passengers will not experience loud engine noise in the same way that present-day passengers do. In the tropical island VE, an additional island sound (waves and birds) was overlaid onto the aircraft sound.

The way in which motion tracking would be implemented within the set-up was also considered. Motion tracking can provide users with a true first-person perspective of a VE. A decision was made to test three configurations of motion tracking: no tracking, partial tracking (on the seat-back and floor displays only) and full tracking (on the seat-back, floor and wall displays). Full motion tracking would only be possible on aircraft in the future with the integration of multi-viewer displays such as those described by Kulik et al. (2011). This would enable multiple passengers to simultaneously view different images on the same displays. This technology is beginning to emerge in the television market (LG, 2013; Samsung, 2013) and it is therefore feasible that this could be introduced into aircraft VR systems. However, it was also important to consider the implementation of motion tracking if multi-viewer displays were not integrated into future aircraft VR systems. Therefore, partial tracking was also considered. This would enable passengers to view a tracked VE on their personal displays but would not track the wall displays.

The full study was piloted for timing and content in Nottingham using a 32 inch television screen to display the VEs. The study was also piloted at Fraunhofer IAO in the cabin mock-up. As a result of these pilot studies, the path of the flight on the invisible aircraft VE was changed to reduce the sickness experienced by some participants and to increase realism during turning. In addition, a question was added to the background questionnaire pertaining to the amount of VR experience that participants had.

Design

The study was designed to take no longer than three hours to complete. It had a within-subjects design in order to eliminate the effects of individual differences. The no VE condition was always completed first as this was the baseline condition. The remaining conditions were grouped according to the VE used and the order of presentation was counterbalanced within these groups. The seven conditions were as follows:

- No VE (baseline condition)
- Tropical island VE, no motion tracking
- Tropical island VE, partial motion tracking (personal displays only)
- Tropical island VE, full motion tracking (personal and ambient displays)
- Invisible aircraft VE, no motion tracking
- Invisible aircraft VE, partial motion tracking (personal displays only)
- Invisible aircraft VE, full motion tracking (personal and ambient displays)

During all conditions, the sound of an aircraft engine and cabin sound was played. The location of the displays within the set-up are shown in Figure 4-1.

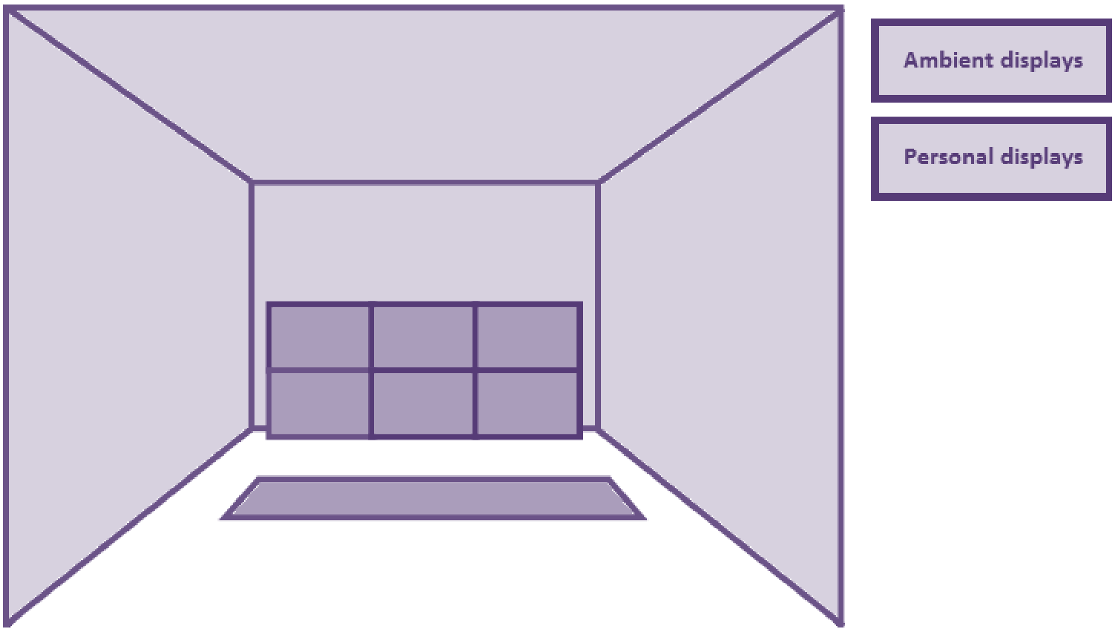

Figure 4-1 Location of personal and ambient displays in the set-up

Upon completion of the study, participants were given a €30 Amazon voucher. The study was approved by the ethics committee at the University of Nottingham, Faculty of Engineering.

Procedure

The participants took part in the study individually. They were welcomed and introduced to the study, given information to read and were asked to complete a demographics questionnaire. The participants were told that the study was investigating the use of VEs in future aircraft. They were asked to leave their belongings outside the mock-up. They were then led into the set-up and informed that they would experience VEs in all but one of the conditions but would not be given a specific task to complete. Their eye height while sitting was then captured using the motion tracking system in order to ensure that the VEs were presented at the correct height for each individual. The participants were given five minutes to experience each condition and were told to behave as if they were on a real aircraft, which included being allowed to recline their seats if they wished to do so.

Prior to each condition, participants were asked to complete a short questionnaire which included a rating of overall comfort/discomfort and the short symptoms checklist (SSC) (Cobb et al., 1995). It should be noted that the SSC was used solely for monitoring purposes and was not included in any data analysis. Following each condition, the participants completed a similar questionnaire and were interviewed about their experiences. After all of the conditions had been completed, a longer post-study interview was carried out. The interviews contained questions relating to comfort/discomfort, user experience and technology acceptance.

4.2.2. Results

The results of this study are divided into four sections: comfort/discomfort, user experience, passenger acceptance and observable behaviours. These are detailed in the following sections.

It should be noted that most of the participants were not native English speakers. As such, where quotes are provided in the following sections, these may not be in perfect English.

Comfort and discomfort

The participants were asked to rate their overall levels of comfort/discomfort both prior to and following each experimental condition. The ratings carried out following the conditions related to how they were feeling during the condition that they had just experienced. Ratings were made on a seven-point ordinal scale with anchors 'extremely uncomfortable' (-3), 'neither uncomfortable nor comfortable' (0) and 'extremely comfortable' (3). The descriptive statistics for these ratings can be found in Table 4-2.

Table 4-2 Descriptive statistics and Wilcoxon test results for overall comfort/discomfort ratings

Condition	Median comfort/discomfort rating prior to the condition (IQR)	Median comfort/discomfort rating during the condition (IQR)	Results of Wilcoxon tests comparing pre- and during-ratings
No VE	2 (1.25)	1.5 (2)	(W=0; N=3; p>0.05)
Untracked tropical island VE	2 (1.5)	1 (1.5)	(W=7; N=6; p>0.05)
Partially tracked tropical island VE	1.5 (2)	1 (2)	(W=4; N=5; p>0.05)
Fully tracked tropical island VE	2 (2)	1 (3)	(W=9; N=6; p>0.05)
Untracked invisible aircraft VE	1.5 (2)	0.5 (2)	(W=2; N=4; p>0.05)
Partially tracked invisible aircraft VE	2 (2)	1 (2)	(W=4; N=5; p>0.05)
Fully tracked invisible aircraft VE	1.5 (2)	1 (2)	(W=14; N=7; p>0.05)

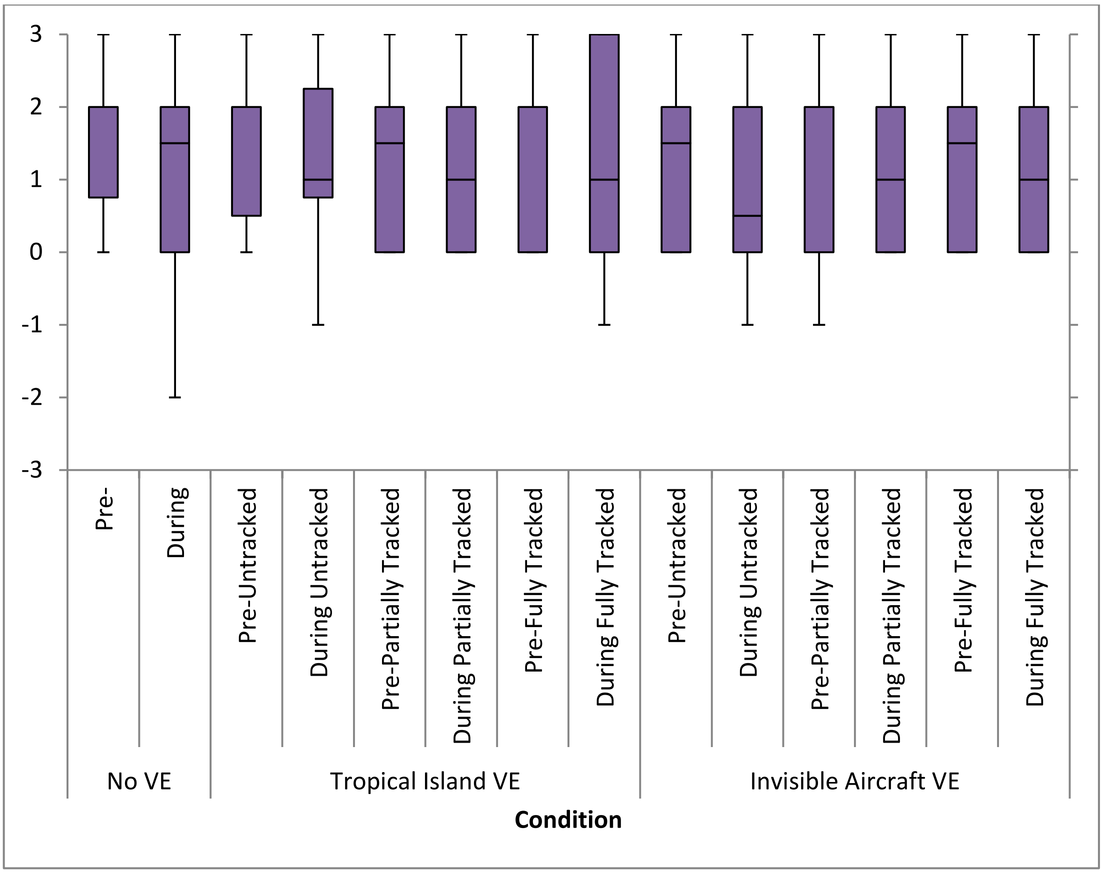

Figure 4-2 Box plots showing descriptive statistics for overall comfort/discomfort ratings

A Friedman test revealed that there were no significant differences between the ratings of comfort prior to the conditions (X^2=4.337; df=9; p>0.05). As a difference in the participants' levels of comfort prior to the conditions could not be proven, their states were regarded as homogenous. Therefore, a Friedman test was also carried out to compare the ratings of comfort/discomfort during the conditions. This also revealed no significant differences (X^2=5.426; df=6; p>0.05) indicating that the presence of a VE and the introduction of motion tracking did not change the participants' comfort levels. The box plots in Figure 4-2 illustrate these similarities.

Wilcoxon tests were also carried out to determine whether there were any differences in comfort/discomfort levels prior to and during each of the conditions. These tests found no significant differences for all conditions indicating that the VEs did not affect the participants' overall comfort/discomfort levels. The results of these tests can be found in Table 4-1.

Semi-structured interviews were also carried out asking questions concerning the factors affecting the participants' comfort and discomfort during each condition. The responses to these questions are presented by condition in the following sections. The questions asked related to the following:

- How the (virtual) environments affected the participants' comfort/discomfort,
- Descriptions of the factors which affected the participants' comfort or discomfort during each of the conditions.

_No VE_

In this condition, the participants reported that the lighting conditions were not comfortable, often stating that it was too dark. For example, a participant said,

> *"I mean, maybe, well it could be quite tiring like if you're in there for a longer time because it's not so bright and maybe if I would have wanted to read something. For a longer time, it would have been nice to have a bit more light."* – P9

The participants generally reported that the seat provided was comfortable, with a small number of participants stating that it was uncomfortable. Most of the participants also commented that they had enough space surrounding them (both in front and to the sides) to feel comfortable in this condition.

Aspects of social comfort and discomfort were only reported by participants in this condition. The majority of participants who mentioned these factors commented that a lack of other people positively impacted on their comfort due to an increase of physical space.

> *"That gave me space to the sides and I think it was more comfortable than if you have some people that you don't know"* – P8

A small number of participants suggested that the absence of other people had a negative impact on their comfort, giving the reason that *"there was nobody to talk to"* (P6).

Tropical island VE – untracked

In this condition, participants generally reported that the sound of the waves and birds was a source of comfort, for example:

> *"The sound was nice. It made me a bit tired but in a comfortable way...Yeah relaxed."* – P2

The participants generally reported that the levels of lighting were comfortable in this condition.

> *"It [the lighting] was very good, comfortable. It was bright and like at the beach, exactly like that."* – P10

One of the participants who stated that the seat was uncomfortable in the no VE condition stated that they did not notice this discomfort when they were experiencing the tropical island VE.

In this condition, some of the participants reported that they perceived the amount of physical space surrounding them to have increased compared to the no VE condition.

> *"It definitely feels like you have more space... you had this feeling that you could look into the wide and see the ocean which makes you have the feeling that you have more space."* – P1

Tropical island VE – partially tracked

As with the untracked tropical island VE condition, participants in this condition reported that factors contributing to their comfort included the lighting, the increased perception of space compared to the no VE condition and the sound of the waves and the birds.

> *"The sounds of the waves and the birds was very nice and relaxing."* – P2

The motion tracking caused some participants discomfort in this condition. This was attributed to both the amount of movement and the mismatch between the displays.

> *"I didn't like it that much because I'm sitting still and the screens before me are moving with my head and the ones at the side don't and in addition, the fact that I just move a little bit and the front screens are changing the perspectives...Yeah. I think it's the relation because the sides don't move and the front screens move. I didn't like it that much this time. But when you take a seat and relax and don't move, there's no difference."* – P10

Tropical island VE – fully tracked

Similarly to both of the other tropical island VE conditions, participants felt that the lighting and the sound of the waves and birds were sources of comfort. The participants also reported that they perceived the amount of space surrounding them to be greater than in the no VE condition. One participant also commented that the motion tracking on the walls led to a feeling of increased lateral space.

> *"I had the feeling I had more space above me because the walls were moving as well. That was quite nice...I think it was more space to the sides but not in front of me."* - P1

A source of discomfort in this condition was the motion tracking. Participants often stated that the VE moved too much and that this was distracting.

> *"Sometimes I think it's a little bit more discomfort when you notice that you actually, that with these movements, the bigger walls are moving around."* – P3

Invisible aircraft VE – untracked

In this condition, some participants reported that the VE distracted them from the discomfort that they had experienced in the no VE condition as a result of the flight sound. A participant reported:

> *"I didn't realise the noise of the flight, I was so distracted."* – P4

Participants generally felt that the lighting in this condition was comfortable. For example:

> *"It [the lighting] was good. I could, for example, if I would have wanted to read, I think also for a longer time, this would have been no problem"* – P9

In this condition, an additional source of discomfort was introduced for some participants in comparison to the no VE and tropical island VE conditions. This discomfort manifested as unease or vertigo and resulted from the floor displays.

> *"That [the floor display] was kind of strange for me. It was like feet are…flying in the nowhere, I might fall in the ground something like that but it was not too bad but it was kind of strange to look there…Yeah kind of this falling if you feel like a bit, a very bit anxious of."* – P8

The same participant who stated that the tropical island VE distracted them from the discomfort that they experienced due to the seat in the no VE condition also commented that the invisible aircraft VE distracted them from this discomfort.

> *"No. I didn't notice [the seating discomfort] but then I remembered I'm so upright and then I lay it back a little bit* [reclined the seat] *but it was not that bad. It was better than before, very much better."* – P10

Some of the participants in this condition reported that they perceived the amount of physical space surrounding them to be greater than in the no VE condition.

> *"Much more [space]...in all directions, especially the sides. You have the feeling that you can look really far away but because the environment was moving and also on the floor, you had the feeling that you have much more space."* – P1

Invisible aircraft VE – partially tracked

As with the untracked invisible aircraft VE, the participants felt that the lighting levels were comfortable in this condition. They also perceived an increased amount of space surrounding them compared to the no VE condition.

Similarly to the tropical island VE conditions, the motion tracking caused some participants to experience discomfort in this condition due to the mismatch between the displays.

> *"You really notice clearly if there is this discrepancy between the screens, that it doesn't match with the horizon."* – P9

One participant found that the motion tracking caused them to experience eye strain and a headache.

Invisible aircraft VE – fully tracked

Similarly to both other invisible aircraft VE conditions, participants found the lighting levels comfortable in this condition and felt that they had an increased amount of space in their immediate vicinity compared to in the no VE condition.

As with the other tracked conditions, the motion tracking caused some participants to experience discomfort. The specific causes of discomfort relating to motion tracking in this condition were the over-sensitivity of the movement and the lack of realism of the movement. Participants in this condition also reported that the motion tracking led to feelings of disorientation.

> *"I think it's just kind of a disorientation…there's nothing stable anymore. I mean usually…if you're flying around, I love to watch the horizon. The horizon gives you the stability of where you are and also about the orientation about your movement in space but if the horizon does not feel to be stable, it's moving itself, then you're losing everything*." – P3

The same participant who reported eye strain and headaches in the partially tracked invisible aircraft VE condition also reported that the motion in this condition caused eye strain and headaches. It is therefore possible that these symptoms were affected by exposure to the previous conditions.

> *"I had a headache from the movement...From the movement of the flight because I had, I felt the pressure on my eyes and I had the movement of my eyes and the movement of the surroundings so I got some kind of headache."*
> - P2

Summary of findings relating to comfort and discomfort

The interviews revealed a number of factors which related to participants' comfort and discomfort. These are summarised in Figure 4-3. This diagram shows the commonalities and differences in these sources of comfort and discomfort across the conditions and the ways in which these change with the addition of VEs and motion tracking. It should be noted that this diagram is related to the findings of these interviews. Therefore, it is possible that factors which are shown to cause comfort or discomfort in some conditions but not others may have still been present but not mentioned by the participants (e.g. the absence of other people).

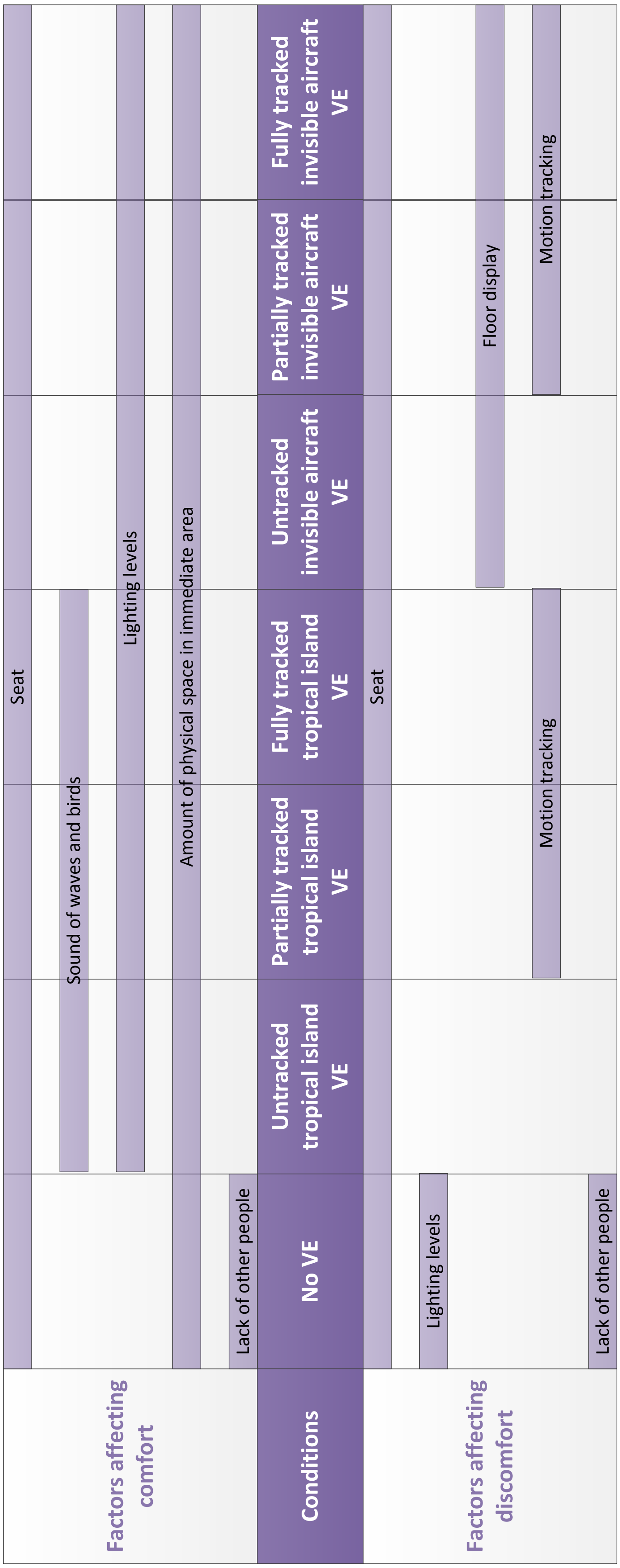

Figure 4-3 Factors affecting comfort and discomfort emerging from qualitative data

User experience

For the purposes of data analysis, the data collected relating to user experience was broken down into threads according to the framework set out by McCarthy and Wright (2004) and Wright et al. (2004) in the following sections. The four threads of this framework are compositional, spatio-temporal, emotional and sensual. As the emotional and sensual threads are intrinsically interlinked, these have been combined in this data analysis.

The data relating to user experience was collected through the use of questionnaires and interviews. The interview questions related to the following:

- The way in which the (virtual) environments made the participants feel.
- What the participants liked/disliked about the visual aspects of the VEs.
- The realism of the VEs.
- What the participants liked/disliked about the sounds.
- The realism of the sounds.
- The effect of the head tracking on the participants' overall experiences.
- Which of the displays (e.g. floor, walls, ceiling etc.) contributed most/least to the overall experience of using the VEs.
- How the participants thought that the VEs could be improved in order to enhance their experiences/comfort.

Compositional thread

Likes and dislikes

The participants were asked to rate how much they liked each of the conditions on an 11 point scale with anchors 'did not like it at all' (0) and 'loved it' (10). A Friedman test was conducted to determine whether there were any differences in these ratings. The descriptive statistics for this test can be found in Table 4-3.

Table 4-3 Descriptive statistics for ratings of how much the conditions were liked

Condition	Median rating of how much the condition was liked (IQR)
No VE	5 (4.25)
Untracked tropical island VE	6 (3.25)
Partially tracked tropical island VE	7 (3.25)
Fully tracked tropical island VE	7 (3.5)
Untracked invisible aircraft VE	7 (1.75)
Partially tracked invisible aircraft VE	7 (2.5)
Fully tracked invisible aircraft VE	7 (1.75)

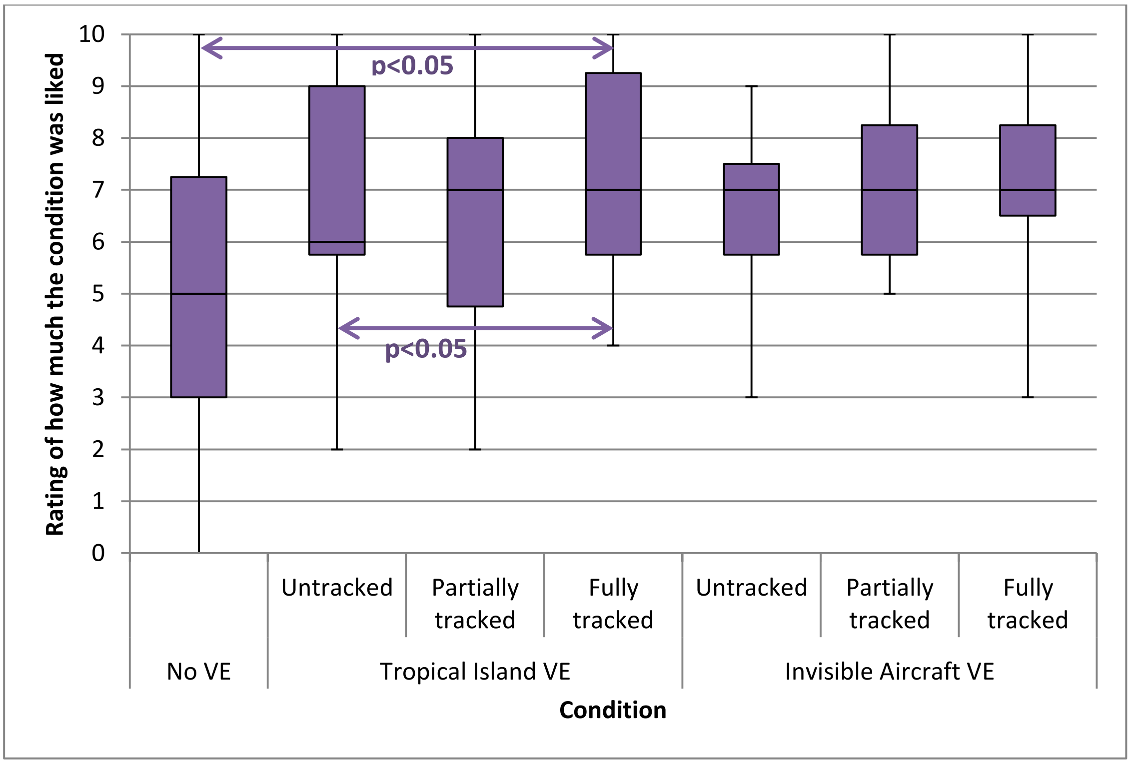

Figure 4-4 Descriptive statistics for ratings of how much the conditions were liked

The Friedman test revealed significant differences between the conditions (X^2=12.596; df=6; p<0.05). Planned post-hoc Wilcoxon tests were then carried out to determine the source of this difference. These tests revealed significant differences between the no VE and fully tracked tropical island VE (W=10; N=11; p<0.05) as well as the partially and fully tracked tropical island VEs (W=8; N=7; p<0.05). The box plot in Figure 4-4 shows that the fully tracked tropical island VE was liked more than its partially tracked counterpart and the no VE condition.

During the post-study interview, the participants were asked to describe what they liked and disliked about the VEs and their associated sounds. The participants generally liked the sand, the sea and the movement of the waves and the leaves in the tropical island VE. They also liked the spatial composition of this VE for example the horizon, the feeling of space and the combination of the distances at which elements were positioned.

> *"Kind of a mixture that the trees are so near which gives you the feeling that you're really in, really on an island because so close and on the other side, you can like have this ocean view which like gives you the impression of a lot of space around you. Yeah I really liked that."* – P1

In addition to these elements, in both tracked tropical island VE conditions, participants liked the visual perspective and the ability to look around the VE, stating that the head tracking made it *"more interesting and entertaining"* (P9). For example, a participant said,

> *"When it was fully tracked then the environment became a bit interesting because it reacted strongly to the head movements."* – P11

Particular elements of the tropical island sound were liked including the sea and the birds. Participants also commented that the tropical island sound created positive feelings or associations, for example:

> *"Yeah it made me just feel comfortable and relaxing…creates positive associations and thoughts."* – P12

A small number of participants disliked elements of the sounds thinking that they were too loud or that the island sound overlaid onto the aircraft sound was too much.

Participants also liked the elements that made up the invisible aircraft VE. These included the buildings, the mountains and the sky. They also liked that the VE depicted a real and recognisable place.

> *"Yeah what I liked is that you just could see real environment...Yeah. That didn't feel real but you know that it is somewhere, there is this environment, you would be flying over that now...But for the flight, somehow, because I knew that it's a flight over the campus, then at least you have some, you have this connection to the reality."* – P9

Similarly to the tropical island VE, they also liked the spatial elements of the VE, making reference to the feeling of more physical space and the wide field of view depicted. The participants also liked the improved visual perspective and the reactions to head movements with the addition of both tracking configurations. For example, when talking about the fully tracked condition, a participant said,

> *"I liked that I could bend over and look out further behind. So if I missed to look at a certain house, then I still could bend over and see it in the back"* – P11

For both tracked invisible aircraft VE conditions, participants also commented that the VE seemed very realistic.

> *"That it was really realistic...For both because the one on the bottom was really realistic and not an everyday view".* – P5

The participants tended not to express liking or disliking the aircraft sound, making comments such as it is unavoidable, expected or normal and that it is a sound that is easy to get used to.

> *"I think it's a sound you can get easily used to it...you can read a book, it doesn't disturb. It's not like crying babies or water drops, this is annoying. It's just steady"* – P4

Participants commented that both VEs gave them opportunities to experience an environment which they would not encounter on an everyday basis. When discussing the invisible aircraft VE, one participant said, *"I think the landscape was pretty interesting and to see the whole landscape on the walls and the bottom, which is not normal if you're on an airplane."*- P6

The participants tended to dislike the poor image quality and lack of details in some parts of both VEs. For example, when discussing the invisible aircraft VE, a participant reported the following:

"What I didn't like, well in some parts, you couldn't really see that much because, the graphics, the resolution was not really high…over the trees and the first houses…there were not much details, you could only see the form of the houses, there were no textures on them…and I think it doesn't give you much if the graphics are not so good. Like in the beginning when you only had like the rough shape of the landscape, then it could be everywhere and it could be everything so it doesn't really look so real but later when there were really the houses and you can see the windows, or you could see the cars, then this is nice because you think then, 'ah yeah, that's really a real world' because if it's not detailed enough, you don't think that this is real, an environment. It could also just completely be generated at a computer." – P9

The participants also reported a number of mismatches which they did not like in the untracked tropical island VE condition. There were instances where the elements of the VE were misaligned from the perspective of the participant when looking across more than one display or set of displays. In addition, one participant reported that they did not think that the seat fabric and their sitting position matched this VE.

"I couldn't really bring it together, my sitting position in my chair, my upright chair and the beach. The fabric, quite warm fabric on the seat wouldn't fit in an environment with sand and heat." – P11

In both of the partially tracked conditions, participants reported mismatches between the displays (specifically the seat-back displays and the wall displays). A participant commenting about the partially tracked tropical island VE said,

"With the partial tracking… there was always the gap between the walls and the screen [seat-back displays]." – P6

A participant talking about the partially tracked invisible aircraft VE said, *“Again here, you have that it doesn’t really fit together when it’s only partially tracked.”* – P9

Other disliked elements of all of the tracked VEs related to the movement of the VE in relation to users’ movements. This included lag, the over-sensitivity of the movement of the VE and the movement not feeling realistic.

In all tracked conditions, an additional issue was noted with regard to the tracked movement. This related to the way in which the VE responded when moving closer to and further away from the VE and was particularly prominent on the seat-back displays which had black surrounds and therefore provided a real-world reference point. It should be noted that these displays were designed to simulate looking out of a window. When participants moved closer to the displays, they expected objects in the VE to appear larger. However, they actually appeared smaller. In fact, this was implemented correctly in the virtual world but was not consistent with their mental model of what should happen.

Realism

The participants were asked to comment on the realism of the VEs and their associated sounds. Whilst a small number of participants thought that the visual elements of the untracked tropical island VE were realistic, they generally felt that the VE was not realistic and was obviously a graphic. For example, one participant noted that the textures used on the trees were repeated. When partial tracking was integrated into this VE, some participants commented that the realism improved. When full tracking was integrated into the tropical island VE, participants generally commented that the VE was more realistic than with the other two tracking configurations, for example:

“It was a bit more realistic...probably because then I had the feeling that my head movements have an effect on the angle when I see the palm trees.” – P11

The participants also felt that the untracked invisible aircraft VE was not visually realistic, often commenting that some elements lacked detail, for example:

"The invisible plane, there were some parts which were really detailed and some parts like in the woods and everything which was just not detailed at all." – P1

Although the invisible aircraft VE was not detailed enough to be perceived as a real environment, participants were able to recognise the environment that they were flying over.

"With respect to the environment, it was not detailed enough. It looked like a simulation of course. But it depends what you expect. Of course, I was able to recognise the environment, the real environment that I knew" – P11

Similarly to the tropical island VE, when partial tracking was integrated some participants commented that the realism improved. When full tracking was used, they generally felt that the VE was more realistic than the other two tracking configurations, for example:

"It felt comfortable and a little bit more realistic than before. In directly comparison, it was much more realistic…because the movement was completely realistic so as if I was flying." – P10

When asked about the realism of the sounds, participants generally commented that the tropical island sound was realistic. One unrealistic element that was reported was the number of birds in this environment or that birds would not be expected in this environment.

"Except the birds maybe...I cannot remember having heard birds at the beach. And I think in reality, the waves would be louder compared to the sound of the birds." – P12

One participant also commented that they could hear birds but not see them. The sound of the waves was also reported to not match the VE. Participants suggested that the waves sounded intense but looked calm and or said that the fixed position in the VE was too far from the water given the volume of the sound of the waves.

"The waves, they sound pretty loud and strong but they were just small waves on the beach." – P5

Participants generally thought that the aircraft sound was realistic but similarly to the island sound, there were certain elements which were less realistic. Participants often thought that the sound was quieter than in a real aircraft. They also stated that on a real aircraft, other or more sounds would be heard, for example, more people speaking or interacting with each other.

> *"Usually if you are on a plane, the voices are much more louder so they were just like some but this noise was perhaps during night time when everyone sleeps, then you have a noise level like this but during daytime, people are talking all the time."* – P1

Effect of head tracking

The participants were asked to comment on the effect that they felt each of the tracking configurations had on their overall experiences. In general, the participants felt that the partial tracking had a negative impact in the tropical island VE. Specific reasons included making the environment less relaxing and mismatches between displays. Some participants stated that the partial tracking in this VE had no effect on their experience with one participant stating that this was because they didn't move their head much and therefore didn't experience the tracking.

> *"Not a big impact...I didn't move my head so much that I would realise it or experience it."* – P8

When the tropical island VE was fully tracked, the participants generally felt that the motion tracking had a positive effect on their experiences. This positive effect was attributed to an increase in realism and presence, making the VE more interesting and creating a perception of increased physical space. One participant also said that they would be able to use this VE for longer in this condition than with other tracking configurations.

> *"I think I could have stayed there longer because it was so real."*- P4

Like the partially tracked condition, some participants did not think that the motion tracking had any effect on their overall experience. A small number of comments were also made regarding negative impacts on experience. These included a reduction in realism, increased discomfort and a reduction in the relaxing effect of the VE.

In both tracked tropical island VE conditions, some participants reported that they thought that the motion tracking was unnecessary because there was nothing extra to explore in this VE with the addition of the motion tracking.

> *"Also, I didn't see the use of the head tracking at all. I couldn't discover more because of this...No. I would say no added value."* – P11

Another participant commented that the tracking was interesting in the beginning but after a while did not add anything extra to the experience in this VE.

> *"In the beginning, it was interesting, like it was something new and you could test out everything…try to…see what is behind you or something. You could have a look at places that you couldn't see before so this was quite cool in the beginning but…after, I don't know, one or two minutes, I'd seen everything"* – P9

In contrast to the tropical island VE, the participants generally felt that both tracking configurations had a positive effect on their experiences of the invisible aircraft VE. This was attributed to increase in realism and presence, making the VE more interesting and being able to have a good perspective on the view shown in the VE. Participants also commented that time passed more quickly and that they perceived an increased amount of physical space.

> *"I could look more around and see everything so it was already interesting on the TV* [partially tracked] *but much more better with the walls* [fully tracked] *and the visual feeling was better with the invisible plane with the walls because it was more real for me because I had this landscape and this far view on the landscape and when I move it felt real for me, how the environment reacted."* – P1

One participant also said that they would be able to use this VE for longer due to the increased realism. The negative comments made with regard to the partially tracked invisible aircraft VE only related to mismatches between displays.

Contribution of displays

Participants were asked which of the displays that the VEs were presented on contributed most and least to their experiences. They were allowed to select more than one display. Table 4-4 shows the number of participants who named each of the displays as having the greatest contribution to their overall experience. Table 4-5 indicates the number of participants naming each display as having the least contribution to their overall experience. The cells in these tables are shaded from dark to light, where a dark colour is associated with a high number of participants and a light colour relates to a low number of participants. All values are out of a possible 12. Figure 4-5 shows the location of each of these displays within the set-up.

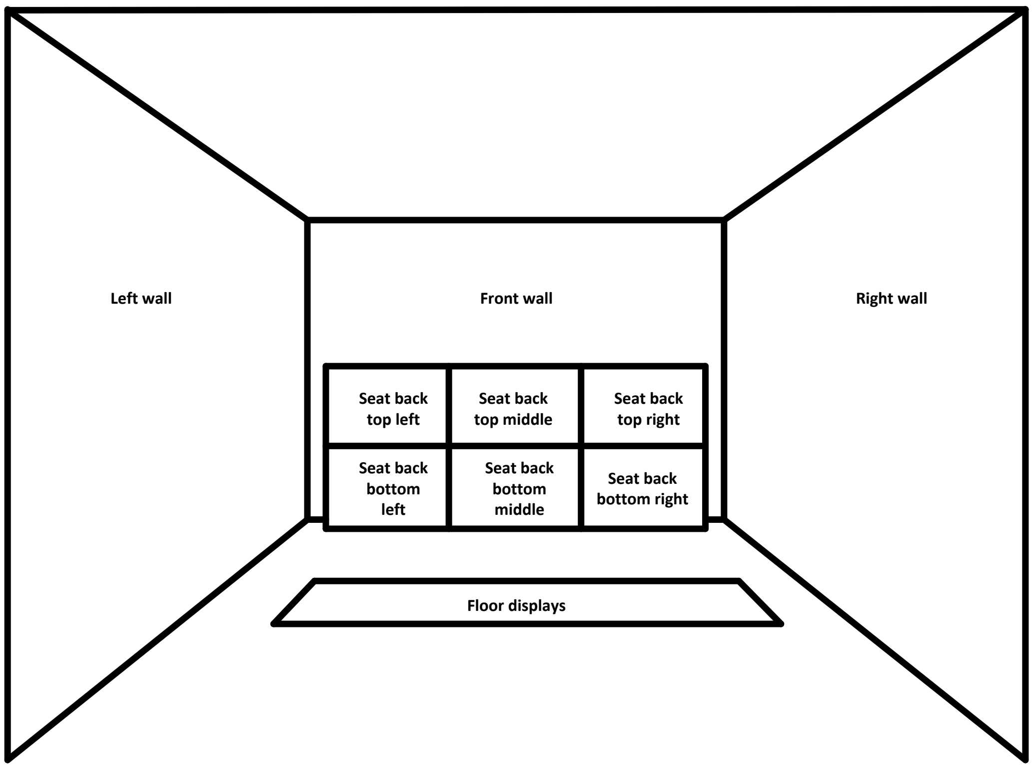

Figure 4-5 Location of each display in the set-up

Table 4-4 Displays contributing most to the overall experience

	Seat-back top left	Seat-back top middle	Seat-back top right	Seat-back bottom left	Seat-back bottom middle	Seat-back bottom right	Left wall	Front wall	Right wall	Floor
Island_untracked	7	7	6	4	5	4	5	5	6	1
Island_partial	8	9	8	5	6	5	5	5	5	1
Island_full	5	6	5	3	4	3	6	5	7	1
Flight_untracked	8	8	6	6	6	5	5	2	3	6
Flight_partial	10	10	8	9	9	9	6	3	5	7
Flight_full	8	8	7	8	7	6	8	4	7	6

Table 4-5 Displays contributing least to the overall experience

	Seat-back top left	Seat-back top middle	Seat-back top right	Seat-back bottom left	Seat-back bottom middle	Seat-back bottom right	Left wall	Front wall	Right wall	Floor
Island_untracked								1		11
Island_partial			1	1		2		1		10
Island_full								1		10
Flight_untracked							1	3	1	2
Flight_partial	1		1				1	3	1	2
Flight_full								3		2

It is evident that for all of the tropical island VE conditions, the floor display made the least contribution to the experiences of the participants. This is unsurprising given that this display only showed an image of sand. However, the participants may have found the VE less compelling without the floor display. In the partially tracked tropical island VE, the impact of the seat-back displays also appeared to increase slightly in comparison to the untracked and fully tracked conditions. Similarly, the left and right-hand wall displays' contributions seemed to increase slightly when this VE was fully tracked.

In the invisible aircraft VE, a similar trend can be seen in that the seat-back and floor displays' importance increased in the partially tracked condition compared to the untracked and fully tracked conditions. In addition, all of the wall displays appeared to increase in their contribution to the participants' overall experiences when the VE was fully tracked.

In all conditions across both VEs, the relative importance of the front wall appeared to be less than all of the other displays. It is likely that this was due to most participants not being tall enough to have a clear view of this display.

Improvements

When asked how the VEs could be improved to enhance passenger comfort and experience, participants gave very different suggestions for the two VEs. In general, participants did not want interaction or to be able to move around the tropical island VE, giving reasons such as this not being necessary or not feeling compelled to move in a relaxing environment.

> *"I don't need to. The island is more a relaxing place. You're not so feeling 'oh I need to move'."* – P4

However, a small number of participants reported that they would like to be able to virtually walk around this VE.

The majority of participants made suggestions for adding further artefacts to the tropical island VE, giving reasons such as wanting something to happen within the VE to make it more interesting. Suggestions included animals on the beach, birds, shells, boats sailing past, for example:

> *"Some animals. Sometimes a turtle coming out of the water...I expected more animals, a little bit of variation, not a lot but some animals or maybe some birds flying around sometimes. It was very, just the movement of the palms and the sea, there was nothing...Not a lot variation but there should be some."* – P4

Some participants also mentioned that they would like the sound to be more varied as well as the visual imagery. Some participants also stated that they would like their fixed position to be closer to the sea.

For both VEs, the visual image quality and details were also suggested improvements. Suggestions were also made regarding the displays used in both VEs. The most common of these for the tropical island VE was requesting a ceiling display:

> *"Strange that there is no sky. So it would be really, like if you have this kind of big space and it ends a metre above your head then it's a strange feeling."* – P1

In the invisible aircraft VE, the most common display-related suggestion was the ability to turn off the floor display or not providing this feature.

> *"It's interesting because you see what's beneath you but it was too much for me."* – P2

In contrast to the tropical island VE, for the invisible aircraft VE, interactivity was the most common theme of suggestions for improvement. This included the provision of additional information such as names of places on the ground and facts about these places, for example:

> *"Yeah that would be good, if I have the information about the city we're passing...I think the name at least and maybe the sights, so what's interesting or what's the highest building."* – P5

Many participants suggested the provision of multiple levels of information so that they could select which places in the environment they would like more information about.

> *"Either more details of the architecture or of actions, movings, things that are going on actually...I could imagine there was a Fraunhofer logo above the campus...Yeah or that I could point on something and get the Wikipedia information about it."* – P11

Participants also generally said that they would not want this additional information to be displayed all of the time but would turn it on when wanted, for example:

> *"Which city, maybe for special buildings, when there's a church or something like this, when it was built, some history things maybe, how many people live in this city. But not automatically."* – P10

Another suggested method of interactivity was being able to zoom in to be able to see places in greater detail.

> *"That would be a really nice feature if you can zoom in and out because I think you're very high on an airplane and you can't see very much, only shapes perhaps. If you can zoom in, that would be a nice feature."* – P6

Suggestions for the invisible aircraft VE also included those relating to the representation of the time of day or weather conditions. There were mixed opinions regarding this with some participants wanting the real outdoor conditions to be displayed whilst others preferred specific conditions or to be able to switch between real and desired external conditions, for example:

> *"Maybe that I can choose so when there is landscape that I am interested in, I would like another video that shows the day but when I just want to watch what's really outside, I would prefer to have the real one so with rain or at night."* – P2

One participant suggested not only being able to change the representation of time of day or weather but also the period of time:

> *"If you can do that and say like, 'OK and now let's see how the environment would look at night or how it looked 100 years ago' so of course, if you can play*

with the environment, it would be really cool. I think you would, like, could sit there for hours and hours." – P1

<u>*Spatio-temporal thread*</u>

After each condition, participants were told that their previous experience lasted for five minutes and were asked whether they perceived it to be longer, shorter or five minutes. Figure 4-6 shows how time was perceived in each of the conditions. For all conditions apart from the No VE and fully tracked tropical island VE conditions, N=12. N=11 in for the No VE and fully tracked tropical island VE conditions as a participant in each of these conditions was unsure.

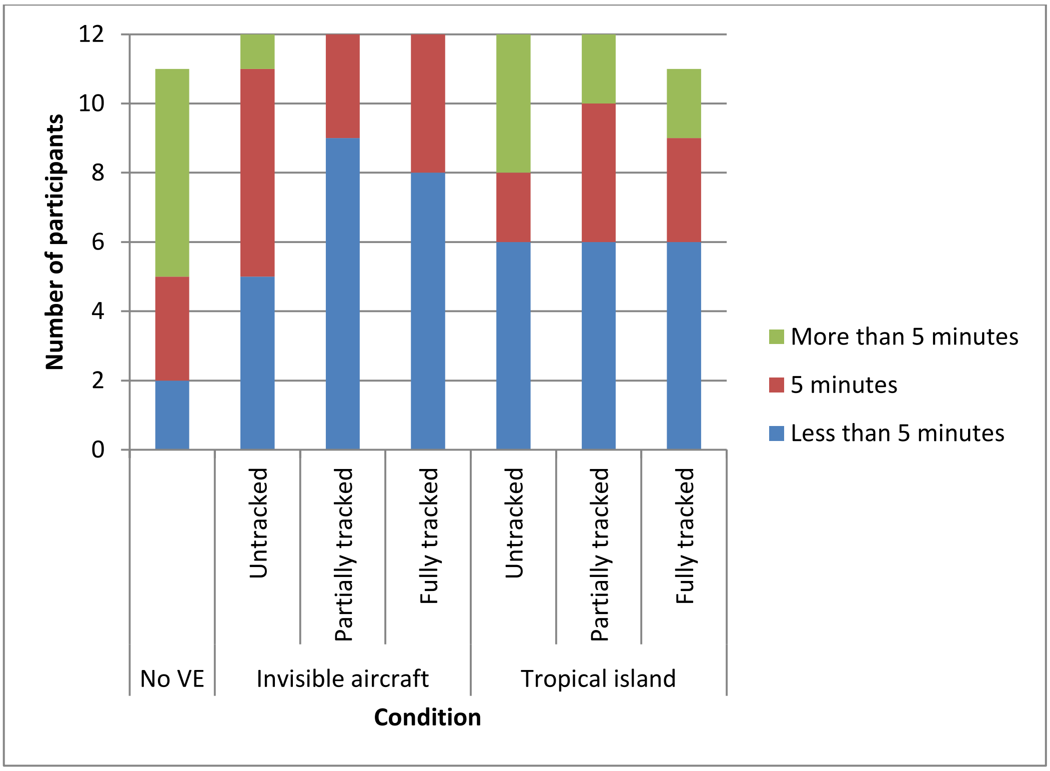

Figure 4-6 Perception of time

It can be seen that the profile of perceived experience duration changed according to the study conditions. In the No VE condition, nine out of 11 participants perceived the experience to last five minutes or longer. This is possibly an indicator of boredom. In all of the VE conditions, the number of participants who perceived the experience to last five minutes or longer was fewer than in the no VE condition. In particular, the two tracked invisible aircraft VE conditions show a large change perceived duration of the experience. This indicates that the use of a VE in an aircraft has the potential to make passengers perceive time to pass more quickly. It is possible that the invisible aircraft VE was more effective as it was constantly changing and therefore more engaging than the tropical island VE.

For the invisible aircraft VE, it can be seen that the motion tracking resulted in the participants perceiving time to pass more quickly. For the tropical island VE, this effect appeared to be present but the difference was less marked. One reason for this could be that many participants thought that the tracking was an unnecessary feature for a VE such as this one which did not promote movement and exploration in the same way as the invisible aircraft VE. As a result, many participants reported that they did not move their heads as much in this condition and some even closed their eyes. Both of these behaviours render the tracked conditions similar (in terms of experience) to the untracked condition.

As reported in the 'comfort and discomfort' section of this chapter (page 66), a number of participants experienced that the amount of physical space surrounding them appeared to increase in the VE conditions. It is likely that this is because both of the VEs depicted large, open, outdoor spaces with artefacts positioned at various distances from the participant and distant horizons. In addition, the increased perception of space when motion tracking was introduced could be due to the fact that motion parallax is known to enhance depth perception.

<u>Emotional and sensual threads</u>

In the post-condition interviews, the participants were asked to report any feelings or emotions that they experienced during the previous condition.

In the no VE condition, a number of negative feelings and emotions were reported including boredom, tiredness and not knowing where to look.

"I was bored and didn't know what to do actually, just sitting around, I didn't know where to look at, was the problem." – P5

Some participants reported that they felt relaxed in this condition. One participant also reported that the sound of the aircraft engine made them feel safe and comfortable:

"Actually, I like that sound, I really like it on a plane so I always have this noise around me and I feel completely comfortable and safe" – P1

The participants tended to report that the untracked invisible aircraft VE was interesting, exciting and that they liked having something to look at as it was a distractor from boredom.

"I think it was more interesting because the picture was moving. So there was something to look on and to be distracted from boredom" – P3

Participants also commented that the VE being recognisable made it a more interesting experience, for example:

"It was certainly much more interesting…because it was also nice that it was the flight around here over the campus so it was, in the beginning, I didn't see that and there were the first bigger buildings and, 'oh yeah, this might be around here in Vaihingen somewhere, ah yeah this is the campus'. This was entertaining to see that...it was more interesting and I thought about, 'is this the campus? Oh yes it is Fraunhofer. This is what the buildings look like from above' so this was interesting." – P9

The untracked invisible aircraft VE also induced some negative feelings, causing some participants to experience vertigo or a fear of falling, for example:

"Well, I mean, I couldn't sleep. I mean it was exciting, it was cool but at the same time, I was like, 'err what if I fall off the plane'. But I think it's fun but at the same time, a little scary." – P7

Some of the participants who experienced this also said that after a while, they would get used to this feeling and would be more at ease, for example:

"I would get relaxed, just get comfortable with the feeling that I am on an invisible plane. I think at one point you would get relaxed just because you would get used to it." – P1

The addition of the motion tracking led the participants to find the invisible aircraft VE more interesting and exciting due to the flexibility and control over their visual perspective.

"It was more interesting…I could look back a bit so I had a new perspective so this was interesting and nice." – P9

One participant reported feeling more uncomfortable in both of the tracked invisible aircraft VE conditions as a result of the combination of their movement and the VE's movement.

"Actually more discomfort...because it's some kind of stress for my eyes or brain to accept that the images are moving according to my head movement because when I'm moving my head here in the real environment, things are not moving too...It felt like I was moving and things were moving as well." – P12

When discussing the untracked tropical island VE, the participants tended to report that they felt comfortable and relaxed, for example:

"Positively. It was more relaxing. Gave you a sense of being on the beach and relaxing" – P12

A number of participants reported that it was a positive experience in the beginning but after a while, it started to get boring:

"In the beginning it was OK. Then after a few minutes, I get bored because, like I said, it looked like a picture to me and nothing was moving and I couldn't find anything interesting in the picture anymore." – P5

However, one participant also reported that it was acceptable to be bored in this VE due to its relaxing nature.

"Because it is relaxing, there doesn't happen so much...It was more acceptable [for it to be boring]." – P8

Although they reported that the motion tracking detracted from the relaxing nature of the tropical island VE, most participants still thought that the VE was relaxing to some degree and comfortable.

> *"It was quite real and a very nice beach so it felt relaxing, like I could stay there a while and read a book"*- P4

Descriptors such as 'fascinating', 'cool', 'fun' and 'interesting' were also used to describe this VE when the tracking was integrated.

Some participants commented that the tropical island VE became less relaxing or not at all relaxing with the addition of the tracking. Comments were made such as the following:

> *"At the end it was also relaxing because I didn't move anymore but before, when I was moving, it was not very relaxing. It was disturbing, I can say"* – P10

Other negative descriptors used to describe this VE in both tracked conditions included 'uncomfortable' and 'stressed'.

<u>Passenger acceptance</u>

The participants were asked about the circumstances under which they would and would not use these VEs in a real aircraft. A commonly mentioned circumstance for using the tropical island VE was when participants would want to sleep or relax. Often this was mentioned in combination with being on a longer flight:

> *"It might be worth it on a longer flight, having half an hour or an hour or something like that relaxing before to go to sleep."* – P3

A small number of participants also commented that it would be a nice environment to wake up to.

The participants mentioned that they would not use the tropical island VE for a long period of time. Some also said that they would not use it on a short flight, giving reasons such as wanting to carry out other activities on short flights or not wanting to relax on these occasions, for example:

"I think, on a short flight, usually I want to…you know usually if you're on to a plane and you're in a hurry and you do whatsoever, and once you're on the plane, you want to read your newspaper or check out your emails, stuff like that. Do some stuff rather than sitting there…" – P3

The participants also suggested that they might use the tropical island VE when carrying out other activities. Reasons given for this included it not being too distracting an environment and it not being engaging enough to simply view without doing anything else.

"I could just put it on and read a book and yeah it would be actually a better environment for something if you wanted to do something in parallel, I would choose the island because it doesn't distract you so much." – P1

However, they also commonly mentioned that they would not want to use this VE when watching a film or when using the displays for another purpose.

Other instances in which the participants suggested that the tropical island VE may be used related to wanting to escape from reality, such as escaping from a loud or busy environment or as a distraction for passengers who are afraid of flying. In contrast, it was reported that during specific phases of flight such as take-off and landing and when the view outside is interesting, it would be preferable to not use this VE.

The suggested circumstances for using and not using the tropical island VE were the same for both tracking configurations and the untracked condition. Some participants explicitly said that they would or would not use specific tracking configurations with this VE but there was little agreement.

The circumstances under which participants reported that they would use the invisible aircraft VE were very different from those under which they would use the tropical island VE. The most common emerging theme was wanting to experience and look at the VE. When the VE was switched on, the participants generally suggested that they would be actively viewing it and they would use it when they were interested in the landscape, to see where they were and to obtain a new perspective on their environment.

> *"I think it's when there is something interesting…situations like cities or water or crossing something like on a plane. Sometimes it's very interesting to watch out."* – P3

In particular, the participants commented that they would use and watch this VE during the take-off and landing phases of flight. The participants mentioned specific landscapes over which they would not use the invisible aircraft. These included the desert, countryside or bodies of water at night time or large expanses of water. Reasons given for this were that these are repetitive and would become boring. In the event of flying over oceans, nervousness was also given as a reason.

> *"I think, if I'm going over the Atlantic and just see this big body of water below me, it don't want to see this. I don't want to see this at all."* – P8

Some participants stated that they would keep the invisible aircraft VE switched on in the background while they were doing other things and would only engage with it when they were interested, for example:

> *"Read a book maybe and then over the cities, you put it on the side, my book, and have a look what happens around but when leave the city again, then you can do other things."* – P10

Other participants commented that they would not have this VE switched on in the background. This appeared to be particularly pertinent when they would be carrying out other activities which require concentration such as working, for example:

> *"I think, at night, for example and when I read a book and I don't really have to concentrate, if it's not really important what I read, I just read for free time, I could use the invisible plane as well but if I would have to concentrate on something, it would be hard to do it with the invisible plane."*- P1

Another circumstance under which participants reported that they would not use this VE was when trying to sleep or relax due to it being engaging and slightly scary, in particular if passengers were to wake up with the VE switched on.

"When I want to sleep or relax, I think it would be too much. I think then you always want to look at the movement and you would not be able to get to sleep" – P2

As with the tropical island VE, the circumstances under which the participants would use the invisible aircraft VE were unchanged with the addition of motion tracking. Again, some participants explicitly said that they would always or never use specific tracking configurations with this VE but there was little agreement amongst these participants.

<u>Observable behaviours</u>

During the studies, behaviours which could negatively impact on the comfort and experience of other passengers were observed. As a result, a coding scheme was developed in order to assess the prevalence of these behaviours and was used when carrying out video analysis. Table 4-6 shows the number of participants who exhibited each of these behaviours in each condition (all values are out of a possible 12). Participants were only counted if they exhibited these behaviours persistently (i.e. for more than 30 seconds over the five minute exposure period). Extreme movement was defined as lateral movements made outside of the perimeter of their seating area as well as leaning forwards towards the seat in front.

Table 4-6 Number of participants exhibiting potentially negative behaviours

Condition	Extreme movement	Reclining
No VE	0	4
Untracked tropical island VE	0	2
Partially tracked tropical island VE	8	4
Fully tracked tropical island VE	9	4
Untracked invisible aircraft VE	2	3
Partially tracked invisible aircraft VE	9	2
Fully tracked invisible aircraft VE	9	4

While the data in Table 4-6 indicates some possible changes in behaviour which could be attributed to the presence of or lack of VE or motion tracking, it does not reflect the changes in behaviours for individual participants across the conditions. For example, two participants who reclined their seats in the no VE condition did not do this in either of the untracked VE conditions. In addition one participant only reclined their seat in the invisible aircraft VE. However, it can be seen from this data that the presence of a VE, in particular, with the addition of motion tracking may lead passengers to make more extreme movements than they normally would.

4.2.3. Discussion

The study presented in this section aimed to determine the effect of two VEs on participants' comfort and experience as well as the circumstances under which passengers would and would not use these VEs on future aircraft. The study also aimed to determine the effect of motion tracking in various configurations in conjunction with these VEs on participants' comfort and experience. This was with a view to understanding the best method of implementing motion tracking into each of the VEs in order to enhance comfort and experience.

Although there were no differences in the participants' subjective ratings of comfort or discomfort across the conditions, analysis of interview responses revealed that the sources of comfort and discomfort could be changed by the presence of a VE (and motion tracking). For example, the tropical island VE had an effect on environmental comfort, with a number of participants reporting the sound and lighting conditions as being sources of environmental comfort. The invisible aircraft VE also had a positive effect on environmental comfort as a result of better lighting. However, this VE also had the potential to induce vertigo in some participants due to the floor displays. The motion tracking also had a negative effect on environmental comfort due to the ways in which the VE moved. This finding illustrates that a common rating of overall comfort or discomfort may result from a number of different combinations of contributory factors and therefore highlights the complexity of comfort and discomfort as constructs.

From a methodological perspective, this study identified that without inducing a consistent source of discomfort, it is difficult to determine the effect of VEs on comfort. The study showed that the sources of comfort and discomfort can be changed with the addition of VEs but did not show the benefits that VEs might offer in terms of acting as a distractor from specific sources of discomfort. Therefore, it is concluded that further study should investigate the extent to which VEs can distract people from specific sources of discomfort.

The findings suggest that the VEs created the illusion of increased physical space for some participants and this illusion was increased with the addition of motion tracking. It is likely that this is due to the VEs portraying large, open spaces with distant horizon lines. Existing literature reveals that the use of pictorial cues in monoscopic VEs can enhance depth perception in VEs. These cues are underpinned by real-world depth perception cues. Such cues, which were present in both VEs used in this study, include the relative size of objects, distance and direction of objects from the horizon line, shading, perspective and occlusion of objects in the background by objects in the foreground (Bruce et al., 1996; May & Badcock, 2002).

The additional increase in space perception when motion tracking was implemented is also not surprising as motion parallax is known to enhance depth perception (Bowman et al., 2005). Further research should investigate whether this illusion remains present when multiple seats are occupied in the set-up. The presence of additional participants would both further reduce the amount of physical space available whilst also occluding the views of the displays.

As well as having the potential to increase the perceived amount of space around a passenger, the VEs also had the effect of making time seem to pass more quickly than in the no VE condition. More participants reported this effect for the invisible aircraft VE than the tropical island VE and the number of reports increased with the addition of motion tracking. Studies have shown that when a task has greater attentional demands, time is perceived to pass more quickly (Chaston & Kingstone, 2004; Lamotte et al., 2012). It is therefore possible that time was perceived to pass more quickly in the invisible aircraft VE as it was constantly changing and therefore potentially was more interesting and engaging than the tropical island VE. Therefore, the addition of small events, such as boats sailing past or animals on the beach, may increase interest in the tropical island VE and therefore also increase the perception of time passing more quickly.

Although they were generally comfortable in the no VE condition, the participants tended to dislike this condition, often stating that they were bored. With the addition of the VEs, the participants experienced more positive feelings and emotions. In particular, the tropical island VE promoted feelings of relaxation and the invisible aircraft VE created feelings of interest and excitement. It is therefore important to consider the desired effects of VEs and to provide choice to passengers to ensure that the VEs available can support their desired activities or emotional states.

Although the motion tracking appeared to add additional sources of discomfort, it is evident that the benefits of the motion tracking for the invisible aircraft VE outweighed the disadvantages. When discussing this VE, participants often commented on the improved visual perspective and the increased realism with the addition of the motion tracking. They also tended to find the VE more interesting and exciting with the addition of the motion tracking. Many participants thought that it was unnecessary for the motion tracking to be used in conjunction with the tropical island VE. This was due to the lack of additional artefacts within the VE to experience with the motion tracking combined with it becoming less relaxing. It is possible that with the additional implementation of animals moving around and boats sailing past, as suggested by the participants, this opinion may change. In this VE, many participants also found their experiences less relaxing with the addition of motion tracking. It is likely that this is because the VE itself was conducive to sitting still and relaxing, as observed in the untracked conditions, but the motion tracking led participants to physically move around and explore this feature. It is, however, possible that the results were affected by participants being made aware of the presence of the motion tracking.

In the invisible aircraft VE, all displays seemed to be relatively important in their contribution to the overall experience, whether positive or negative. In the tropical island VE, all displays apart from those on the floor were important. This was not surprising given that this display only showed an image of sand. However, if this display was not present, the VE may have been less compelling. Therefore, there is an argument for future implementation in aircraft to be fully immersive. If VEs are motion tracked and presented on ambient displays, these will need to be multi-viewer displays in order for passengers to experience a fully tracked, immersive VE without the distraction and confusion caused by the misalignment of the image across the displays.

All displays were reported to have similar levels of contribution to the overall experiences (apart from the floor display in the tropical island VE). This indicates that they were all important to some degree in terms of creating the experience. It was surprising that the front wall appeared to have as much impact on overall participant experience as the seat-back displays appeared to occlude the view of the front wall to some degree for most participants.

A number of participants were observed to exhibit behaviours which could impact negatively on the comfort and experience of other neighbouring passengers. In particular, when motion tracking was integrated into the VEs, participants were observed to make extreme movements which extended to beyond the confines of their allocated space. It is possible that these behaviours were due to the participants being made aware of the motion tracking. Therefore further investigation should examine whether these behaviours are still present when more than one person is sitting in the set-up and when the participants are not made aware of the motion tracking.

Finally, it is worth considering the usefulness of the Technology as an Experience Framework (McCarthy & Wright, 2004; Wright et al., 2004) for the analysis of the data collected relating to UX. The framework provided a means of ensuring that a holistic view was taken to the analysis of the users' experiences. It also helped to ensure that the breadth of the elements which make up the user experience were considered when designing data collection. However, the framework was also very broad which made it difficult to apply to the specific cases evaluated in this research, although this did provide a useful means of obtaining a holistic view of users' experiences and identifying areas for further research.

4.2.4. Conclusions

The results of the study indicate that the use of VEs in-flight could provide people with opportunities which are not available on aircraft today. These include the potential to enhance the experience of a flight or the possibility for passengers to perceptually remove themselves from the aircraft environment should they wish to do so. Augmenting the flight experience would provide passengers with an experience which is unique to flight, one which could not be experienced in the same way on the ground. The perceived displacement of a passenger from the aircraft environment would enable those passengers who are afraid of flying to feel as if they are elsewhere. VEs of this nature could also be used to escape from sources of discomfort or annoyance in the environment and may provide passengers with opportunities to experience places which they do not encounter on a daily basis.

The results indicate that VEs could have a positive effect on passenger experience. The suitability of motion tracking depends on the VE being experienced and whether this is designed to promote interest and exploration or relaxation.

The findings suggest that VEs and motion tracking can change the sources of comfort/discomfort (see Figure 4-3) and can also create the illusion of increased amounts of physical space and reduced passage of time. It is not clear from this study whether VEs are an effective means of overcoming sources of discomfort. In order to investigate this, it would be necessary to start studies from a position of discomfort. It would be interesting to investigate whether VEs can enhance comfort when individuals are experiencing sources of discomfort which differ in the sensory channel through which they are perceived (e.g. auditory, tactile, visual or olfactory).

The findings also indicate that the presence of VEs and motion tracking can affect the behaviours exhibited by participants. It is therefore necessary to investigate the use of these VEs with the presence of multiple participants in order to determine whether these behaviours are still exhibited and to examine their effect on the comfort and experience of others.

Virtual reality has the potential to enhance passenger comfort and experience in future air travel. The use of motion tracking may have a positive effect on the overall passenger experience but may also have some negative consequences. Further investigation is required to determine the extent to which VEs can distract participants from sources of discomfort.

4.3. **Influence of other passengers**

One of the findings of the passenger experience study was that many of the participants made extreme movements beyond the perimeter of their allocated space or by leaning forwards. These behaviours were particularly prominent when motion tracking was implemented into the VEs. As the findings indicated that motion tracking was an important addition to the invisible aircraft VE, it was important to investigate whether these behaviours were present when multiple people were occupying the set-up. In addition, literature has shown that the presence or lack of other people can influence passenger comfort (Bor, 2007; Budd et al., 2011; Patel et al., 2012; Vink et al., 2012). As a result, a small follow-on study was carried out to determine whether these behaviours were present when multiple people were occupying the set-up. If these behaviours remained present, the effect that they had on adjacent passengers was also assessed.

4.3.1. Method

Participants

Eighteen participants were recruited from Fraunhofer IAO and Stuttgart University. They had a mean age of 32.5 years (SD=9.13) and were recruited on the basis that they could speak English and had taken a flight in the past three years. They were excluded from participation if they had any conditions which are known to be indicators of susceptibility to VRISE (e.g. those in Ramsey (1999)). Criteria included susceptibility to motion sickness, migraines, epilepsy (photosensitive or otherwise), recurring headaches, back pain or back problems, neck or shoulder pain, asthma, problems with depth perception, heart conditions or any other serious injury or illness as well as those who were pregnant.

The participants were recruited in pairs. It was ensured that the pairs of participants did not know each other prior to the study taking place. It was also ensured that they had not used the VE before.

The participants were asked to complete a short background questionnaire which included measures of how much they like flying, are scared of flying and their experience using VR using 11 point scales. The descriptive statistics for this data can be found in Table 4-7.

Table 4-7 Descriptive statistics for background data

	Median (IQR)	Anchors
Like flying	7 (0.75)	0 = I hate flying 10 = I love flying
Scared of flying	1.5 (2.5)	0 = Not at all scared 10 = Extremely scared
VR experience	7.5 (6)	0 = No experience 10 = Extremely experienced

Equipment

The study took place in the Fraunhofer IAO cabin mock-up and made use of the fully tracked invisible aircraft VE. Details of the hardware and VE can be found in chapter 3 of this thesis.

A video camera was placed behind the seat-back displays in order to capture any participant behaviours. Voice recorders were used to record the interviews and all questionnaires were paper-based.

Design

The study comprised a single condition in which two participants simultaneously experienced the fully tracked version of the invisible aircraft VE and corresponding aircraft sounds. This VE and motion tracking combination was used as the behaviours which were being observed were prominent in this condition in the previous study and because the previous study found that motion tracking enhanced the experience of this VE. As only one person could control the motion tracking, the participants were asked to swap seats and control of the motion tracking after five minutes (halfway through the experience).

The study was designed to last no longer than 30 minutes (with ten minutes exposure to the VE) and was approved by the ethics committee at the Faculty of Engineering, University of Nottingham.

Procedure

Upon arrival, the participants were welcomed, introduced to the study and asked to complete a demographics questionnaire. They were told that the study was investigating the use of VEs in future aircraft. They were asked to leave their belongings outside the set-up and to behave as they would on a real aircraft when carrying out the study.

Upon entering the set-up, one participant sat in the middle seat and took control of the motion tracking. The other participant sat in the left-hand aisle seat and the experimenter sat in the right-hand aisle seat (in order to simulate a fully occupied row of seats on an aircraft). After five minutes, the two participants swapped positions and control of the motion tracking.

Participants were asked to complete the short symptoms checklist (SSC) (Cobb et al., 1995) pre- and post-condition. A post-study interview was also carried out. It should be noted that the SSC was only used for monitoring purposes and was not included in any data analysis.

4.3.2. Results

Structured post-study video observations were carried out to determine the prevalence of extreme movements during the study.

Of the 18 participants, only four were observed to make extreme movements which extended to beyond their allocated seating areas. Examples of these movements can be found in Figure 4-7. In comparison to the findings of the passenger experience study, proportionately, this is a substantial decrease. It is unclear from these observations alone why this is. It is possible that this could be attributed to either the presence of other people in the set-up or the participants not being explicitly told about the motion tracking in advance of the study. Of the participants who commented on their extreme movements in this study, one stated that this was due to the novelty of the technology and that they would not do this throughout a flight:

> *"I wanted to move it just to see how it works but I think if I would wear it longer, I wouldn't move anymore, I would just move like I would without the glasses as well."* – P9

Some of the participants who did not make extreme movements commented on their reasons for not doing so. Reasons included these behaviours not being natural to them in an aircraft context or not feeling the need to move too much, for example:

> *"I guess this is more of the point that if I do sit on a plane, I'm not really…looking around on everybody else or anything. I'm more focussed on myself so it's just more something that is usual to my behaviour on a plane…well sometimes I'll just take a look on the aisle or anything if there is anything coming up that might be interesting but other than that, not really."* - P1

Another participant stated,

> *"Well maybe I may add, because before I wore the glasses the colleague next to me had them on and I bent forward briefly and realised - ok, actually I can see everything just sitting like this. I don't have to move around much. And that's why I maybe did not move as much, when I had the glasses on."* – P3

Figure 4-7 Examples of participants making extreme movements

The participants who were sitting next to someone who exhibited these behaviours were interviewed about how the behaviours affected their comfort and their experiences. Two of these participants did not notice the movements which were made by their neighbouring participants and were therefore not affected by these behaviours. These participants were unable to attribute reasons this but it is possible that they were distracted by the VE. Two participants did notice the extreme movements of their neighbours but were not negatively affected by them. One stated that on a real aircraft this would have a negative impact but because of the particular situation that they were in during the experiment, they did not mind:

> *"Well if he'd done that all the time, yes, surely [would be bothered] but I mean, in this situation, I knew that he was trying out the system so I was curious with him about it. In a usual situation, that would usually bother me, yeah."* – P21

4.3.3. Discussion and conclusions

The findings of this study indicate that the extreme movements which were exhibited in the passenger experience study were less prominent when other people are present and when the capabilities of the motion tracking system were not highlighted to them. Whilst some air passengers might exhibit these behaviours, it is possible that this would only be when the system is novel to them, in order to test its capabilities. It is also worth noting that not all participants noticed when their neighbours were making large movements. Although they were unable to attribute reasons for this, it is possible that the VEs distracted them from noticing their neighbours.

Further investigation should determine the extent to which VEs can distract people from sources of discomfort which are commonly present on board aircraft. Considering the variability in terms of the behaviours exhibited by other passengers and the artificiality of an experimental context, a decision was made that the behaviours of other people is not a source of discomfort which would be investigated further within an experimental context in this research. Rather, consistent and controllable sources of discomfort which are also common to the aircraft environment would be used. Chapter 5 presents a series of studies which were used to select and test such sources of discomfort.

4.4. **Chapter summary**

The first study presented in this chapter aimed to determine the effect of two VEs and various motion tracking configurations on comfort and experience. Alongside findings relating to these aims, an additional outcome was discovered relating to behaviours exhibited by participants which might negatively impact on other passengers nearby. Therefore a small follow-up study was also carried out to determine the prevalence of these behaviours when the set-up was occupied by other people and, if present, their effect on the adjacent participants' comfort and experience.

The studies revealed a number of possible areas for further research. In order to narrow the focus of this research, it was decided to use the findings relating to passenger experience in order to select the most appropriate combinations of VE and motion tracking to be used in further study (no motion tracking for the tropical island VE and full motion tracking for the invisible aircraft VE). As the findings relating to comfort did not identify whether VEs could reduce discomfort, this was selected as a line of further research. Chapters 5-9 investigate this further.

5. METHODOLOGY REVISITED: SELECTING AND TESTING DISCOMFORT-INDUCING STIMULI

5.1. **Introduction**

The passenger experience study (presented in chapter 4) revealed that the use of VEs can change the ways in which comfort and discomfort are experienced. The study also illustrated that it is difficult to assess the effects of a VE on perceived overall comfort levels without a common source of discomfort being experienced by all participants. As the previous study did not induce discomfort deliberately, discomfort was not experienced by all participants. In addition, amongst those who did experience discomfort, the sources of discomfort varied. As not all participants experienced discomfort, it was not possible to determine the extent to which the VEs could enhance their comfort. Benford et al. (2012) agree with this observation, stating that the introduction of discomfort allows for the assessment of how good the consequences of an intervention are. In addition, Helander and Zhang (1997) suggested that a reduction in discomfort could lead to the perception of comfort.

Vink (2014) spoke about 'the sweetness of discomfort' and embedding discomfort into designs in order for passengers to experience relative improvements in comfort. He highlighted that the perception of comfort changes based on previous experiences and therefore embedding discomfort may lead to exaggerated perceptions of comfort later. Both Vink (2014) and Helander and Zhang (1997) highlight the importance of relativity in perception of comfort and discomfort and imply that in order for users to become aware of their experience of comfort, discomfort must be experienced first.

This chapter presents two studies which aimed to develop a new approach to measuring the extent to which VEs could distract people from sources of discomfort. This was achieved by (a) selecting sources of discomfort to be used in subsequent experiments and (b) assessing the effectiveness of the selected stimuli at inducing discomfort.

5.1.1. Sources of discomfort

Vink and Brauer (2011) and Vink et al. (2005c) proposed a 'comfort input/output schema' which described the sensory inputs which, along with the history and state of the individual, affect the experience of comfort or discomfort (the output) (see Figure 2-7, page 22). Drawing on multiple resources theory, these inputs could be viewed as visual or auditory (Wickens, 1978, 2002) as well as being perceived through the tactile, olfactory or taste senses. Figure 5-1 builds on the comfort input/output schema proposed by Vink and Brauer (2011) and Vink et al. (2005c) but considers the output in terms of its nature (i.e. physical, environmental, social or psychological) as well as whether comfort, discomfort or no discomfort are experienced.

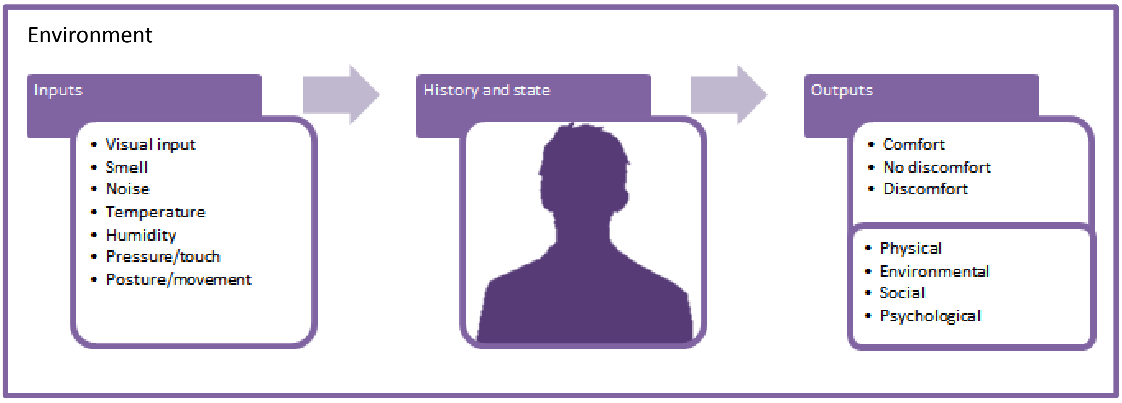

Figure 5-1 Adapted input/output diagram of comfort and discomfort based on the schema proposed by Vink and Brauer (2011) and Vink et al. (2005c)

For example, another passenger sitting next to an individual who makes undesired conversation would be an auditory source of discomfort but may manifest as a source of social comfort or discomfort depending on the situation (e.g. the relationship between the passengers, the mood of the person being spoken to etc.). Similarly, a high pitched sound, such as the sound of microphone feedback, would provide auditory input which is likely to manifest as physical discomfort. Considering comfort and discomfort in terms of sensory input in combination with their expected output modalities could be useful when selecting sources of discomfort for subsequent experiments.

For the purposes of this research, when selecting sources of discomfort, emphasis was placed on tactile and auditory sources of discomfort as these were easiest to experimentally induce consistently without specialist input. Tactile discomfort (such as space restrictions or invasions of personal space) and auditory discomfort (such as loud people, crying babies or engine noise) have been found to contribute to discomfort in an aircraft context (Patel et al., 2012). In addition these are sensory inputs which are easy to manipulate within an experimental setting.

5.1.2. Why use VEs to distract people from discomfort?

Although VEs have not been used in previous studies to distract people from sources of discomfort, studies have shown that VEs can be an effective means of distracting people from pain (see chapter 2 for more detail). A number of these studies were carried out in controlled conditions where participants were exposed to experimentally induced pain (e.g. Dahlquist et al., 2010; Dahlquist et al., 2007; Dahlquist et al., 2009; Jameson et al., 2011; Law et al., 2011; Loreto-Quijada et al., 2011; Raudenbush et al., 2011; Weiss et al., 2011). In these studies participants were exposed to painful stimuli, such as ice water, alongside a distractor stimulus. The effectiveness of the distractors was measured by recording pain tolerance, pain threshold or subjective ratings of pain. This chapter draws on the approaches taken in the pain domain by developing a new approach to measuring the extent to which VEs can distract people from sources of discomfort.

Various theoretical explanations have been put forward to explain why distractors can be effective means of reducing pain. These may also be useful in explaining if and why VEs can distract from discomfort (which could be regarded as less severe but similar in nature to pain). McCaul and Malott (1984) suggest that the effectiveness of a distractor will increase with attentional capacity that it demands. Therefore a distractor which demands high levels of attention will be more effective at distracting someone from a source of discomfort than one which has low attentional demands. Multiple resource theory (Wickens, 2002) would suggest that a distractor will be more effective if it demands the same sensory resources as the source of discomfort. For example, an auditory stimulus would be more distracting than a visual stimulus if a person was subject to an auditory source of discomfort. Eccleston (1995) and Eccleston and Crombez (1999) argue that as people are predisposed to attend to pain, distractors will be more effective if they make use of central attentional resources. Therefore should be complex and interesting rather than being boring and repetitive.

5.1.3. Ethics of inducing discomfort

In studies, particularly those which deliberately induce discomfort, ethics need to be considered. Benford et al. (2012) provide an ethical framework for uncomfortable interactions. This framework was used alongside the University of Nottingham's code of research ethics and research conduct (University of Nottingham, 2013) to ensure that risks to participants are mitigated and included the elements described as follows. In the studies presented in this thesis, participants were made aware of the stimuli which they would be exposed to prior to completing the study. They were given the opportunity to withdraw from the study at any point. Specific recruitment criteria were also used so as to minimise risks to participants. Where VEs were included in the studies presented in chapters 6-8 of this thesis, this comprised considering the potential for VEs to induce virtual reality induced symptoms and effects (VRISE). Where applicable, people who had any conditions which are known to be indicators of susceptibility (VRISE) were excluded from participation (e.g. those in Ramsey, 1999). Criteria included susceptibility to motion sickness, migraines, epilepsy (photosensitive or otherwise), recurring headaches, back pain or back problems, neck or shoulder pain, asthma, problems with depth perception, heart conditions or any other serious injury or illness as well as those who were pregnant. Most importantly, for the studies presented in this chapter as well as in subsequent studies, the sources of discomfort and study protocols were designed to only induce discomfort in the short term and to not have any lasting effects on participants' comfort, health or well-being. A researcher was present at all times during the studies and monitored participants for negative effects (e.g. signs of discomfort or distress) and was ready to intervene and stop the study if necessary.

5.1.4. Study aims

This chapter presents two studies which aimed to select sources of discomfort and to determine their effectiveness at inducing a state of discomfort. This was with a view to using these stimuli in subsequent studies in order to measure the effect of interventions on discomfort experienced.

5.2. **Selecting an auditory source of discomfort**

5.2.1. Method

There was not an obvious choice for an auditory source of discomfort which would be effective in an experimental setting whilst maintaining a level of ecological validity. As a result, a workshop was carried out in order to aid the selection of this source of discomfort. Five human factors researchers participated in the workshop.

The participants were presented with five sounds which were selected based on a study conducted by Cox (2008) in which sounds were ranked according to how horrible people perceived them to be. Three of the sounds selected were those which could be made by people and therefore were more ecologically valid for simulating an aircraft environment. The other two sounds emanated from objects rather than people and would not commonly be heard on an aircraft. The five sounds played were microphone feedback, flatulence, people arguing, scraping/squeaking metal and a crying baby.

The sounds were played to participants using a laptop and stereo speakers. After listening to each sound, participants were asked to comment on the effectiveness of the sound in terms of inducing discomfort and to consider this within the context of a simulated aircraft environment. They were also asked to consider the nature of the discomfort experienced (if any) by the sounds.

5.2.2. Results

The participants stated that the microphone feedback sound was painful and that they could not tolerate this for a prolonged period of time. They said that it was not completely out of context for an aircraft environment as it was possible that this could occur when announcements were being made if a sound system was not working. However, this sound is rarely heard in an aircraft context and the participants felt that this would decrease future study participants' sense of being in a simulated aircraft environment.

The sounds of flatulence and people arguing were not felt to be effective at inducing discomfort. Participants stated that the sound of flatulence would probably amuse them and that they would be able to easily ignore the sound of people arguing during an experiment.

The sound of scraping/squeaking metal was painful due to its high frequency. Participants stated that they could not ignore this and it would be irritating. They also said that within the context of an aircraft environment, it would be scary to hear this noise as this is not a sound which they would hear in normal flying conditions.

Participants felt that the sound of a baby crying was effective in inducing discomfort as well as being ecologically valid. They said that this sound induced discomfort in a different way to other sounds as it was not physically painful but rather, induced a negative emotional response. They also thought that the response to this sound may vary depending on whether or not participants had children.

From this study, it would appear that the most effective sound, of those presented for inducing discomfort in a simulated aircraft context, is the sound of a baby crying due to it inducing a negative emotional response whilst also being ecologically valid. This sound was therefore selected for further investigation.

5.3. **Testing the effectiveness of the selected stimuli at inducing discomfort**

The previous study suggested that playing the sound of a crying baby would be an effective and ecologically valid means of inducing an auditory source of discomfort in a simulated aircraft environment. An easy and ecologically valid way in which to induce a tactile source of discomfort was to restrict the legroom of each participant. This has been repeatedly reported as a source of discomfort for air passengers (Ahmadpour et al., 2014a; Patel et al., 2012; Vink & Brauer, 2011). A second study was carried out to determine the effectiveness of the sound of a baby crying and limited legroom at inducing discomfort. The data collected was subsequently used and added to in the study reported in chapter 6 to compare perceived comfort/discomfort levels when experiencing discomfort-inducing stimuli with and without the addition of a VE.

5.3.1. Method

The study was a between-subjects design where participants sat in the Fraunhofer IAO physical cabin mock-up (see chapter 3 for details) and were exposed to either the sound of a baby crying or an adjustable board which limited their legroom (see Figure 5-2).

Figure 5-2 Adjustable board designed to limit the legroom of participants

Twenty-one people participated in this study. They were recruited from Fraunhofer IAO and Stuttgart University and had a mean age of 21 years (SD=8.46). The participants were recruited on the basis that they had taken flights in the past three years and could speak English. Eleven participants experienced the crying baby sound and ten experienced the limited legroom condition.

Participants took part in the study individually and were asked to leave their belongings outside the set-up. They were not provided with any stimuli other than the source of discomfort and the sound of an aircraft (engine noise and muffled conversation) which was included to enhance the simulated aircraft environment experience. Exposure to the experimental condition lasted for 15 minutes. Those participants who experienced the limited legroom condition, were asked to put their feet back as far as they could and then the board was moved towards them until it was touching their feet. The participants' legroom was restricted at their feet rather than their knees due to the constraints of the mock-up and the position of the displays. A board was used to restrict legroom as this controlled for differences in anthropometry by restricting all participants' legroom by the same degree. Prior to, and following the study, the participants were asked to provide a rating of their overall levels of comfort or discomfort.

5.3.2. Results

Participants were asked to rate their overall level of comfort/discomfort on a 7-point ordinal scale (with anchors 'extremely uncomfortable' (-3), 'neutral' (0) and 'extremely comfortable' (3)) both prior to and following exposure to these stimuli. The rating following exposure to the stimuli referred to how the participants were feeling during the study. Table 5-1 shows the descriptive statistics for these ratings.

Table 5-1 Descriptive statistics and results of Wilcoxon tests for comfort/discomfort ratings

	Median comfort/discomfort rating prior to the study (IQR)	Median comfort/discomfort rating during the study (IQR)	Results of Wilcoxon tests comparing pre- and during-ratings
Crying baby	0 (2)	-1 (2)	(W=2.5, N=10; p<0.05)*
Limited legroom	1 (1)	-1 (1.5)	(W=0; N=9; p<0.05) *

*Result significant at p<0.05

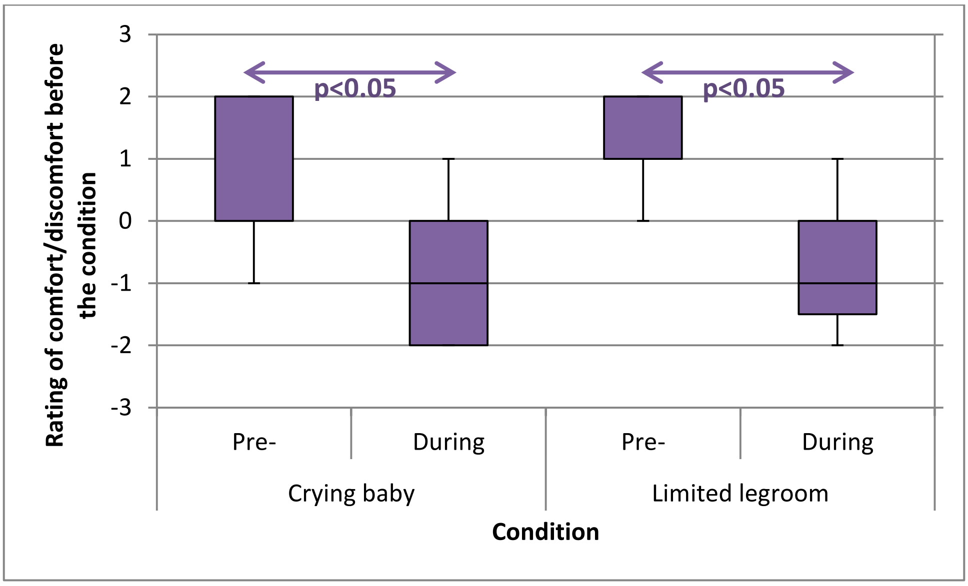

Figure 5-3 Box plots showing the descriptive statistics for comfort/discomfort ratings

Mann-Whitney tests revealed that there were no significant differences in subjective ratings of comfort/discomfort prior to commencing the study ($U=38$; $N_1=11$; $N_2=10$; $p>0.05$) or during both conditions ($U=53.5$; $N_1=11$; $N_2=10$; $p>0.05$). This indicates that both groups of participants were in a similar state of comfort/discomfort prior to the study and that both stimuli induced similar states of comfort/discomfort. It can be seen from the descriptive statistics that the median ratings of comfort/discomfort during the study were on the discomfort side of the scale used. Therefore both stimuli could be said to be equally effective at inducing discomfort.

Wilcoxon tests were also carried out to determine the difference in ratings of comfort/discomfort before and during the study. The tests revealed significant differences during exposure to both discomfort-inducing stimuli in comparison to their ratings prior to the study (see Table 5-1). The box plot in Figure 5-3 shows that there was an increase in discomfort during the conditions compared with the ratings carried out prior to the study. This indicates that both stimuli were effective in reducing overall levels of comfort.

5.4. **Discussion**

The two studies reported in this chapter aimed to select and measure the effectiveness of two sources of discomfort which were perceived through different sensory modalities (tactile and auditory).

The first study aimed to select an auditory source of discomfort which was ecologically valid within the context of a simulated aircraft environment. Of the five sounds, only three were found to be sources of discomfort. These were the sounds of scraping metal, microphone feedback and a baby crying. The participants felt that it was important that the auditory source of discomfort was ecologically valid in order to produce results which are transferrable to a real aircraft environment. Therefore the sound of the baby crying was selected for further evaluation.

The nature of the discomfort that the sounds induced was variable: the scraping metal and the microphone feedback sounds caused physical pain due to the high frequency of the sounds whereas the crying baby sound induced a negative emotional response (i.e. psychological discomfort). This is congruent with the input/output diagram in Figure 5-1 and illustrates that the modality through which a source of discomfort is sensed does not, alone, dictate the way in which discomfort is perceived or experienced. This may have implications for the ways in which interventions influence perceptions of discomfort-inducing stimuli.

When tested under experimental conditions, both the sound of the baby crying and the limited legroom reduced the levels of comfort compared to pre-study ratings. In addition, both stimuli induced similar levels of discomfort. The findings revealed that exposure to these stimuli for 15 minutes was enough for participants to experience discomfort without habituating to them (i.e. experiencing a decreased response to increased exposure to stimuli (Rankin et al., 2009)) and whilst ensuring that there would not be any lasting negative effects resulting from exposure to them.

The sound of a crying baby and the restriction of legroom were used to experimentally induce discomfort in subsequent studies presented in chapters 6-8 of this thesis, allowing for the investigation of the effectiveness of interventions to enhance comfort.

5.5. **Study plan**

On the basis of the results of the studies presented in this chapter and the findings of the studies in chapter 4, decisions were made regarding the design of the subsequent studies (in chapters 6-8).

The studies presented in chapters 6-8 of this thesis, aimed to determine whether VEs could be effective at distracting people from sources of discomfort. Therefore, in all of these studies, discomfort-inducing stimuli were used to begin studies with participants in a state of discomfort. Two studies have been presented in this chapter which selected and tested discomfort-inducing stimuli which are ecologically valid within the context of a simulated aircraft environment. The results of the first study led to the selection of the sound of a baby crying as an auditory source of discomfort. The second study indicated that both of the selected stimuli (restricted legroom and the sound of a baby crying) are effective at reducing discomfort.

A decision was made for people to participate in the studies presented in chapters 6-8 individually in order to maintain experimental control. This decision resulted from the second study presented in chapter 4 which highlighted the inconsistency of people’s behaviours. In order to understand whether VEs could fundamentally be used to distract people from discomfort, experimental control was considered important.

Decisions were also made regarding the motion tracking configurations to be used with each of the VEs as a result of the first study in chapter 4. It was decided that full motion tracking would be used in conjunction with the invisible aircraft VE as this provided an improved visual perspective and made the experience more interesting. Motion tracking would not be used with the tropical island VE as this detracted from its relaxing nature. Table 5-2 details the plan for the studies presented in chapters 6-8 of this thesis including their aims and the independent variables. The rationales for the stimuli used in each study are described in the relevant chapters.

Table 5-2 Study plan

Chapter number	Study aims	Discomfort-inducing stimuli	Distractors
6	To determine the extent to which a VE could distract people from two sources of discomfort	• Sound of a crying baby • Restricted legroom	• No distractor • Invisible aircraft VE
7	To determine whether the extent to which people could be distracted from an auditory source of discomfort varied with distractors which differed in their natures (i.e. visual, auditory or audio-visual)	• Sound of a crying baby	• No distractor • Tropical island VE • Sound of waves and birds • Tropical island VE with sound of waves and birds
8	To compare the extent to which a VE and a video depicting similar scenery could distract people from an auditory source of discomfort	• Sound of a crying baby	• No distractor • Tropical island VE with sound of waves and birds • Video showing tropical island scenery

6. USING A VE TO DISTRACT PEOPLE FROM DIFFERENT SOURCES OF DISCOMFORT

6.1. Introduction

The study presented in chapter 4 of this thesis investigated the ways in which a tropical island VE and an invisible aircraft VE might affect passenger experience. These studies illustrated that it is difficult to measure the effect of an intervention on perceived levels of comfort without participants starting studies from a state of discomfort. As a result, the pilot studies presented in chapter 5 of this thesis selected two sources of discomfort (restricted legroom and the sound of a crying baby) to be used in subsequent studies and tested the extent to which these stimuli could induce discomfort. It was found that both of these stimuli could induce discomfort for a period of 15 minutes without participants habituating to them. This chapter presents a study which aimed to determine the extent to which the invisible aircraft VE used in the passenger experience studies could distract participants from two sources of discomfort: the sound of a crying baby and restricted legroom.

Two VEs were available for use in this study (as described in chapter 3), a tropical island VE (which also had an associated sound) and an invisible aircraft VE. The findings of the study presented in chapter 4 of this thesis indicated that motion tracking detracted from the relaxing qualities of the tropical island VE but that it enhanced the experience of the invisible aircraft VE. Therefore, for the remainder of this research, the two VEs were used in these configurations only. Table 6-1 uses literature to try to understand how each of the VEs might positively influence the discomfort caused by restricted legroom or the sound of a crying baby.

Table 6-1 Using literature to understand how each of the VEs may reduce the discomfort caused by two stimuli

	Tropical island VE (with associated sounds, without motion tracking)	Invisible aircraft VE (with full motion tracking)
Restricted legroom		• Greater demands on central attentional processing due to being more interesting than tropical island VE (Eccleston, 1995; Eccleston & Crombez, 1999) • More engaging than tropical island VE (Hoffman et al., 2001b; Simmonds & Shahrbanian, 2008) • Motion tracking provides an element of interactivity (Dahlquist et al., 2007; Law et al., 2011)
Sound of a crying baby	• The auditory element of the distractor would be expected to demand the same attentional resources as the source of discomfort (Wickens, 2002)	

The study presented in this chapter draws on research concerning VR to distract from pain, the model of comfort and discomfort proposed by Vink and Brauer (2011) and Vink et al. (2005b) which proposed that comfort/discomfort result from sensory inputs as well as a person's history and current state (see chapter 2 for detail), and the results of the passenger experience studies (see chapter 4). The study aimed to investigate the extent to which the invisible aircraft VE could distract people from two sources of discomfort: the sound of a crying baby or restricted legroom. These sources of discomfort were used as they vary in terms of the sensory channels through which they are perceived (i.e. auditory or tactile). The invisible aircraft VE was selected in combination with full motion tracking as the passenger experience study found this combination to be interesting and engaging. This VE was also used because, as Table 6-1 shows, it was more likely to be an effective distractor from both sources of discomfort than the tropical island VE.

6.2. **Method**

6.2.1. Participants

Forty-three participants were recruited from Fraunhofer IAO and Stuttgart University. Thirty participants were male and 13 were female. They had a mean age of 30 years (SD = 8.73). All participants were required to be able to speak English and to have taken a flight in the last three years. People who had any conditions which are known to be indicators of susceptibility to virtual reality induced symptoms and effects (VRISE) (e.g. those in Ramsey, 1999) were excluded from participation. Criteria included susceptibility to motion sickness, migraines, epilepsy (photosensitive or otherwise), recurring headaches, back pain or back problems, neck or shoulder pain, asthma, problems with depth perception, heart conditions or any other serious injury or illness as well as those who were pregnant.

The participants were asked to complete a short background questionnaire which included measures of how much they like flying, are scared of flying and their experience using VR using 11 point scales. The descriptive statistics for this data are reported in Table 4-1.

Table 6-2 Descriptive statistics for background data

	Median (IQR)	Anchors
Like flying	7 (1)	0 = I hate flying 10 = I love flying
Scared of flying	2 (2.5)	0 = Not at all scared 10 = Extremely scared
VR experience	6 (6)	0 = No experience 10 = Extremely experienced

6.2.2. Equipment

The Fraunhofer IAO cabin mock-up was used in this study in combination with the invisible aircraft VE and full motion tracking. Details of these can be found in the chapter 3. During all conditions, the sound of an aircraft (engine noise and muffled conversation) was played. An audio recorder was used to capture interview responses. All questionnaires provided were paper-based.

During this study, participants were exposed to one of two sources of discomfort: either their legroom was restricted or the sound of a crying baby was played (see chapter 5 for details).

6.2.3. Piloting and study refinements

The study was piloted with two participants. As a result, the lighting inside the set-up during the no VE conditions was adjusted to ensure that it was not too dark.

6.2.4. Design

The study was a between-subjects design to eliminate a learning effect with regard to participants building up strategies to cope with any discomfort experienced. It is acknowledged that a between-subjects design introduces a potential confounding factor of individual differences due to a lack of consistent participants across groups. However, it is likely that this effect would have a smaller impact than the effect of participants becoming more accustomed to the experimental protocol if a within-subjects design was used.

Participants were exposed to one of four experimental conditions. These are described in Table 6-3. The data collected for the NoVECry and NoVELeg conditions was also collected for and reported on in the second study in chapter 5. In this chapter, this data was added to (additional participants) and analysed further.

Table 6-3 Description of study conditions

Abbreviation	Description of condition	Total number of participants
NoVECry	No VE with an auditory source of discomfort (sound of a baby crying)	11
NoVELeg	No VE with a tactile source of discomfort (restricted legroom)	11
VECry	Invisible aircraft VE with an auditory source of discomfort (sound of a baby crying)	10
VELeg	Invisible aircraft VE with a tactile source of discomfort (restricted legroom)	11

The study was designed to last no longer than 30 minutes, with 15 minutes exposure to the experimental condition. The study was approved by the ethics committee at the Faculty of Engineering, University of Nottingham.

6.2.5. Procedure

Participants took part in the study individually. They were welcomed and introduced to the study before being asked to complete a demographics questionnaire. They were told that the study was investigating the use of VEs in future aircraft and were also told whether or not they would be experiencing a VE. They were informed that either their legroom would be restricted or that they would hear the sound of a crying baby for the duration of the condition. The participants were asked to leave their belongings outside the set-up. They were told that there was no specific task for them to complete and that they should behave as they would on a real aircraft when carrying out the study. Exposure to the experimental condition lasted for 15 minutes. Participants were not told how long they would be in the experimental condition for but were aware during recruitment that their participation would be required for 30 minutes.

Prior to the condition, the participants were asked to complete a short questionnaire. This comprised the short symptoms checklist (SSC) (Cobb et al., 1995) and an overall rating of comfort/discomfort. Following each condition, a similar questionnaire was completed and a post-study interview was carried out. The SSC was completed solely to monitor any VRISE symptoms and was not included in any data analysis.

6.3. **Results**

6.3.1. Quantitative data analysis

The following sections detail the findings from the questionnaires which were issued prior to and following exposure to the experimental conditions.

Subjective ratings of comfort and discomfort

Participants were asked to rate their levels of comfort/discomfort on a seven point ordinal scale (with anchors ‘extremely uncomfortable’ (-3), ‘neither comfortable nor uncomfortable’ (0) and ‘extremely comfortable’ (3)) both prior to and following the condition experienced. The ratings given after the condition related to the participants’ comfort/discomfort levels during the study. Participants were asked for a general rating of comfort/discomfort rather than a rating related to the restricted legroom or crying baby sound for two reasons: firstly, a general rating could be compared to ratings of their states prior to completing the study and secondly, ratings of comfort/discomfort relating to the discomfort inducing stimuli alone would not necessarily account for the effect of the distractors. Therefore, general ratings were used and interviews were carried out to further understand these ratings.

A Kruskal-Wallis test was carried out in order to determine whether there were any differences in the comfort/discomfort of the participants in each group prior to completing the study. The descriptive statistics for this test can be found in Table 6-4. A box plot which shows the pattern in and distribution of data across the conditions can be found in Figure 6-1.

Table 6-4 Descriptive statistics and results of Wilcoxon tests for ratings of comfort/discomfort prior to and during the study

Condition	Median comfort/discomfort rating prior to the study (IQR)	Median comfort/discomfort rating during the study (IQR)	Results of Wilcoxon tests comparing pre- and during-ratings
NoVECry	0 (2)	-1 (2)	(W=2.5; N=10; p<0.05)*
NoVELeg	1 (1)	-1 (1.5)	(W=2.5; N=10; p<0.05)*
VECry	0.5 (2)	0 (1.75)	(W=9.5; N=8; p>0.05)
VELeg	1 (2)	2 (1.5)	(W=9; N=7; p>0.05)

*Result significant at p<0.05

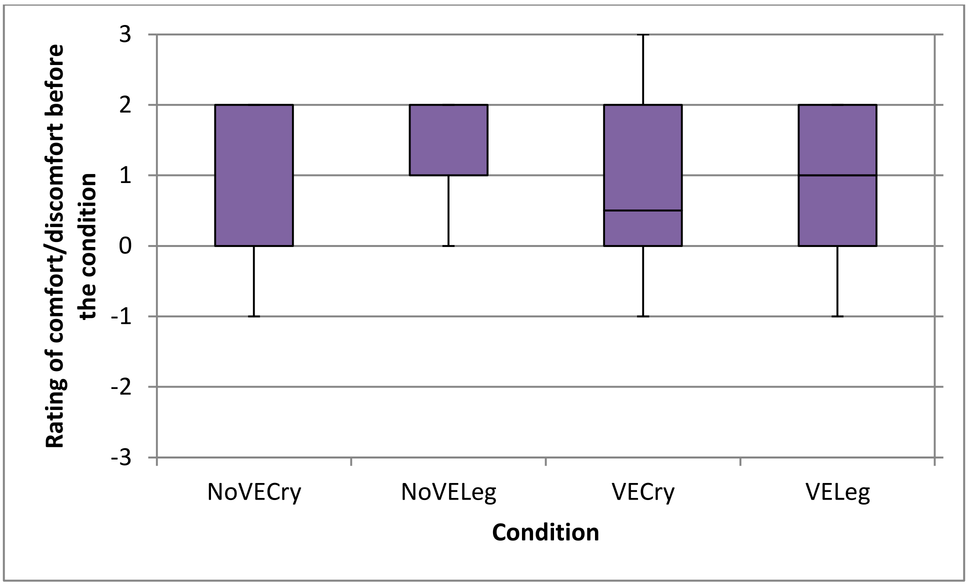

Figure 6-1 Descriptive statistics for ratings of comfort/discomfort prior to the study

No significant differences were found between the ratings ($H=1.01$; $df=3$; $p>0.05$). As no differences could be proven, participants in each of the groups could be regarded as homogenous and the ratings of comfort/discomfort during the study were compared.

As a result of the homogeneity of the participants' comfort/discomfort levels prior to the study, a Kruskal-Wallis test with planned post-hoc Mann Whitney tests was carried out comparing the differences in ratings of comfort/discomfort during the study. The descriptive statistics for this test can be found in Table 6-4. A box plot showing the pattern of data, in particular the relative increase in comfort in the VELeg condition, can be found in Figure 6-2.

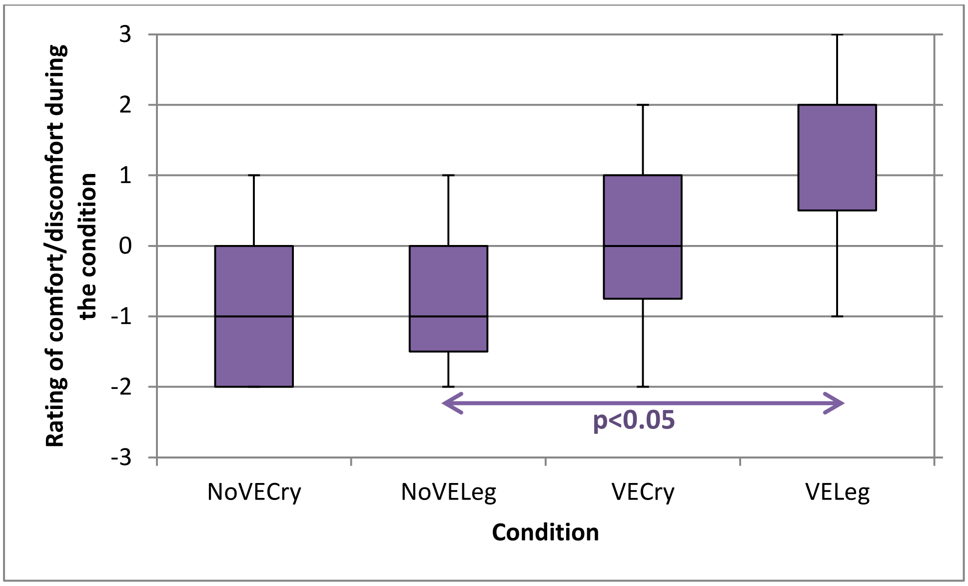

Figure 6-2 Descriptive statistics for ratings of comfort/discomfort during the study

The Kruskal-Wallis test revealed a significant difference in comfort/discomfort ratings during the study ($H=13.599$; $df=3$; $p<0.05$). Planned post-hoc Mann Whitney tests revealed that there were no significant differences between the NoVECry and NoVELeg conditions ($U=54.5$; $N_1=11$; $N_2=11$; $p>0.05$), the NoVECry and the VECry conditions ($U=34.5$; $N_1=11$; $N_2=10$; $p>0.05$) or the VECry and VELeg conditions ($U=28.5$; $N_1=10$; $N_2=11$; $p>0.05$). There was a significant difference between the NoVELeg and VELeg conditions ($U=28.5$; $N_1=10$; $N_2=11$; $p<0.05$). The findings indicate that the two discomfort inducing stimuli were similarly uncomfortable when no distractor was provided. It can be seen from Figure 6-2 that the results also indicate that the VE significantly enhanced comfort or reduced discomfort when legroom was restricted. However, the VE had no effect when the sound of a baby crying was played.

Wilcoxon tests were performed on the ratings of comfort and discomfort before and during the study for each condition to determine what effect the stimuli had on participants' perceptions of comfort/discomfort. The descriptive statistics for and results of these tests can be found in Table 6-4. A box plot which shows the pattern of pre- and during condition ratings of comfort/discomfort across all of the conditions can be found in Figure 6-3.

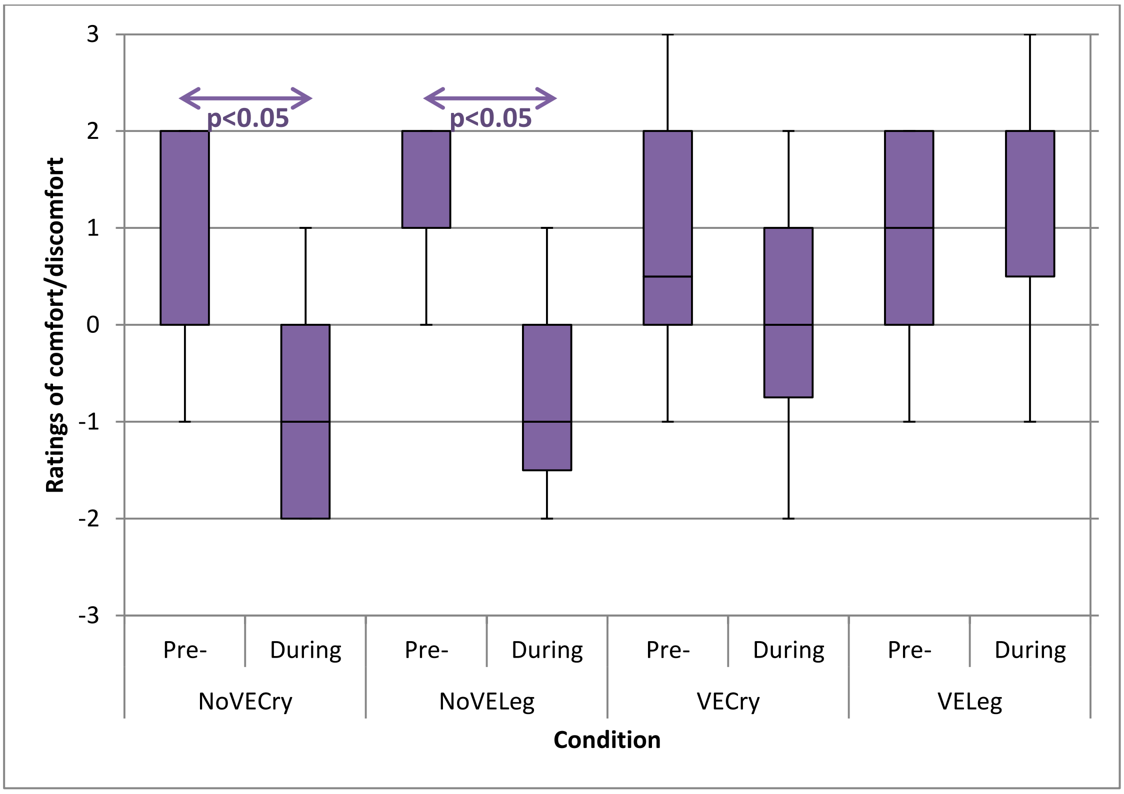

Figure 6-3 Descriptive statistics for ratings of comfort/discomfort prior to and during the study

The Wilcoxon tests revealed that there were significant differences in pre- and during condition ratings for the NoVECry and NoVELeg conditions therefore indicating that the discomfort inducing stimuli were effective (see Figure 6-3). No significant differences were found in pre- and during the study ratings of comfort/discomfort for the VECry and VELeg conditions indicating that the VE provided was an effective distractor from the discomfort inducing stimuli (see Figure 6-3).

Subjective ratings of presence

After the two VE conditions, participants were asked to rate their agreement with the following statement: 'I had a strong sense of really 'being there' within the virtual environment' as a measure of their presence in the VE. Ratings were given using a five-point scale with anchors 'strongly disagree' (-2), 'disagree' (-1) 'neutral' (0), 'agree' (1) and 'strongly agree' (2). The descriptive statistics for these ratings can be found in Table 6-5. Figure 6-4 shows the box plot distributions for these ratings.

Table 6-5 Descriptive statistics for ratings of presence

Condition	Median presence ratings (IQR)
VECry	0.5 (1)
VELeg	0 (1.5)

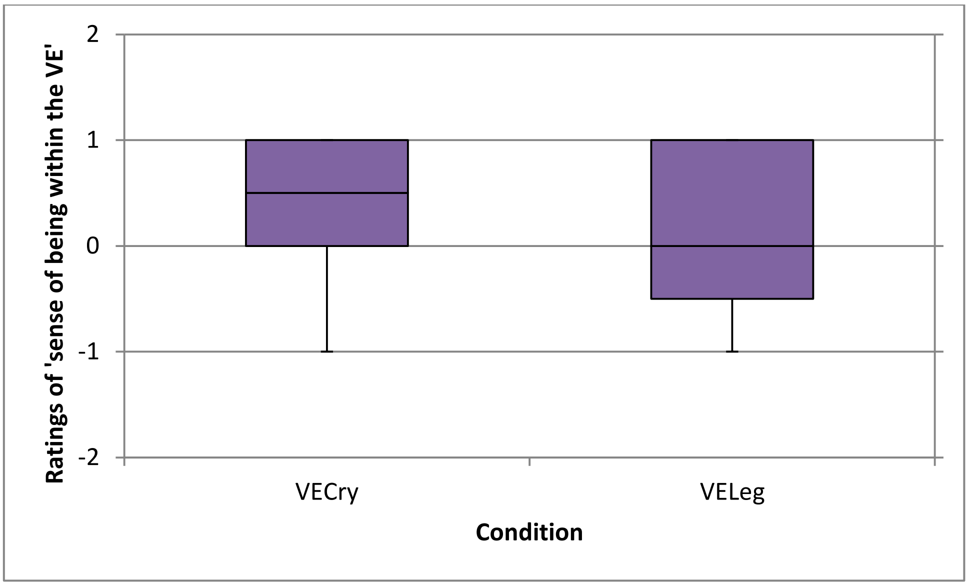

Figure 6-4 Descriptive statistics for ratings of presence

A Mann Whitney test indicated that there were no significant differences in ratings of presence in the VECry and VELeg conditions ($U=65.5$; $N_1=10$; $N_2=11$; $p>0.05$) therefore indicating that the two discomfort inducing stimuli had similar effects on presence in the VE to each other. The descriptive statistics revealed that the participants in both conditions generally rated their presence as ‘neutral’.

Correlations of ratings of presence and comfort/discomfort

Spearman tests were carried out to determine whether there was any correlation between ratings of presence and ratings of comfort/discomfort in the VECry and VELeg conditions. No significant correlations were found between presence and comfort ratings in the VECry condition (r_s=0.425; N=10; p>0.05) or the VELeg condition (r_s=0.268; N=11; p>0.05). This indicates that levels of presence did not impact on comfort/discomfort experienced in either of these conditions or vice versa. However, given that these ratings were ‘neutral’ on average, with ‘neutral’ central tendencies, this finding is unsurprising.

6.3.2. Qualitative data analysis

Following exposure to the experimental conditions, interviews were conducted to ask participants about their experiences. Interview questions related to the following:

- The factors affecting the participants’ comfort/discomfort.
- The participants’ awareness of the discomfort inducing stimuli.
- The effect of the discomfort inducing stimuli on the participants’ overall experiences.
- The strategies used to overcome the discomfort inducing stimuli.
- The effect of the VE on the participants’ perceptions of the discomfort inducing stimuli.

The findings resulting from these interviews are detailed in the following sections.

It should be noted that the study was carried out in Germany with participants who are not native English speakers. Therefore, where quotes are provided in the following sections, these may not be in perfect English.

Comfort and discomfort

Following exposure to the experimental condition, participants were asked to describe the factors affecting their comfort and discomfort.

Unsurprisingly, the most commonly mentioned source of discomfort for both of the restricted legroom conditions was the limited legroom. For example, a participant in the NoVELeg condition stated,

> *"The limited legroom obviously. You don't have much options to move your legs into a comfortable position because there's simply no room."* – P18

For some participants in the NoVELeg condition, the lack of legroom led to physical manifestations of discomfort including numbness.

> *"And then at a certain time then you feel numb because you cannot move (sic)"* – P16

An inability to find a comfortable sitting position was another reported source of discomfort in the NoVELeg condition.

> *"Uncomfortable as well just trying to shift around to get more comfortable but it wasn't really possible."* – P12

The lack of activity or other stimulation also led to boredom. This was reported in both the NoVELeg and the NoVECry conditions.

Apart from the limited legroom, the sources of discomfort in the VELeg condition were somewhat different to the NoVELeg condition and tended to centre on the hardware and software. For example, some participants felt that the seat-back displays were too close to them and others found that this led to headaches.

> *"What I didn't like so much was that the build quality wasn't that good and I think when I sat so close to the computers [seat-back displays] that made me feel a little bit of headache (sic)."* - P43

The main factors affecting comfort (or lack of discomfort) reported during the NoVELeg condition were the noise levels and the seats. One participant stated, *"The seat was quite alright and yeah the main thing was the seat and the sound, it wasn't too loud so the noise was quite OK. I'd say I'm used to this level of sound. Not disturbing."* – P42

Participants in all conditions also liked that they were able to recline their seat to create a more comfortable seating position.

"I think what I like is that I was a bit tired so I really, I moved back [reclined] the chair and I could try to relax in a way, not completely sleeping, but in that, I mean that's normally what you do in an airplane if you are not reading or watching videos…It was more comfortable but also it gives you, because it moves you back, you have more headroom and you feel obviously more…It's just more space up there [at head height] but then you close your eyes and it's more about the posture." – P16

Participants in the VELeg and NoVECry conditions also reported that not having any other participants in the adjacent seats was comfortable.

"And comfortable was that I had no seat neighbours so I can stretch out my arms a little bit and move around."- P13

The sources of comfort which were commonly mentioned in the NoVELeg condition were also present in the VELeg condition. In addition to these, participants often reported feeling relaxed and generally enjoyed watching the VE.

"I think comfortable is the sound because I like travelling in the plane and I think I associate it with being there for a while and then I think subjectively I calm down because I don't have to go anywhere (sic). I just have to sit in the plane and wait until I arrive somewhere and so from this experience, I think it's somehow relaxing. What I also liked and I recognised the scenery and we flew over our building and it was interesting…but the whole experience was not…intense yeah, but rather calming." - P27

A number of participants in this condition reported that although there was limited legroom, this was not disturbing or uncomfortable for them.

"Yeah there wasn't so much legroom but it wasn't disturbing for me." – P24

Some participants reported that they did not feel any discomfort or generally felt comfortable in this condition.

In the NoVECry condition, all participants mentioned that the sound of the crying baby was a source of discomfort for them.

> *"I heard a baby crying. I didn't like it. It was annoying in a way and the longer it didn't stop, the more it became annoying…I couldn't really chill or relax on the plane. I was in an intense mood."* – P9

Some participants also commented that alongside leading to boredom, the lack of other stimuli made it more difficult to cope with the sound of the baby crying in this condition.

> *"Yes crying and because the absence of all other effects like people so you had no possibilities to cope with the issue (sic)."* – P6

The majority of participants reported that the sound of a crying baby was a source of discomfort in the VECry condition. This indicates that presence of a VE when the sound of a crying baby was played did not have a substantial distracting effect. Other sources of discomfort in the NoVECry condition included environmental factors such as lighting or temperature and a general feeling of discomfort. For example, a participant in the NoVECry condition said,

> *"There was nothing that made me feel comfortable so everything was uncomfortable...The baby crying of course...nothing to do, the boredness."* – P4

The amount of legroom available was also a source of discomfort for a some participants in both the NoVECry and VECry conditions. A participant in the VECry condition stated,

> *"The less present space for my legs because I'm pretty tall. That's normal in the plane for me."* – P38

It should be noted that the seat pitch in these conditions was similar to that of an average economy cabin on a present day airline (approximately 32 inches) and therefore tall participants were likely to be affected by this.

Like the VELeg condition, in the VECry condition the main source of discomfort, aside from the deliberately introduced stimuli (in this case, the sound of a baby crying), was the VE hardware and software. Specific sources of discomfort included vertigo, blurry images and headaches caused by the tracking glasses, for example:

> *"And it was also uncomfortable when the vision was not clear on the front screens...Some of the times and also on the foot row [floor], it's extremely blurred."* – P36

Sources of comfort which were reported during the NoVECry condition included legroom for one participant and, more generally, the seats and environmental factors such as the sound of the aircraft engines or the lighting. In the VECry condition, an additional source of comfort was the view portrayed in the VE and that this was interesting to look at. One participant also commented that the VE created an opportunity to have a view, even while sitting in the middle seat.

> *"Yeah there was the view of the area around. I think it's a really nice idea to have. Also in the middle seat, opportunity to have some experience and some impressions from the outside world and that you can look around what's going on outside and where are you and what's there, in which area. And it's also interesting because the university campus of course."* – P30

Some participants also commented that the VE was calming and distracted them from the sound of the baby crying.

> *"Yeah because it was just going on and on and it was just calming, sort of and I even, at times, didn't really hear the baby crying anymore."* – P35

It is evident from these findings that the discomfort inducing stimuli and the VE were the main factors contributing to participants' comfort or discomfort experiences. However, other factors such as the seat and the legroom (in the crying baby sound conditions) did also play a part and would have contributed to their subjective ratings reported in section 6.3.1.

Awareness of discomfort inducing stimuli

Participants were asked whether or not they were aware of the discomfort inducing stimuli during the condition experienced. Some participants in the NoVELeg reported that they were always aware of the board in front of their legs, with one stating that it was difficult to forget about this. A small number of participants reported that they sometimes forgot about the board in this condition but that for the most part, they were aware.

> *"I tried to close my eyes and forget about it but I think most of the time, I was aware of it. I tried to distract me but I think it didn't have much [effect]… (sic)"* – P13

Of the participants who reported that they were able to forget about the board in this condition, one participant stated that they were only aware of the board when they needed to move their legs.

> *"Only when I needed to move my legs. So basically when the position got really uncomfortable and tried to shift, yeah can't shift my legs."* – P12

Another participant stated that they were unaware of the board when they had found a comfortable position to sit in. Other participants were able to relax, doze or think about other things and therefore forget the limited legroom momentarily. Only one participant in this condition was able to completely forget about the board in front of their legs and attributed this to thinking about something else.

A number of participants in the VELeg condition reported that they were mostly or completely unaware of the board in front of their legs. The reasons that participants attributed to forgetting about the board in this condition generally related to the characteristics of the VEs, for example, when the resolution was higher or when the VE was interesting (e.g. over the city).

> *"I think I realised the space and the feet board when I was bored when the environment was only trees and then it was boring and then I would recognise it and then when the city came and the HDM and Fraunhofer and I looked where the streets are, 'ah ok' and then I forget it and then I was bored and I realised it."* – P25

In contrast, when the VE was boring (e.g. over the countryside) or when it was of a lower resolution, participants tended to become more aware of the board.

> *"Maybe the resolution of the picture was bad. When it was high definition picture, I thought, 'ah great, I recognise the university and so' and then there was forest and not as good as before and I realised, 'oh something hurts my leg'."* – P29

Other occasions at which some participants became aware of the board in front of their legs were when they needed to move their legs or felt their leg muscles tense. Conversely some participants did not feel a need to move their legs and therefore didn't notice the board. This may have been due to the short exposure time and may have changed if the study was carried out for the duration of a flight. Some participants also reported that they only became aware of the board when they looked down at the displays beneath their feet.

> *"It's only when I watched on the floor to see what's under me, I saw it...but when I looked left, right or up, I didn't recognise it."* – P40

Similarly to the NoVELeg condition, in the NoVECry condition some participants stated that they were always aware of the sound of the crying baby, often reporting that it was difficult to forget about this sound.

> *"I was really aware what she was doing because there was nothing else that could shift my point of focus"* – P4

Some participants in this condition reported that they were mostly aware of the sound of the crying baby but did manage to forget about the sound at times. Occasions when participants were able to forget about the sound of the crying baby included when they were resting or relaxing, when the sound became monotonous or when they were thinking about something else.

> *"I tried to think about something so I don't notice the sound so much anymore and it worked for a short while. When I was thinking about stuff then I forgot about the crying for a short time."* – P9

During the VECry condition, some participants were always aware of the sound of the crying baby whilst others reported that they were able to completely forget about the sound. A large proportion of the participants experienced variable levels of awareness of the crying baby sound (i.e. moments when they were more aware and other moments when they were less aware).

> *"I even, at times, didn't really hear the baby crying anymore. Once in a while, you know, I realised it but it was not disturbing. Normally it's very disturbing during a flight but it wasn't because I was just looking at the environment and just enjoying it and then I realised, 'oh I haven't heard the baby, is it still crying?'. So that was kinda nice."* – P35

Similarly to the VELeg condition, participants often reported that they became more aware of the sound of the crying baby when the VE was boring (e.g. over the countryside) and less aware when they were interested in the VE (e.g. over the city).

> *"Well it depends on what I saw in the environment. When I was flying above the city or above the buildings, then I had a lot to look at and when I was flying over the woods, then I was bored by the vision so I heard the baby more."* – P37

<u>Effect of the discomfort inducing stimuli on the participants' overall experiences</u>

The participants were asked to describe the effect that the discomfort inducing stimuli had on their overall experiences. During the NoVELeg condition, some participants reported that the board in front of their legs did not have any effect on their experience or comfort but that after a longer period of time, they would become uncomfortable.

> *"If it was any longer than 15 minutes, I would have been really uncomfortable so now it's after 15 minutes, I don't have stiff legs or anything but that would have definitely happened. That would affect my overall comfort."* – P12

Unsurprisingly, many participants reported that the board in front of their legs restricted their legroom, making them generally feel restricted and unable to move, highlighting the importance of perceived control.

> *"I think it obviously restricts your legroom and that leads to a little bit more discomfort but on the other hand, I think for the overall comfort, I don't think*

that it's everything. It's a kind of, it's a physical emanation of what you feel. You feel restricted and this is obvious that at some points, you touch something and you cannot move." – P16

Feelings experienced during this condition included annoyance and stress as well as a compulsion to move because they knew that they were not able to do so.

"It takes away your space and it takes away the ability to shift in your seat. You want to shift positions after a while. It wasn't that bad because it wasn't a long time compared to a real flight but just sitting in the same position for a long time is uncomfortable and to take away that option already in your head does something with you." – P18

One participant also stated that restricted legroom is just one of a number of factors which, in combination, can induce discomfort on an aircraft and that the attenuation or removal of this factor alone would not automatically lead to a comfortable situation.

"I wouldn't say this is the most or the worst thing and if you remove that then I'm happy. It's just one of the bits and pieces which count up to feeling [uncomfortable]." – P16

During the VELeg condition, a number of participants reported that the board in front of their legs did not affect their experience, in particular when they were looking at or interested in the VE.

"Not really [board didn't affect experience]...I was looking at the scenery and heard the sound from the plane flying. I didn't pay so much attention on the board." – P27

One participant stated that when they were bored during the countryside elements of the VE, the board had a negative impact on their experience.

"I think negatively. I would say it would be much better without the board and maybe the not interesting parts like with less resolution and the forest, I think it wouldn't be as bad as it was for me because of the board." – P29

Another participant stated that they found the board *"disturbing"* (P28) in general.

In the NoVECry condition, all participants were negatively affected by the sound of a crying baby. Many participants found the sound of a crying baby to be overpowering in terms of affecting their ability to concentrate on other things, to relax or their ability to overcome the sound.

> *"It was also distracting me, like I couldn't concentrate on anything else."* – P8

Feelings experienced as a result of the sound of a crying baby in this condition included annoyance, stress, discomfort and anger.

> *"I heard a baby crying. I didn't like it. It was annoying in a way and the longer it didn't stop, the more it became annoying."* – P9

One participant also commented that they perceived time to pass more slowly in this condition.

> *"It felt like the time was running very slow. If I think about a long distance flight like this, it would be horrible."* – P4

In the VECry condition, some participants did not think that the sound of a crying baby affected their experience or were able to overcome the sound after a period of time.

> *"It had a little [effect] because in the beginning, it was really disturbing and since I don't have kids myself, kids crying is always kinda disturbing to me because I'm just not used to that sound. So in the beginning, it was really disturbing but as I said, after a while, I just didn't hear it."* – P35

Some participants in this condition found the sound of a crying baby to be overpowering in terms of either always being present or affecting their ability to concentrate.

> *"I mean it's annoying, you can't…concentrate on thoughts easily. So it's harder to think about something. You get distracted."* – P32

Feelings experienced as a result of the sound of a crying baby included annoyance, stress and a lack of relaxation.

> *"I think it was because it was present all the time, it didn't stop...so perhaps because of this constant noise, it was always there and annoying."* – P38

Strategies used to overcome discomfort inducing stimuli

The participants were asked to report whether they used any techniques or strategies to overcome the discomfort inducing stimuli. During the NoVELeg condition, the most commonly reported strategy was for participants to try to find a more comfortable sitting position.

> *"Really I put the back of my foots up and so for normal it was too small to the space for the feet. Five or ten centimetres more would have done better."* – P42

Often, participants would position their legs in such a way that more space was created. This included crossing their legs, moving them to the sides or tilting their feet so that only their toes were in contact with the ground.

> *"Yeah I tried to give my legs a little more room by crossing my feet. That was a little better but not much."* – P18

A number of participants in this condition tried to relax or doze in order to overcome the restricted legroom.

> *"The only strategy is sort of relax and try to sleep. So find a comfortable sleep position or change positions because there is no really comfortable solution. So this is what I do."* – P21

Other participants tried to distract themselves from the restricted legroom by thinking about other things.

> *"I tried to look for something to stimulate my mind…work basically. Tried to either get my mind on a problem I'm currently having to solve, thinking about nothing, tried to listen to noises…I didn't forget that I'm not fully able to move. Didn't really work."* – P12

Of the participants who reported on the effectiveness of their chosen strategies in this condition, some stated that they did not help them, some felt that their strategy made the situation more comfortable and one participant reported that their strategy helped for periods of time.

> *"I tried to get a more comfortable position, had one for a while then it didn't work anymore, tried to shift again and yes."* – P12

In the VELeg condition, some participants reported that they did not use any strategies. Of those participants, most found that they were looking at the VE but reported that this was not a deliberate strategy.

> *"Yeah I think I just concentrated on the pictures so I didn't need a technique to forget about it."* – P43

Like the NoVELeg condition, some participants adjusted their sitting position in order to feel more comfortable, some tried to sleep or relax and others tried to distract themselves, either through deliberately concentrating on the VE or by thinking about something else. One participant thought about the length of the experiment and used this as reassurance that they would not be experiencing this condition for too long.

> *"I tried to think about the whole experiment and thought 'only 20 minutes' and so not as bad."* – P29

During the NoVECry condition, participants frequently tried to distract themselves from the sound of the crying baby. They often did this by thinking about something else or by trying to find something interesting in their environment.

> *"Yes I tried to think about something so I don't notice the sound so much anymore and it worked for a short while. When I was thinking about stuff then I forgot about the crying for a short time. And I tried to look through the plane if I can see something new or can see the baby maybe or something but I didn't see anything."* – P9

Some participants tried to sleep or relax during this condition and others tried to analyse the musical elements of the sound of the crying baby.

> *"I was trying to find the rhythm for the baby crying"* – P4

Some participants in this condition did not use any strategies to cope with the sound of a crying baby. Of those who reported on the effectiveness of their strategies, some stated that these did not help them and some stated that their strategies led them to become unaware of the sound of the crying baby.

"I was a little bit surprised but sometimes it works really and then you don't hear the sound of the baby crying." – P5

In the VECry condition, some participants reported that they did not use any strategies to cope with the sound of a crying baby. Similarly to the NoVECry condition, of those who did use strategies, common approaches included relaxation and trying to distract themselves. Methods of distraction included concentrating on the VE and thinking about other things.

"Looking around and be interested in the simulation and in the details of the simulation and yeah to focus on other topics." – P30

Of those who reported on the effectiveness of their strategies, some stated that the strategies used were helpful and one reported that the crying baby dominated the situation.

<u>Effect of virtual environments on perceptions of discomfort inducing stimuli</u>

The participants in the VELeg and VECry conditions were asked to describe the effect that they thought the VE had on their perceptions of the discomfort inducing stimuli. In the VELeg condition a number of comments were made regarding the VE being an effective distractor from the restricted legroom.

"If I would not have this visual and audio stimulus, I would maybe focus more on the board or on being constrained in the seat or not being able to stand up so in that respect, I think it diverted my attention." – P27

When the VE was interesting, participants found it was particularly distracting from the restricted legroom. Conversely, when it was boring, it was less effective as a distractor.

"I think something like…when I was bored, I realised it and when the virtual environment was attractive or nice, I forget it and focussed on the view." – P25

One participant stated that regardless of the fact that their legroom was constrained, the VE gave them an overall feeling of spaciousness all around them.

Some participants in this condition did not think that the VE affected their experience of the limited legroom, thinking that their perception of the board in front of their legs would have been the same without a VE.

> *"The problem with the legs is always present during the whole flight and I don't think that it would make any changes if the environment is there or not there."* – P22

Other participants felt that the effect of the VE was no different to activities that they might currently use on aircraft to distract themselves in this situation.

> *"Would be the same if I would have something to read or a laptop. I would read for one and a half, two hours and then I would start trying to move."* – P24

In the VECry condition, most participants thought that the VE had a positive effect on their perception and experience of the sound of a crying baby, giving reasons such as it helped them to relax, gave them something to look at or distracted them.

> *"It's very interesting. You look and you don't hear the baby. But the baby here is extremely loud."* – P33

Some participants did not think that the VE had an effect in this condition giving the reason that the sound of the baby is dominant.

> *"It's too dominant. I think it's a possibility to maybe forget the time or some other things you can forget but just crying is unforgettable or not not hearable. It's always present in the situation and I guess the time is one of the most factors. Maybe the space, the room around you, something like that. That are things you can forget but the dominant and present thing is not easy to ignore it."* – P30

6.4. **Discussion**

This chapter presents a study which aimed to determine the effectiveness of the invisible aircraft VE at distracting participants from two sources of discomfort: limited legroom or the sound of a crying baby. These sources of discomfort were selected as they differed in terms of the sensory modalities through which they are perceived.

The main finding of this study was that the participants felt more comfortable when a VE was present than when it was not and that this effect was stronger when their legroom was restricted than when the sound of a crying baby was played. This finding was consistent amongst both the subjective ratings of comfort/discomfort and also the interview responses. The findings indicated that the VE had a comfort-enhancing effect therefore indicating that it overpowered the discomfort inducing stimuli to some degree, leading to a state of comfort or reduced discomfort. This contrasts with Kuijt-Evers et al. (2005) who proposed that discomfort will always dominate comfort. The findings also indicated, in agreement with Kolcaba and Kolcaba (1991), that comfort and discomfort can be experienced simultaneously. This was particularly evident in the VECry condition where participants experienced comfort resulting from elements of the VE as well as discomfort associated with the crying baby sound. The findings of this study therefore also contrast with the suggestion by Helander and Zhang (1997) that comfort can only be experienced during low levels of discomfort. Although participants were able to experience comfort and discomfort simultaneously, they were also able to rate their overall comfort levels and therefore select whether their comfort dominated their discomfort or vice versa.

The increase in comfort in the VELeg and VECry conditions compared to the no VE equivalents could be attributed to the VE providing a distraction therefore leading to a reduction in awareness of the discomfort inducing stimuli. Participants reported that they were less aware of these stimuli when the VE was interesting (e.g over the city where the view was more varied) and became more aware of them when the VE was boring (e.g. over rural areas). This corresponds with the finding that the effectiveness of VEs at distracting from pain increases with their levels of engagement (Hoffman et al., 2001b; Shahrbanian et al., 2012) Reports of emotional responses such as stress or annoyance were also reduced with the addition of the VE and fewer strategies were employed to overcome discomfort, indicating that the VE provided a positive distraction.

It should be noted that this study only tested the extent to which these VEs could distract people from discomfort for a short period of time. It is not clear whether this effect would remain for the duration of a flight although the findings indicate that if the VEs provided are interesting, they are more likely to distract people from sources of discomfort. However, there may be occasions when people are made aware of sources of discomfort, even when distracted. For example, when legroom is restricted, naturally adjusting their sitting position could lead passengers to become aware of the limited space surrounding them which could, in turn, increase their discomfort.

Although the results of this study indicate that VEs can effectively distract people from the discomfort associated with restricted legroom, the findings do not suggest that legroom should be further reduced on passenger aircraft. As well as the possible health implications of reduced legroom, there are safety guidelines which stipulate minimum seat pitch (Civil Aviation Authority, 2011). The results of this study simply suggest that in a worst-case scenario, where a person does not have enough space for their legs due to the combination of their anthropometry and the available legroom, their discomfort may be alleviated by using VEs. However, it is not known how long this effect would last for.

It is unclear from this study why the VE distracted participants more from the limited legroom than from the sound of a crying baby. It is possible that this is due to the specific sources of discomfort and ease of overcoming these but it could also be due to the combinations of sensory modalities through which the stimuli are perceived. Within the context of this study, multiple resources theory (Wickens, 2002) would suggest that a visual distractor would be more effective when the discomfort inducing stimulus was also perceived visually. This may partially explain the findings of this study as the VE was found to be less effective at distracting from the crying baby (auditory stimulus) than the limited legroom, the perception of which has a visual element (i.e. people can see that their space is restricted) but is predominantly tactile.

Capacity theories (Kahneman, 1973) might also explain the findings in terms of the attentional resources that the discomfort inducing stimuli demand. These theories might suggest that the crying baby sound demanded more attention than the restricted legroom, therefore leaving less available resources to attend to the VE. An explanation for why the crying baby sound might demand a greater attentional resource could be due to a visceral response to the sound of the crying baby. Norman and Ortony (2003) describe such responses as being biologically-based automatic reactions to the perceptual properties of a stimulus without any interpretation. Even though participants were aware that this sound was only a recording, the sound itself could trigger a biological or evolutionary response which has been found to manifest in adults as a state of high alert in preparation to respond to the baby's distress (Giardino et al., 2008). Many participants reported that the sound of the crying baby overpowered the VE and therefore it is possible that the VE was not compelling enough or was of the wrong type of sensory input to be fully effective in this situation. Further investigation should determine whether an auditory distractor would have a greater effect than a visual one.

6.5. **Conclusions**

This research has identified that VEs can be an effective way of distracting passengers from some sources of discomfort for short periods of time, in particular, when a passenger has a limited amount of legroom. The findings indicate that when the VE provided is interesting, participants are less aware of the sources of discomfort. The findings of this study also suggest that the VE used had some effect at distracting participants from the sound of a crying baby but this was not as strong an effect as for when legroom was restricted. Further research should investigate whether this was due to the combination of sensory inputs or due to the nature of the specific discomfort inducing stimulus.

7. THE INFLUENCE OF DIFFERENT TYPES OF DISTRACTION ON DISCOMFORT PERCEPTION

7.1. **Introduction**

The study presented in chapter 6 revealed that the invisible aircraft VE reduced the discomfort experienced as a result of restricted legroom and the sound of a crying baby. However, the findings indicated that this effect was not as strong for the sound of a crying baby as it was for restricted legroom. It is unclear from the findings of this study why this VE was less effective at distracting participants from the sound of a crying baby. A possible explanation for this could be the differences in the sensory modalities through which the distractor (VE) and the discomfort were perceived. Multiple resources theory (Wickens, 2002) would predict that an auditory stimulus would be more effective than a visual stimulus at distracting participants from the sound of a crying baby as this would demand the same sensory resource as the source of discomfort. An alternative explanation for why the invisible aircraft VE was less effective at distracting participants from the sound of a crying baby than restricted legroom could be due to it triggering a biological or evolutionary response to attend and respond to this sound (Giardino et al., 2008).

The study presented in this chapter aimed to determine whether the extent to which stimuli designed to distract participants from the discomfort caused by the sound of a crying baby varied with the sensory modalities through which they are perceived. In order to test this, the tropical island VE was used as it had an associated sound.

7.2. **Method**

7.2.1. Participants

Forty participants were recruited from the Max Planck Institute for Biological Cybernetics's participant database of which 19 were male and 21 were female. They had a mean age of 31 years (SD = 11.56). Due to the potential emotional response to the sound of a crying baby, in this experiment, the demographics questionnaire also asked the participants whether or not they were parents. In the sample, only five out 40 participants had children and of these, only one participant had young children (5 and 2 years old). All participants were required to be able to speak English and to have taken a flight in the last three years. People who had any conditions which are known to be indicators of susceptibility to virtual reality induced symptoms and effects (VRISE) were not excluded from participation from this study due to the relatively static nature of the VE presented. However, all participants who experienced the VE were warned about the possibility of VR sickness and were informed that they should terminate the study if they experienced any symptoms.

The participants were asked to complete a short background questionnaire which included measures of how much they liked flying, were scared of flying and their experience using VR using 11 point scales. The descriptive statistics for this data are reported in Table 7-1.

Table 7-1 Descriptive statistics for background data

	Median (IQR)	Anchors
Like flying	7 (2.25)	0 = I hate flying 10 = I love flying
Scared of flying	1 (2.25)	0 = Not at all scared 10 = Extremely scared
VR experience	5 (5)	0 = No experience 10 = Extremely experienced

7.2.2. Equipment

The large screen display set-up at the Max Planck Institute for Biological Cybernetics (MPG) was used in this study in combination with the tropical island VE without motion tracking (see chapter 3 for details). The tropical island VE was selected as it had an associated sound (waves and birds). Motion tracking was not used in this study as findings from the passenger experience study (see chapter 4) indicated that tracking reduced the relaxing element of the tropical island VE.

During the study, the sound of a crying baby was played through stereo speakers and the sound of the water and waves was played through an iPad and headphones. An audio recorder was used to capture interview responses and all questionnaires were paper-based.

7.2.3. Piloting and study refinements

During study piloting the sound levels were adjusted so that the sound of the crying baby could be heard above the sound of the VE. This adjustment was made in order to ensure that the sound of the crying baby was perceivable and therefore would induce a state of discomfort. In addition, the questionnaire questions were refined to include a question relating to how much the participants liked the condition.

7.2.4. Design

The study was a between-subjects design in order to eliminate any learning effect related to participants building up strategies to overcome the sound of the crying baby. It is acknowledged that this design introduces individual differences. However, it is likely that a learning effect would have a greater impact on the results of this study than individual differences.

Participants were assigned to one of four experimental conditions which are described in Table 7-2. There were ten participants in each group. Three of the participants who had children were in the no distractor condition, one was in the VE condition and one was in the VE/sound condition.

It should be noted that this study was run alongside the study reported in chapter 8 (which comprised a condition which is not reported in this chapter). The data relating to the no distractor and VE/sound conditions are reported in both this chapter and chapter 8. Therefore, where participant numbers are provided in the results section of this chapter, these may range from 1-50.

Table 7-2 Description of study conditions

Abbreviation	Description of distractor
No distractor	No distractor
VE	Visual distractor (tropical island VE)
VE/sound	Visual and auditory distractors (tropical island VE with the sound of waves and birds)
Sound	Auditory distractor (sound of waves and birds)

The study was designed to last no longer than 30 minutes, with fifteen minutes exposure to the experimental condition and the participants' time was acknowledged by giving them €4. The study was approved by the ethics committees at the Faculty of Engineering, University of Nottingham and at the Max Planck Institute for Biological Cybernetics.

7.2.5. Procedure

The participants took part in the study individually. They were informed that the study was investigating the use of VEs in aircraft. They were told that not all participants would see a VE in the study and were informed of which condition they would experience. They were also told that during the study, they would hear the sound of a crying baby. They were instructed that there was no specific task for them to complete. Prior to completing the study, the participants were asked to complete a demographics questionnaire. They were then asked to leave their belongings at the side of the room and were led to their seat.

Prior to the condition, the participants were asked to complete a short questionnaire. This comprised the short symptoms checklist (SSC) (Cobb et al., 1995) and question asking for an overall rating of comfort/discomfort. Following each condition, a similar questionnaire was completed and a post-study interview was carried out. The SSC was completed solely to monitor any VRISE symptoms and was not included in any data analysis.

7.3. **Results**

7.3.1. Quantitative data analysis

The following section details the findings from the questionnaires which were completed by participants prior to, and following, exposure to the experimental condition.

Subjective ratings of comfort and discomfort

Participants were asked to rate their overall comfort/discomfort on a seven point ordinal scale (with anchors 'very uncomfortable', 'uncomfortable', 'neither comfortable nor uncomfortable', 'comfortable' and 'very comfortable' coded from -3 to 3 respectively). These ratings were made both prior to and following exposure to the experimental condition experienced. The ratings carried out post-exposure related to the participants' experiences of comfort/discomfort during the study.

A Kruskal-Wallis test was carried out in order to determine whether there were any differences in subjective experiences of comfort/discomfort prior to the study across the conditions. The descriptive statistics for this test are shown in Table 7-3. A box plot showing the distributions and similarities in the ratings across the conditions can be found in Figure 7-1.

Table 7-3 Descriptive statistics and results of Wilcoxon tests for ratings of comfort/discomfort

Condition	Median comfort/discomfort rating prior to the study (IQR)	Median comfort/discomfort rating during the study (IQR)	Results of Wilcoxon tests comparing pre- and during-ratings
No distractor	2 (0.75)	-1 (2)	(W=0; N=8; p<0.05) *
VE	2.5 (1.75)	-2 (1.75)	(W=0; N=10; p<0.05)*
VE/sound	1.5 (1.75)	-0.5 (2.75)	W=0; N=8; p>0.05
Sound	1.5 (1)	-0.5 (1.75)	(W=0; N=8; p<0.05)*

*Result significant at p<0.05

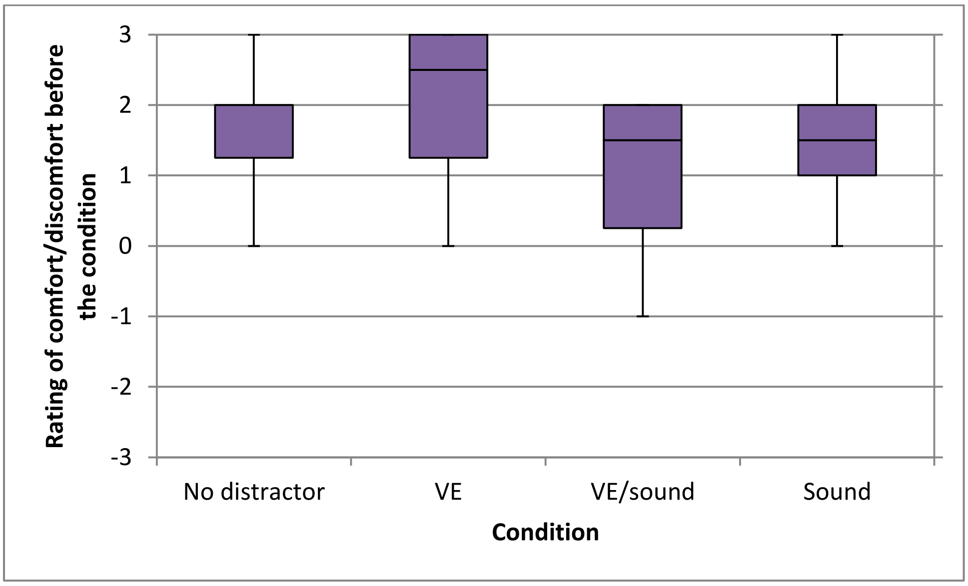

Figure 7-1 Descriptive statistics for ratings of comfort/discomfort prior to the study

As no significant differences were found between the ratings (H=3.644; df=3; p>0.05), the participants in each of the groups were considered to be homogenous. As a result of this, a Kruskal-Wallis test was carried out to compare the ratings of comfort/discomfort during the study. The descriptive statistics for this test are also shown in Table 7-3. A box plot showing the similarities in the ratings can be found in Figure 7-2.

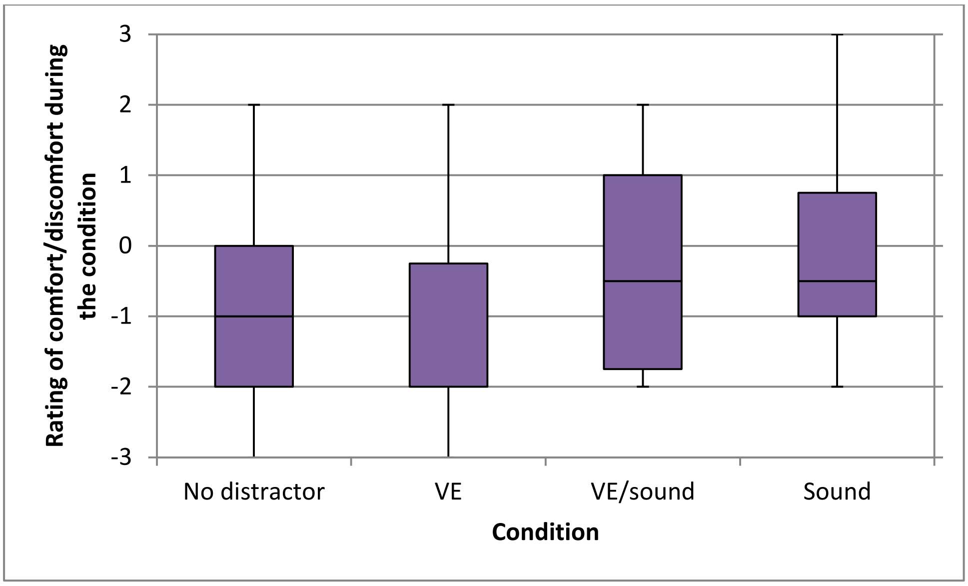

Figure 7-2 Descriptive statistics for ratings of comfort/discomfort during the study

The Kruskal-Wallis test revealed no significant differences between subjective ratings of comfort/discomfort during the study (H=3.967; df=3; p>0.05) indicating that the VEs and/or sounds of waves and birds did not have any effect on the participants' experiences of comfort/discomfort compared to the no distractor condition.

Wilcoxon tests were also carried out on the ratings of comfort/discomfort before and during each condition in order to determine the effects of the stimuli on participants' perceptions of comfort/discomfort. The descriptive statistics are shown in Table 7-3 along with the results of the Wilcoxon tests. Figure 7-3 illustrates the differences in the pre- and during exposure condition ratings of comfort/discomfort for all conditions.

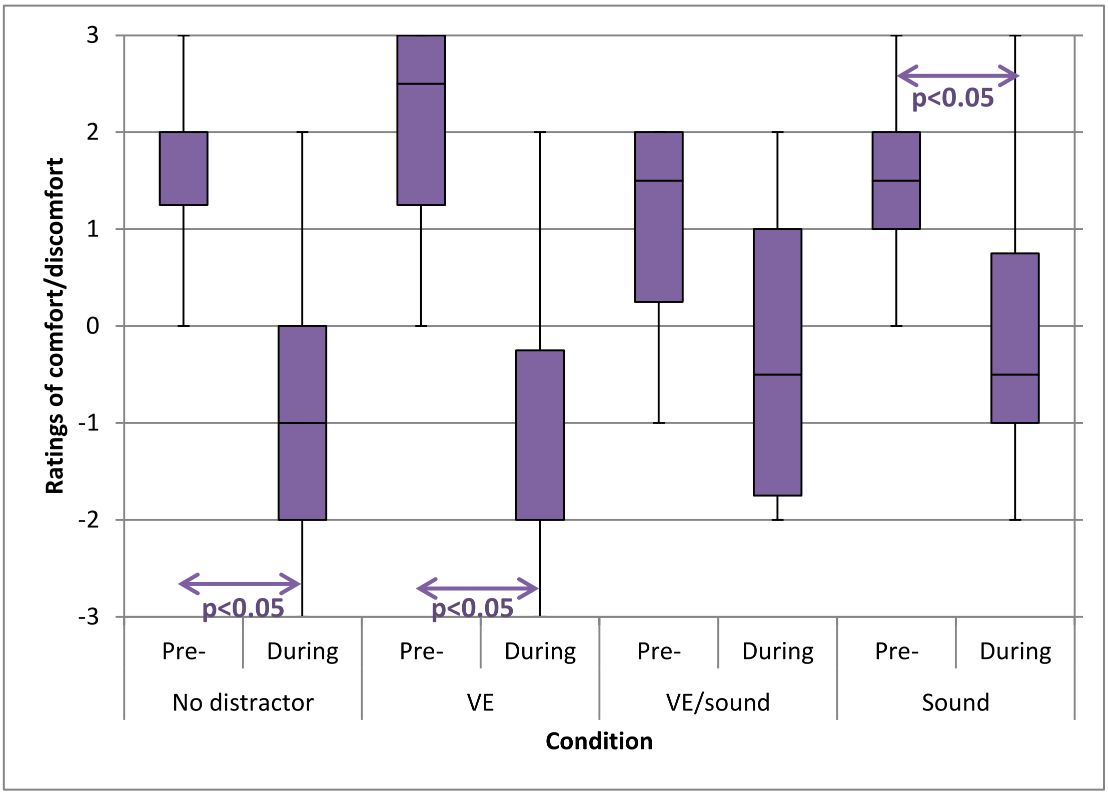

Figure 7-3 Descriptive statistics for ratings of comfort/discomfort prior to and during the study

The Wilcoxon tests revealed that there was no significant difference between ratings of comfort/discomfort prior to and during the VE/sound condition but there were significant differences for the no distractor, VE and sound conditions. This indicates that the combination of an auditory and visual distractor was effective at distracting participants from discomfort caused by the sound of a crying baby. However, for all other conditions, there was a significant reduction in comfort levels with the addition of the sound of the crying baby. This indicates that the auditory or visual distractors alone were not powerful enough to distract participants from discomfort.

Subjective ratings of presence

After the three conditions in which distractors were provided, participants were asked to rate their agreement with the following statement, ‘I had a strong sense of really ‘being there’ within the virtual environment/sound of the waves and birds’ as a measure of their presence in the VE. Ratings were made using a five-point scale with anchors ‘strongly disagree’ (-2), ‘disagree’ (-1), ‘neutral’ (0), ‘agree’ (1) and ‘strongly agree’ (2). The descriptive statistics for these ratings can be found in Table 7-4.

Table 7-4 Descriptive statistics for ratings of presence

Condition	Median presence ratings (IQR)
VE	0 (0.75)
VE/sound	-0.5 (1)
Sound	0 (2)

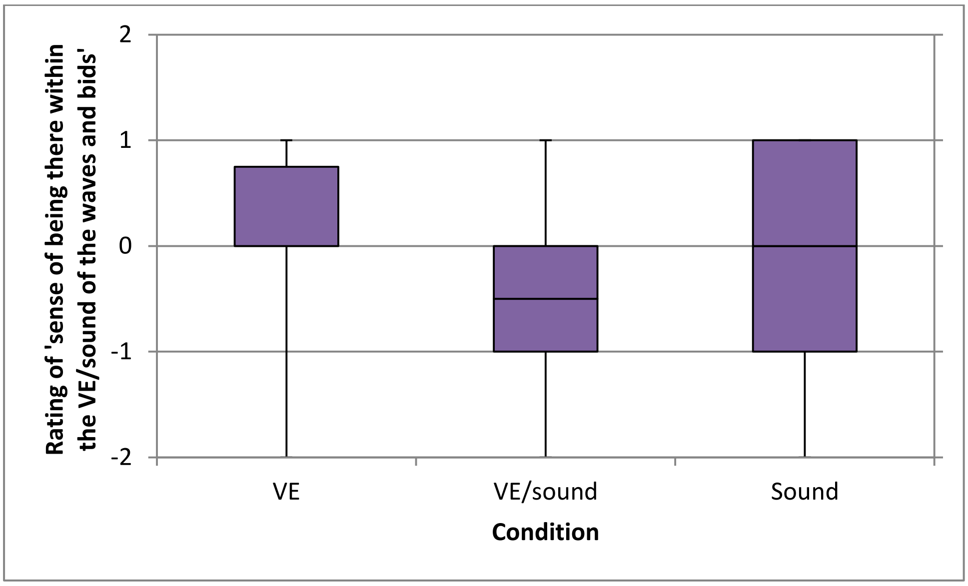

Figure 7-4 Descriptive statistics for ratings of presence

A Kruskal-Wallis test revealed that there were no significant differences in ratings of presence between the conditions ($H=0.876$; $df=2$; $p>0.05$). Figure 7-4 shows the similarities in these ratings across the conditions. This indicates that the participants felt similar levels of presence in all three conditions where distractors were provided. The descriptive statistics reveal that the participants generally had ‘neutral’ levels of presence in all of the conditions.

<u>Correlations between ratings of presence and comfort/discomfort</u>

Spearman tests were carried out to determine whether there were any correlations between ratings of presence and ratings of comfort/discomfort during the conditions. No significant correlations were found for the VE condition ($r_s=-0.095$;

N=10; p>0.05), the VE/sound condition (r_s=0.494; N=10; p>0.05) or the sound condition (r_s=0.157; N=10; p>0.05). This indicates that the level of presence in the distractors did not impact on perceptions of comfort or discomfort in any of these conditions. This finding is unsurprising considering the generally 'neutral' median ratings of presence.

<u>Subjective ratings of how much the conditions were liked</u>

After all conditions, participants were asked to rate how much they liked the condition on a seven-point scale with anchors 'disliked it a lot' (-3), 'neither liked nor disliked it' (0) and 'liked it a lot' (3). The descriptive statistics for these ratings can be found in Table 7-5. Box plots showing the distributions of the data can be found in Figure 7-5.

Table 7-5 Descriptive statistics for ratings of how much the conditions were liked

Condition	Median rating of how much the condition was liked (IQR)
No distractor	-2.5 (2)
VE	-1.5 (1)
VE/sound	0 (2.75)
Sound	0 (0.75)

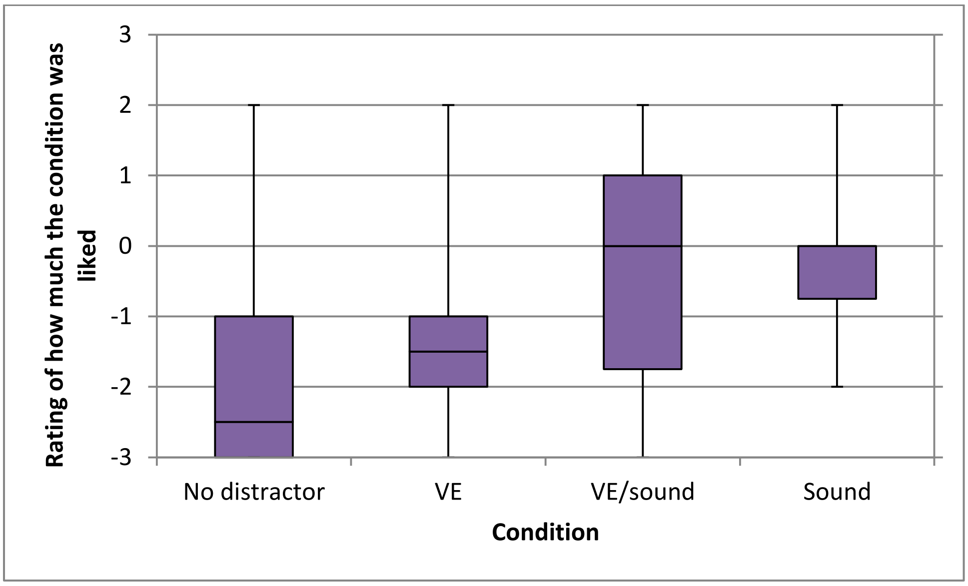

Figure 7-5 Descriptive statistics for ratings of how much the conditions were liked

A Kruskal-Wallis test revealed that there were no significant differences between how much each of the conditions were liked ($H=6.874$; $df=3$; $p>0.05$).

<u>Correlations between ratings of how much the conditions were liked and comfort/discomfort</u>

Spearman tests were carried out to determine whether there were any correlations between ratings of how much the conditions were liked and comfort/discomfort in the respective conditions. No significant correlations were found for the No distractor condition ($r_s=0.524$; $df=10$; $p>0.05$) or the sound condition ($r_s=0.569$; $df=10$; $p>0.05$). Significant positive correlations were found for the VE condition ($r_s=0.822$; $df=10$; $p<0.05$) and the VE/sound condition ($r_s=0.767$; $df=10$; $p<0.05$).

7.3.2. Qualitative data analysis

The participants were interviewed on their experiences following exposure to the experimental condition. The interview questions related to the following:

- The factors affecting their comfort and discomfort.
- Their awareness of the sound of the crying baby.
- The effect of the sound of the crying baby on their overall experience.
- Any strategies used to overcome the sound of the crying baby.
- The effect of the distractors on their perceptions of the sound of the crying baby.

The results of these interviews are presented in the following sections.

It should be noted that many of the participants were not native English speakers. Therefore, the quotes provided in the following sections may not be in perfect English.

<u>Comfort and discomfort</u>

Following exposure to the experimental conditions, participants were asked to describe the factors which contributed to their comfort and discomfort.

Unsurprisingly, the most commonly mentioned source of discomfort across all conditions was the sound of the crying baby. In all conditions, some participants found the seat provided to be comfortable whilst others found it uncomfortable.

Where no VE was displayed (no distractor and sound conditions), the white projector screen caused discomfort to some participants.

> *"What was really irritating was the white screen all the time. I got the feeling that my vision is lost because you can't really focus and when I tried to not get confused, I just saw anything."* – P46

In the VE/sound and VE conditions, the display also caused discomfort for some participants either due to its brightness or its proximity.

> *"It was mostly just being close to the screen. That was quite terrible…It was mostly the vision"* – P38

In the VE condition, the most commonly stated source of comfort was the view depicted in the VE with some participants stating that this was calming.

> *"Comfortable, the ocean was very nice and the swaying of the trees made me relax a little bit more. Just the general environment, yeah that made me feel more comfortable"* – P37

Similarly, in the sound condition, the most frequently mentioned source of comfort was the sound of the waves and birds. During the VE/sound condition, both the VE and the associated sound were mentioned by participants as sources of comfort, again often due to their relaxing qualities. However, the sound was mentioned more frequently than the VE in this condition.

> *"The whole environment made me feel very comfortable, the sloshing noise of the water, the palm trees, the view into the landscape. That was very relaxing and comfortable. I liked that a lot"* - P23

<u>Awareness of the sound of a crying baby</u>

The participants were asked whether or not they were aware of the sound of the crying baby during the experimental conditions. During all conditions apart from

VE/sound, most participants were aware of the sound of the crying baby for some or all of the time. However, they also often stated that they were able to get used to this sound and therefore, although they were aware of it, they did not always find it annoying.

> *"Sometimes I kinda like got used to it after a while but…it was always there. It's not like I was like 'oh I don't hear a baby crying anymore'… there were times when it was less irritating but then it would come back to the forefront of your mind".* – P11

During the no distractor condition, some participants attributed this awareness of the crying baby sound to a lack of distraction. Some participants stated that although they were always aware of the sound of the crying baby in this condition, they were able to get used to it or found it less irritating at times. Others found the sound increasingly stressful as time went on.

> *"At the beginning, I thought I could try to forget it and I wanted to think of something else but it was not possible. It was always there and the more I thought about it, the more it annoyed me…There were moments where I was not that annoyed or where it didn't matter that much to me but in the end, it got worse. I think the longer you listen to it, the more it stresses you."* – P26

During the VE condition, some participants were able to forget about the sound of a crying baby at times, for example, when they were focussing on the VE or thinking about something else. They were often more aware of the sound of a crying baby when they were bored or focussing on the sound.

> *"At the start, I just sat there and listened to the baby crying because that was the main thing in my head but then, it just became background noise because I was looking around rather than just sitting there and being annoyed about it…Well it's quite basic as in there's not much to look at I guess. If there was more to explore then it would be easier to be immersed in it and the background noise wouldn't be so noticeable. So…once I'd explored it, I…remembered there's a baby screaming behind me."*- P37

In the VE/sound condition, some participants reported that they were always or mostly aware of the sound of a crying baby whilst others stated that they were mostly unaware of this sound. Like the VE condition, participants were generally able to forget about the sound of the crying baby when they were focussed on the VE or the sound of waves and birds.

> *"I don't know, I think it was the other sounds which distracted me. Yeah, like then I started noticing the birds in the background and stuff like that and while I concentrated on that, I forgot about the baby's cries."* – P48

Some participants were also able to think about something else thereby forgetting about the crying baby sound.

> *"At first it was a little bit uncomfortable to hear the baby crying when it started crying but after like 2 or 3 minutes, I just got thrown away by all the kind of relaxed feeling because the sound of the ocean was so calming. I was really calming down and I started to somehow lose myself in all my thoughts and I was thinking about holidays and the beach. Like the baby's crying was not disturbing me at all after a while. Like after, I would say, 5 minutes or so, I was not even thinking about the baby."* - P18

During the sound condition, participants were generally aware of the crying baby sound. However, similarly to in the VE/sound condition, some did manage to forget about the sound either when listening to the sounds of waves and birds or when thinking about something else. Other participants were not able to completely forget about the crying baby sound but were able to reduce their awareness through the same means.

Effect of the sound of a crying baby on the participants' overall experiences

The participants were asked to describe the effect that the crying baby sound had on their overall experiences. Across all conditions, a small number of participants reported that the sound of a crying baby had little or no effect on their experiences for the entirety or a large proportion of the study.

> *"A bit but not that much [of an effect]. I was surprised how much I could still enjoy the other sounds although there was a baby crying all the time."* – P48

During all of the conditions, participants commonly reported emotional responses to the sound of a crying baby. These included anger, annoyance, stress or sympathy.

> *"I was getting angry because no one was caring after the child. And it was like up and down. It was sometimes sympathy and then aggression again and I was thinking poor child and then stupid parents."* – P1

In all of the conditions, the crying baby sound was overpowering for some participants, preventing them from relaxing or distracting them from their thoughts.

> *"Yeah I was trying to think about everyday life and just normal things but I always came back to the baby sound, so yeah, it was really annoying and you just couldn't relax, you couldn't really sit down your chair and lay back."*- P26

In the conditions where the sound of waves and birds and/or the VE were provided, the crying baby sound also made it difficult for some participants to focus on these additional stimuli thereby reducing their levels of immersion in these stimuli.

> *"It's like you're trying to be in another reality, you're trying not to be here when you're listening to the waves. It helps, but this baby sound returns you to the reality…That is actually much easier to be in, to this worried reality…With the crying baby, I cannot explain why but if you feel yourself uncomfortable you can imagine that much easier than you feel relaxed."* – P4

<u>Strategies used to overcome the sound of a crying baby</u>

The participants were asked to describe any techniques or strategies that they used during the experimental conditions to overcome the sound of the crying baby. The most commonly mentioned strategy across all conditions was for participants to attempt to distract themselves from this sound. In all conditions, one of their approaches to this was to think about something unrelated to the study. Additionally, where a VE and/or associated sounds were provided, the participants would often try to focus their attention on these stimuli in order to distract themselves from the crying baby sound. However, the participants had mixed opinions as to how successful these strategies were.

> *"I started concentrating on the beach and on the palm trees and I could actually forget about the baby a while but then it came back into my consciousness. Then I started counting the leaves on the palm trees…and counting how many trees there were and that kind of thing…In the beginning it distracted me but then it became a bit boring."* – P12

In all conditions, some participants tried to relax or daydream to overcome the sound of the crying baby.

> *"I really focussed on the sound. I tried, not really to sleep but to remain in a state of between sleep and being awake."* – P19

Other participants analysed the musical elements of the crying baby sound in an attempt to hear the rhythm and changes in pitch and tone rather than the sound of a baby.

> *"Putting it in a melody and thinking about how I could use the sound and which tones there are and analysing it."* – P46

A small number of participants in the VE and the sound conditions attempted to integrate the crying baby sound with the other stimuli provided in order to create an imaginary situation which was more comfortable for them. For example, a participant in the VE condition said,

> *"Yeah I tried to make it part of my imagination so that I really thought OK this is a beach with people and there is a baby next to me crying, to still have the nice feeling of the beach."* – P42

A participant in the sound condition said,

> *"I tried to imagine that I'm on a beach and I can relax and the baby is with his mother and maybe it's a little bit annoying because she isn't able to make him stop crying but it was OK."* – P19

A small number of participants in all of the conditions reported that they did not use any strategies to overcome the sound of the crying baby. For those who did use a strategy, there were mixed reports regarding their successfulness. Commonly, participants reported that their strategies helped to some degree but did not completely distract them from the sound of the crying baby.

<u>The effect of the distractors on perceptions of the sound of a crying baby</u>

The participants who experienced the VE, VE/sound and sound conditions were asked to describe the effect that they thought the VE and/or sound of the waves and birds had on their perceptions of the crying baby sound.

In the VE condition, a number of comments were made regarding the positive effect that the VE had on the participants' experiences of the crying baby sound. However, some participants also said that although this VE helped their situation to some extent, it was not a powerful enough distractor but it was better than not having any distractor.

> *"Well it was easy just to forget about the baby crying when I could really explore the virtual environment. But if there was more to explore, I think it would have been a lot easier to forget about it for a longer time."* – P37

As well as being a distractor, some participants stated that the relaxing and calming attributes of the VE helped them to cope with the sound of the crying baby.

> *"If I wouldn't have had this in front of me, it would have been worse I think because this was actually a calming picture with slow motions in it but it wasn't strong enough."* - P12

In the VE condition, some participants did not think that the VE had any effect on their perception of the crying baby sound.

> *"Because the sound environment is more affecting me than the visual situation…I cannot say it helped me."* – P7

One participant felt that the VE had a negative impact on their experience of the crying baby sound as it made them feel guilty.

"Yes I think helped me but on the other side, I thought, while I'm here on the beach and everything is great for me, a small baby must cry so hard...I feeled a little bit of guilty that everything it's OK but such a small baby needs help and doesn't get it."- P2

Participants in the sound condition often found the sound of the waves and birds to be a distractor from the sound of the crying baby. Some participants commented that this was due to the mismatch between the sounds leading them to only be able to focus on one sound or the other.

"The sound of the baby was so not matching to the sound of the waves because the sound of the baby… a sound like this could not be on the beach…and that's why it was really unnatural to hear both sounds. Either you ignore one and hear another…because they're so different so that you cannot hear both." - P4

Some participants also highlighted the importance of the calming and relaxing elements of the sound of the water and the waves.

"Yes also and it was a nice distraction. If it would have been, for example, music, or, I don't know, funny music, loud music, I wouldn't have felt comfortable because then the contrast between the sound of the baby and the music is too…well it's bizarre…I think the waves had a very relaxing sound and I think that's important." – P19

Some participants in the sound condition felt that the sounds of the birds and the waves was not strong enough to completely alleviate their negative responses to the sound of the baby crying.

"It made it more comfortable. It was relieving or not relieving but it helped." – P19

Some participants in this condition thought that the sounds of the waves and birds did not have any effect on how they perceived the sound of the baby crying.

"Well, I don't know. So I liked the sound of the beach in principle, better than not having anything I think, but it doesn't really cancel the effect of the baby." – P39

No participants in the sound condition reported any negative impact of the sounds of the waves and the birds on their experiences of the crying baby sound.

Like in the other conditions, in the VE/sound condition, a number of comments were made regarding the positive impact that the VE and sound of the waves and birds had on perceptions of the crying baby sound. These included comments relating to distraction and also the calming influence of these stimuli. Some participants made comments about the combination of the VE and associated sounds. However, many comments related specifically to the sounds of the water and the waves rather than the VE itself.

> *"It made it easier to not concentrate on and the kind of sound was emitted was very relaxing and it helped me, overall, have a higher level of calm than I normally would have, I believe."* - P33

A number of participants commented that they were still aware of the crying baby sound but that the other stimuli alleviated the negative effects of this sound.

> *"I think it just made me more relaxed. It really brought me to a point where I was like 'OK I mean the baby is there but you're relaxed, you're at the beach, you can just chill out'. I think the sound itself would be the same effect but I was just carried away by the sound and that made me kind of forget the baby. Like the baby was there, I was aware of the baby but it did not really matter that it was crying."* – P18

In the VE/sound condition, a small number of participants did not think that the VE and associated sound had an impact on their perceptions of the crying baby sound. Some participants also experienced negative effects as a result of the VE and associated sound with one participant commenting that this was due to these stimuli distracting them from their strategies.

> *"I think it made it worse actually… because what I really wanted to be doing was doing these other strategies but it took away some attention from my other strategies so it was distracting not just from the baby, which is a good thing, but it was distracting from the way I was trying to deal with it…I think*

this was probably worse than having nothing at all. Then I could, at least, close my eyes." – P28

7.4. **Discussion**

This chapter presents a study which aimed to determine the extent to which three stimuli which varied in the sensory channels through which they were perceived (auditory, visual and audio-visual) were able to distract participants from an auditory source of discomfort (sound of a crying baby).

The results of this study indicate that the tropical island VE was not powerful enough alone to serve as a distractor from the sound of a crying baby. The sounds of the waves and birds were also not effective in themselves at distracting participants from this source of discomfort. The combination of the VE and the associated sounds were more effective at distracting the participants from the sound of a crying baby. However, even this combination tended to simply alleviate any negative responses to the sound of the crying baby but did not lead participants to forget that the crying baby sound was being played.

It is possible that the distractors provided in this study were not entirely effective due to their relatively repetitive natures. Participants were able to experience everything that they would see or hear for the entire exposure time in a matter of seconds and nothing new was delivered to them thereafter. This could have led to boredom or a lack of engagement in the stimuli. Studies in pain research have shown that although passive distractors can increase pain tolerance, interactive distractors are more effective (Dahlquist et al., 2007; Law et al., 2011). In addition, the findings from a study by Konstantatos et al. (2009) indicated that using relaxation to alleviate the experience of pain is less effective than using distraction techniques. It is therefore possible that the stimuli provided were not distracting enough and that the relaxing element of the stimuli was not compelling enough to overcome the sound of the crying baby. Another reason that the distractors may not have been completely effective could be due to a person's predisposition to enter a state of high alert upon when a baby is distressed (Giardino et al., 2008). It is unclear whether or not this was the case in this study as only five of the participants had children. Nevertheless, it is possible that participants (regardless of whether or not they were parents) may have reacted to the crying baby sound due to a predisposition to do so.

The findings indicate that in the VE/sound condition, the participants felt that the sound was a more effective distractor than the VE. This corresponds with multiple resources theory (Wickens, 2002) which would predict that an auditory stimulus would be more effective than a visual stimulus at distracting people from an auditory source of discomfort. This is also consistent with comments made by participants in both the VE/sound and sound conditions who stated that they could not focus on both of the sounds at the same time. However, it is also clear from the results of this study that the provision of an auditory distractor alone was not as effective as the combination of a VE and associated sounds. Although no differences were found in ratings of presence across the conditions (and contrary to findings by Hoffman et al. (2004) whose study showed correlations between pain reduction and presence), it is possible that either the VE enabled participants to immerse themselves more in the sounds of the waves and birds or that the sounds became more compelling with the addition of the VE.

Although the study by Konstantatos et al. (2009) found that relaxing VEs were not effective for reducing pain perception, the results of this study indicate that the relaxing nature of the distractors provided were important. The participants felt that this enabled them to reach a level of calm which they would not have been able to achieve without these stimuli.

It is interesting to consider these results with respect to the debate surrounding the definition of comfort and discomfort. During this study, it is clear that many participants experienced discomfort as a result of the crying baby but could also simultaneously experience comfort as a result of the other stimuli provided. The VE and/or the associated sounds were reported by participants to be sources of comfort due to their calming and relaxing nature. This is clearly in line with theories that suggest that comfort is a positive sensation which is something more than simply a lack of discomfort (Oborne & Clarke, 1973; Richards, 1980; Vink & Brauer, 2011). The results of this study also question whether discomfort does always dominate comfort, as suggested by Kuijt-Evers et al. (2005). For some participants, the stimuli provided enabled them to not be bothered by the sound of the crying baby even though they were still aware of the presence of this sound. This would suggest that for these participants, the comfortable stimuli dominated the uncomfortable stimulus.

7.5. **Conclusions**

This research has identified that a tropical island VE and/or the sound of waves and birds can have some positive influence on a person's experience of the sound of a crying baby. Although, these particular stimuli were not powerful enough to completely distract people from the sound of a crying baby, they were able to relax people and could make this experience less stressful or annoying.

The qualitative results of this research indicate that an auditory distractor is the most important when people are experiencing an auditory source of discomfort. However, this is made more effective when a corresponding visual distractor is also used. It is possible that more interesting or engaging stimuli would be more effective at distracting people from this particular source of discomfort and this is something which should be further researched.

8. THE INFLUENCE OF MEDIA (VE VS. VIDEO) ON DISCOMFORT PERCEPTION

8.1. **Introduction**

The studies presented in chapters 6 and 7 investigated the extent to which VEs and/or sounds could distract participants from sources of discomfort which are commonly experienced during air travel. These studies illustrated that the discomfort caused by the sound of a crying baby was difficult to fully alleviate. The study presented in chapter 7 revealed that distractors with an auditory element were more effective at distracting participants from this source of discomfort. Contrary to findings from Konstantatos et al. (2009), the study also highlighted the importance of a distractor having calming properties when participants were subjected to the sound of a crying baby. The study presented in chapter 6 revealed that when a distractor was interesting, participants experienced a reduction in their awareness of both the crying baby sound and the restricted legroom. However, VR was more effective at distracting participants from the discomfort associated with restricted legroom than the sound of a crying baby.

In order to determine the value of introducing VEs into aircraft with a view to enhancing passengers' comfort, it is important to compare their effectiveness to activities which passengers use during present-day air travel to improve their comfort. It is known that passengers can perform a number of different in-flight activities including listening to music, working, watching IFE or watching programmes on their personal devices (Patel et al., 2012). It is also known that aircraft passengers will try to distract themselves from sources of discomfort by performing activities such as these (Patel et al., 2012). Studies have shown that activities can both influence and be influenced by comfort. For example, discomfort can result if a passenger's ability to carry out an activity is impaired (Oborne, 1978a) and comfort levels can determine the ease of performing activities (Richards & Jacobson, 1975). Performing activities may provide passengers with a distraction thereby drawing attention away from their discomfort (Richards et al., 1978). Therefore providing participants with an activity may provide a distraction and therefore increase their comfort levels. However, if the source of discomfort hampers their ability to carry out their activity, their discomfort levels may increase.

The study presented in this chapter aimed to compare the extent to which the tropical island VE and a video provided on an iPad could distract participants from the discomfort caused by the sound of a crying baby. This was with a view to comparing a VE to the current in-flight activity watching a video on a personal device.

8.2. **Method**

8.2.1. Participants

Thirty participants were recruited from the Max Planck Institute for Biological Cybernetics' participant database. Fourteen participants were male and 16 were female. They had a mean age of 30 years (SD = 11.36). Four participants had children, of which, only one had young children (5 and 2 years old).

Participants were recruited on the basis that they could speak English and had taken a flight in the past three years. People who had any conditions which are known to be indicators of susceptibility to VRISE were not excluded from participation from this study due to the relatively static nature of the VE presented. However, all participants who experienced the VE condition were warned about the possibility of VRISE and were informed that they should terminate the study if they experienced any symptoms.

The participants completed a short background questionnaire which asked them to rate how much they like flying, how scared they are of flying and their experience of using VR on 11 point scales. The descriptive statistics for this data are reported in Table 8-1.

Table 8-1 Descriptive statistics for background data

	Median (IQR)	Anchors
Like flying	7.7 (1.75)	0 = I hate flying 10 = I love flying
Scared of flying	1 (2)	0 = Not at all scared 10 = Extremely scared
VR experience	5 (4.75)	0 = No experience 10 = Extremely experienced

8.2.2. Equipment

The large screen display set-up at the Max Planck Institute for Biological Cybernetics was used for this study. During the VE condition, this displayed the tropical island VE. During the other conditions, the screen was blank. Details of the hardware and VE can be found in chapter 3.

Tropical island VE included the sound of waves and birds. This combination of stimuli was selected as it was the most effective condition in the study presented in chapter 7. The videos shown on the iPad were a series of four tourism videos with minimal narration, showing similar scenery to that displayed in the VE. These videos were linked together and had a total length of 15 minutes. The videos were selected in order to be as comparable to the VE as possible to reduce confounding variables.

A fourth generation iPad in combination with headphones was used to play the sounds of the water and waves in the VE condition and to play the video in the other condition. The sound of the crying baby was played over stereo speakers in all conditions. An audio recorder was used to capture the interview responses. All questionnaires were paper-based.

8.2.3. Piloting and study refinements

During study piloting, the sound level of the video was adjusted so that it could be heard above the crying baby sound without completely blocking it out.

8.2.4. Design

The study was a between-subjects design in order to eliminate any learning effects relating to participants building up strategies to overcome the sound of the crying baby. Whilst it is acknowledged that this introduces individual differences between the conditions, it is likely that a learning effect would have a greater influence on the results than individual differences.

Participants were assigned to one of three experimental conditions which are described in Table 7-2. There were ten participants in each group.

Table 8-2 Description of study conditions

Abbreviation	Description of condition
ND	No distractor
VE	Visual and auditory distractors (tropical island VE with the sound of waves and birds)
Video	A video depicting tropical beaches with soft music and limited speech overlaid

The data reported in this chapter was collected alongside that reported in chapter 7. The data relating to the ND and VE conditions are the same data as in chapter 7 but has been re-analysed comparing these conditions to a video. For the purposes of study facilitation, the video condition was run as an extra condition alongside those reported in chapter 7 (including the conditions which are not reported on in this chapter). Therefore, where participant numbers are used in subsequent sections of this chapter, they may range from 1-50.

The study was designed to last no longer than 30 minutes with 15 minutes exposure to the experimental condition. The participants' time was acknowledged by giving them €4 upon completion of the study. The study was approved by the ethics committees at the Faculty of Engineering, University of Nottingham and at the Max Planck Institute for Biological Cybernetics.

8.2.5. Procedure

The procedure for this study was the same as that reported in section 7.2.5 on page 153.

8.3. **Results**

8.3.1. Quantitative data analysis

The following section details findings from the questionnaires which were completed before and after exposure to the experimental conditions.

Subjective ratings of comfort and discomfort

The participants were asked to rate their overall levels of comfort or discomfort on a seven point ordinal scale (with the anchors ‘very uncomfortable’, ‘uncomfortable’, ‘neither comfortable nor uncomfortable’, ‘comfortable’ and ‘very comfortable’ coded from -3 to 3 respectively). These ratings were made both prior to and following exposure to the experimental condition. The rating made after the condition related to their levels of comfort or discomfort during the study.

A Kruskal-Wallis test was carried out in order to determine whether there were any differences in subjective experiences of comfort/discomfort between the participants in the three conditions prior to the study. The descriptive statistics for this test can be found in Table 8-3 and box plots showing the distributions of the data can be found in Figure 8-1.

Table 8-3 Descriptive statistics and results of Wilcoxon tests for ratings of comfort/discomfort

Condition	Median comfort/discomfort rating prior to the study (IQR)	Median comfort/discomfort rating during the study (IQR)	Results of Wilcoxon tests comparing pre- and during-ratings
ND	2 (0.75)	-1 (2)	(W=0; N=8; p<0.05) *
VE	1.5 (1.75)	-0.5 (2.75)	(W=0; N=8; p>0.05)
Video	2 (1)	-0.5 (1.75)	(W=2; N=9; p<0.05)*

*Result significant at p<0.05

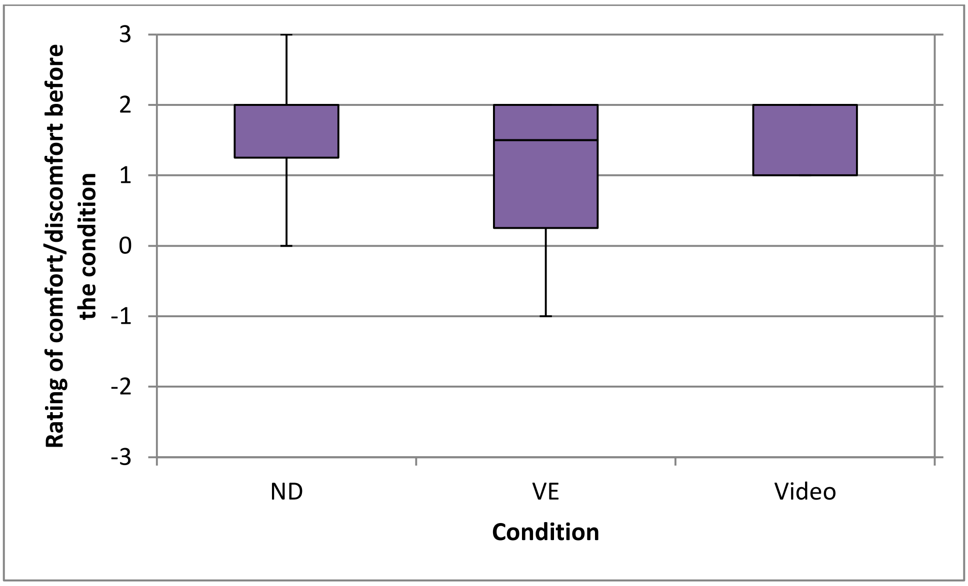

Figure 8-1 Descriptive statistics for ratings of comfort/discomfort prior to the study

No significant differences were found between the ratings (H=1.895; df=2; p>0.05), therefore the states of the participants in each group were considered to be homogenous. A further Kruskal-Wallis test was carried out to compare the ratings of comfort/discomfort during the study. The descriptive statistics for this test can be found in Table 8-3.

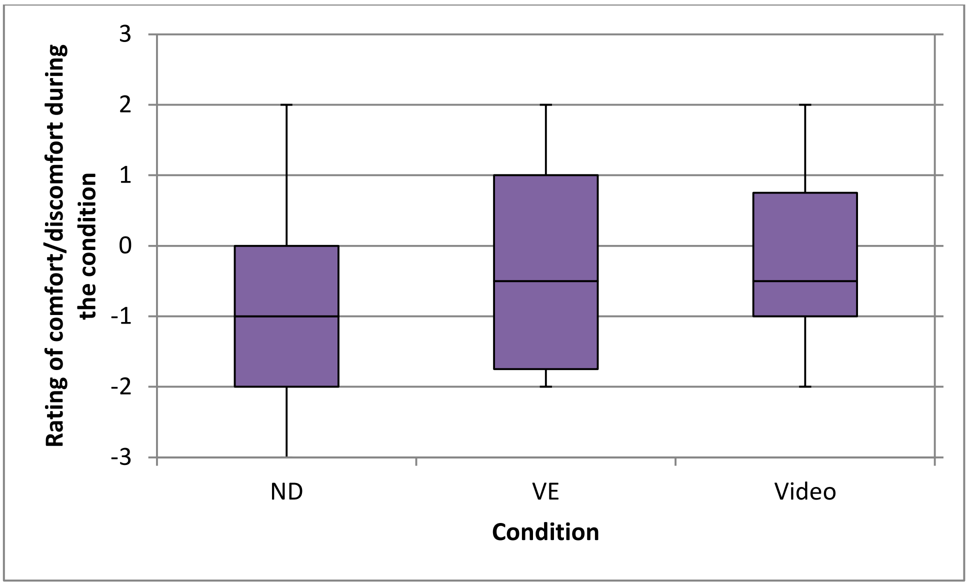

Figure 8-2 Descriptive statistics for ratings of comfort/discomfort during the study

Although Figure 8-2 shows a slight decrease in discomfort in the VE and video conditions compared to the ND condition, no significant differences were found between the ratings of comfort/discomfort across the conditions ($H=0.96$; $df=2$; $p>0.05$). This indicates that neither the VE nor the video had any impact on the participants' comfort or discomfort levels compared to the baseline ND condition.

Wilcoxon tests were also carried out to compare ratings of comfort and discomfort prior to and during each condition. The descriptive statistics and results of the Wilcoxon tests can be found in Table 8-3. The box plots in Figure 8-3 show the differences in the ratings prior to and during each of the conditions.

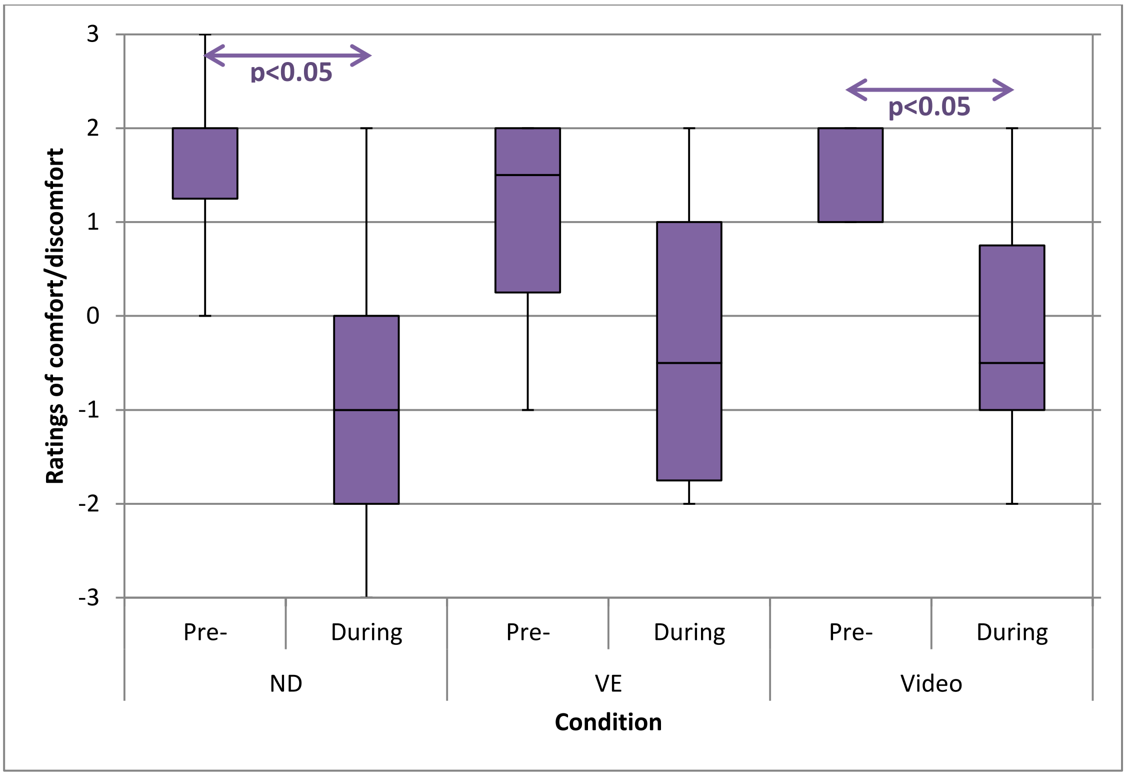

Figure 8-3 Descriptive statistics for ratings of comfort/discomfort prior to and during the study

The Wilcoxon tests revealed significant differences in ratings of comfort and discomfort prior to and during the conditions for the ND (W=0; N=8; $p<0.05$) and video (W=2; N=9; $p<0.05$) conditions but no significant differences for the VE condition (W=0; N=8; $p>0.05$). This indicates that the VE was effective at maintaining the participants' pre-study levels of comfort or discomfort. However, the ND and video conditions led to a significant reduction in comfort levels indicating that the video was not an effective distractor from the sound of a crying baby.

Subjective ratings of presence

Following the VE and video conditions, the participants were asked to rate their agreement with the following statement as a measure of their presence: 'I had a strong sense of really 'being there' within the VE/video'. This rating used a five-point ordinal scale with the anchors 'strongly disagree' (-2), 'disagree' (-1), 'neutral' (0), 'agree' (1) and 'strongly agree' (2). The descriptive statistics for these ratings can be found in Table 8-4. The box plots in Figure 8-4 show the distributions of these ratings.

Table 8-4 Descriptive statistics for ratings of presence

Condition	Median presence ratings (IQR)
VE	-0.5 (1)
Video	0 (1.75)

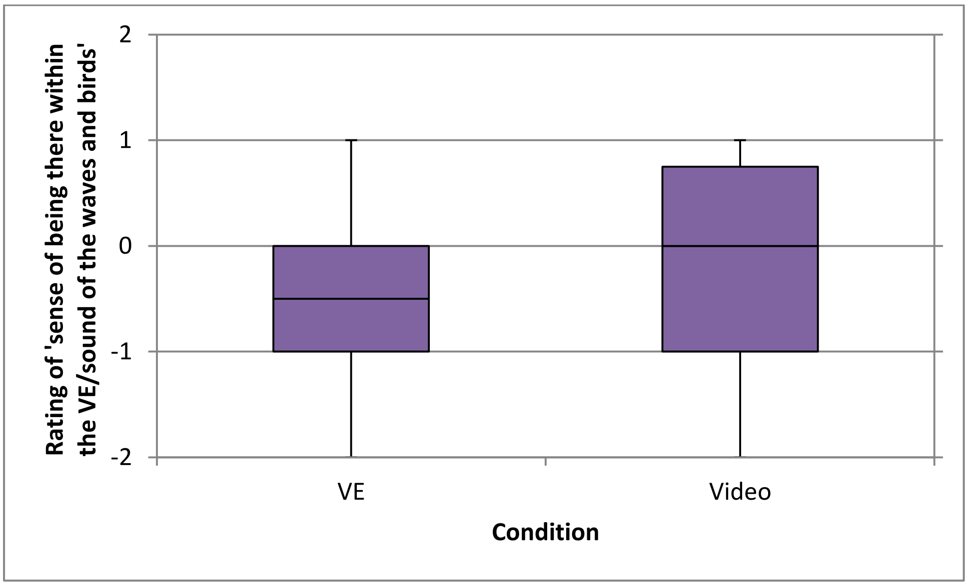

Figure 8-4 Descriptive statistics for ratings of presence

A Mann Whitney test revealed that there were no significant differences in these ratings ($U=56$; $N_1=10$; $N_2=10$; $p>0.05$) indicating that participants felt similar levels of presence in both the VE and the video. The descriptive statistics revealed that the participants generally felt that their presence was 'neutral' in both conditions.

<u>Correlations between ratings of presence and comfort/discomfort</u>

Spearman tests were carried out to determine whether there was any correlation between ratings of presence and ratings of comfort/discomfort during the conditions. No significant correlations were found for the VE condition ($r_s=0.494$; $N=10$; $p>0.05$) or the video condition ($r_s=0.033$; $N=10$; $p>0.05$) therefore indicating that presence did not affect perceived comfort levels or vice versa. This is unsurprising considering that the ratings of presence were generally 'neutral'.

Subjective ratings of how much the conditions were liked

The participants were asked to rate how much they liked the condition that they experienced on a seven-point ordinal scale with the anchors ‘disliked it a lot’ (-3), ‘neither liked nor disliked it’ (0) and ‘liked it a lot’ (3). A Kruskal-Wallis test was carried out to determine whether there were any differences in these ratings across the conditions. The descriptive statistics for this test can be found in Table 8-5 and box plots can be found in Figure 8-5.

Table 8-5 Descriptive statistics for ratings of presence

Condition	Median rating of how much the condition was liked (IQR)
ND	-2.5 (2)
VE	0 (2.75)
Video	-0.5 (1)

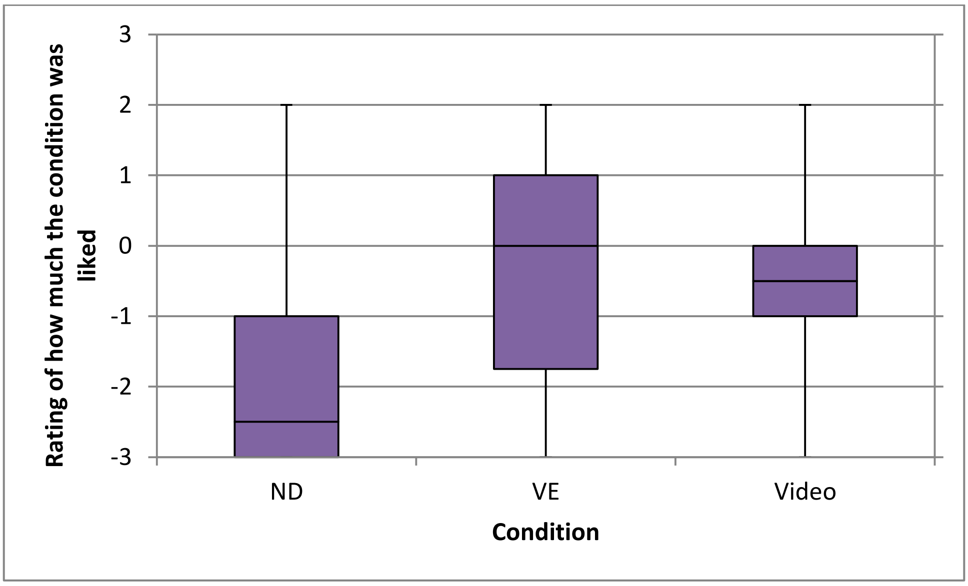

Figure 8-5 Descriptive statistics for ratings of how much the conditions were liked

Although the box plot in Figure 8-5 shows higher ratings for how much the VE and the video conditions were liked relative to the ND condition, the Kruskal-Wallis test did not find any significant differences (H=4.878; df=2; 0>.05). It is likely that this is due to the high variability in the responses.

Correlations between ratings of how much the conditions were liked and comfort/discomfort

Spearman tests were carried out to determine whether there were correlations between the participants' ratings of how much they liked the conditions and their ratings of comfort during the study. The tests revealed that there was no significant correlation for the ND condition (r_s=0.524; N=10; p>0.05) but that there were significant positive correlations for the VE condition (r_s=0.767; N=10; p<0.05) and the video condition (r_s=0.849; N=10; p<0.05). The lack of a significant correlation for the ND condition could be attributed to the clustered presence ratings in this condition. The results for the other conditions indicate that the more the conditions were liked, the greater the perceived levels of comfort.

8.3.2. Qualitative data analysis

Following the experimental conditions, the participants were interviewed about their experiences. The interview questions were related to the following:

- The factors that affected the participants' comfort and discomfort.
- The participants' levels of awareness of the crying baby sound.
- The effect of the sound of the crying baby on the participants' overall experiences.
- Any strategies that the participants used to overcome the sound of the crying baby.
- The effect of the VE or the video on the participants' perceptions of the crying baby sound.

The findings from these interviews are presented in the following sections.

It should be noted that most of the participants were not native English speakers. Therefore, many of the quotes presented in the following sections are not in perfect English.

Comfort and discomfort

The participants were asked to describe the factors which affected their comfort and discomfort during the experimental condition. Unsurprisingly, the most common source of discomfort across all conditions was the sound of the crying baby. Other sources of discomfort included the legroom available or the proximity to the projector screen. In the ND condition, some participants experienced boredom and some experienced discomfort due to the white projector screen. Across all conditions, some participants found the seat comfortable whilst others found it uncomfortable.

As reported in the study presented in chapter 7, the VE and the associated sound were sources of comfort for some participants. This was often due to their relaxing qualities. The video was also a source of comfort for many participants, due to the relaxing scenery, music and narration.

> *"The videos, they were all soothing, calming and it really helped to forget about the baby crying but not for a long time, just for some periods of time."* – P40

Awareness of the sound of a crying baby

The participants were asked whether or not they were aware of the sound of the crying baby during the experimental conditions. A small number of participants in the ND condition were able to forget about the sound of the crying baby for short periods of time when relaxing or when thinking about something else. Some participants in the ND condition were able to get used to the sound and therefore found it less annoying. One participant said,

> *"Well I heard the crying all the time. I don't think there were a second where I didn't notice it but at some point, I was just, as I said, it was a bit less loud for me and I could even fall asleep…I didn't but I could have done. Most of the time it was like this."* – P36

During the VE and video conditions, there were mixed reports relating to awareness or lack of awareness of the crying baby sound. In both of these conditions, some participants reported that they were always or mostly aware of the crying baby sound but that they were able to get used to this sound. For example, a participant in the video condition said,

> *"Well it was…just in the background for me but it was always there. I couldn't completely forget about it, no…It wasn't as disturbing as I thought in the beginning… in the beginning, it really disturbed me."* – P35

Other participants in these conditions were able to completely, or for the most part, forget about the crying baby sound. Some participants were able to forget about the sound when focussing on the VE or the video provided or when thinking about something else. A participant in the video condition stated,

> *"Always a little bit aware of it but definitely didn't notice it so much or it didn't bother me if I did notice it…when it was interesting and when the sound [of the video] was higher maybe and the voice of the narrator, if it was quite a nice voice."* – P50

Another participant in the VE condition said,

> *"I was away from it [crying baby sound]. When I was deep into my thoughts, I was away and it didn't bother me. At first it was really uncomfortable and then after I started to think, it was OK.."* – P33

<u>Effect of the sound of a crying baby on the participants' overall experiences</u>

The participants were asked to describe the effect that the sound of the crying baby had on their overall experiences. In all of the conditions, a small number of participants reported that the sound of the crying baby had no effect on their overall experiences.

In all conditions, there were a number of reports of emotional responses to this sound including anger, annoyance, stress or sympathy. For example, a participant in the video condition stated,

> *"It kind of disturbed me and raises my stress level"* – P45

A participant in the ND condition said,

"It was really annoying and you just couldn't relax, you couldn't really sit down your chair and lay back." – P26

In all of the conditions, some participants reported that the crying baby sound was overpowering. It prevented them from thinking about other things or relaxing in the ND condition. In the VE condition, the participants found it more difficult to relax, the sound distracted them from the VE and it also seemed to reduce their levels of immersion in the VE. For example, a participant in this condition said,

> *"It made it so that I could not fully relax. Like when I was listening to the ocean waves and everything, it was calming me down and when I heard the baby crying, I was like, 'oh that would be stressful' and then I thought about how my muscles were like tensing. Then I started to calm them down again by listening to the ocean sound and then I'd go back."* - P33

In the video condition, the participants found the crying baby sound distracted them from the video. A participant in this condition stated,

> *"I just wanted to watch the video but I wasn't able to so it was a little stressed. You couldn't escape from the noise…so I just wanted to hear what they were telling about the islands and I just couldn't understand what they said…so I just heard a few words…but then you couldn't focus to what they said."* – P15

<u>Strategies used to overcome the sound of a crying baby</u>

The participants were asked to describe the strategies that they used, if any, to overcome the sound of the crying baby. Across all three conditions, the most commonly mentioned theme of strategies was for participants to attempt to distract themselves. In all conditions, one distraction technique was to think about something else. A participant in the VE condition said,

> *"I let my mind wander and thought about different things, things I still need to do and stuff like that. Tried to think about pleasant things."* – P23

In the VE condition, participants would also try to focus their attention on the VE or the associated sound. For example:

"I was just like relaxing and hearing the sound of the ocean…made me think about other things." – P18

In the video condition, the participants would try to concentrate on the video. For example, a participant said,

"I just tried to move focus to the video, that you are really focussed on the video that you forgot the sound around." – P15

In the ND and VE conditions, some participants listened to the crying baby sound but analysed its musical attributes rather than hearing that it was the sound of a baby. A participant in the ND condition said,

"Yes, sometimes, maybe I tried to find the rhythm of the repeat noise" – P6

In all of the conditions, where techniques and strategies were used, some participants felt that these were effective whilst others did not think that they helped. A participant in the video condition said,

"I tried to focus on the images…tried to follow the calm music but that didn't work... maybe because the videos were a bit homogenous...maybe I could try to watch something more entertaining." – P20

In all conditions there were a small number of participants who did not use any strategies.

<u>The effect of the distractors on perceptions of the sound of a crying baby</u>

The participants in the VE and video conditions were asked to describe the effect that they felt the distractors provided had on their perceptions of the crying baby sound.

As described in chapter 7, the participants generally felt that the VE and associated sound had a positive effect on their experience of the crying baby sound. A small number of participants did not think that it had an effect and a small number also thought that the VE and associated sound made their experience worse as it distracted them from their coping strategies. Where the VE and associated sound was seen to be beneficial, this was often attributed to the calming and relaxing elements of the stimuli as well as providing a source of distraction.

Many participants who experienced the video condition felt that the videos had a positive effect on their experiences of the crying baby sound. For example, one participant said,

> *"It made it easier to tolerate it. And it gave me an opportunity to concentrate on something else. Because if I would have just heard the baby and I would have got more angry, easier."* – P45

However, a small number of participants felt that the video had no effect or made the situation worse.

> *"I think it made me find the baby crying more annoying because the video was quite relaxing on the whole but I still felt agitated with the baby."* – P25

One participant reported that when the content of the video was interesting, they were more distracted from the crying baby sound.

> *"I think when the content of the video…was something that interested me, that definitely distracted me a little bit more. If it didn't interest me so much, my mind would start to wander and I'd start to notice the baby a little bit more again."* – P50

For those participants who found that the video had a positive effect, this was usually attributed to the video being calming and a source of distraction.

> *"These are really beautiful videos and I was thinking…about going there sometime maybe with my husband or with my family and friends and it also helped me to forget about the baby because I was picturing myself there sometime later and I was thinking this is a real environment for me."* – P40

However, some participants did comment that the videos were not compelling enough to fully alleviate the negative feelings associated with the crying baby sound as the crying baby sound was the stronger of the two stimuli. For example:

> *"My attention was getting lower and lower and I was paying more attention to the baby but nothing else I think."* – P20

8.4. **Discussion**

This chapter presents a study which compared the effectiveness of a VE and associated sounds to videos depicting similar scenery at distracting participants from the discomfort caused by the sound of a crying baby. This was with a view to comparing a VE to the present day flight activity of watching a video on a personal media device.

The results of this study indicate that neither the VE nor the video provided were able to fully distract the participants from the sound of the crying baby. It appears from the data analysis that the VE and associated sound was marginally more effective than the video at maintaining the comfort levels that the participants had before the study commenced. The need for participants to make an effort to listen to the narration on the video may have been a confounding factor. Given that both the VE and video conditions were rated similarly in terms of how much they were liked and how present the participants felt in them, the reason why the VE was marginally more effective than the video is unclear. However, the findings did indicate that the more an individual liked a condition, the more comfortable they were. In addition, the interview data revealed that the VE and the video conditions were similar in a number of respects, for example: in levels of awareness of the crying baby sound, the extent to which the crying baby sound distracted them from the VE or video and the effectiveness of the stimuli at distracting them from the crying baby sound.

Both the VE and the video alleviated the boredom which was experienced by participants in the ND condition. They also both distracted the participants to some extent, providing them with something else to focus their attention on. However, neither of these stimuli distracted the participants to the extent that they were able to completely forget about the crying baby sound. A study in pain research found that passive distractors are less effective than interactive distractors (Dahlquist et al., 2007; Jameson et al., 2011; Law et al., 2011). It is possible that the lack of interactivity was a contributory factor to both the VE and the video not fully distracting participants from their discomfort.

Like the findings of the study presented in chapter 7 of this thesis, the participants generally felt that the relaxing qualities of both the VE and the video helped them to overcome some of the discomfort associated with the crying baby sound but that they generally were still aware of the crying baby sound most or all of the time. Konstantatos et al. (2009) found that relaxing VR was not an effective means of reducing pain perception. The findings of this study indicate that the relaxing qualities of the stimuli provided were helpful but that these stimuli were not compelling enough to fully overpower the discomfort associated with the sound of a crying baby.

It is interesting to note that some participants were unable to focus on the spoken information in the video due to the crying baby sound. This is similar to findings by Oborne (1978a) who suggested that discomfort can result from an inability to carry out an activity. This outcome could be linked to multiple resources theory (Wickens, 2002) which would suggest that people would find it difficult to attend to both auditory cues (the crying baby sound and the verbal information in the video). It is therefore possible that for these participants, the crying baby sound dominated the video. This is akin to the suggestion made by Kuijt-Evers et al. (2005) that discomfort dominates comfort. However, other participants were able to use the video to alleviate the discomfort caused by the crying baby sound (the same is true of the VE) therefore indicating that for these participants, discomfort did not dominate comfort.

The results indicate that there may be an optimum amount of attentional resource that a distractor should demand in order to be effective. This contrasts with findings from Simmonds and Shahrbanian (2008) and Hoffman et al. (2001b) who suggested that stimuli are more effective at distracting people from pain when they are more engaging. Some participants in the study presented in this chapter did not find the VE or the video compelling enough to distract them from discomfort while others were unable to use the video as a distractor due to the crying baby dominating this.

It is possible that a distractor needs to be engaging enough to distract a person from a source of discomfort but there is a point at which this distractor would require more attention than can be allocated thereby causing a person to be unable to focus on it and rendering it ineffective. Figure 8-6 illustrates this idea. It should be noted that this diagram is not based on any quantitative data and is purely illustrative. It is also based purely on the results of this study and does not encompass other situations such as where a person does not attend to the source of discomfort, only focussing on a distractor. As discussed in chapter 2, there are a number of factors which affect a person's experience of comfort or discomfort. It is therefore likely that the shape of this curve would vary not only with how uncomfortable a stimulus is, the nature of the discomfort, the nature of a distractor and extent to which they are engaged by the distractor but also with other factors such as a person's expectations or attitudes, the context etc. Further research should attempt to determine the optimum attentional requirements of a distractor under different circumstances. Such quantification would enable interventions to be designed for optimum effectiveness.

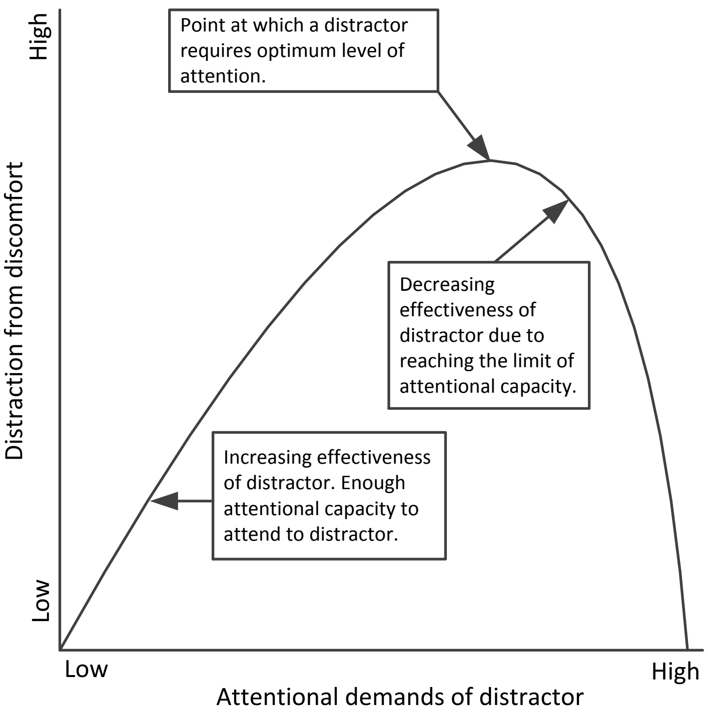

Figure 8-6 Illustration of the ways in which the attentional demand of a distractor may influence its effectiveness

It is acknowledged that the videos used in this study were not directly comparable to IFE or the types of videos which passengers would commonly watch on their personal devices (e.g. television programmes or films). It is likely that the results of this study may have differed if such videos were used. However, for the purposes of experimental control, the videos used were selected to be as comparable to the VE as possible (in terms of levels of engagement and scenery depicted). Future research should compare the extent to which entertainment videos distract participants from discomfort compared to VEs. In addition, other present-day methods of distraction such as listening to music, reading or working should also be compared.

8.5. **Conclusions**

The research presented in this chapter has revealed that both a VE and a video depicting relaxing scenery can have a positive influence on a person's experience of a crying baby sound. The specific stimuli used in this study were not compelling enough to completely alleviate any negative responses to the crying baby sound. However, they did provide participants with something other than the uncomfortable stimulus on which to focus their attention. The relaxing elements of both the VE and the video appeared to be important in helping the participants to overcome the crying baby sound.

The findings of this study question the optimum level of attentional resources that a distractor should require. Some of the participants found it difficult to focus on the video commentary as it required the same attentional resources (auditory) as the source of discomfort. For these participants, the source of discomfort overpowered the video and reduced their ability to use this as a distractor. It is possible that there is a point at which a distractor requires so much attention that a person will (possibly unconsciously) select whether to focus on the source of discomfort or the distractor. If they select the source of discomfort, the distractor will be rendered ineffective. Further research should investigate the optimum level of attentional resources that distractors require in order to be as effective as possible, bearing in mind that this will likely vary based on individuals, context etc.

9. Understanding the effect that discomfort-inducing stimuli might have on real flight experiences

9.1. Introduction

Chapters 6-8 of this thesis detail studies which investigated the extent to which various stimuli could influence the perceived levels of comfort or discomfort associated with either the sound of a crying baby or restricted legroom. In these studies, data was captured relating to the effect that the discomfort-inducing stimuli had on the participants' overall experiences during the experimental conditions and the strategies that they used to overcome these stimuli. The studies identified the negative effects that these stimuli had on the participants' experiences of the experimental conditions including discomfort, emotional responses and distraction. The studies also identified the strategies which the participants used to overcome the discomfort that they experienced including, changing their body position (for the restricted legroom), trying to distract themselves or trying to relax.

A study by Patel et al. (2012) found that air passengers adopt a variety of adaptive behaviours in order to cope with sources of discomfort. These include using activities to distract themselves, talking to other passengers, eating or drinking, taking medication or using products such as blankets, pillows, eye masks and earplugs to change their environments. It is important to understand the effect that the sources of discomfort used in the studies presented in this thesis may have on passengers during present day air travel. This will provide a greater understanding of the extent to which distractors can enhance comfort when these sources of discomfort are experienced and therefore, the added value of integrating VEs into future aircraft. As a result, this chapter aims to determine the effect that these sources of discomfort (crying baby and restricted legroom) might have on air travellers and the strategies that they might currently use to overcome these sources of discomfort.

9.2. **Method**

During all of the studies presented in chapters 6-8 of this thesis, two interview questions were asked in order to understand the effect that the sources of discomfort used (restricted legroom or the sound of a crying baby) might have on passengers' real flight experiences. This chapter examines the responses to these questions across the three studies.

A total of 83 people participated in the studies at either Fraunhofer IAO (FhG) or the Max Planck Institute for Biological Cybernetics (MPG). They experienced one of the two sources of discomfort (restricted legroom or the sound of a crying baby) and were only interviewed about the source of discomfort that they experienced during the experiment. The breakdown of participants is described in Table 9-1.

Table 9-1 Number of participants categorised by set-up and source of discomfort

Source of discomfort	Technical set-up		Total number of participants
	Fraunhofer IAO (FhG)	Max Planck Institute for Biological Cybernetics (MPG)	
Restricted legroom	22	0	**22**
Sound of a crying baby	21	50	**71**

The interview questions asked related to the following:

- The effect that the participants thought the sound of the crying baby/restricted legroom would have on their overall experience of a real flight.
- The strategies that the participants thought that they would use to overcome the sound of the crying baby/restricted legroom on a real flight.

It should be noted that the studies were carried out in Germany and therefore most of the participants were not native English speakers. As such, where quotes are presented in the results section, these may not always be in perfect English. Alongside the quotes, the participant number and study location are also provided.

9.2.1. Results: restricted legroom

<u>The effect that restricted legroom might have on the participants' real flight experiences</u>

The participants were asked to describe the way in which the restricted legroom experienced during the experimental conditions would affect their experiences on a present-day flight.

The most commonly mentioned effects related to physical manifestations of discomfort or pain in their legs. For example, a participant said,

> *"If the flight would be longer, I guess sometimes you need to stretch your legs or… it would be uncomfortable I think."* – P23 (FhG)

Some participants reported that this physical discomfort could have negative knock-on effects, for example:

> *"Then I would have limb aches and I would feel really uncomfortable because of aches. I wouldn't be able to doze off and it would become really boring."* – P12 (FhG)

Another commonly mentioned theme of effects that restricted legroom would have on passengers' experiences was a general feeling of restrictedness, leading passengers to feel that they are unable to move.

> *"The main problem is to really stay in a fixed position all the time. I think that creates, on the long run, it [discomfort] can from the arms, from the shoulders, from the legs, it's everything...Uncomfortable in a way that I cannot move."* - P16 (FhG)

One participant reported that the restriction of physical space would prevent them from using the footwell for storage purposes.

> *"Normally I do my backpack in front of me or something like that and this is not possible with the space."* - P29 (FhG)

Some participants mentioned that the length of the flight might dictate the extent to which restricted legroom would affect their discomfort. One participant suggested that this is due to expectation.

> *"On a real flight it would be even worse because you know it's going to be two hours, three hours or even worse and I think with that, if you sit in a seat like that and you know it's gonna be a ten hour flight, even within the first ten minutes, you're going to feel more uncomfortable than in the first ten minutes of a 20 minute experiment."* - P18 (FhG)

Other participants simply suggested that the discomfort experienced would increase with the length of the flight. For example:

> *"I think that if you have a long flight, it's a bit more uncomfortable or it's getting more uncomfortable during the time with the legs."* – P22 (FhG)

Other effects that restricted legroom would have on the participants' flight experiences include those relating to their emotional states. Participants suggested that this physical restriction of space would lead to reduced enjoyment of their flight and becoming annoyed. For example:

> *"Yes. I think it will go on my nerves. It's very uncomfortable for some hours."* – P14 (FhG)

A small number of participants reported that if their legroom was restricted in this way on a present day flight, there would be no effect on their flight experiences.

> *"I think at the first time, I would think, 'ah a little bit more space would be nice' but I think after a while, I would get used to it."* - P43 (FhG)

Finally, some participants reported that if their legroom was restricted to this degree on a real flight, their transport decisions would be affected. Some participants would choose alternative airlines, others would only take short flights and some would choose to travel by alternative modes of transport altogether.

"Oh that would be terrible. Maybe I wouldn't enjoy the flight and maybe I would choose another transport. Maybe I would go by car and not fly." – P29 (FhG)

<u>Strategies which might be used on a real flight to overcome restricted legroom</u>

The participants were asked to describe the strategies that they would use to overcome their discomfort if their legroom was restricted on a real aircraft to the same degree as they experienced during the experimental conditions. Two broad themes of strategies were identified: changing their body positions and distraction.

A number of participants reported that they would adjust their body positions in order to increase their comfort if their legroom was restricted on a real aircraft. A common approach was to adjust the way in which they were sitting in order to find a more comfortable position. For example:

"Maybe on a really long flight I would have tried to take my shoes off and drop my knees. I've done that before. Sometimes on a plane, I would pull up my knee and put it against the seat in front of me." - P18 (FhG)

Another approach which was commonly suggested was to walk around the cabin.

"Where sometimes what you do is you get up and sometimes it's also you go to the toilet even if you don't feel that urge because it gives you a reason to get up and move. And sometimes in long flights, people do that, just walk up and down." – P16 (FhG)

Many participants reported that they would attempt to distract themselves from their restricted legroom. Suggested methods of distraction included reading, listening to music, sleeping, talking to other passengers or watching videos.

"On a real plane, I think what might be interesting also is what I'd normally do is listen to music or read something… And that gives you exactly this, you leave the physical space and enter some virtual space." – P16 (FhG)

9.2.2. Results: crying baby

<u>The effect that the sound of a crying baby might have on the participants' real flight experiences</u>

The participants were asked to describe the effect that a crying baby would have on their current typical flight experiences. The two main themes which emerged from the analysis of responses to this question were emotional responses to the crying baby and a sense that this sound would overpower passengers' abilities to carry out activities.

A number of participants reported that they would have emotional responses if a baby was crying during a flight. Often these suggested responses were negative and included feelings of anger, stress, annoyance or anxiety. For example:

> *"Yeah, really badly. I sat once in a flight for 14 hours. There was a baby crying nearly all the time, and sure, I thought about it when I heard the baby crying again and, yeah if I would be in a real flight and a baby would be crying, I probably would be annoyed..."* – P46 (FhG)

Some participants reported that they would feel sympathy towards the baby or its parents if they were in this situation on a real flight.

> *"I would feel sorry for the baby. I wouldn't get mad or anything because there is nothing you can do and the baby would be the one that's suffering."* – P22 (MPG)

The participants also commonly reported that if a baby was crying during a flight, this would have an overpowering effect both on their activities and their ability to escape from the sound.

> *"It's the most annoying thing that can happen in a flight is a baby crying side by you or really nearby you…it's difficult to turn off."* – P17 (MPG)

The in-flight activities which participants thought might be negatively affected by a crying baby included reading, watching videos, working, or listening to music. For example:

"If I have to write something like work, I wouldn't be able to focus on it. Just watching a movie, maybe it would be easier but still I would drift away by hearing the baby." - P20 (MPG)

The participants often commented that the sound of a crying baby would affect some activities more than others. The activities which participants thought would be affected least were listening to music or watching videos.

"Maybe if I have a magazine or something to read, I think I couldn't concentrate, I think I would always be kind of distracted. Maybe it would be better if I watch a movie because you always have the headphones plugged into your ears so the sound of the baby's a little bit lower but if you just read something or maybe if you want to work on something or write something, no, I think I could not really concentrate or focus on the task." – P26 (FhG)

Another activity which the participants highlighted as something which could be affected by a crying baby was sleeping or relaxing. One participant also emphasised the knock-on effect that being prevented from sleeping would have if travelling on a long-haul flight.

"I would be exhausted after the flight because I can't completely concentrate on other stuff or relax because it's always there and you're always thinking about it." - P46 (FhG)

Some participants also suggested that they would find it more difficult to have conversations with other passengers if a baby was crying during a flight. For example:

"Probably make me less likely to have a conversation…because I speak quite quietly, the baby would probably be louder than me." – P44 (MPG)

A small number of participants reported that they did not think that a crying baby would affect their flight experience in any way. For example, a participant reported,

"I think a couple of times, it happened to me. I don't think that it was really uncomfortable for me. I understood that it's normal, it's the usual situation but yeah, maybe on the plane, crying, it's like you can do not that much as you could do…" - P4 (MPG)

Strategies which might be used on a real flight to overcome the sound of a crying baby

The participants were asked to report the strategies that they would use to overcome any discomfort associated with the sound of a crying baby on a real flight.

Similarly to the restricted legroom scenario, the most commonly reported strategies were those relating to distraction. Participants often reported that they would try to distract themselves from the sound of the crying baby by listening to music, reading, watching videos, thinking about something else, sleeping or looking out of the window, for example:

> *"On a real flight, I would try to hear music and…or try to sleep or something. Well I read newspapers or books or something and if there is a good movie then, on a long flight, then I would probably watch that."* – P37 (MPG)

Often participants reported that having an auditory distractor was important and that other activities such as reading or working would only be an effective distraction in combination with an auditory stimulus such as music.

> *"The focus is always on the baby crying, you're always thinking of it and if you try to read, you have to be a little concentrated and you have to get into the start again. I think it will only work in combination with the music but only reading, I think I couldn't concentrate on."* – P46 (FhG)

Many participants reported that auditory or audio-visual distractors such as music or videos would help them to overcome the sound of a crying baby not only because of the distracting elements but also because they could be used to block out the sound. Other participants reported that they would use earplugs to block out the sound of the crying baby, for example:

> *"I would have put headphones on if there were any and watch a movie or listen to music so I don't hear the baby crying. Or if I don't have headphones, I would put something in my ears."* - P9 (MPG)

Other strategies which the participants suggested that they might use to overcome the sound of a crying baby on a real flight included asking either the parents or the cabin crew to try to ease the situation.

> *"After a few minutes, it's getting critical, maybe after 10 minutes or so and especially when no one is caring to solve the problem, especially the people who are responsible for it like the parents and then the crew and then the third place, maybe the seat neighbours and then maybe I would go there any ask them to do something."* – P1 (FhG)

Other participants suggested that rather than asking someone else for assistance, they would offer the parents help in an attempt to calm the baby down, for example:

> *"I would see the situation, what the mother is doing or what the other people are doing and according to the situation, I would maybe try to offer my help, to give the baby something that may turn his attention away from crying…"* – P36 (FhG)

Some participants also suggested that they would try to remove themselves from the situation either by asking to change their seat or by walking around the cabin.

> *"Well if there is the possibility to change the seat, to go far away, I'd definitely go for it."* - P13 (MPG)

A small number of participants reported that if they were on a flight with a crying baby, they would not use any strategies to overcome their discomfort, often giving reasons such as this being a natural situation which is difficult to overcome.

9.3. **Discussion**

The findings presented in this chapter determined the effect that two sources of discomfort (a crying baby and restricted legroom) have on present-day air passengers' flight experiences. They also determined the strategies that air passengers would use to overcome the discomfort associated with these situations.

The participants reported a number of ways in which these sources of discomfort would affect their flight experiences. Figure 9-1 summarises these effects and shows the commonalities in the effects caused by the two sources of discomfort. What is most evident from this diagram is that there is a very small overlap between the ways in which the two sources of discomfort would affect passengers' flight experiences. One of the studies presented in chapter 5 identified that both of these stimuli induced a state of discomfort in participants. However the findings of this study illustrate that the effects that these sources of discomfort would have on passengers are very different with one group of exceptions, negative emotional states (such as anger and annoyance). The participants reported that extreme restriction of their legroom would generally have effects which are physical or environmental in nature, i.e. relating to bodily sensations or to the experience of the surrounding environment (Kolcaba, 1992; Kolcaba, 1991). In contrast, the participants reported that a crying baby would lead to psychological responses such as distraction from their activities.

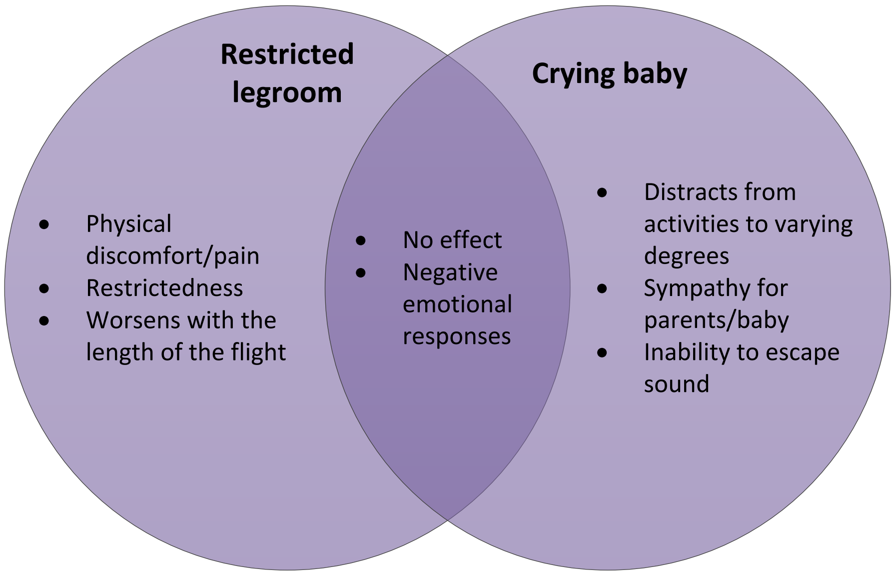

Figure 9-1 Ways in which two sources of discomfort might affect current flight experiences

This highlights the complexity and breadth of comfort and discomfort as concepts, showing that different stimuli can lead to different experiences which can both be classified as 'uncomfortable'. From a methodological perspective, the findings illustrate that it is not enough to simply ask participants to rate their comfort. Rather, deeper insights into their experiences should be obtained in order to fully understand the factors which constitute an experience of comfort or discomfort. If designers are able to understand the reasons why a situation is comfortable or uncomfortable, they will be able to make informed decisions when designing for comfort.

It is important to consider the results presented in this chapter with respect to the findings of the studies presented in chapters 6-8. The study reported in chapter 6 found that the restricted legroom had little effect on many of the participants' overall experiences, particularly when the VE was interesting. Therefore, it could be said that the VE reduced the negative responses which are typically experienced during a present day flight situation. The studies reported in chapters 6-8 revealed that a VE can reduce the negative responses to a crying baby sound for some participants and that this is more effective if a sound is also provided. However, this did not alleviate the negative effects for all participants. Therefore, it could be said that, compared to a present-day flight scenario, VEs (with or without corresponding sounds) can enhance the flight experience for some passengers when discomfort is caused by a crying baby.

Figure 9-2 shows the strategies that participants reported they would use to overcome the two sources of discomfort experienced on a real flight. Similarly to the results relating to flight experiences, there are also both overlaps and differences in the strategies that the participants reported for the two sources of discomfort. It should be noted that distraction strategies were the most commonly reported group of strategies for both sources of discomfort. Therefore, although the ways in which these stimuli would affect the flight experience vary substantially, there is a large overlap in the strategies that passengers would use to overcome them. However, given the different sensory natures of these stimuli, participants also reported different strategies for the two sources of discomfort. Although, behaviourally, these strategies are quite different (changing the body position compared to trying to stop the sound of a crying baby), they are also similar as they attempt to interfere with the sensory channels through which the discomfort is perceived. If their legroom is restricted, the participants reported that they would try to change their body position or walk around the cabin in an attempt to intercept the physical discomfort experienced. Similarly, if a baby is crying, they would either try to block their ability to hear the sound or stop the baby from crying thereby reducing their discomfort.

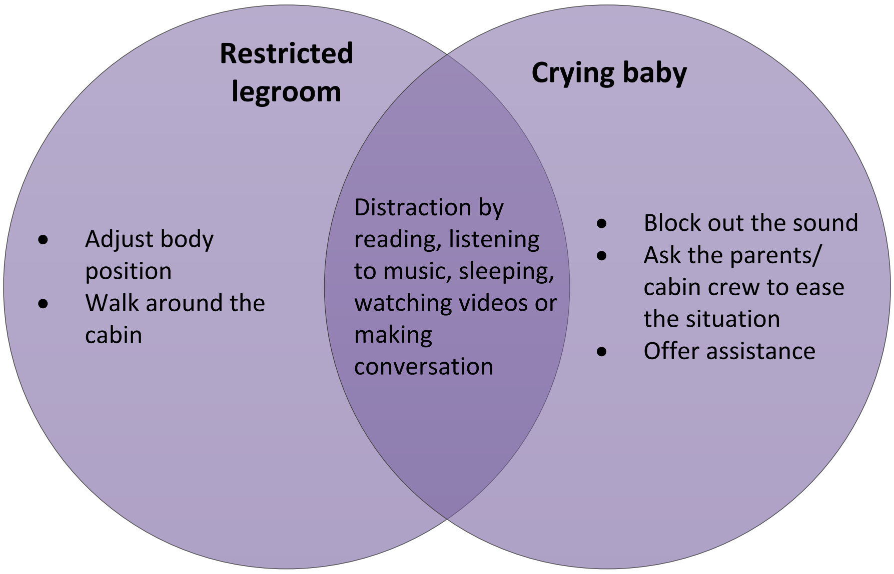

Figure 9-2 Strategies that aircraft passengers might use to overcome two sources of discomfort

Considering the findings presented in this chapter with respect to those in chapters 6-8, it is evident that VEs provide a means of supporting some of the existing strategies used in aircraft to counteract or minimise discomfort. In the studies presented in chapters 6-8, participants would use the VEs and/or associated sound as a means of distraction from sources of discomfort. This is comparable with currently reading, listening to music, watching videos etc. as a means of distraction. Where sounds were provided, these also provided a means of occluding auditory sources of discomfort whilst also providing a distraction. This is comparable to the present day strategy or blocking out the sound by using headphones or earplugs.

9.4. **Conclusions**

The research presented in this chapter identified the ways in which two discomfort-inducing stimuli would affect the present-day flight experience. It also identified the strategies that passengers would use under these circumstances on a real flight to overcome these sources of discomfort. The findings illustrate the complexity and breadth of comfort and discomfort as constructs by showing how two uncomfortable stimuli can have very different effects on passengers' experiences. The findings also indicate that although restricted legroom and the sound of a crying baby can have quite different effects on passengers' flight experiences, there is an overlap in the ways in which passengers try to overcome these sources of discomfort. The ways in which VEs can be used in future flight to support existing strategies in order to enhance the flight experience are also highlighted.

10. Discussion

10.1. **Introduction**

The research presented in this thesis draws on various areas within the literature to take a novel approach to investigating the ways in which aircraft passengers' comfort and experiences can be enhanced. The idea for the use of VR to enhance passengers' comfort emerged from the VR-HYPERSPACE project along with the EC's visions for enhancing passengers' experiences in the year 2050 (European Commission, 2010, 2011). This concept for enhancing passenger comfort would be comparatively cheaper than changing the physical parameters of aircraft as this would incur costs with respect to both redesign and a reduction in passenger capacity. A review of the scientific literature revealed that there has been extensive research into using VR to distract people from pain (e.g. Dahlquist et al., 2007; Hoffman et al., 2000; Law et al., 2011). However, there have not been any studies which have investigated the use of VR to enhance comfort. This thesis aimed to address this by conducting a series of experiments to assess people's experiences of comfort/discomfort when viewing different VEs under simulated conditions designed to replicate sources of discomfort which are currently experienced by aircraft passengers.

Previous research in the comfort domain has investigated the factors which can influence a passenger's comfort or discomfort in various transport domains (e.g. Ahmadpour et al., 2014a; Ahmadpour et al., 2014b; Patel et al., 2012; Vink et al., 2012; Vink & Brauer, 2011). In this thesis, this literature was considered alongside the literature investigating the use of VEs to distract people from pain in order to take a novel approach to enhancing passenger comfort through the use of VEs.

The thesis contributed knowledge in terms of reflecting on the design of VEs to be used to enhance passengers' comfort and experiences, including consideration of the suitability of motion tracking. It also reflected on designing VEs which passengers can use to ensure that their transit time is used in positive ways, whether this is for work or leisure activities or to support desired emotional states. Passengers' abilities to use their transit time to their benefit is something which was highlighted by Mayr (1959) as being associated with passenger comfort.

A new approach to measuring the effect of an intervention on the perception of discomfort was also developed, drawing on approaches in pain research. It was identified early on in this doctoral research that in order to determine the extent to which VEs can distract people from discomfort, studies needed to begin from a state of discomfort. Chapter 5 reported on studies which selected and tested discomfort-inducing stimuli (restricted legroom and the sound of a crying baby). These were subsequently used in the studies presented in chapters 6-8 as these studies showed that this approach was appropriate to meet the aims of this research.

The outcomes from the studies presented in chapters 6-9 show that VEs have the potential to either fully distract people from, or minimise their negative responses to, sources of discomfort which they might encounter on a real aircraft. The studies highlighted the elements of VEs which are likely to have the greatest effect on distracting people from their discomfort (e.g an auditory element for an auditory source of discomfort, a relaxing element to counteract stressful situations or interesting elements in order to be more engaging).

10.2. **Summary of research findings**

Figure 10-1 provides a summary of the studies conducted as part of this doctoral research, including the aims of the individual studies and the key findings. These studies are associated with the corresponding research objectives which were set out in chapter 1.

Consideration has been given to differences which may have arisen between the studies presented in chapters 6-8 as a result of individual differences in participants and differences in technology. Appendix 4 provides a comparison of these studies in terms of participant demographics and the results of the quantitative data analysis. This shows that the participant demographics and ratings for presence, how much the conditions were liked and VRISE (using the SSC (Cobb et al., 1995)) were comparable across the studies and therefore are unlikely to have impacted on the results.

A number of considerations for the design of VEs in order to enhance aircraft passengers' comfort and experiences have also been developed (see appendix 5), arising from the results of the studies presented in chapters 4 and 6-8. It is suggested that these are used by technical developers when designing VEs for testing these concepts.

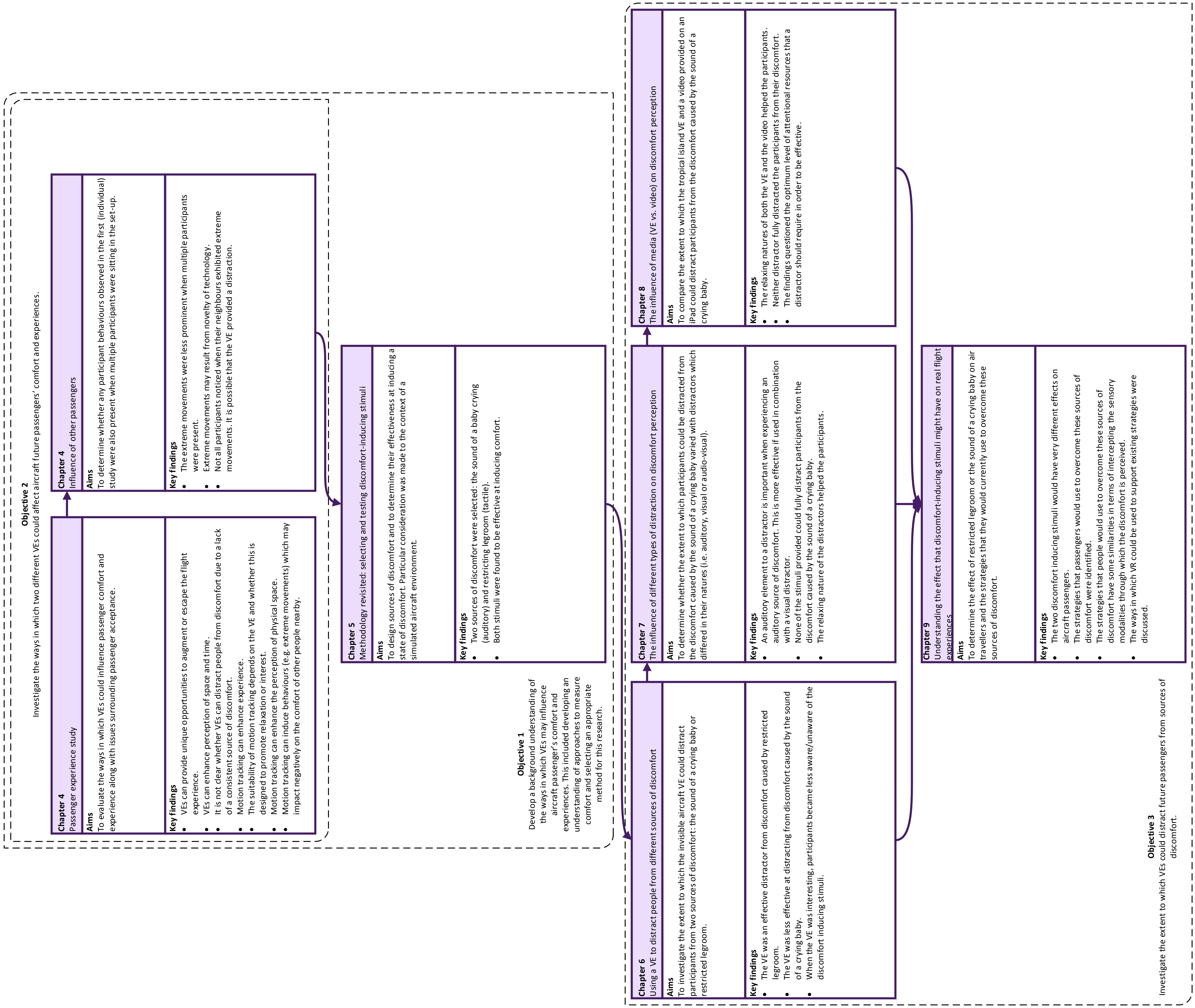

Figure 10-1 Key findings of studies

10.3. **Achievement of research objectives**

This PhD research aimed to investigate the ways in which VEs could influence comfort and experience in a simulated aircraft setting. The three research objectives which were set out in chapter 1 are as follows:

1. Develop a background understanding of the ways in which VEs might influence aircraft passengers' comfort and experiences and understanding approaches to measuring comfort.
2. Investigate the ways in which two different VEs could affect aircraft passengers' comfort and experiences.
3. Investigate the extent to which VEs could distract aircraft passengers from sources of discomfort.

This section reflects on the achievement of these objectives.

The investigation of the ways in which VEs can influence people's comfort and experiences with a view to enhancing future flight experiences has not been previously researched. As a result, the research presented in this thesis draws on three main bodies of literature: user experience, comfort/discomfort and VEs as a means of distracting people from pain.

Early studies in this thesis showed that VEs could be used to provide people with novel experiences which would enable them to use their travel time to their advantage. These experiences might become activities themselves (e.g. actively viewing the landscape beneath the aircraft), enabling passengers to carry out other activities more easily or helping passengers to achieve desirable emotional states (e.g. promoting relaxation). Part of the user experience is concerned with a product or system's positive affective consequences on users (Hassenzahl & Tractinsky, 2006). Providing these experiences may be attractive from a marketing perspective as well as allowing passengers to use their time in transit to their benefit.

The research presented in this thesis involved the development and use of a novel approach to measuring the extent to which a stimulus can influence people's comfort. This method draws on the approaches taken in pain research by inducing discomfort to determine the extent to which interventions could distract people from these sources of discomfort. This approach could be used to make judgements on whether interventions could reduce discomfort. However, it is debatable if judgements could be made on whether interventions could increase comfort (as this would depend on which side of the scale the ratings fell).

Consistent with the findings of studies by Dahlquist et al. (2007), Weiss et al. (2011) and Law et al. (2011), this research has found that passive VEs can be used as distractors from sources of discomfort. Their effectiveness is varied, changing with a number of possible parameters which have been identified. However, at the very least, VEs can reduce people's negative responses to sources of discomfort, if not fully distract them from their discomfort. Variables which may influence the effectiveness of distractors include:

- The extent to which users like the distractor
- How interesting the user finds a distractor
- The attentional demands of the distractor
- The attentional demands of the source of discomfort

The variables relating to distractors are illustrated in Figure 10-2 and the variable relating to the source of discomfort is illustrated in Figure 10-3. It should be noted that these diagrams are purely illustrative and the heights, angles and shapes of the curves are not based on quantitative data. They also only encompass findings from the studies presented in chapters 6-8 and therefore may not illustrate all possible scenarios.

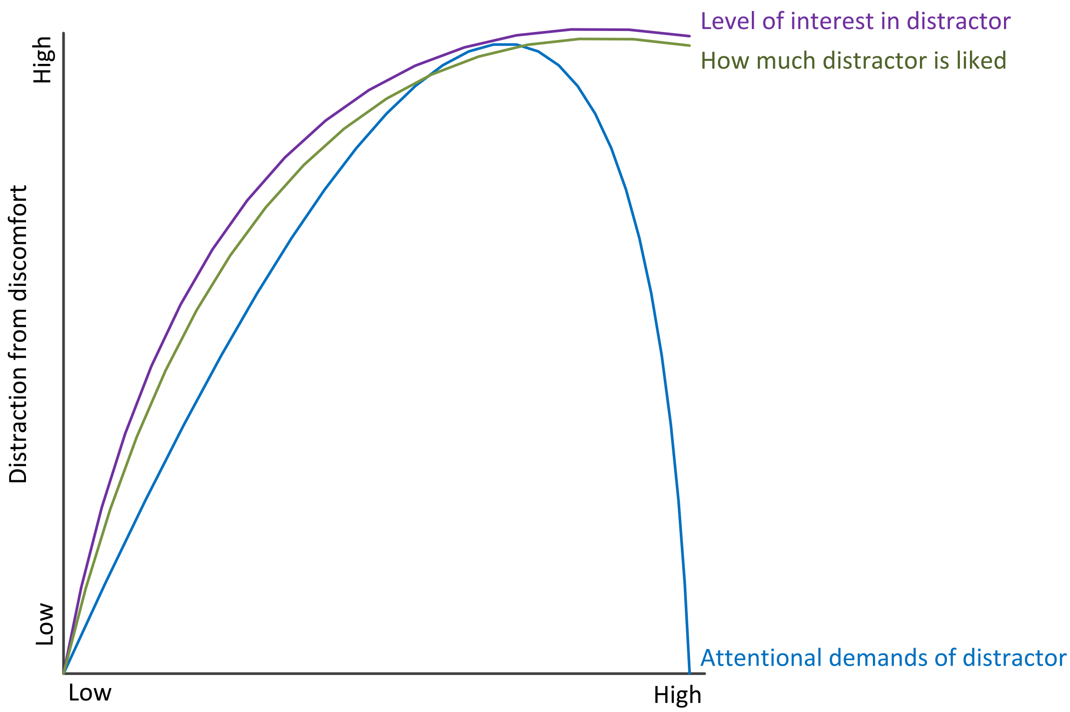

Figure 10-2 Illustration of the ways in which various parameters might affect the extent to which a person can be distracted from their discomfort when experiencing discomfort-inducing stimuli

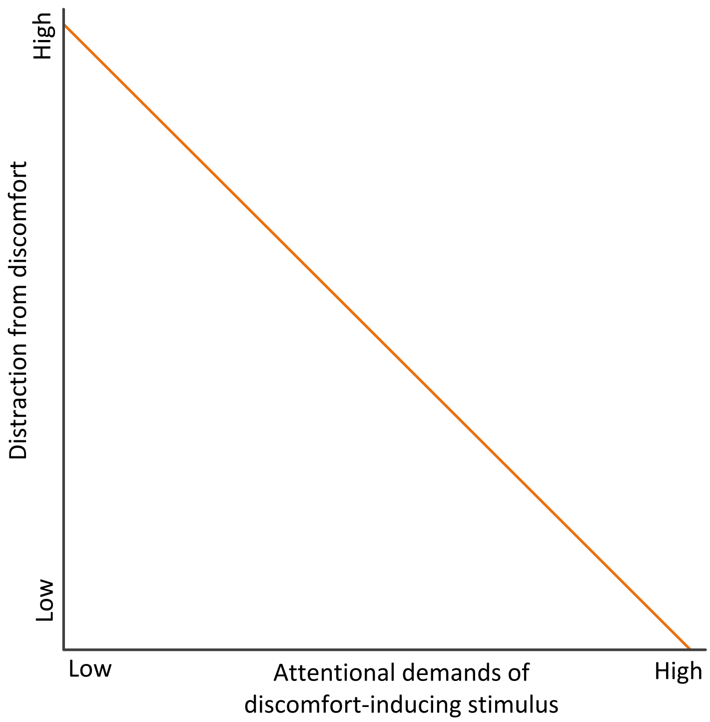

Figure 10-3 Illustration of the way in which the attentional demands of a source of discomfort might affect the extent to which a person can be distracted from their discomfort

The findings of the studies indicated that there is a relationship between the extent to which a distractor is liked and the extent to which it can distract people from sources of discomfort (see green line in Figure 10-2). Aligned with this, the studies also found that when VEs are interesting, they become more effective distractors and that, conversely, when they are boring, they are less effective. This is illustrated by the purple line in Figure 10-2. This finding is comparable to those of Hoffman et al. (2001b) and Simmonds and Shahrbanian (2008) who found that stimuli become more effective distractors from pain when they are engaging. However, engagement would also imply use of attentional resources. The findings of the studies presented in this thesis also suggested that if the attentional demands of a distractor are greater than the total capacity available, people (possibly unconsciously) will select whether to attend to their discomfort or a distractor. If they attend to their discomfort, the distractor will become ineffective (see blue line in Figure 10-2). It is possible that this finding does not relate to attentional capacity as a whole but rather, to specific attentional resources (e.g. in chapter 8 this may have only related to attention of the auditory modality). It is possible that the lines in Figure 10-2 can be interpreted together. The point at which the three lines meet may indicate the combination of the attentional demands of a distractor, how much it is liked and how interesting it is which is optimal for distraction from discomfort.

Figure 10-3 illustrates that there may be a relationship between the attentional demands of a source of discomfort and the extent to which people can be distracted from this. The study findings indicated that it is easier to distract people from the discomfort associated with restricted legroom than the sound of a crying baby. As previously discussed it is possible that this is due to a biological or evolutionary predisposition to attend to this sound and enter a state of high alert (Giardino et al., 2008). This, in turn, could lead to this particular source of discomfort demanding greater attentional resources, thereby leaving less capacity available to attend to distractors.

Another finding of this research was that when people experienced negative emotional responses to sources of discomfort, providing distractors which had relaxing qualities enabled the participants to achieve a level of calm. This finding contrasts with that of Konstantatos et al. (2009) whose research found that VR relaxation increased the perception of pain intensity. This difference could be attributed to the studies presented in this thesis aiming to distract people from discomfort rather than pain.

The studies also found that VEs can be used to support existing strategies that people might use to overcome sources of discomfort in present day flight. For example, VEs with auditory elements could be used to mask auditory sources of discomfort. In addition, VEs in general can be used as distractors from discomfort instead of, or in combination with, other activities.

10.4. **Reflections on the definitions of the terms 'comfort' and 'discomfort'**

At the beginning of this doctoral research, a decision was made to not take an opinion on the definitions of the terms 'comfort' and 'discomfort' in order to not restrain the data collected. Rather, qualitative data were collected with respect to both comfort and discomfort (separately) in order that the debate surrounding the definitions of the terms 'comfort' and 'discomfort' could be reflected on with respect to the findings of this research. Figure 2-5 (presented on page 20) shows some of the viewpoints in the debate surrounding the definition of these terms in the literature. These include the debate on whether comfort and discomfort are opposite ends of a continuum (Richards, 1980; Shackel et al., 1969) or separate constructs (De Looze et al., 2003; Vink & Brauer, 2011; Vink et al., 2005a; Vink & Hallbeck, 2012; Zhang et al., 1996) and whether comfort is simply the absence (Branton, 1993; Hertzberg, 1958) of discomfort or something extra (Mayr, 1959; Oborne & Clarke, 1973; Richards, 1980).

The findings of the research presented in this thesis indicate that comfort and discomfort are separate but not distinct constructs. The findings indicate that whilst there are some causes and effects which are only attributable to one of comfort or discomfort, there are others which may be related to both constructs. For example, dim lighting could lead a person to feel tired. This may be viewed as uncomfortable under some circumstances (e.g. when social convention dictates that this is not appropriate) but may also be comfortable in an appropriate context (e.g. when wanting to rest during a flight). Helander and Zhang (1997) noted that although comfort and discomfort are separate constructs, they do not act completely independently. They stated that high levels of discomfort can only be experienced if comfort levels are low. Their view was that these two constructs, while separate, do influence each other. The findings of the studies presented in this thesis also indicate that comfort can be experienced when people are subjected to a stimulus which could be perceived as uncomfortable. Contrary to Helander and Zhang (1997), this indicates that when distracted from their discomfort, people can achieve high levels of comfort.

Contrary to De Looze et al. (2003), the findings of the studies presented in this thesis indicate that discomfort is not only influenced by factors which are physical in nature but other factors such as those which are social, psychological or environmental in nature. Similarly, and in agreement with De Looze et al. (2003), all such factors can also influence comfort.

This research also indicated that comfort is more than simply the absence of discomfort. For example, in agreement with Kolcaba and Kolcaba (1991) and Zhang et al. (1996), comfort can result from feelings of relaxation or pleasure.

In agreement with Kolcaba and Kolcaba (1991), the results of the studies showed that both comfort and discomfort can be experienced simultaneously. Helander and Zhang (1997) proposed that discomfort dominates comfort. However, the findings of the studies presented in this thesis indicate that this is not always the case and that when a distractor is provided, this can overpower discomfort-inducing stimuli, leading to a state of comfort or reduced discomfort. Considering all of the factors identified in chapter 2 which can affect comfort or discomfort, dominance of one of these experiences over the other will likely depend on the specific factors at play, a person's intrinsic factors (e.g. demographics, anthropometrics, attitudes, expectations etc.) and ways in which all of these factors interact for a given individual.

The subjectivity of comfort and discomfort was also highlighted in the studies conducted. Individual participants were subject to controlled experimental conditions with little or no variability in the stimuli and other environmental conditions, yet some individuals' experiences were different to the experiences of others. Linked to this, the studies indicated that it is important to think about comfort in terms of both causal factors and their effects on people. Consideration of comfort and discomfort in terms of cause and effect was noted by Kolcaba and Kolcaba (1991). In this vein, it is interesting to note that different individuals might experience the same causal factors but their effects could be variable. For example, a specific amount of legroom might lead to physical discomfort, pain or numbness for one person but feelings of spaciousness for another person depending on their anthropometry. Similarly, a sound might be perceived as relaxing and therefore comfortable by one person but annoying and therefore uncomfortable by another. This highlights that the interplay between causal factors will have varied effects on different people's comfort/discomfort experiences. Vink et al. (2012), Vink et al. (2005a) and Vink and Brauer (2011) highlighted the challenge of designing for comfort, making particular reference to the subjectivity of the experience of comfort. The findings of this research correspond with this viewpoint. Whilst there are trends which can be drawn out which would indicate that an experience is likely to be perceived as comfortable or uncomfortable, it is difficult to be certain that any given individual will experience the levels of comfort desired by a designer.

The findings of this research also highlighted the complexity of comfort and discomfort as constructs in terms of both the causes and manifestations of the comfort experience. Two comfort or discomfort experiences could be quantitatively rated at the same level but may result from different underlying factors and may also manifest in different ways. For example, one comfort experience could be made up of a pleasant sound, good lighting but an uncomfortable seat. Another comfort experience, which could be rated as equally comfortable as the first experience, might comprise a comfortable seat, good lighting but an uncomfortable view. These two experiences would not only have different underlying factors but would have different effects on the people experiencing them. Kolcaba and Kolcaba (1991) considered comfort and discomfort in terms of both their causes and their effects. Given the complexity of comfort and discomfort, it is useful to consider both the causes and effects of comfort/discomfort in order to more fully understand the experiences. This could assist when designing for comfort.

10.5. **Limitations of research**

This section addresses the limitations of the research presented in this thesis and the methodological approach taken.

One of the limitations of this research was related to participant recruitment. The studies were advertised on the basis that participants would be able to experience future cabin concepts for flights. The recruitment inclusion criteria were the need for participants to speak English and to have taken a flight in the past three years. Where relevant, they were also screened and excluded from participation if they had any conditions which were indicators of susceptibility to VRISE (e.g. those noted by Ramsey (1999)). As a result of this, there may have been a bias in the types of people who participated in the studies due to self-selection issues. It is possible that the participants were more experienced with technology and enjoyed flying more than the average aircraft passenger. In addition, many of the participants were experienced with using or developing VR. This was a result of the study locations having a number of students and staff who work with VR on a regular basis.

Another limitation of the studies was that they were carried out on the ground as it would not have been possible to put the technology into real aircraft. An effort was made to simulate the aircraft environment as far as possible by using a simulated cabin mock-up (described in chapter 3). However, some of the contextual factors of flight were difficult or impossible to replicate on the ground and these may influence the transferability of the results to a real aircraft environment. Such factors included a passenger's knowledge that they are unable to leave the aircraft and have limited opportunities to move away from sources of discomfort. An attempt to simulate this was to not inform the participants of the length of time that they would be sitting in the set-ups. However, they were recruited for a specific amount of time and were therefore aware that they would not be subject to sources of discomfort for prolonged periods of time. In addition, in line with the ethical framework proposed by Benford et al. (2012), the participants were made aware of their right to withdraw from the study and therefore had control over their abilities to remove themselves from uncomfortable situations should they feel the need to do so.

As exposure to the sources of discomfort and distractors was for no longer than 15 minutes, it is not known for how long VR can distract people from discomfort. Given that passenger flights can range in length from under an hour to almost a day, it is important that this is considered in order to fully understand how the results of this research transfers to real aircraft environments.

Considering the set-ups used, the studies presented in chapters 7 and 8 used the set-up at the Max Planck Institute for Biological Cybernetics (described in chapter 3). This set-up was not ecologically valid as it simply comprised a large back-projected display, stereo sound and a chair. Therefore it is difficult to know the extent to which the results of these studies transfer into a real aircraft context. This is arguably less important for the study presented in chapter 7 as this study was more theoretical. However, the study presented in chapter 8 was designed to compare VR interventions to distractors that aircraft passengers currently use. This set-up was used as the pool of participants at Fraunhofer IAO had been used in previous studies. Therefore a decision needed to be taken as to whether to use participants who had already seen either the VEs or experienced the experimental protocol or whether to use a less ecologically valid set-up. It was decided that knowledge of the studies and the VEs was likely to be a greater confounding variable than the ecological validity of the set-up and therefore the later studies were carried out at the Max Planck Institute for Biological Cybernetics.

Some of the data collected, for example in chapters 4 and 9 asked the participants to speculate on how they thought that discomfort-inducing stimuli or VR would influence their real flight experiences. Given that these questions were speculative and not asked within a real aircraft context, it is difficult to gauge the accuracy of these responses.

In the studies presented in chapters 5-8, the participants were asked to rate their overall levels of comfort rather than being asked a question targeting the extent to which the specific stimuli which they were subjected to induced comfort or discomfort. Asking targeted questions would have avoided the issue of an overall rating absorbing all factors influencing a participant's comfort/discomfort levels. However, these questions may have led the participants' responses by drawing their attention to the discomfort-inducing stimuli. Given these studies aimed to investigate the extent to which VEs could distract people from discomfort, drawing attention to the discomfort-inducing stimuli may not have yielded useful responses (although it is acknowledged that when asking people to self-report on comfort in general, they often become aware of their discomfort). In addition, pre- and during-exposure ratings of discomfort caused by the restricted legroom/sound of a crying baby would not have been comparable as it would not have been possible to rate comfort/discomfort relating to these stimuli prior to exposure.

The results of the studies only reflect on the experience of comfort or discomfort but do not refer to a state of no discomfort (i.e. lack of awareness of either comfort or discomfort. This occurred as a result of the design of the studies and data collection which made participants aware of their comfort or discomfort. In addition, it is acknowledged that the experience of comfort and discomfort comprises an unconscious element which may have affected the results. For example, Mellert et al. (2008) reported increased neck pain and increased awareness of swollen feet under noisy flight conditions compared to quiet conditions. The research presented in this thesis did not attempt to measure the unconscious element of comfort or discomfort as it would be difficult for people to reflect on something which they are not aware of.

Finally, it is worth noting that none of the improvements to the VEs which came about as a result of the study presented in chapter 4 were implemented for the subsequent studies. Had these been integrated into the VEs, the results of the subsequent studies may have differed. Such improvements included enhancing the image quality, detail and realism of the VEs as well as the inclusion of additional artefacts within the VEs.

10.6. **Suggestions for future research**

One of the findings of this research was that there may be a point at which the attentional demands of a distractor are greater than the available capacity. In this instance, a person would (possibly unconsciously) select whether to attend to the distractor or the source of discomfort. If they attend to the discomfort, the distractor would be rendered ineffective. In order to optimise the effectiveness of distractors, further research is required to determine the point at which they demand more attention than is available. It is acknowledged that this is likely to vary between individuals and contexts.

The research presented in this thesis was conducted on the ground, under controlled conditions. Whilst this research is important to understand whether, fundamentally, VEs can distract people from discomfort, the specific contextual factors of flight which cannot be replicated on the ground mean that it is important to also test this in the field. Currently, the technology used is not developed enough to be transferred into real aircraft. However, with developments in technology, it is possible that this could be integrated into cabin architecture in the medium to long-term future (Frangakis et al., 2014). However, in the short-term, it may be possible to test cut-down versions of the technology in real aircraft environments. When testing in the field, there is no means of controlling for sources of discomfort. Therefore careful consideration is required to select the approaches for measuring the extent to which VEs can distract people from discomfort in field studies.

Prior to testing in the field, other fundamental research should be carried out. The research presented in this thesis only tested the effect of distractors on perception of discomfort-inducing stimuli for up to 15 minutes. A research priority should be to determine how long these illusions last for. Consideration should be given to the ways in which sources of discomfort affect people over prolonged periods of time. It is possible that people could habituate to discomfort-inducing stimuli but they might also become preoccupied by their discomfort. In addition, this research only considered the extent to which VEs could distract people from their experiences of a single source of discomfort. Further research should evaluate the extent to which VEs can distract people when they experience multiple sources of discomfort simultaneously. Finally, VR distraction should be compared to distractors which are currently used by passengers (e.g. music, reading, watching films) in order to fully investigate the value that VEs can add in terms of enhancing passengers' comfort.

10.7. **Concluding statement**

The research presented in this thesis has investigated the ways in which VEs could be used to enhance passengers' comfort and experiences on future aircraft by providing novel experiences. This unique approach to enhancing comfort drew on existing research in both the comfort and pain domains.

The findings suggest that VEs can both positively influence people's experiences and can distract people from sources of discomfort which are commonly experienced in air travel. It is acknowledged that the research was conducted in a controlled environment on the ground. However, the findings provide initial indications that this approach to enhancing comfort and experience may be effective within the aircraft context and provide the foundations from which further research can continue. A number of avenues for further research have been highlighted. These include experiments which would provide greater understanding of the extent to which VEs can distract people from discomfort. These also include field studies (although it is acknowledged that these would currently be difficult to carry out). The studies identified would be the next steps needed to understand the ways in which VEs could influence passengers' comfort and experiences within a real flight context.

A new approach to measuring the effects of interventions on comfort has also been developed, drawing on the approaches taken in pain research. Inducing discomfort in order to measure the extent to which interventions can distract people from their discomfort was found to be an effective means of determining the effectiveness of distractors. The findings also highlighted the importance of taking a mixed-methods approach to measuring comfort in order to quantify the effects of interventions and obtain a rich understanding of these effects.

This research has considered existing research in the areas of both comfort and pain to investigate the ways in which VEs could influence air passengers' comfort and experiences. The findings indicate this novel approach is promising, having potential to distract people from sources of discomfort. Further investigation is required in order to develop these concepts, however, the findings of this research form the basis for future work in this area.

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Appendix 1: Summary of VR-HYPERSPACE concepts

Current and future cases and scenarios (UNott, VTT, TAS-I)

This research involved running workshops to determine the factors which currently affect passenger comfort and how VR could be used to enhance comfort in future flight. From these workshops, a number of personas and scenarios (current and future) were developed. This background work informed the demonstrators which were subsequently designed and tested.

Project partners

- University of Nottingham (UNott), UK
- Fraunhofer IAO (FhG), Germany
- Valtion Teknillien Tutkimuskeskus (VTT), Finland
- Bauhaus-Universität Weimar (BUW), Germany
- Institute of Communications and Computer Systems (ICCS), Greece
- University of Barcelona (UB), Spain
- Max Planck Institute for Biological Cybernetics (MPG), Germany
- Thales Alenia Space (TAS-I), Italy
- Airbus, Germany

Changing perception of cabin environment (FhG, UNott)

This research used ambient displays to provide users with virtual environments. The research used two concepts, 'super here' and 'super there' which could enhance the flight experience or allow passengers to experience another environment unrelated to flight respectively. Research investigated the extent to which VEs could distract people from sources of discomfort which they might experience on board an aircraft.

This PhD research

Changing perception of others (BUW)

This research was concerned with using technology to encourage social interaction. This included using large multi-viewer 3D displays which would span the backrests of several seats, enabling shared experiences. Another concept was for a group-to-group telepresence system which would enable interaction with other people who are not on board the aircraft. Another telepresence application which was considered was for virtual cabin crew (in order to reduce workload).

Positive illusions of self (UB)

This research aimed to provide people with the illusion of comfort by changing the ways in which people perceived their own bodies. The research used head mounted displays (HMDs) with avatars which represented the users' own bodies. Research included using body ownership illusions to improve comfort by providing avatars which were in comfortable postures, providing the illusion of walking in an extended space or mapping small arm movements to large virtual movements

Positive illusions of space (MPG)

This research used VEs to investigate the cues which are important for space perception. The research investigated cultural differences in space perception, perception of vast spaces, the role of eye height, gravity and virtual bodies on space perception.

APPENDIX 2: EXAMPLE OF QUESTIONNAIRE

Below is an example of the questionnaires used in this research. The exact questionnaires used varied slightly between individual studies.

Participant number:

Demographics questionnaire

1. **Age:** _______________________

2. **Male/Female** (please circle)

3. **Nationality:** ____

4. **Please tick the option from the list below to indicate how many return flights you take.**

○	○	○	○	○	○	○
Never	Every few years	1 or 2 per year	Every few months	1 or 2 per month	1 or 2 per week	More than 2 per week

5. **Please tick a point on the scale below to indicate how much you like flying.**

○	○	○	○	○	○	○	○	○	○	○
I hate flying										I love flying

6. **Please tick a point on the scale below to indicate how scared you are of flying.**

○	○	○	○	○	○	○	○	○	○	○
Not at all scared										Extremely scared

7. **Please tick a point on the scale below to indicate how experienced you are with using virtual reality**

○	○	○	○	○	○	○	○	○	○	○
No experience										Extremely experienced

8. **Please write below details of where you have used virtual reality (e.g. for leisure, in your work etc.)**

____

Pre-condition questionnaire

1. **Please rate your current level of overall comfort by ticking a point on the scale below.**

○	○	○	○	○	○	○
Extremely uncomfortable			Neither uncomfortable nor comfortable			Extremely comfortable

2. **Please state your current levels of the following symptoms by ticking points on the scales below.**

	No symptom at all										**Unbearable level of symptom**
Headache	0	1	2	3	4	5	6	7	8	9	10
Eyestrain	0	1	2	3	4	5	6	7	8	9	10
Blurred vision	0	1	2	3	4	5	6	7	8	9	10
Dizziness (eyes open)	0	1	2	3	4	5	6	7	8	9	10
Dizziness (eyes closed)	0	1	2	3	4	5	6	7	8	9	10
Sickness	0	1	2	3	4	5	6	7	8	9	10
Any other noticeable symptom <u>(please state)</u>	0	1	2	3	4	5	6	7	8	9	10

Post-condition questionnaire

1. **Please rate your level of overall comfort during the experiment by ticking a point on the scale below.**

○	○	○	○	○	○	○
Extremely uncomfortable			Neither uncomfortable nor comfortable			Extremely comfortable

2. Please tick a point on the scale below to indicate how much you agree with the following statement.

   I had a strong sense of really 'being there' within the virtual environment/sound/video.

○	○	○	○	○
Strongly disagree	Disagree	Neutral	Agree	Strongly agree

3. **Please rate how much you liked the last condition by ticking a point on the scale below.**

○	○	○	○	○	○	○
Disliked it a lot			Neither liked nor disliked it			Liked it a lot

4. **Please state your current levels of the following symptoms by ticking points on the scales below.**

	No symptom at all										**Unbearable level of symptom**
Headache	0	1	2	3	4	5	6	7	8	9	10
Eyestrain	0	1	2	3	4	5	6	7	8	9	10
Blurred vision	0	1	2	3	4	5	6	7	8	9	10
Dizziness (eyes open)	0	1	2	3	4	5	6	7	8	9	10
Dizziness (eyes closed)	0	1	2	3	4	5	6	7	8	9	10
Sickness	0	1	2	3	4	5	6	7	8	9	10
Any other noticeable symptom (please state)	0	1	2	3	4	5	6	7	8	9	10

Appendix 3: Example of interview

Below is an example of the interviews used in this research. The exact interviews used varied slightly between individual studies. Although the interviews were scripted, these were used as guides and the interviews, themselves, were semi-structured.

Condition:		Participant number:

Post-condition interview – to be completed by researcher

1. Please describe the factors which affected your comfort during the last condition. Please remember that these factors could be physical, environmental, social or psychological.

2. Please describe the factors which affected your discomfort during the last condition. Please remember that these factors could be physical, environmental, social or psychological.

3. Were you aware of the board in front of your legs/sound of a baby crying?

1. Did the board in front of your legs/sound of a baby crying affect your comfort or experience? How?

2. What effect would this have on a real flight?

3. Did you use any techniques or strategies to cope with any negative effects of the board in front of your legs/sound of a baby crying?

1. Would you have used any other techniques or strategies to cope with these behaviours if they were happening on a real flight for a prolonged period of time?

2. What effect did the virtual environment have on any negative effects of the board in front of your legs/sound of a baby crying?

3. Based on your experience today, would you use a VE on an aircraft in the future to overcome sources of discomfort?

APPENDIX 4: CONSOLIDATION OF FINDINGS

	Chapter 6	Chapter 7	Chapter 8	Comparison
Age of participants	• Mean age = 30 years (SD = 8.73)	• Mean age = 31 years (SD = 11.56)	• Mean age = 30 years (SD = 11.36)	• Similar demographics across studies (with the exception of male/female split). • Unlikely to contribute to any differences in results.
Male/female split	• 30 male, 13 female	• 19 male, 21 female	• 14 male, 16 female	
Ratings of how much the participants liked flying (0 = hate flying, 10 = love flying)	• Median = 7 (IQR = 1)	• Median = 7 (IQR = 2.25)	• Median = 7.7 (IQR = 1.75)	
Ratings of how scared the participants were of flying (0 = not at all scared, 10 = extremely scared)	• Median = 2 (IQR = 2.5)	• Median = 1 (IQR= 2.25)	• Median = 1 (IQR = 2)	

	Chapter 6	Chapter 7	Chapter 8	Comparison
Ratings of VR experience (0 = no experience, 10 = extremely experienced)	• Median = 6 (IQR = 6)	• Median = 5 (IQR = 5)	• Median = 5 (IQR = 4.75)	
Comparison of pre- and during-study comfort/discomfort ratings	• No significant differences for both VECry and VELeg conditions.	• No significant differences for VE/sound condition. • During-condition ratings were significantly lower for VE and sound conditions than pre-ratings.	• No significant differences for VE condition (same data as VE/sound condition in chapter 7). • During-condition rating was significantly lower for video condition than pre-ratings.	• The use of the invisible aircraft VE maintained pre-condition comfort/discomfort levels for both discomfort-inducing stimuli. • Use of the tropical island VE and sound maintained pre-condition levels of comfort/discomfort when experiencing the sound of a crying baby. • All other conditions did not maintain subjective levels of comfort/discomfort.

	Chapter 6	Chapter 7	Chapter 8	Comparison
Comparison of comfort/discomfort ratings with/without distractors	• VELeg significantly more comfortable than NoVELeg. • No significant differences between NoVECry and VECry conditions.	• No significant differences.	• No significant differences.	• Invisible aircraft VE could reduce discomfort/enhance comfort when legroom was restricted compared to no distractor. • None of the stimuli were more effective at reducing discomfort/enhancing comfort than no distractor.

	Chapter 6	Chapter 7	Chapter 8	Comparison
Comparison of presence ratings	• No significant differences between VECry and VELeg conditions.	• No significant differences between VE, VE/sound and sound conditions.	• No significant differences between VE and video conditions.	• Similar levels of presence across all conditions (within studies). • Descriptive statistics reveal that presence was generally 'neutral' in all studies. Therefore the hardware differences in studies did not impact on presence.
Correlations between presence ratings and comfort/discomfort ratings	• No significant correlations for VECry or VELeg conditions,	• No significant correlations for VE, VE/sound or sound conditions.	• No significant correlations for VE or video conditions.	• No correlations between presence in any condition. This is unsurprising considering that ratings of presence were generally 'neutral' with small measures of dispersion in all conditions.

	Chapter 6	Chapter 7	Chapter 8	Comparison
Comparison of how much the conditions were liked	• Data not collected.	• No significant differences.	• No significant differences.	• Similar ratings of how much the conditions were liked (generally negative but with some large measures of dispersion).
Correlations between ratings of how much the conditions were liked and comfort/discomfort ratings	• Data not collected.	• No significant correlations for the no distractor or sound conditions. • Significant positive correlations for the VE and VE/sound conditions.	• No significant correlations for the no distractor condition (same data as chapter 7). • Significant positive correlations for the VE (same data as VE/sound condition in chapter 7) and video conditions.	• Indicates that the more liked a distractor is, the more comfortable they feel. • Looking at the descriptive statistics the data relating to how much the no distractor condition was liked is less dispersed than the other conditions which may explain why this result was not significant.

	Chapter 6	Chapter 7	Chapter 8	Comparison
SSC scores	• Mean ratings of all components of SSC were below 1.1 out of 10	• Mean ratings of all components of SSC were below 1 out of 10	• Mean ratings of all components of SSC were below 1 out of 10	• Sickness scores were low on average for all conditions in all studies. Therefore sickness is unlikely to contribute to any differences in results.

APPENDIX 5: CONSIDERATIONS FOR THE USE OF VR TO ENHANCE PASSENGERS' COMFORT AND EXPERIENCE

Below are 14 considerations for the design of VEs in order to enhance aircraft passengers' comfort and experiences which were derived from the results of the studies presented in chapters 4 and 6-8. It is suggested that these are used by technical developers when designing VEs for testing these concepts.

	Consideration	Chapter	Research finding	Impact
1.	A choice of VEs should be provided to support passengers' desired activities or emotional states.	4	The circumstances under which participants would use the VEs tested will vary with different activities, moods etc.	Experience
2.	Users should have the flexibility to be able to turn off displays. This is particularly pertinent when a display or the information shown has a negative impact on the user.	4	The floor display induced vertigo for some participants using the invisible aircraft VE. A number of participants would have liked to have been able to turn off this display.	Experience Comfort

	Consideration	Chapter	Research finding	Impact
3.	VEs should be immersive in order to have greater impact on users' experiences. The exception to this is where displays or information have negative impacts on users.	4	All displays were found to be of similar importance in their contribution to the participants' overall experiences. The exception to this was when the floor display only showed an image of sand in the tropical island VE.	Experience
4.	Where motion tracking is integrated into VEs, this should be across all displays to ensure a seamless experience.	4	Partial tracking was found to have a negative experience on participants due to mismatches between the displays. This led to confusion, discomfort and disorientation.	Experience
5.	If ambient displays are used in future aircraft cabins, they should have multi-viewer capabilities. This would enable multiple passengers to view different VEs on the same displays simultaneously.	4	Participants wanted to use different VEs under different circumstances. These circumstances are likely to vary between individuals and therefore multiple passengers may want to use the same displays to view different VEs simultaneously.	Experience

	Consideration	Chapter	Research finding	Impact
6.	Motion tracking should be made available for VEs which are interesting, engaging and promote relaxation. If VEs are relatively static, unchanging and therefore less conducive to interaction, motion tracking is less necessary.	4	Some participants felt that the motion tracking was unnecessary in the tropical island VE as there was nothing extra to explore but enhanced the experience of the invisible aircraft VE as it was interesting and engaging. Motion tracking was found to enhance the realism of both VEs.	Experience
7.	Motion tracking can detract from the experience of VEs which aim to create a state of relaxation and therefore should be used with caution, if at all.	4	Some participants found the tropical island VE less relaxing with the addition of motion tracking.	Experience
8.	VEs should be designed with depth cues in mind in order to enhance the feeling of spaciousness.	4	The two VEs led some participants to perceive that there were greater amounts of physical space surrounding them. It is possible that this was due to the depth cues in the VEs.	Experience Comfort
9.	In order to provide more enjoyable experiences, good levels of detail and realism should be provided.	4	Participants did not like the lack of realism in both of the VEs. Where the invisible aircraft VE was less detailed, it became less engaging.	Experience

	Consideration	Chapter	Research finding	Impact
10.	VEs which are interesting and engaging should be provided in order to be more effective distractors from sources of discomfort.	6	Participants reported that they were less aware of the discomfort-inducing stimuli when the VE was interesting and became more aware when the VE was boring.	Comfort
11.	VEs should be provided which promote relaxation. As well as helping passengers to sleep or relax during their flights, these VEs will help some passengers to overcome stressful situations.	7/8	The participants felt that the relaxing natures of the tropical island VE, sound of the waves and birds and the video (provided in chapter 8) were important for reducing the discomfort associated with the sound of a crying baby.	Comfort
12.	Auditory elements should be included in the design of VEs in order to aid distraction from auditory sources of discomfort.	7	The VE/sound condition was more effective at distracting people from discomfort than when they were presented with only the VE or its associated sound. The auditory element was found to be particularly important in this condition.	Comfort

	Consideration	Chapter	Research finding	Impact
13.	VEs should include other sensory stimuli (e.g. audio). A multisensory distractor may be more effective at distracting people from discomfort which is perceived through different sensory modalities.	6/7	In chapter 6, the invisible aircraft VE was more effective at distracting people from the discomfort associated with restricted legroom than the sound of a crying baby. It is possible that this was partially due to the VE diverting participants' attention away from (visually) noticing that their legroom was restricted. In chapter 7, the sound of the waves and birds was found to be particularly important for distracting people from an auditory source of discomfort.	Comfort
14.	Consideration should be given to the amount and type of attention that distractors demand. If a distractor demands more attention (of a specific modality) than can be allocated, it may become ineffective.	8	Some participants were unable to focus on the narration in the video provided. It is possible that this is because it demanded the same attentional resource as the source of discomfort (sound of a crying baby) and therefore, they unconsciously chose to attend to the discomfort rather than the distractor.	Comfort