

# Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems

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## Abstract

Virtual reality (VR) systems are used in a variety of applications within industry, education, public and domestic settings. Research assessing reported symptoms and side effects of using VR systems indicates that these factors combine to influence user experiences of virtual reality induced symptoms and effects (VRISE). Three experiments were conducted to assess prevalence and severity of sickness symptoms experienced in each of four VR display conditions; head mounted display (HMD), desktop, projection screen and reality theatre, with controlled examination of two additional aspects of viewing (active vs. passive viewing and light vs. dark conditions). Results indicate 60–70% participants experience an increase in symptoms pre–post exposure for HMD, projection screen and reality theatre viewing and found higher reported symptoms in HMD compared with desktop viewing (nausea symptoms) and in HMD compared with reality theatre viewing (nausea, oculomotor and disorientation symptoms). No effect of lighting condition was found. Higher levels of symptoms were reported in passive viewing compared to active control over movement in the VE. However, the most notable finding was that of high inter- and intra-participant variability. As this supports other findings of individual susceptibility to VRISE, recommendations are offered concerning design and use of VR systems in order to minimise VRISE.

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## 1. Introduction

In the early 1990s there was a rapid increase in the development of commercial virtual reality (VR) systems and expectation of widespread application of the technology in industrial, public and domestic environments. At that time the interest was mostly in systems using head mounted displays (HMDs) and datagloves for personal viewing and interaction with a virtual environment (VE). So-called non-immersive systems, which display the VE on a standard PC monitor, were often not regarded as ‘true’ VR. Interest in VR applications led to speculation of potential side-effects

from using these systems, ranging from anecdotal reports of flash-backs producing driving difficulties post-exposure to scientific reports of ‘simulator sickness’ following participation in VR [18,30,39].

However, in recent years the focus of display technologies has moved from HMD based systems to projection displays. Projection displays have the advantage of the potential for collaborative viewing and interaction and are an attractive financial option as the technologies can often have multiple uses rather than requiring expensive purchase of dedicated VR displays. This paper presents a series of studies examining projection based VR display systems.

### 1.1. Health and safety implications of virtual reality

Early work into VR health and safety established a number of findings relating to the health and safety implications

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of virtual reality [26,6]. Firstly, a framework of factors influencing the production of VR induced symptoms and effects was developed, with four main factor groups identified as; VR technical system, Virtual Environment (the content of the virtual “world”) design, circumstances of use and individual participant characteristics [26]. Secondly, although the symptoms and effects identified were similar to those found with other simulators and in transportation, the causes and symptom patterns were considered to be sufficiently different to justify a new term: virtual reality induced symptoms and effects (VRISE) [6]. The term “cybersickness” has also been used to describe the sickness element of this symptom set. Thirdly, a wide variety of individual differences in susceptibility to, and experience of, effects was observed. From data obtained from over 200 participants, 80% of participants across all experiments reported some experience of VR induced symptoms. For most people these were mild and short-lived but 5% of participants experienced symptoms so severe that they had to end their period of VR exposure [6].

### 1.2. Projection based displays

One of the advantages of desktop viewing is that it allows several users to view a VE at the same time. Whilst two or three viewers may sit comfortably at a PC workstation, the potential for additional VE viewers may be facilitated by projecting the VE onto a larger screen using a standard PC-compatible projector. Such displays are commonly used for slide presentations and can be used to display a VE for viewing by a group or with which the participants can interact in real-time using the PC input devices, although some degradation in display quality is experienced. In addition, a number of higher resolution methods of displaying a VE in stereo or monoscopic modes are available. These technologies include CAVES, passive and active stereo systems with magnetic or infra red tracking and horizontally curved screen displays (sometimes termed “reality theatre”). A curved display set-up typically consists of a room containing a 7.5 m diameter screen over 150° of arc across the room, and from floor-to-ceiling. Three colour projectors are used to display computer generated images on this screen, and an advanced audio sound system enhances the impression of immersion in the VE. Although these display systems require expensive computing resources they can be used to display VEs created on standard PC-based systems and therefore may be used for final presentation of designs, layouts or training to a group of users. These displays are not stereoscopic but do attempt to promote a sense of immersion (physical enclosure in the display, thought to be associated with a sense of presence) via the size of the display.

It is feasible to envisage that VE applications in the workplace may use standard PC displays for single users (e.g. in the development of product design, architecture, or training applications) and projection screen displays for meetings and presentations. This has been seen by the

authors in a number of industrial contexts (including aerospace and automotive) over recent years as a useful tool for communicating rationale behind design decisions that have been made using virtual prototype models or for supporting the design decision making process.

Each of these different types of viewing conditions produce varying combinations of sensory input to the participant. In all of the conditions there is a basic difference between the information received by the visual system and the vestibular or non-vestibular proprioceptive system during movement around a VE, where the visual information indicates that the participant is moving, but the vestibular and proprioceptive informs the participant that they are stationary. Sensory conflict theory [29] uses this difference as the basis for the causative theory of motion sickness. This theory also states that where *unexpected* conflict occurs between sensory inputs, the participant is more likely to experience sickness. There are differences in the extent to which this conflict occurs, and the degree to which this conflict is expected, in different VE viewing conditions. For example, in the desktop viewing condition, the participant usually has control over their movement within the VE, whereas in a curved large screen display, the most likely scenario is that the movement around the VE is governed by an independent controller. The participants in the desktop viewing condition will have a higher degree of expectation about the direction in which they are likely to travel, and the interactions with the VE that might be performed. Therefore it is necessary to consider not only how participants’ experiences of sickness differ in the different viewing conditions, but what the underlying differences between these conditions are, and therefore what might cause the differences in VRISE experienced. In addition, the lighting conditions in the viewing room may vary from light to dark, and this may affect the symptoms experienced by the participants. In this paper, both a general examination of the prevalence and severity of sickness in four display conditions, and a controlled examination of the role of two aspects of VE display conditions (active vs. passive viewing, light vs. dark viewing) are presented.

### 1.3. Effects of display types on VRISE

One of the main aims of this research project was to complete a controlled assessment of the influence of different VE display types on VRISE. This section of the literature review summarises previous work that has examined the effects of different display media.

#### 1.3.1. Head mounted displays

The range of commercially available HMDs and the variety of conditions under which they are used (e.g. different virtual environments, users completing different tasks under different constraints and over differing time periods) make comparisons in symptom profiles between headsets difficult. The following section summarises the prevalence

and severity of symptoms observed by the dominant researchers in the field. Mon-Williams et al. [22] state

“a number of factors have the potential to cause such stress to the visual system. These factors include poor illumination, poor contrast, and an unusually close working distance. All of these factors diminish as the quality of design improves and the technology of the components increases” [22, p. 207].

The dangers of such visual stresses following immersion in the workplace are summarised by

“The possibility of causing long- term problems through repeated immersions appears remote, although no studies have directly addressed this issue yet...of greater concern is the potential for a VR user to drive, or operate machinery, with unstable binocular vision and a decrease in visual acuity following immersion in a virtual world” [22, p. 210].

In a group of 20 adult volunteers with normal vision, a ten minute immersion in a virtual environment wearing a stereoscopic Head Mounted Display (EyePhone LX) resulted in 60% of participants reporting symptoms of eye-strain, headache and nausea, and 20% reporting a reduction in binocular visual acuity. In addition, 95% of participants demonstrated significant shifts in heterophoria towards asophoria and the number of subjects with associated heterophoria increased from 5% pre to 55% of participants post immersion [23].

Regan and Price [30] reported that 61% of participants immersed in a VE for a 20 min period reported symptoms, of which the greatest were reported at the end of the immersive period, with 45% of participants reporting some symptoms (whilst wearing a DVisor HMD). Similarly, Lampton et al. [20] investigated symptom severity during and following immersion in a range of HMDs. They reported that 4–16% of participants dropped out of the immersion due to adverse symptoms before their allotted time was over. However, they stated that most participants enjoyed the experience but reported some discomfort.

### 1.3.2. Standard desktop displays

The prevalence and severity of side-effects associated with standard PC use were investigated in a review of the current literature by Dillon and Emurian [8]. They found that self report of visual fatigue may be evoked by: viewing distance, time on task, glare and lighting. They concluded a viewing distance of 65 cm was optimum [34], task time on extended periods of work (3–4 h) can cause temporary discomfort and should be avoided or include rest breaks. Workstations should be glare free and contain stable character presentation and proper lighting should be available [37].

### 1.3.3. Comparisons between different viewing displays

Few papers have directly compared the presentation of similar stimuli on different display mediums. Burns [3] reviewed the differences between viewing electronic

print (displayed on a VDU) vs. print (displayed on paper). He identified certain characteristics of CRT displays that may decrease the eyes comfort and efficiency as: screen flicker (disrupts fine eye movements affecting perception); spatial regularity of the display (minor effects on contrast sensitivity and post-task colour vision); screen declination (might necessitate separate spectacles for comfortable use of VDU). He concluded VDU and paperwork viewing of print possess different visual ergonomic attributes based on the characteristics identified above.

Deisinger et al. [7] investigated the differences between viewing a personal computer monitor screen vs. an HMD and screen based projection compared in an interactive environment. They found screen based projection gave inexperienced users the best feeling of immersion, and it was preferred to that of the HMD. The monitor display had much more acceptance with participants as they were familiar with using it in a normal working environment. Within the HMD, subjects had difficulty reading numbers on far away objects and hence task completion time was greater for this condition.

Garris-Reif and Franz [11] conducted a comparison in simulator sickness scores following viewing a HMD and personal computer screen system. Twenty-four participants, completed the Simulator Sickness Questionnaire (SSQ, developed by Kennedy et al. [17]) after completing a target location task viewed on a conventional table-top computer screen or a head slaved HMD. They found that average sickness scores were higher in the HMD group than the personal computer screen group ( $p < 0.026$ ). Howarth [14] investigated symptom changes over 20 min immersions in 41 participants across five experimental conditions, two of which involved using a VDU (playing solitaire or DOOM), and the remaining three involved different head mounted displays (I-glasses, Virtuality, Visette and Division, PV100). He found that

“HMDs used to view environments, cannot be considered as a homogeneous group...symptom patterns are idiosyncratic to each HMD, or system” [14].

Howarth points out that many studies to date have examined the consequences of immersion in a single virtual environment and HMD and side effects reported cannot readily be attributed to any specific aspect of the environment, HMD, or hardware and software and such findings can therefore relate only to the consequences of immersion applicable to their specific equipment and not HMDs generally. His main results were found on visual, sickness and dizziness symptom subscales of the SSQ. Visually, blurred vision was significantly greater with the I-glasses than in any of the other displays, and general visual discomfort was significantly greater with both the I-glasses and Division conditions. Sickness increased with the I-glasses and Division HMDs compared to no changes in virtuality or either VDU conditions; for dizziness increases were ob-

served for the Division HMD compared to VDU conditions, but not between the other HMD conditions.

Peli [27] measured the visual effects of completing a thirty minute task wearing I-glasses (in mono and stereo mode) and using a conventional desk-top computer display. No functional visual differences were found between the HMD and desk-top computer, however subjective data concerning comfort of the display types revealed using the HMD in stereo mode was significantly less comfortable than viewing the desk-top computer screen.

#### 1.3.4. Projection screen and curved large screen displays

Despite an extensive literature search on projection screen technology and curved large screen displays (“reality theatres”), almost all published articles describe development of the technology itself rather than evaluating the effect of viewing displays on this technology on the participant. However, anecdotal reports indicate that some people, perhaps 0.5–1%, have found viewing VEs on a large display uncomfortable, in some cases distressing. Objective data is however difficult to obtain since the severity of the VR experience, whether it be simple viewing or purposefully dramatic, such as during simulated exposure to falling from a great height, appear to influence the effects (Rhodes, personal communication).

#### 1.4. Impact of user control on VRSE

Interaction within virtual environments is achieved by using various input devices from keyboards, joysticks and three dimensional mice to data gloves. Using such inputs the user can determine the speed and direction of movement and the manipulation of objects. Such manipulations are responsible for the action occurring within the environment and so the user who generates such actions has ‘control’.

The other aspect of user control refers to ‘*perceived control*’ [31] based on the subjective cognitive appraisal of a situation, where the presence of perceived control can reduce the aversiveness of a situation [1,38]. Unfortunately the amount of control a user has within a virtual environment varies between different virtual systems/environments. Some systems/environments allow user control over the speed and direction of travel and the ability to pick up and manipulate objects within the environment. However, other systems/environments might restrict user movements by slaving movement to a set path that cannot be deviated from. Such differences in user control may affect the quality of the users immersive experience, which might, in turn influence the incidence and severity of VRSE experienced.

Rolnick and Lubow [31] investigated the role of controllability in motion sickness by exposing 22 pairs of yolked subjects to nauseogenic rotation. Only one of each pair had any control over the rotation and head movements and the other was passively exposed to the same stimulus. They found that the subject in control reported fewer motion sickness symptoms than their passive yolked part-

ner. Several subjects (15.9%) dropped out of the experiment due to severe malaise, of these five (71.4%) were from the passive group and two (28.6%) were from the control group. Similarly, when asked if they would like to participate in any future experiments eighteen (81.8%) of passive subjects declined compared to only nine (40.9%) of control subjects.

Hash and Stanney [12] highlighted research into the impact of a number of technical factors that may contribute to VRSE. However they state that the actual impact of these factors is not clear as issues of user control within the different experimental scenarios were not the same. The importance of user control is summarised:

“control may provide users with a means of adapting or to accommodate cue conflicts by building conditioned expectations through repeated interactions with a virtual world (e.g., when a users head turns the user learns to expect the world to follow milliseconds behind). Lack of control would not allow such expectations to be established since users would not be aware of which way they were turning at any particular moment (i.e., the course would be determined by the system)” [12].

Stanney and Hash [35] tested influence of user-initiated control on the level of cybersickness experienced by 24 college students participants immersed in a virtual environment. They found that the level of control a participant had over their immersive experience was highly significant for all factors on the SSQ with passive conditions leading to more severe symptom reports than active which led to more severe symptom reports than passive-active. Overall, the levels of symptoms reported and the percentages of subjects affected adversely were greater in this experiment than had been reported previously. Participants (95%) reported some adverse effects due to immersion compared to 60% of aircraft pilots in comparable studies [19]. In their conclusions Stanney and Hash [35] state that: firstly, passive observers can be expected to experience a high rate of incidence and severity of symptoms. Secondly, active participants may experience less symptoms but may have problems updating their neural stores due to the amount of sensory information they will be exposed to due to their unrestricted movement and thirdly, coupled control is an effective method of minimising symptoms by allowing participants to have task-oriented control within a VE.

#### 1.5. Experimental aims

The aim of the experiments presented in this paper was to compare the effects of four different VR viewing conditions on VR induced sickness symptoms. The four conditions compared were; head mounted display, desktop, standard projection screen and reality theatre (horizontally curved large screen display). In addition, two specific variables of interest, lighting conditions and user control, were examined.



## 2. Experimental approach

### 2.1. Experimental VE

The VE used throughout the experimental programme was a Virtual Factory. This environment was originally developed as a VE to teach adults with learning disabilities about potential health and safety hazards that might be encountered in the workplace [5]. It was chosen as the experimental environment as it was quite complex, and thus included enough potential interactivity and tasks to keep experimental participants occupied for the chosen length of VE exposure of 30 min. It was also quite visually detailed, including a number of textured images. For active viewing conditions, during their period of VE use, participants were verbally instructed to move around the VE according to the experimenter's directions. They were instructed to follow a set path at a normal walking pace around the VE, and complete a number of tasks within the VE in a set order. These tasks required participants to search for specific items within the environment (Health and Safety check forms). In addition, the participants were asked to do other tasks throughout the environment to encourage them to explore different methods of interaction, such as putting on safety clothes, locating specific objects (e.g. first aid box), exploring rooms, washing hands and opening cupboards. All of the interaction with objects in the environment was achieved by clicking with a standard PC mouse. However, there was still some variability between the visual images viewed by different participants, due to differences in the speed and exact direction of movement of different participants around the VE. For passive viewing conditions, the movement and interactivity was controlled by an experimenter, but followed the same path and order as the instructions issued to participants in the active viewing conditions. This will inevitably have led to some differences between the passive and active conditions, with greater variability in participant movement for the active condition, but it was felt that this approach was more realistic in terms of the actual likely situation of industrial use than a conventional "playback" approach. Fig. 1 shows a view of the Virtual Factory.

### 2.2. Participants

All participants were paid volunteers who were screened in a telephone call to ensure that they were of suitable health and fitness. All the experiments conducted within this experimental programme were approved by the ethical review committee in the Division of Manufacturing Engineering and Operations Management at the University of Nottingham. Care was taken to ensure that any participants showing symptoms that might interfere with their subsequent behaviour were given ample opportunity to return to their normal state of health, and participants were informed that they should not drive, cycle or roller-blade within 30 min of completing the experiment. Participants were required to sign a disclaimer form stating that any

symptoms they had experienced during the experiment had subsided before they left the experimental laboratory. All participants were asked to complete a number of individual characteristics questionnaires, including participant experience of computers – results from these are reported elsewhere [25].

### 2.3. Apparatus

Four display types were used to view VEs in the experimental programme (see Table 1).

For all four viewing conditions the frame rate ranged from 15–25 Frames per second (FPS), depending on the content of the VE at any one moment. Table 1 shows the technical specifications of the VR systems used in the experimental programme.

### 2.4. Design

All the experiments were of a between subjects design. Although this type of experimental design means that it is more likely that differences in individual participant susceptibility may mask differences between experimental conditions, the phenomenon of VE habituation, where participants have been found to experience lower levels of symptoms on second and subsequent exposures to VR means that if a within subjects design was used a large period of time (up to 1 month) would have to pass between experimental conditions. This was impractical for this programme of research, and is likely to lead to a higher level of participant drop-out. In order to minimise the interference of individual participant susceptibility with the impact of different experimental conditions, the largest sample sizes that time would allow were used.

### 2.5. Procedure

A consistent experimental procedure was used for all of the experimental trials. This procedure consisted of four major stages:



Fig. 1. View of hazard (dangerous loading of trolley) within virtual factory.

Table 1  
Technical specifications of VR systems used

Display	Technical specification
HMD	Virtual research V8, HMD resolution 1920 * 480 per eye, display resolution 640 * 480, Field of View (FOV): 60° diagonal; Weight: 0.82 kg
Desktop	Viewed on 17 in. monitor. Resolution 800 * 600
Reality theatre	Viewed on a concave screen 7.5 m horizontally by 2.5 m vertically, FOV 150° * 43°. The resolution was 1024 * 3556
Projection screen	A plus UP-1100 data projector with a light output of 1000 ansilumens was used. Viewed on a 1220 mm × 1200 mm screen, 1725 mm diagonal, 750 mm off the floor. Resolution 800 * 600

- *Pre-experiment questionnaire*: Collection of data about participants' individual characteristics (e.g. gender, age, attitudes, motion sickness history).
- *Pre-exposure assessment*: Collection of data referring to participants' pre-exposure state of well-being (e.g. stress arousal, menstrual phase, pre-exposure symptom level).
- *During exposure monitoring*: Monitoring of participant's symptom levels during exposure. This was completed only for participants in individual viewing conditions (this was not possible in passive viewing experiments, as up to ten participants viewed the VE at the same time).
- *Post-exposure assessment*: Collection of data describing participants' post-exposure state of well-being.

All periods of VR use lasted for 30 min.

## 2.6. Materials

The results reported here were obtained from administration of the Simulator Sickness Questionnaire (SSQ) [17] before and after each period of VR exposure. This questionnaire yields interval data making parametric analysis of differences between conditions possible. The data obtained from symptom reports can be classified using the nausea, oculomotor or disorientation subscales as well as a total symptom score. In addition to the SSQ other measures of individual characteristics and effects such as stress/arousal and presence were also applied. The results from these measures are reported elsewhere [25].

## 3. Experiment 1: comparison of VRISE in four viewing conditions

### 3.1. Experimental conditions

Experiment 1 was a comparison of VRISE in the four display conditions of interest, with lighting conditions configured as they would normally be expected to be used in the workplace. Table 2 describes the experimental conditions used.

### 3.2. Participants

Seventy-one participants completed the experiment, 38 male and 33 female. The sample consisted mainly of students from the University of Nottingham. The

volunteers were paid for their participation in the experiment.

### 3.3. Symptom reports

SSQ scores reported before and after exposure to the VE, together with calculated change in symptom scores are shown in Table 3.

Ideally to analyse these results a 2 \* 4 ANOVA would be completed, where the first factor is exposure (whether the participant is completing the questionnaire before or after VR use) and the second factor is viewing condition (HMD, Desktop, Projection screen or Reality Theatre). However, as Table 3 shows, there is a huge variety in the amount of variance in the different participant groups, meaning that the homogeneity of variance assumption for ANOVA is not met. Therefore two one-way ANOVAs were performed - the first using the post-exposure SSQ score as a dependent variable (DV), and the second using the pre-post change score as a DV. This approach reduces the number of cells in the ANOVA and, combined with the omission of the pre-exposure SSQ scores, minimises the heterogeneity of variance.

Examination of skew and variances indicated that transformations needed to be performed due to significant positive skew and some heterogeneity of variance. The transformation applied was square root ( $k - x$ ).

One way ANOVAs for each SSQ subscale and the total SSQ score were performed on both the change in symptoms from pre to post exposure and the post exposure symptom scores. Post-hoc t-tests were applied on all subscales and total symptom scores, in all cases, regardless of whether the ANOVA had revealed a main effect. Whilst it is acknowledged that this may result in a Type I error, it is felt that it is important to detect the possible source of differences in VRISE from different viewing conditions, and the *t*-test is more likely to detect differ-

Table 2  
Experiment 1: experimental conditions

Viewing condition	Mode of interaction	Lighting	Participants
HMD	Active	Excluded	10 male, 9 female
Desktop	Active	Light	9 male, 10 female
Reality theatre	Passive	Dark	8 male, 9 female
Projection screen	Passive	Dark	11 male, 5 female

Table 3  
Experiment 1: results from SSQ

Time of administration of SSQ	SSQ subscale	SSQ mean score (SD)			
		HMD	Desktop	Projection	Reality theatre
Pre-exposure	Nausea	9.04 (10.77)	11.05 (11.14)	11.58 (14.09)	9.54 (12.62)
	Oculomotor	12.37 (12.94)	9.18 (9.65)	11.91 (12.86)	16.50 (12.64)
	Disorientation	3.66 (6.30)	2.20 (5.21)	3.98 (8.51)	7.37 (9.99)
	Total	14.17 (11.60)	9.84 (8.66)	12.29 (13.24)	15.62 (11.32)
Post-exposure	Nausea	28.62** (24.63)	14.06 (17.23)	17.89 (18.39)	10.10 (11.91)
	Oculomotor	27.53** (22.35)	15.96* (14.49)	24.16* (17.77)	19.17 (18.00)
	Disorientation	32.97** (31.54)	12.45* (19.07)	14.79* (16.45)	17.02* (20.61)
	Total	29.92** (21.59)	15.35* (13.25)	26.18* (21.59)	22.88* (16.88)

\*\* indicates *t*-tests comparing pre–post symptom levels significant at  $p < 0.01$  level, \* indicates significance at 0.05 level.

ences than other post-hoc tests such as Tukey or Scheffe tests, due to its increased robustness and power. However, it may be necessary to perform further experiments with larger participant samples to ensure the reliability of these results.

The results of the ANOVA indicated a significant main effect of display media for post exposure nausea symptoms ( $F = 3.927$ ;  $df = 3, 67$ ;  $p < 0.02$ ) and pre–post change in nausea symptoms ( $F = 4.658$ ;  $df = 3, 65$ ;  $p < 0.005$ ). In addition, the results for post exposure disorientation symptoms ( $F = 2.720$ ;  $df = 3, 67$ ;  $p = 0.051$ ), post exposure total symptom score ( $F = 2.579$ ;  $df = 3, 67$ ;  $p = 0.061$ ) and pre–post change in disorientation symptoms ( $F = 2.561$ ;  $df = 3, 65$ ;  $p = 0.062$ ) approached significance.

Post-hoc tests revealed the source of the main effect on post-exposure nausea to be due to the significantly higher SSQ score for HMD compared with Desktop display ( $t = 2.631$ ;  $df = 36$ ;  $p < 0.02$ ) and HMD compared with Reality Theatre ( $t = 3.357$ ;  $df = 34$ ;  $p < 0.005$ ).

When pre–post change in nausea symptoms was examined, the HMD SSQ score was found to be significantly higher than all the other three display media (HMD vs. desktop:  $t = 2.626$ ;  $df = 36$ ;  $p < 0.02$ ; HMD vs. reality:  $t = 3.166$ ;  $df = 30.304$ ;  $p < 0.005$ ; HMD vs. projection:  $t = 2.385$ ;  $df = 28.541$ ;  $p < 0.05$ ).

No significant differences were found in either post exposure oculomotor scores or pre–post change in oculomotor scores between any of the display media.

Post-exposure disorientation was found to be significantly higher for participants in the HMD condition compared with those in the desktop condition ( $t = 2.634$ ;  $df = 36$ ;  $p < 0.02$ ). In addition pre–post change in disorientation symptoms was found to be significantly higher for participants in the HMD condition compared with those viewing the VE in the Reality Theatre ( $t = 2.098$ ;  $df = 34$ ;  $p = 0.043$ ).

Finally, the post-exposure total symptom score was found to be significantly higher in the HMD condition compared with the desktop condition ( $t = 2.708$ ;  $df = 36$ ;  $p = 0.010$ ).

## 4. Experiment 2: comparison of VRISE in light and dark viewing conditions

### 4.1. Experimental conditions

Two experimental conditions were run to compare the symptoms experienced in light and dark viewing conditions. For dark conditions the windows in the experimental room were blacked out completely with fixed plywood screens that covered the windows preventing any natural light from entering the room. For light conditions – the windows in the experimental rooms were uncovered and natural light could enter the room. In addition, artificial light, which came from fluorescent lights present in the room also, illuminated the scene. The screen orientation was set up at 90 degrees from the window to avoid glare. These conditions used a desktop display, and the VE was the Virtual Factory (Table 4).

### 4.2. Participants

Thirty-seven participants completed the experiment, 18 male and 19 female. The participants were mainly students from the University of Nottingham, and were paid for their participation in the experiment.

### 4.3. Symptom reports

Table 5 shows the SSQ results. *t*-Tests were performed to examine the difference between the symptoms experienced by participants in the light and dark conditions. Although there was an observed difference between disorientation in light and dark conditions, no significant differences were found.

Table 4  
Experiment 2: experimental conditions

Viewing condition	Mode of Interaction	Lighting	Participants
Desktop	Active	Light	9 male, 10 female
Desktop	Active	Dark	9 male, 9 female

Table 5  
Experiment 2: results from SSQ

Time of administration of SSQ	SSQ subscale	SSQ mean score (SD)	
		Light	Dark
Pre exposure	Nausea	11.05 (11.14)	4.77 (6.97)
	Oculomotor	9.18 (9.65)	7.58 (6.19)
	Disorientation	2.20 (5.21)	1.74 (4.75)
	Total	9.84 (8.66)	8.42 (5.20)
Post-exposure	Nausea	14.06 (17.23)	8.48 (10.80)
	Oculomotor	15.96** (14.49)	14.74 (17.14)
	Disorientation	12.45* (19.07)	6.19 (14.50)
	Total	15.35* (13.25)	13.92 (12.92)

\*\* indicates *t*-tests comparing pre–post symptom levels significant at  $p < 0.01$  level, \* indicates significance at 0.05 level.

## 5. Experiment 3: comparison of VRIFE with active and passive control

### 5.1. Experimental conditions

Two experimental conditions were run to compare the symptoms experienced in active and passive control conditions. These conditions used a projection screen display in dark conditions, and the VE was the Virtual Factory. Table 6 describes the experimental conditions used.

### 5.2. Participants

Thirty-one participants completed the experiment, 18 male and 13 female. The participants were mainly students from the University of Nottingham, and were paid for their participation in the experiment.

### 5.3. Symptom reports

Table 7 shows the SSQ reports pre and post VR exposure in the two experimental conditions.

*t*-Tests were performed to examine whether there were any differences between symptoms experienced pre and post exposure. Firstly, it was noted that there was actually a significant difference between nausea symptom levels *pre* exposure ( $t = 2.434$ ;  $df = 15.146$ ;  $p < 0.03$ ). This indicates that participants in the passive control condition experienced a higher level of symptoms *before* the experiment than those in the active control condition. This is unfortunate, and must be taken into account when interpreting any differences in symptoms post exposure.

Table 6  
Experiment 3: experimental conditions

Viewing condition	Mode of interaction	Lighting	Time	VE	Participants
Projection screen	Passive	Dark	30 min	Virtual factory	11 male, 5 female
Projection screen	Active	Dark	30 min	Virtual factory	7 male, 8 female

Table 7  
Experiment 3: results from SSQ

Time of administration of SSQ	SSQ subscale	SSQ mean score (SD)	
		Active	Passive
Pre exposure	Nausea	2.04 (4.06)	11.58 (14.09)
	Oculomotor	6.50 (6.55)	11.91 (12.86)
	Disorientation	3.98 (8.51)	3.98 (8.51)
	Total	5.88 (6.99)	12.29 (13.24)
Post-exposure	Nausea	7.63 (13.59)	17.89 (18.29)
	Oculomotor	12.13 (11.74)	24.16* (17.77)
	Disorientation	10.21 (18.58)	14.79* (16.45)
	Total	12.72** (13.47)	26.18* (21.59)

\*\* indicates *t*-tests comparing pre–post symptom levels significant at  $p < 0.01$  level, \* indicates significance at 0.05 level.

No significant differences were found between the change in symptoms from pre to post exposure for either of the two different control conditions. However, participants in the passive control condition were found to have significantly higher oculomotor and total symptoms post exposure than those in the active control condition (oculomotor:  $t = 2.208$ ;  $df = 29$ ;  $p < 0.05$ ; total:  $t = 2.066$ ;  $df = 29$ ;  $p < 0.05$ ).

## 6. Overview of symptom profiles

Fig. 2 shows the post-exposure symptom profiles for all the experimental conditions run throughout the experimental programme. It can be seen that there is a general predominance of oculomotor symptoms, particularly in the projection screen conditions, and the majority of the Reality Theatre conditions. This is interesting, as it is a symptom profile more familiar in simulator sickness than VR-induced sickness [16]. This may be due to a number of differences between the HMD and projection-based displays, including the field of view, level of vection experienced and optics display type. In addition, the participant may experience discomfort from wearing the HMD (some physical ergonomics issues associated with VR HMD design have previously been noted by Nichols [24], such as weight, weight distribution, fit and adjustability of HMD), which may exacerbate any symptoms they are experiencing.

Table 8 shows the levels of symptoms experienced in each experimental condition. Table 8 shows that in all but condition B (desktop, light) the highest proportion of participants experienced a “large increase” in symptoms (i.e. an increase of two or more symptoms). In particular, in the two desktop conditions (B & E) the proportion of participants experiencing symptoms was less than 40%. In addition, more than 65% of participants in conditions A (HMD – 68.4%) and D (Projection, passive – 71.4%) experienced a large increase in symptoms. Due to the relatively small numbers of participants in each of these experimental groups, it is not appropriate to assume that these figures are indicative of the expected prevalence of symptoms in a user population, however, they can be taken as indicators



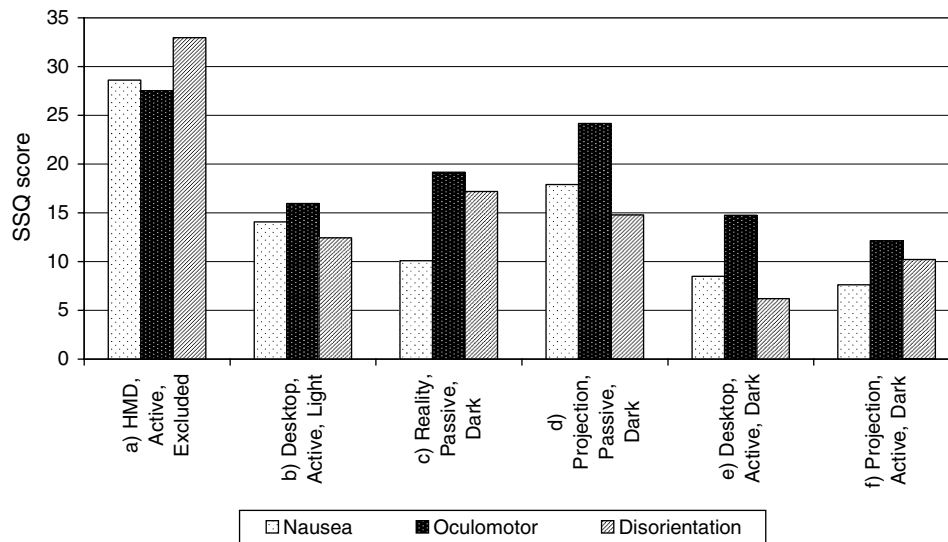


Fig. 2. SSQ Symptom profiles for all experimental conditions.

of the VR conditions that may provoke higher levels of symptoms.

## 7. Discussion

### 7.1. Discussion of findings

This study provides the first direct comparison of viewing the same virtual environment under alternative display configurations. A series of experiments were conducted to examine VR-induced sickness reported under the following conditions: HMD, desktop, standard projection screen and Reality Theatre under normal viewing conditions; active desktop viewing under light versus darkened room conditions; active versus passive control of a VE viewed on a standard projection screen in a darkened room; and passive viewing of three different VEs in a darkened Reality Theatre.

Analysis of simulator sickness symptoms reported before and after exposure to the virtual environment revealed a significant difference in pre–post change scores between HMD and desktop (for change in nausea symptoms) and HMD and Reality Theatre (for nausea, oculomotor and disorientation). In both cases, participants experienced higher increases in symptoms as a result of participation in the HMD condition. No other significant differences were found in this analysis.

Examination of the overall prevalence of symptoms revealed that a larger number of participants in the HMD, reality theatre and projection screen conditions experienced high levels of symptoms compared with those in the desktop conditions. The overall proportion of participants experiencing a “large increase” in symptoms in the projection screen, HMD and Reality Theatre conditions was approximately 60–70%. These results are comparable with other measures of post-exposure symptoms in HMD viewing [23,30]. It should be noted that the general prevalence figure of 60–70% does not include those participants who experienced only a “small increase” in symptoms – i.e. an increase in severity of one symptom or the “slight” experience of one new symptom. It was considered that given the relatively large number of participants reporting low levels of symptoms pre-exposure, it was not appropriate to consider minor changes in symptoms. In addition, the sample used in this experimental programme was civilian, compared with previous studies which have often used a military population (e.g. [30,36]). Previous research has found a higher rate of incidence and severity of symptoms in university students compared with military personnel [35].

There are no published data on the prevalence of effects resulting from the use of projection screen virtual environments. Some research has however suggested that viewers of large screen cinemas may experience Visually Induced Motion Sickness (VIMS) [2,21], and anecdotal reports sug-

Table 8  
No. participants reporting levels of symptoms experienced in each experimental condition

Condition no.	Viewing condition	Mode of interaction	Lighting	Decrease	No change	Small increase	Large increase
A	HMD	Active	Excluded	3 (15.8%)	2 (10.5%)	1 (5.3%)	13 (68.4%)
B	Desktop	Active	Light	8 (42.1%)	1 (5.3%)	3 (15.8%)	7 (36.8%)
C	Reality theatre	Passive	Dark	4 (23.5%)	1 (5.9%)	4 (23.5%)	8 (47.1%)
D	Projection screen	Passive	Dark	1 (7.1%)	3 (21.4%)	0	10 (71.4%)
E	Desktop	Active	Dark	2 (12.5%)	5 (31.3%)	3 (18.8%)	6 (37.5%)
F	Projection screen	Active	Dark	4 (28.6%)	0	4 (28.6%)	6 (42.9%)

gest that between 0.5% and 1% Reality Theatre viewers find the experience uncomfortable or even distressing. This may be affected by VE activity (e.g. “falling”) and the influence of elements of visual display content on participant experience has been investigated in a number of other studies [10,15,33,9]. In the present study one out of 31 participants asked to leave the Reality Theatre due to the experience of severe adverse symptoms.

## 7.2. Implications of VE viewing configurations for VRSE

This experimental programme systematically evaluated the impact of three different VE viewing configuration variables on VRSE. The results relating to each of these variables can be considered in turn.

### 7.2.1. Effect of lighting condition

It was expected that there might be a difference between VRSE experienced by participants in the dark and light viewing conditions. It has been suggested that degree of presence and self motion may impact severity of symptom [16], and it could be assumed that viewing a VE in a dark room may increase the level of “immersion” – and therefore the level of presence experienced. In the experimental comparison of light and dark viewing, no significant differences were found. However, this hypothesis was only examined for desktop viewing as it was technically not possible to view projection type displays in light conditions, and generally a low level of symptoms were experienced by viewers in the desktop condition, so it is not surprising that no significant differences were observed.

### 7.2.2. Impact of user control

Participants who do not have control over their movement in the VE appear to experience a higher level of symptoms. Significant differences were found in reported oculomotor and total SSQ symptoms between passive and active viewing conditions, with those in the passive viewing condition experiencing higher levels of symptoms. This result supports other findings in the literature. Stanney and Hash [35] found that level of control over immersive VE experience was highly significant on all factors of the SSQ. In motion sickness research, Rolnick and Lubow [31] found that when exposed to nauseogenic rotation, participants in control reported fewer motion sickness symptoms than their ‘yolked’ partner. Ruddle [32] identified that the level of control within a VE influenced the time taken for a participant to perform a task.

These results could be explained by sensory conflict theory – where *unexpected* conflict occurs between sensory inputs (passive viewing), the participant is more likely to experience sickness. However, it could also be because in passive condition participants were more able to concentrate on the screen but in active viewing they may have needed to look away at control devices.

## 8. Recommendations and conclusions

The different designs of VE used in this project did provide an indication of the implications of VE design on VRSE, but as they were not manipulated systematically it was not possible to make inferences regarding particular VE design characteristics and VRSE. So et al. [33] have attempted to quantify visual scene movement within a VE with the potential to link this to levels of sickness experience, and the authors have developed a prototype classification – Virtual Environment Description and Classification System (VEDACS) to support this approach [25]. The use of such tools could enable these inferences to be made in the future, and close examination of participant experience during a period of VR use (e.g. via monitoring tools such as the Short Symptom Checklist [26] or physiological monitoring) may allow the identification of specific elements of Virtual Environments that are most likely to provoke VRSE.

Since these experiments were conducted, average frame rates have generally increased to 20–40 fps on average, with some less complex environments displaying as much as 60 fps and this is likely to be more acceptable to the human visual system; the frame rate is highly dependent on the number of viewers, whether the display is mono or stereoscopic. However, the frame rate is only one contributory factor towards participant symptoms, and the sensory conflict between the visual and the vestibular senses still remains for all frame rates.

### 8.1. Recommendations

On the basis of the results presented, a number of recommendations can be made regarding both future use of VR and future research into VRSE.

There is a need to develop methods to identify susceptible individuals without requiring them to experience sickness. Some methods employed during other work not reported here (see [25]) do appear to provide an indication of individuals who may be likely to experience VRSE – notably motion sickness susceptibility, VR attitude, performance on a pre-experiment task [25], and headache/migraine history. These methods should be used to identify susceptible individuals, so that they can be informed about negative effects of VR and take appropriate action if needed. It may also be appropriate to limit initial periods of exposure for these individuals. However, there are a number of general guidelines that can be applied to all periods of VR exposure, where generally extra care and attention must be taken with participants whom are likely to be more susceptible. These guidelines include:

- Education about potential negative effects of VR use, with the aim of minimising anxiety about the experience.
- Designing VEs so that the minimum level of symptom-provoking elements is present for susceptible individuals.

- Informing participants about appropriate behaviour strategies that may minimise negative symptoms but not detract from their experience of using the VE, including training in use of input devices.
- Where possible, allowing participants control over their movement around the VE.
- Monitoring of VR participants, and providing assurance that they may terminate their period of exposure at any time (this point should particularly be emphasised for susceptible individuals).
- Education of people responsible for monitoring VR participants about possible physiological signs and behaviours that participants who are experiencing negative symptoms may exhibit (e.g. sweating, pallor, fidgeting with HMD, looking away from display, closing eyes).

In addition, on the basis of previous findings relating to habituation (see [4,13]) it may be appropriate for participants to undergo a series of short introductory VE exposures.

There may be a small subset of VR users who, despite all appropriate precautions being taken, will always experience negative symptoms of VR use. Research into migraines [28] suggests that this may be one group of users for whom this is the case, therefore until further research is completed, migraine susceptible individuals should use VR with caution.

## 8.2. Conclusions

This paper has described a comprehensive and controlled study of the effects experienced by participants in different types of VR systems viewing different VEs. The data indicates that the main situation in which symptoms are induced is for HMD use. Effects are also experienced in projection screen and Reality Theatre displays, although the level of effect depends on other factors, such as VE design and amount of control afforded to the participant. For desktop VR the symptoms appear to be negligible for the periods of exposure examined here. Although these results indicate that generally there is no cause for widespread concern, for some individuals there is a definite, potentially distressing, experience of severe negative effects.

VR is still a developing technology, and there is a need to continue research into monitoring the types and levels of symptoms experienced by VR participants as systems develop. Some VR participants are still experiencing symptoms to an uncomfortable and distressing level – it is therefore still necessary to identify the *exact* causes of these symptoms. It may be the case that there is a small subset of the population who will be more likely to experience symptoms and therefore it may be appropriate to examine such specific participant samples in detail. However, it is also desirable to identify how the symptom levels can be minimised for those people who are particularly susceptible. This can be done by more controlled experiments using tools to classify VE design, and using this information to provide guidelines for VE design to minimise VRSE. VR

is an exciting technology that allows participants to have a highly interactive and potentially rewarding, educational and enjoyable experience, therefore it is important that this research continues so that negative effects experienced by participants can be minimised.

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## References

- [1] J.R. Averill, Personal control over aversive stimuli and its relationship to stress, *Psychological Bulletin* 80 (1973) 286–303.
- [2] R.C. Benfari, Perceptual vertigo: a dimensional study, *Perceptual and Motor Skills* 18 (1964) 633–639.
- [3] D.H. Burns, Characteristics of visual display units that may cause visual difficulties, *Ophthalmic and Physiological Optics* 15 (2) (1995) 99–104.
- [4] S. Cobb, S. Nichols, A. Ramsey, J.R. Wilson, Health and safety implications of virtual reality: results and conclusions from an experimental programme, in: *Proceedings of FIVE'96, Framework for Immersive Virtual Environments*, Italy, 21st December, 1996, pp. 158–166.
- [5] S.V.G. Cobb, D.J. Brown, Promotion of Health and Safety at Work using a Virtual Factory, in: *Proceedings of Virtual Reality in Education and Training, VRET'97*, 1997.
- [6] S.V.G. Cobb, S.C. Nichols, A.R. Ramsey, J.R. Wilson, Virtual reality induced symptoms and effects, *Presence: Teleoperators and Virtual Environments* 8 (2) (1999) 169–186.
- [7] J. Deisinger, C. Cruz-Neira, O. Riedel, J. Symanzik, The effect of different viewing devices for the sense of presence and immersion in virtual environments: a comparison of stereoprojections based on monitors, HMDs and screen, in: M. Smith, G. Salvendy, R. Koubek (Eds.), *Design of Computing Systems: Social and Ergonomic Considerations*, Elsevier Science Publications, Amsterdam, 1997.
- [8] T.W. Dillon, H.H. Emurian, Some factors affecting reports of visual fatigue resulting from use of a VDU, *Computers in Human Behaviour* 12 (1) (1996) 49–59.
- [9] H. B.-L. Duh, J.J.W. Lin, R.V. Kenyon, D.E. Parker, T.A. Furness, Effects of characteristics of image quality in an immersive environment, *Presence: Teleoperators and Virtual Environments* 11 (3) (2002) 324–332.
- [10] H.B.-L. Duh, D.E. Parker, T.A. Furness, An independent visual background reduced simulator sickness in a driving simulator, *Presence: Teleoperators and Virtual Environments* 13 (5) (2004) 578–588.
- [11] R. Garriss-Reif, T.M. Franz, Simulator sickness and human task performance in conventional and virtual environments, in: A.C. Bittner, P.C. Champney (Eds.), *Advances in Industrial Ergonomics and Safety VII*, Taylor & Francis, 1995.

- [12] P.A.K. Hash, K.M. Stanney, Control: a primary driver of cybersickness, in: A.C. Bittner, P.C. Champney (Eds.), *Advances in Industrial Ergonomics and Safety VII*, Taylor & Francis, London, 1995.
- [13] K. Hill, P.A. Howarth, Habituation to the side effects of immersion in a virtual environment, *Displays* 21 (1) (2000) 25–30.
- [14] P.A. Howarth, The multi-factorial visual causes of virtual simulation sickness, *VISERG Report*, 1997.
- [15] W. Ijsselstein, H. de Ridder, J. Freeman, S.E. Avons, D. Bouwhuis, Effects of stereoscopic presentation, image motion and screen size on subjective and objective corroborative measures of presence, *Presence: Teleoperators and Virtual Environments* 10 (3) (2001) 298–311.
- [16] R.S. Kennedy, M.E. Lane, M.G. Lilienthal, K.S. Berbaum, L.J. Hettinger, Profile analysis of simulator sickness symptoms: application to virtual environment systems, *Presence* 1 (3) (1992) 295–301.
- [17] R.S. Kennedy, N.E. Lane, K.S. Berbaum, M.G. Lilienthal, Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness, *The International Journal of Aviation Psychology* 3 (3) (1993) 203–220.
- [18] R.S. Kennedy, C.J. Massey, M.G. Lilienthal, Incidences of fatigue and drowsiness reports from three dozen simulators: relevance for the sopite syndrome, in: *Presented at the First Workshop on Simulation and interaction in Virtual Environments (SIVE '95)*, July 13–15, 1995, University of Iowa, Iowa City, IA, 1995.
- [19] R.S. Kennedy, M.G. Lilienthal, K.S. Berbaum, D.R. Baltzley, M.E. McCauley, Simulator sickness in US navy flight simulators, *Aviation Space and Environmental Medicine* 60 (1989) 10–16.
- [20] D.R. Kolasinski Lampton, E.M. Knerr, B.W. Bliss, J.H. Bailey, B.G. Witmer, Side effects and aftereffects of immersion in virtual environments, in: *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, 1994, pp. 1154–1157.
- [21] J.W. Miller, J.E. Goodson, Motion sickness in a helicopter simulator, *Aerospace Medicine* 31 (1960) 204–212.
- [22] M. Mon-Williams, J.P. Wann, S. Rushton, Design factors in stereoscopic virtual-reality displays, *Journal of the SID* 3 (4) (1995) 207–210.
- [23] M. Mon-Williams, J.P. Wann, S. Rushton, Binocular vision in a virtual world: visual deficits following the wearing of a head-mounted display, *Ophthalmic and Physiological Optics* 13 (1993) 387–391.
- [24] S. Nichols, Physical ergonomics issues for virtual environment use, *Applied Ergonomics* 30 (1999) 79–90.
- [25] S. Nichols, A.D. Ramsey, S. Cobb, H. Neale, M. D'Cruz, J.R. Wilson, Incidence of virtual reality induced symptoms and effects (VRISE) in desktop and projection screen display systems, *HSE report 274/2000*, 2000.
- [26] S.C. Nichols, S.V.G. Cobb, J.R. Wilson, Health and safety implications of virtual environments: measurement issues, *Presence: Teleoperators and Virtual Environments* 6 (6) (1997) 667–675.
- [27] E. Peli, The visual effects of head-mounted display (HMD) are not distinguishable from those of desk-top computer display, *Vision Research* 38 (1998) 2053–2066.
- [28] A.D. Ramsey, Virtual reality induced symptoms and effects (VRISE): a psycho-physiological perspective, *Ph.D thesis*, University of Nottingham, 1999.
- [29] J.T. Reason, J.J. Brand, *Motion Sickness*, Academic Press, London, 1975.
- [30] E.C. Regan, K.R. Price, The frequency of occurrence and severity of side-effects of immersion virtual reality, *Aviation, Space and Environmental Medicine* 65 (6) (1994) 527–530.
- [31] A. Rolnick, R.E. Lubow, Why is the driver rarely motion sick? The role of controllability in motion sickness, *Ergonomics* 34 (7) (1991) 867–879.
- [32] R.A. Ruddle, J.C.D. Savage, D.M. Jones, Levels of control during a collaborative carrying task, *Presence: Teleoperators and Virtual Environments* 12 (2) (2003) 140–155.
- [33] R.H.Y. So, A.T.K. Ho, W.T. Lo, A metric to quantify virtual scene movement for the study of cybersickness: definition, implementation and verification, *Presence: Teleoperators and Virtual Environments* 10 (2) (2001) 193–215.
- [34] L.W. Stammerjohn, M.J. Smith, B.G.F. Cohen, Evaluation of workstation design factors in VDT operators, *Human Factors* 23 (4) (1981) 410–412.
- [35] K.M. Stanney, P.A.K. Hash, Locus of user-initiated control in virtual environments: influences on cybersickness, *Presence: Teleoperators and Virtual Environments* 7 (5) (1998) 447–459.
- [36] K.M. Stanney, R.S. Kennedy, J.M. Drexler, Cybersickness is not simulator sickness, *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting* (1997) 1138–1142.
- [37] S. Taptagaporn, S. Saito, How display polarity and lighting conditions affect the pupil size of VDT operators, *Ergonomics* 33 (2) (1990) 201–208.
- [38] S.C. Thompson, Will it hurt less if I can control it – a complex answer to a simple question, *Psychological Bulletin* 90 (1) (1981) 89–101.
- [39] J.R. Wilson, S. Nichols, A. Ramsey, Virtual reality health and safety: facts, speculation and myths, *VR News* 4 (9) (1995) 20–24.