Health and Safety Issues associated with Virtual Reality - A Review of Current Literature

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Abstract

VR techniques provide the user with a new and more powerful method of interacting with computers than the traditional techniques of keyboard and mouse. As such, there are many potential VR applications in areas such as entertainment, medicine and engineering and many research groups in the UK and abroad are now investigating this technology with the view to developing commercially viable products. There are various implementations of VR and these can be placed broadly into three categories; desktop, semi-immersive and fully immersive depending on the sophistication of the technologies being used.. However, the exploitation of this technology has not been without it's drawbacks. A number of recent reports have suggested that the use of VR equipment may have unwanted physical, physiological and psychological side-effects. This report provides an overview of current research in this area, the principal findings and the relationship between potential side-effects and the VR implementation being used. It is hoped that this report will provide a thorough overview of the area of VR health and safety for members of the AGOCG user commumity who are considering buying, or already own, a VR system.

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Introduction

Traditionally, interaction with a computer has involved the use of a keyboard, mouse or joystick/trackball device to input information and the use of a visual display unit (VDU) to receive output from the system. With the development of Virtual Reality (VR) systems, new interaction methods have been developed that allow the user to ‘step into’ computer generated ,or virtual, environments (VEs) which is achieved by ‘immersing’ the user in the synthetic environment. This can be achieved by various means including the wearing of enclosed Head-Mounted Displays (HMDs) which may provide stereoscopic images of the VE and by tracking the motion of the head, hands, fingers, and other limbs of the body using magnetic or optical tracking systems. Ideally, it is desirable that tracked movements of the body are updated in real time, but limitations to the currently available technologies dictate that this is not always the case.

One of the greatest strengths of this new technology is that developers of VEs are not constrained by traditional limits. Kalawsky (1996) identifies a number of key advantages provided by VR techniques:

- Simulation of complex systems.
- Macroscopic and microscopic visualisation.
- Fast and slow time simulation.
- Allow high levels of interactivity.
- Allow a sense of immersion.
- Inherent flexibility/adaptability.

The potential applications of VR technology are vast and a great deal of research is currently underway in many commercial and academic institutions to develop these technologies into effective useable systems. However, a number of recent reports have raised concern that there may be a downside to the exploitation of this new technology, suggesting that users may experience physical, physiological and psychological side-effects after using this type of equipment. Many of the early reports received extensive media coverage, which in many cases was misleading, sensationalist and inaccurate. The purpose of this report is to highlight the *potential* side-effects that have been discussed in literature to date and to attempt to place them in the correct perspective. In this way, users and potential users of VR systems will have some indication of the side-effects that they may experience and the generally accepted reasons for their genesis.

Brief History

Although VR is touted as a revolutionary new technology, the idea of inclusion within an artificial environment is not new. In fact VR can be considered an extension of ideas which have been around for some considerable time such as flight simulation, Sensorama (Heilig, 1962) and wide screen cinema (such as Cinerama and IMAX). Using such systems, the viewer is presented with a screen which takes up a large portion of the visual field giving a powerful sense of presence or ‘being there’.

Two major breakthroughs occurred in the 1960’s with the arrival of the minicomputer and the work of Ivan Sutherland in 1965 entitled "The Ultimate Display ". In this paper Sutherland prophesied the development of the first HMD, which he was later to achieve with an HMD called "The Sword of Damocles". Sutherland also realised the potential of computers to generate images for flight simulation, where, previously images were generated using video camera.

These ideas were combined by two NASA Ames scientists, Fisher and McGreevy, working on a project called the ‘virtual workstation’ in 1984. From these ideas NASA Ames developed the first commercially viable HMD, called the visual environment display (VIVED), which was based on a scuba divers face mask with the optical screen displays supplied from two Sony Watchman hand-held televisions. This development was unprecedented, as NASA had an HMD that could be produced at an affordable price and the VR industry was born.

Examples of Applications

VR research and development projects are currently underway world-wide in large organisations such as NASA, IBM, Intel, Boeing and Rolls Royce. To give some indication of the incredible flexibility of VR techniques, a number of current and diverse VR applications are listed below.

Amoco, in conjunction with Bravo Multimedia, have developed a simulator to evaluate the skills of their tanker drivers. The simulator is known as truck driVR, and uses an Intergraph PC and a Virtual Research FS5 HMD. When using the simulator, the driver is placed in charge of a Kenworth truck hauling 40,000 gallons of fuel. The simulation is made up of 21 events such as a deer crossing the road, a car backing out of a drive and an ambulance on an emergency call driving past and these events can occur on an urban or rural route. The driver is assessed on their ability to cope with the various events and all sessions are video-taped and reviewed with an instructor.

The systems are built into vans and taken around the country. The purpose is to develop a better system of driver evaluation than the one individual evaluation a year that Amoco currently employ. Truck driVR remains under development and is currently being offered to other fleet operators as a driver evaluation tool.

The Wilson Group, based at the University of California, San Diego are developing the Virtual Explorer learning tool. They are currently developing a ‘Fantastic Voyage’ virtual environment that allows the user to shrink down to cellular scale and travel through the human vascular system, observing the interplay of the fundamental components of the immune system and the bodies response to foreign invaders. The purpose is "to interface real textbook biology and critical thinking with action, visceral response and fun."

The system uses three rear projection screens, placed at 60 degree angles to the front of the ship pod. Using stereoscopic display techniques, the screens are used to provide the users view of the virtual world. The experience is further enhanced by a combination of spatialized and ambient sound and motion input from the user is provided by a flybox.

An example of a VR application with a foot in many camps is the Virtual Stonehenge model developed by Intelä; and English Heritage. The application can be regarded as an educational, historical and architectural tool as well as an application that encourages virtual tourism.

The internet model of Stonehenge, which is scientifically accurate, can be explored by connecting a PC to Intel’s corporate site. Users can navigate the environment in ten different eras, stretching from as far back as 8500BC to 2000AD. They can also move forwards and backwards in time, approach the site from any angle or fly over the scene and can observe the site in daylight, moonlight and view a Solstice sunrise. The model also includes educational content pertaining to the prehistoric people who built it, the inspiration for the building of the monument and the techniques used in the construction of the site. The internet model was developed on a PC using Superscape’s VRT authoring software. In addition to the internet model, English Heritage, in association with VR Solutions Limited of Salford, have developed a photorealistic VR model of Stonehenge using photographs of the stones and geographic information system (GIS) data of the surrounding landscape.

Further VR applications in more diverse areas include military applications such as Simulation Networking (SIMNET), the Virtual Solar System educational VE developed by Simon Nee at Loughborough University and VEs for entertainment such as the head-tracked PC version of Hereticä; by ID Software and public-space VR entertainment systems such as Total Recoilä; by Virtuality PLC.

Scope and Purpose of report

The purpose of this report is to outline to members of the AGOCG user commumity the potential health and safety problems that have been associated with VR use in current research. It is envisaged that this information will be of particular interest to those considering purchasing VR equipment, particularly immersive systems. However, it is also intended that the report will be of use to those who already have VR systems of all types as many of the health and safety issues discussed can be related to a number of different VR implementations. The report will categorise VR system implementations into three main types: non-immersive, semi-immersive and fully immersive. The hardware required to deliver each type of implementation will also be discussed.

The potential side-effects that have been suggested in the literature will then be discussed. These will be grouped into three main categories : physical, physiological and psychological symptoms respectively. The relationship between these symptoms and the type of hardware being used will then be evaluated. The intention is to give some indication of the reasons for the genesis of particular problems (if those reasons are currently known) and the VR platforms one which one would expect particular symptoms to occur. Often solutions can be relatively simple as long as the system owner is aware of the genesis of a particular problem.

It must be stressed that this report is not intended to be an in-depth discussion of currently available VR hardware or an analysis of the complex causative factors involved in many of the side-effects that will be discussed. References to research will be provided in each section to allow the reader to investigate particular areas further if they wish. Further, the indication of a potential side-effect in this report does not validate it as an proven occurrence or indicate the authors agreement that such effects occur. The intention is to provide an overview of the literature that will allow the reader to attach the importance to proposed effects that they deem appropriate.

Types of VR system

Although it is difficult to categorise all VR systems, most configurations fall into three main categories and each category can be ranked by the sense of immersion, or degree of presence it provides. Immersion or presence can be regarded as how powerfully the attention of the user is focused on the task in hand. Immersion presence is generally believed to be the product of several parameters including level of interactivity, image complexity, stereoscopic view, field of regard and the update rate of the display. For example, providing a stereoscopic rather than monoscopic view of the virtual environment will increase the sense of immersion experienced by the user. It must be stressed that no one parameter is effective in isolation and the level of immersion achieved is due to the complex interaction of the many factors involved.

As will be shown in this report, the type of VR system being used an important consideration when one investigates the genesis of sickness symptoms and the type of symptoms that may develop.

Non-Immersive (Desktop) Systems

Non-immersive systems, as the name suggests, are the least immersive implementation of VR techniques. Using the desktop system, the virtual environment is viewed through a portal or window by utilising a standard high resolution monitor. Interaction with the virtual environment can occur by conventional means such as keyboards, mice and trackballs or may be enhanced by using 3D interaction devices such as a SpaceBallä; or DataGloveä; .

The non-immersive system has advantages in that they do not require the highest level of graphics performance, no special hardware and can be implemented on high specification PC clones. This means that these systems can be regarded as the lowest cost VR solution which can be used for many applications. However, this low cost means that these systems will always be outperformed by more sophisticated implementations, provide almost no sense of immersion and are limited to a certain extent by current 2D interaction devices. Additionally, these systems are of little use where the perception of scale is an important factor. However, one would expect to see an increase in the popularity of such systems for VR use in the near future. This is due to the fact that Virtual Reality Modelling Reality Language (VRML) is expected to be adopted as a de-facto standard for the transfer of 3D model data and virtual worlds via the internet. The advantage of VRML for the PC desktop user is that this software runs relatively well on a PC, which is not always the case for many proprietary VR authoring tools. Furthermore, many commercial VR software suppliers are now incorporating VRML capability into their software and exploring the commercial possibilities of desktop VR in general.

Semi-Immersive Projection Systems

Semi-immersive systems are a relatively new implementation of VR technology and borrow considerably from technologies developed in the flight simulation field.

A semi-immersive system will comprise of a relatively high performance graphics computing system which can be coupled with either:

- A large screen monitor
- A large screen projector system
- Multiple television projection systems

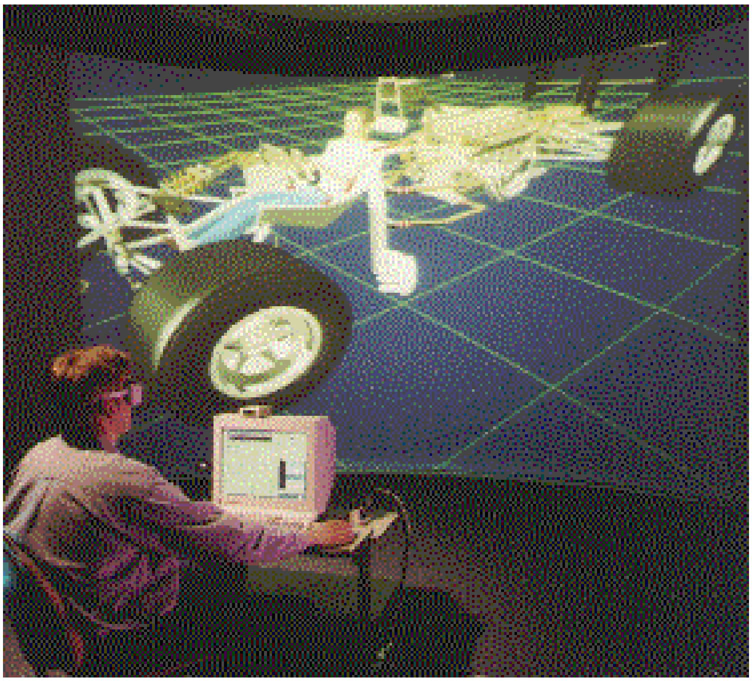
In many ways, these projection systems are similar to the IMAX theatres discussed in section 1.1. Using a wide field of view, these systems increase the feeling of immersion or presence experienced by the user. However, the quality of the projected image is an important consideration. It is important to calibrate the geometry of the projected image to the shape of the screen to prevent distortions and the resolution will determine the quality of textures, colours, the ability of define shapes and the ability of the user to read text on-screen. The resolutions of projection systems range from 1000 - 3000 lines but to achieve the highest levels it may be necessary to use multiple projection systems which are more expensive.

Semi-immersive systems therefore provide a greater sense of presence than non-immersive systems and also a greater appreciation of scale. In addition, images can be provided that are of a far greater resolution than HMDs and this implementation provides the ability to share the virtual experience. This may have a considerable benefit in educational applications as it allows simultaneous experience of the VE which is not available with head-mounted immersive systems. Additionally, stereographic imaging can be achieved, using some type of shuttered glasses in synchronisation with the graphics system.

Shutter Glasses

Liquid Crystal Shutter (LCS) glasses are an important technology when considering semi-immersive systems and consist of a lightweight headset with a liquid crystal lens placed over each eye. Stereopsis works on the principle that in order to perceive depth in a scene, the observer must see slightly different images of the scene under regard in each eye. In the real world this occurs because the two eyes are placed slightly apart in the head, and so each eye views the scene from a slightly different position.

The graphics computer used displays slightly different left and right views (known as a stereo pair) of the virtual environment sequentially on the display system. To achieve the stereoscopic effect, the glasses either pass or block an image that is produced on the VDU or projected display. When the left image is displayed, the left eye lens is switched on, allowing the viewer's left eye to see the screen. The right eye lens, however, remains off, thus blocking the right eyes view. When the right image is displayed, the opposite occurs. This switching between images occurs so rapidly that it is undetectable by the user, who fuses the two images in the brain to see one constant 3D image.



Picture courtesy of Loughborough University Advanced VR Research Centre

Figure 1. A semi-immersive wide-screen projection system in use with shutter glasses.

Examples of this product commercially available include CrystalEyes Shutter Glasses and the 3D Max Shutter Glasses System.

Again however, the increased performance of this VR implementation comes at a cost. Setting up a projection screen system is far more difficult than a desktop system and is considerably more expensive. Additionally, there are problems with current interaction devices for these systems. Firstly, one must consider carefully the applications that such a system may be used for. For a flight simulation system it is possible to simply used an inceptor (joystick) which can be interpreted by the aircraft model as the flight control input. This is acceptable as the simulator is not used for any other applications but becomes problematical when one considers that a semi-immersive installation may have multifarious uses that may require different interaction strategies. Secondly, one must consider multi-user issues, as this is one of the main advantages of these systems. The handover of control between users is one of the issues that must be considered as this technology develops.

Fully Immersive Head-Mounted Display Systems

The most direct experience of virtual environments is provided by fully immersive VR systems. These systems are probably the most widely known VR implementation where the user either wears an HMD or uses some form of head-coupled display such as a Binocular Omni-Orientation Monitor or BOOM (Bolas, 1994).

Head Mounted Displays (HMDs)

An HMD uses small monitors placed in front of each eye which can provide stereo, bi-ocular or monocular images. Stereo images are provided in a similar way to shutter glasses, in that a slightly different image is presented to each eye. The major difference is that the two screens are placed very close (50-70mm) to the eye, although the image, which the wearer focuses on, will be much further away because of the HMD optical system. Bi-ocular images can be provided by displaying identical images on each screen and monocular images by using only one display screen.

The most commonly used displays are small Liquid Crystal Display (LCD) panels but more expensive HMDs use Cathode Ray Tubes (CRT) which increase the resolution of the image. The HMD design may partially or fully exclude the users view of the real world and enhances the field of view of the computer generated world. The advantage of this method is that the user is provided with a 360°; field of regard meaning that the user will receive a visual image if they turn their head to look in ANY direction.

All fully immersive systems will give a sense of presence that cannot be equalled by the other approaches discussed earlier, but the sense of immersion depends of several parameters including the field of view of the HMD, the resolution, the update rate, and contrast and illumination of the display.

Image courtesy of VISERG, Loughborough University

Figure 2. The major components of an HMD. This illustration shows the two screens capable of producing stereo images and speakers located to provide stereo sound.

Fully immersive VR systems tend to be the most demanding in terms of the computing power and level of technology (and consequently cost!) required to achieve a satisfactory level of realism and development is constantly underway to improve the technologies. Major areas of research and development include field of view vs resolution trade-offs, reducing the size and weight of HMDs and reducing system lag times.

Comparison between VR Implementations

Kalawsky (1996) provides a good comparison between the various VR implementations (see Table 2.1). It is also important that these implementations are not regarded as distinct boundaries for implementations. For example, it is possible to turn a desktop system into a semi-immersive system by simply adding shutter glasses and the appropriate software, or a fully immersive system by connecting an HMD.

Table 2.1

Qualitative performance of different VR systems (adapted from Kalawsky, 1996)

Qualitative Performance			
Main Features	**Non- Immersive VR** **(Desktop)**	**Semi-Immersive VR** **(Projection)**	**Full Immersive VR** **(Head-coupled)**
Resolution	High	High	Low - Medium
Scale (perception)	Low	Medium - High	High
Sense of situational awareness (navigation skills)	Low	Medium	High
Field of regard	Low	Medium	High
Lag	Low	Low	Medium - High
Sense of immersion	None - low	Medium - High	Medium - High

Health Issues associated with VR Use

Wilson (1996) suggests that many new technologies undergo some form of public backlash and that this can be because of a number of reasons. The technology may be being oversold, the impact on the environment and the lives of people is generally unpleasant (e.g. the motor car) or there is a backlash due to the frequency and duration of use (e.g. the office computer workstation). Both he, and Howarth (1994) draw parallels with the introduction of Visual Display Units (VDUs) in the early 1980's and the health speculation surrounding the use of VR equipment.

With VR systems, similar problems appear to have come to light. The introduction of VDUs was said to cause physical, physiological and psychological problems and these were exacerbated by the technological limitations of the screens at that time.

Herein, lies one of the biggest problems in defining problem areas as VR technology is new and is constantly being improved and developed by different manufacturers. One only has to look at the range of HMDs on the market to appreciate the different approaches to the design of one facet of VR technology. Therefore, one must consider the attributes of the VR system that is being used.

Similarly, one must expect the user population to extremely diverse. This is an important consideration when one considers the design of equipment that must be placed on the body. Custom fitting may be relatively easy to achieve in the workplace where there may be limited users but the use of VR for public space entertainment applications means that the equipment is available to a potentially large user base who may have little or no knowledge of the health and safety issues involved and little knowledge as to how to use the equipment correctly.

Finally, one must consider the demands of the task itself. For example, a target tracking task which induces considerable head movement may be more uncomfortable than a task which requires little head movement such as reading a document.. However, one must consider the complex interplay of the various factors. If system lag is high and the headset is heavy, tracking may be uncomfortable. If system lag is low, and the headset is light such tracking tasks may not be such a problem. Kolasinski (1995) identifies the number of potential factors that may be associated with the onset of simulator sickness symptoms in a VE. These factors are reproduced in Table 3.1 below.

Table 3.1

Potential Factors Associated with Simulator Sickness in Virtual Environments (adapted from Kolasinski, 1995)

Individual	VR System/Simulator	Task
age	binocular viewing	altitude above terrain
concentration level	calibration	degree of control
ethnicity	colour	duration
experience with real-world task	inter-ocular distance	global visual flow
adaptation	contrast	head movements
flicker fusion frequency threshold	field of view	luminance level
gender	flicker	unusual manoeuvres

illness and personal characteristics	motion platform	rate of linear or rotational acceleration
mental rotation ability	phosphor lag	method of movement
perceptual style	position-tracking error	self-movement speed
postural stability	refresh rate	sitting vs. standing
	scene content	vection
	time lag (transport delay)	type of application
	update rate (frame rate)	
	viewing region	

When one considers that these factors are implicated in the onset of simulator sickness alone it becomes clear that the genesis of symptoms may be due to an extremely complex interaction between the factors in each of the three areas represented above. This may be the case for all suggested symptoms, and the current focus of much research is in trying to determine the most important factors in the onset of particular symptoms.

Ultimately, there is the question of which side effects DO actually occur, and which are more fanciful notions brought about by the general hype surrounding the technologies, applications and symptoms. There has certainly been rigorous research, and no one involved in VR disputes that fact that unpleasant symptoms can occur but little is known. Currently unanswered questions include issues such as the duration of symptoms, predicting individual susceptibility, coping strategies adopted by VR users and the impact upon the VR task and consequent activities such as driving or operating heavy machinery.

The possible side effects that have been suggested to date can be divided into three main areas. Table 3.2 below, outlines these effects.

Table 3.2

Suggested effects resulting from exposure to VR (modified from Costello and Howarth, 1996a)

Physical	**Physiological**	**Psychological**	
		Behavioural	**Cognitive**
physical discomfort hygiene immersion injuries equipment fit	visual asthenopic symptoms postural instability simulator sickness	stress addiction isolation mood changes	perceptual shifts and disorientation changes in perceptual judgement
unnatural postural demands	dissociation of accommodation/ convergence cardiovascular change		change in psychomotor performance
	gastrointestinal change biochemical change		

It must be stressed that these are suggested symptoms and it must also be made clear that certain symptoms may only occur with certain types of VR implementation. The following sections will discuss each category in turn, highlighting the possible effects in each category that can be expected with the different implementations of VR.

Physical

It is important to consider the physical issues involved in the use of VR equipment. In some cases, the interaction techniques used are unique to the system and may present specific problems (such as the weight of some HMDs). In other cases, the demands may be well understood but the user must be aware of the type of problems that may arise. The following sections detail some of the physical issues that must be considered when one uses VR equipment.

Posture

The postural demands of desktop VR systems can be considered to be identical to using a standard PC in that one would expect the user to be sedentary at a desk or worktop. There is much literature on the subject of VDT workstation design (Grandjean, 1987; Lueder, 1986) and indeed in this country, regulations have been laid down as to safe working practices with such installations (Health and Safety Executive, 1983).

Posture issues with semi-immersive implementations may be a little more complex. One would expect that using a large monitor would provide a similar situation to that proposed above but it is quite possible that users of large screen installations may be standing, wearing shutter glasses and using some form of interaction device. In this case there may be some abnormal postural demands as the user interacts with the VE. However, it must be noted that shutter glasses are relatively lightweight (CrystalEyes weigh 3.3 ounces), as are the interaction devices, so the postural demands will be determined primarily by the interaction with the VE and the demands of the task.

Probably of biggest concern are the postural demands of fully immersive implementations. Immersive HMDs tend to be considerably heavier than shutter glasses (see also 3.1.3) and therefore provide additional load on the body. In the authors own research experience, users in an immersive headset were often observed ‘propping up‘ the weight of the headset using one hand, and interacting with the VE using the interaction device with the other. The long term effects of this unnatural posture are difficult to quantify, but user discomfort is often reported while using HMDs.

Repetitive Strain Injuries (RSI)

Repetitive strain injury is now relatively well known due to a number of high profile court cases such as the damages case lost by BT in December 1991. RSI injuries result from carrying out prolonged repeated activities using rapid carpal and metacarpal movements. Injuries such as tendonitis, fibrous tissue hyperplasia and ligamentous injury have been reported in association with using standard input devices such as mice, joysticks and keyboards and can leave the sufferer functionally disabled.

One would therefore expect RSI to be an issue with desktop VR systems and semi-immersive systems using standard interface devices. More difficult to determine is whether users of such devices as 3D mice or datagloves will suffer in a similar way. Howarth (1994) argues that the more ‘natural’ gestures allowed by such devices may alleviate RSI problems although, again, this is dependent on the design of the interface. Any interaction technique that requires continual repetitive movement is undesirable (as it would be for a real world task), so it is important that VE developers appreciate this when interaction strategies are formulated.

Headset Weight and Fit

The issue of headset weight is restricted to fully immersive systems utilising HMDs. Due to the limitations of current display screen technology many HMDs are still relatively bulky in terms of both size and weight, with some HMDs on the market weighing in at approximately 2kg (8lbs). Improperly fitting HMDs can cause discomfort and additional strain can be placed on the neck by large masses. So (1994) suggested that additional strain could be placed on the neck if the user remains relatively still in a VE and one must also consider the additional inertia caused by the HMD as the user executes a head movement. All these problems are exacerbated by heavy, poorly fitting and poorly balanced headsets and users should be made aware of the correct fitting techniques. Future developments will almost certainly mean that headsets will reduce in weight if they are to be commercially acceptable, or developments such as the BOOM system may be considered where the weight of the headset is not supported by the wearer. Ultimately, this issue will cease to be a major drawback of HMDs, but currently this problem is one of the biggest stumbling blocks for fully immersive systems.

Hygiene Issues

Gupta, Wantland and Klien (1996) suggest that much of the peripheral equipment used in VR are potential fomites. A fomite is a harmless object that is able to harbour pathogenic organisms and as such, may serve as an agent for the transmission of infections. They go on to suggest that airborne pathogens and skin flora thrive in environments similar to those of HMDs and hand controller devices. An additional consideration here is that HMDs are often of enclosed design and generate a considerable amount of heat in powering the displays. This can often lead to some sweating for the user particularly if the immersive task demands a certain amount of physical activity.

To put these concerns into context, one must consider that traditional keyboards and mice can be regarded as fomites and their popularity is evident. This issue does become pertinent however, when one considers the use of fully-immersive systems in public space applications. Some HMD manufacturers now provide removable, washable pads positioned where the HMD cradle is in contact with the skin of the wearer.

Immersion Injuries

Both Gupta et al. (1996) and Viirre (1993) suggest there may also be a risk of injury while the user is using a fully immersive HMD. As Viirre suggests, when a user is wearing an HMD, they are functionally blind in real world terms. This can lead to problems due to collision with real world objects or possibly the VR system cabling and even if the user has some external vision, the compelling immersive scene may distract attention from the outside world. Additionally, many HMDs also provide sound cues for the user that effectively cut off aural stimulation from the real world.

Effectively, the situation then occurs where the user is actively involved in a VE that may require a certain amount of movement and yet is receiving little or no input from real world cues. Consequently, it is important that the user is kept in a safe area, preferably protected with railings. A good example with this in mind is the safety barrier utilised in public space applications, where the user is enclosed in an limited area protected by a padded, circular railing during immersion.

Physiological

Physiological issues are probably the most well documented and at present, well researched sickness issues currently attributed to VR systems. Indeed some reported physiological side-effects such as simulator sickness have been researched for some time. Of the possible physiological side-effects, visual symptoms and motion sickness type symptoms appear to cause the most concern. Consequently, much of the research into physiological effects has been concentrated in these areas.

Visual Issues

The visual presentation of the virtual environment is extremely important. The processing and organisation of visual input involves the use of a larger portion of the brain than for any other sense and North (1993) estimated that for a complex task such as driving, 90 per cent of the received information is visual. It is therefore not surprising that manufacturers go to great lengths to provide a compelling visual environment.

The implementation of such visual environments for VR applications have not been without problems. Although the health and safety issues associated with monoscopic displays are relatively well understood, the issues associated with stereoscopic images are more complex.

Monoscopic implementations of desktop and semi-immersive systems essentially provide a visual scenario that is common. The visual environment created using a monoscopic desktop VR system is more or less identical to that experienced when one uses a standard office computer. Much research has been carried out in this area (National Research Council, 1983; Dain, McCarthy and Chan-Ling, 1988; Daum, Good and Tijerina, 1988; Shen, Chiu, Wang and Lo, 1988; Howarth and Istance, 1985) and a large body of literature is available. The principle visual side-effects of this implementation are asthenopia (eyestrain) and visual fatigue. Regulations for safe use of VDU displays have been laid down in this country in the Health and Safety (Display Screen Equipment) Regulations (1992) and internationally in ISO 9241-Part 3: Visual display requirements. Similarly, monoscopic semi-immersive systems provide a viewing scenario similar to a cinema, that of viewing a large screen at some distance. This could be considered the least visually taxing of all the implementations, as the viewing distances involved are usually close to optical infinity (approx. 4m or greater), and thus reduce the accommodative (focus) demand for the user.

As suggested however, stereoscopic semi-immersive systems may have additional side-effects. One of the main reasons for the genesis of side-effects is suggested to be the dissociation of accommodation and convergence in the visual system.

The dissociation of accommodation and convergence when using stereoscopic displays

In 1993, Mon-Williams, Wann and Rushton reported physiological symptoms in a number of subjects following immersion in an HMD. Of the 20 subjects who took part in their experiment, 12 complained of symptoms such as headache, eyestrain and nausea and 4 demonstrated a transient reduction in binocular visual acuity. The subjects also demonstrated signs of binocular stress including changes in heterophoria and an increase in near point of convergence. Mon-Williams and Pascal (1995) suggested that these signs of visual/binocular stress were linked, not only to poor image quality and close working distance of the screens, but more fundamentally with the discrepancy between accommodation and convergence demand when using a stereoscopic HMD. This problem will occur in any stereoscopic system where the main image is produced on a flat screen and stereo images are provided by displaying slightly different images to each eye.

In the natural environment, accommodation and convergence are intrinsically linked. If one accommodates (focuses) on a near object, the eyes will automatically converge. Similarly, if focus is changed to a distant object, the eyes will automatically diverge slightly (see Figure 3). When using stereoscopic display devices such as shutter glasses or HMDs this is not the case. In this situation, the accommodative demand is always constant but the convergence demand changes as the user regards objects at different geometric depths in the virtual world. This accommodation/convergence is not a natural occurrence and has been said to result in visual stress.

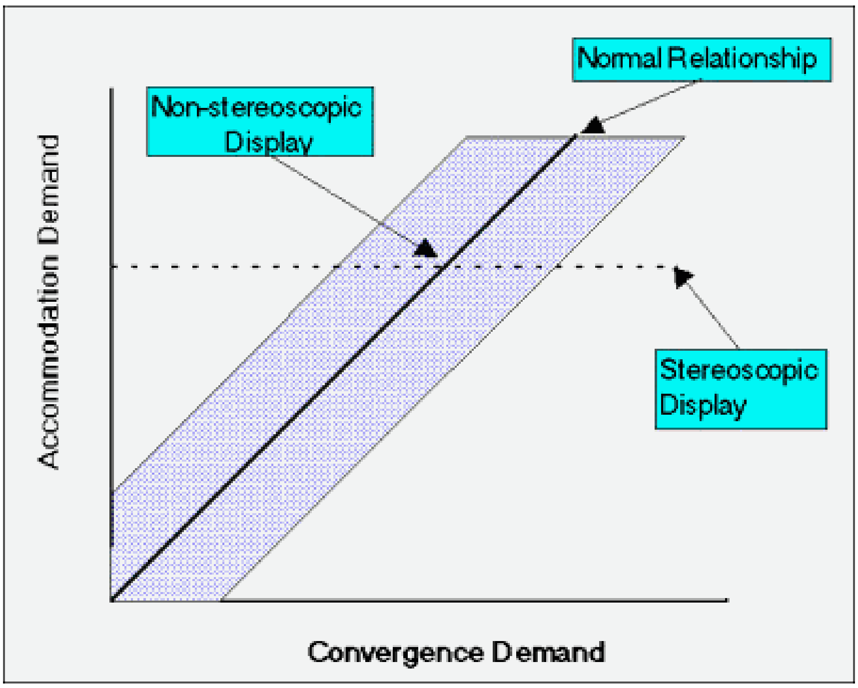


Image courtesy of VISERG, Loughborough University

Figure 3. The relationship between accommodation and convergence in the real world (solid line) and when using a stereoscopic display (dashed line). The shaded area is the zone of clear, comfortable, binocular vision. (from Howarth, 1996)

More recent research (Peli, 1995) seems to suggest that although some symptoms occur due to this problem, the issue may not be as important as it was once thought. This may be due to ‘slack’ within the visual system that can overcome such demands. However, Howarth (1996) suggests that if one is using a stereo display, it is desirable that geometric images are produced closer than the screen focusing plane as this technique produced less discomfort in subjects.

Additional visual considerations with HMDs

A further issue that must be considered with HMDs is the relationship between the inter-screen distance (ISD), inter-ocular distance (IOD) of the lenses and the inter-pupilliary distance (IPD) of the user (Howarth, 1997). The ISD refers to the distance between the centres of the two images on the display screen, the IOD refers to the distance between the optical centres of the lens systems installed in the HMD and the IPD refers to the distance between the centres of the pupils of the user. North (1993) indicated a mean IPD for UK men of approximately 64mm and a mean IPD for UK women of approximately 62mm. Initially, it was suggested that a mismatch between the users IPD and the IOD of the HMD may give rise to visual discomfort symptoms, transient heterophorias or muscle imbalances in the users eyes. A study by Regan and Price (1993b) reported that the greater the mismatch between the two measures, the greater the reported side-effects.

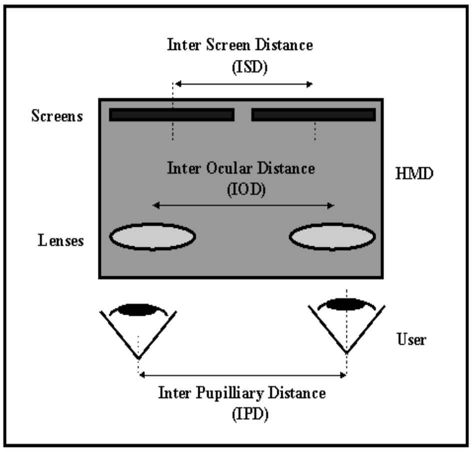


Figure 4. The relationship between ISD, IOD and IPD in a head-mounted display. The shaded grey box represents the HMD casing (adapted from Howarth, 1997).

The reason for the symptoms has been reported to be that viewing of the lens system on an off-centre axis effectively leads to distortion of the image as a convex lens can be regarded as two prisms. The consequences of prism adaption are well reported (Maddox, 1893; Sethi, 1986; Schor, 1986) and include eyestrain and visual discomfort. Recent research (Howarth, 1997) would appear to indicate that the relationship between the IOD and

ISD of the headset is the most important consideration as this affects the image position for the viewer. Some HMD manufacturers now provide IPD adjustability on their HMDs, but this is more important in determining the portion of the image that can be seen in stereo (stereo overlap) of the image.

An additional consideration is that of the HMD users visual ability. Most people are not perfectly sighted meaning that the design of the HMD (or indeed shutter glasses) must allow the user to wear their normal optical correction or provide some sort of adjustability that allows each individual user to tailor the HMD to their own specifications. Some HMD manufacturers now provide focus adjustment on their models. However, providing this functionality does not mean that the user will adjust it correctly without adequate instruction and incorrectly-adjusted optics may be more detrimental to the user as optics with no adjustment at all.

Finally, one must consider the quality of HMD displays. Currently, the most inexpensive displays use LCD displays which tend to have low resolution, poor contrast and low levels of illumination. An informal study by Robinett and Rolland (1992) estimated users vision of a virtual snellen chart to be 6/60 but this situation is improving. Howarth (personal communication, 1997) estimated users vision of a later model low-cost, commercially available HMD to have improved to 6/24 but this still represents a considerable degradation of normal vision (6/6).

A review of the literature in this area certainly provides compelling evidence that physiological changes occur in the visual system following HMD immersion and that subjects do report specific symptoms. In our own studies, we re-measured visual changes at 5 and 10 minute intervals post-immersion. We found that for the vast majority of subjects any measured visual changes had reverted back to the original readings, suggesting that such changes are transient, and no evidence of long term effects has yet been published. Furthermore, physiological changes in the visual system (such as transient heterophorias) have also been shown to occur following more 'mundane' tasks such as reading hardcopy text (Pickwell, Jenkins and Yekta, 1987) and using a VDT display (Howarth and Costello, 1996).

Research continues in this area, both in determining the appropriate optical set-up and in designing adjustability in to the HMD itself. Peli (1996) has recently published preliminary recommendations for optical tolerances in HMDs and manufacturers continue to develop the HMD to provide in-built adjustability in the areas of focus, convergence and adjustability.

Simulator Sickness Symptoms

Simulator sickness is by no means a new phenomenon. It is similar to motion sickness, which has existed for as long as humans have used additional modes of transportation, but can occur without any actual motion of the subject. The first documented case of simulator sickness occurred in 1957 and was reported by Havron and Butler in a US Navy helicopter trainer. The most common identifiable symptoms are general discomfort, nausea, drowsiness, headache and in some cases vomiting.

A number of recent research projects have identified symptoms in users of off-the-shelf VR systems. Regan and Price (1993a) reported that 61% of 146 subjects reported some symptoms following a 20 minute immersion in a VE. Costello and Howarth (1996c), in a study of one non-immersive and three fully immersive commercial VR systems, indicated statistically significant increases in reports of disorientation for all three immersive systems and significant increases in reported nausea for two of the three immersive systems following a 20 minute immersion period. No significant increases in these symptoms were reported by the same subjects using the non-immersive system.

Kennedy and Frank (1985) suggest that simulator sickness is both polygenic (has many sources) and polysymptomatic (induces many symptoms) indicating how difficult it is to predict individual susceptibility and to measure the effects on the user. The research is not all bad news, however, as in a later paper Kennedy, Berbaum, Lilienthal, Dunlap, Mulligan and Funaro (1987) claim that only about 30% of individuals will become ill even under the worst simulator conditions.

Effects of simulator sickness symptoms on the task in a VE

The underlying problem with such symptoms is that they affect the performance of the user both in the VE/simulator and in some cases, afterwards. Simulator sickness symptoms may distract the users attention from the task in hand and, in more severe cases, can actually cause the user to leave the simulation environment (Costello and Howarth, 1996c). This reduces the effectiveness of the simulator and can cause a reluctance on the part of the operator to use the VE/simulator again. The impact on consequent tasks has also caused some concern. This is due to the fact that the symptoms developed in a simulator/VE appear to last far longer than those developed in motion sickness. There are several reports of longer term symptoms and delayed after-effects in the literature. Kellogg, Castore and Coward (1980) reported after effects following simulator use occurring 8-10 hours after leaving the simulator and experimentation carried out by the author has produced anecdotal reports from subjects that simulator sickness symptoms following immersive VR use have persisted for up to two days in some cases.

This has obvious consequences for other tasks such as driving and Pausch, Crea and Conway (1992) indicate that many US Army aviation units have adopted a policy that prohibits flying an aircraft within 6 hours of a simulator flight.

Simulator Sickness Symptom Theories

Of the number of possible theories that have been proposed as the cause for simulator sickness (more detailed reviews of the various theories can be found in literature (Pausch et al. (1992), Kennedy and Frank (1985), Kolasinski (1995)), the theory of sensory conflict is currently regarded as the most popular. This theory was proposed by Steele in the 1960’s under the name ‘perceptual conflict’ and is also referred to in various texts as ‘cue conflict’. Conflict occurs when signals from the various spatial senses, the eyes, the balance organs and the non-vestibular position senses are in conflict with one another and do not correlate with signals received in past experience.

There are a number of ways in which this sensory conflict can occur when using large screen semi-immersive and HMD based VR systems.

Using a large screen semi-immersive system is similar to viewing an IMAX type cinema screen in that the viewing area takes up a considerable portion of the viewers visual field. This gives rise to a phenomenon known as visually induced motion sickness (VIMS) (McCauley and Sharkey, 1992). Here, conflict occurs if there is apparent motion of the image on the screen. The users visual senses indicate that the body is in motion but the balance organs and non vestibular senses indicate that the body is in fact static (assuming there is no motion base). This conflict can lead to the onset of the symptoms described above.

In an HMD based system, there may be an additional cause of sensory conflict. This is related to the time lag experienced when one uses a tracked HMD. In all VR systems, there is a delay between the execution of a head movement and it’s representation on the screen. In 1994 Bolas suggested that immersive systems with passive LCD screens may take in the order of 200 milliseconds to recalculate and redraw the screen image. This provides further potential for sensory conflict to occur. If one executes a head movement and the screen image is not changed for 200 ms the eyes will detect no movement but the balance organs indicate that the head is moving. Similarly, the instant that a head motion stops, it will take 200ms for the screen image to stop moving. Here the eyes indicate movement and the balance organs indicate that movement has ceased causing further sensory conflict. Although the increase in computational power will mean that such lags will be reduced, the contribution of such lag to motion sickness symptoms remains a controversial area. (see Kolasinski, 1995). Furthermore, it must be noted here that the symptoms stll occur in the absence of some putative, causal factors, e.g. accommodation/convergence conflict and tracker lag (Howarth and Costello, 1997).

Psychological

Although a number of psychological effects have been proposed in Table 3.1, there appears to be little research carried out in this area to date. Previous research carried out into attitudes to computer games (Shotton, 1989) suggests that people may become "hooked" and one could postulate that in many ways the same could be said of

VR. Indeed it could be argued that VR has greater potential to hook users due to a more compelling experience but there is little evidence to support this at present. However, as Howarth (1994) argues, people often become obsessed with their hobbies and it is important to view the use of VR equipment in this context.

Further behavioural effects that have been suggested (Wilson, 1996) include hallucinations, dissociation, literalisation and retreat from reality and a number of papers in a special health and safety issue of the VR journal, Presence, deal with these issues in more detail.

Similarly, there has been concern over ethical issues such as the construction of violent or pornographic worlds. Here again, there are similarities with the computer games industry where there has been some concern as to the violent content of computer game material. This does not seem to have been particularly damaging to this industry although there have been calls to censor or restrict certain games to particular age groups.

Gupta et al. (1996) also suggest that additional problems caused by VR may include anxiety and claustrophobia. Although it is possible that these effects may occur, there appears to be little evidence to date of any lasting effects.

Potential Health Benefits

Both Howarth (1994) and Wilson (1996) point out that as well as looking for problems, it is important to recognise that VR techniques may also prove beneficial in many applications. Currently there is much research work being carried out in the VR field that will be of benefit to users.

In terms of physical issues, more natural interaction techniques may reduce static posture problems, the use of LCD screens may minimise vision problems associated with CRT screens and physical loads associated with keying (Wilson, 1996).

VR also provides a much improved technique for health and safety training, though as Howarth (1994) suggests, this role is largely hidden. VR techniques can be used in ergonomic assessment of workspace layout, for rapid prototyping of control interfaces, for the simulation of potentially dangerous environments such as nuclear plant maintenance and in education and training of users in areas such as the maintenance of complex machinery. As Howarth says, the fact that the use of VR has helped an operator avoid an accident or react correctly in the event of a crisis is largely unseen.

VR also has numerous applications that can be directly related to health care. In a white paper on the use of Virtual Environments for Health Care, Moline (1995) indicates several areas where patient care can be assisted by VR techniques. These include:

- The use of VR for remote telesurgery.
- VR techniques used in local surgery such as endoscopy, where the surgeon manipulates instruments by viewing a TV monitor.
- VEs used as surgical simulators or trainers.
- VEs used as therapy devices to reduce anxiety or fear. One example is dentists using 3D eyeglasses to divert a patients attention during dental operations
- VEs are also being used to reduce phobias such as agoraphobia and vertigo.

North, North and Coble (1996) provide an overview of current work in the use of VR techniques to reduce phobias in their book VR Therapy.

Discussion

Research into the side effects of VR use is a complex and difficult business and it is clear that concerns do remain about the effects of using such systems. Academic research does show that some symptoms occur whilst using VR tools and that these effects (such as nausea) can be quite debilitating in the short term. Whether or not there is a long term effect is difficult to determine, partly due to the fact that VR techniques are relatively new and are constantly evolving.

It is also clear that the factors involved in the genesis of symptoms are incredibly complex. Here, there is a complex interaction between the characteristics of the user, the type of system being used and the type of task that is being carried out. Given that there is a large variation between individuals, a huge number of equipment permutations and a vast number of tasks one can see that predicting accurately the effect of any one task in a specific system implementation on a single user is virtually impossible.

The type of system being used certainly has a big impact in the genesis of symptoms. Problems associated with desktop use are well understood, and regulations are in place to determine good working practice. At the other end of the scale are fully immersive systems where current technologies are being pushed to the limit. Although these systems provide the most compelling immersive effect, the genesis of many symptoms have been linked to their use. Somewhere in between these two implementations lie semi-immersive systems. Although it would be reasonable to expect that such systems may cause the genesis of symptoms such as simulator sickness, problems such as immersion injuries, the physical discomfort of an HMD and system lags are minimised. These considerations, and the fact that a reasonably powerful sense of immersion can still be achieved with semi-immersive large screen systems, explain the current trend towards their use. Indeed, many of the VR ‘reality’ centres currently in use concentrate on semi-immersive multi-user implementations rather than fully-immersive single user systems.

Clearly, it is important for any potential VR users to understand the potential of each implementation for the genesis of symptoms. When one chooses a VR system care must be taken to look at the tasks for which the system will be used and the potential user population. If the use of a fully immersive system is imperative for the task then one must understand the health and safety implications. Similarly, if one chooses a desktop system to minimise health and safety problems, one loses the powerful sense of immersion provided by the other implementations. The most important aspect is that the user makes an informed decision and provides a VR set-up that takes into account the needs of the user(s) as well as the demands of the task(s).

Future developments in hardware and software may mean that this scenario will change. Developers are aware of the issues involved and are striving to overcome them. HMD design continues to improve with lighter headsets and better displays with greater fields of view and higher resolution. The effect that this will have on symptoms is also difficult to determine. One could argue that a more realistic experience with minimised lags and more realistic display technologies would reduce the onset of various symptoms as some of the proposed causative factors have been reduced. Not all are in agreement with this hypothesis however, and a quote form Computer Graphics (1992, p. 61) reads

> *"....because of technical improvements, sickness will be more frequent because of the improved ability to create virtual environments involving ‘vehicle’ motions which are naturally nauseogenic."*

If hardware improvements may mean a decrease in physical problems and an arguable reduction in physiological symptoms, what do they imply for psychological problems? Will a more realistic virtual experience provide more powerful psychological cues for the user, making it more difficult to determine real from synthetic? If so, will this lead to greater problems for users? The flip side of this coin is the idea that such improvements may make VR an even more powerful tool.

Recent developments such as the adoption of VRML, improvements in hardware design and the almost constant increases in PC computing power mean that VR technologies are now available to an even greater user population at more affordable prices. Ultimately, it is the users who will decide whether the benefits of VR outweigh the problems. Presently, human factors research has improved awareness of the problems that may occur and to date, none have been shown to be long-term or a serious threat to well being. These problems can however, bring about a reluctance on the part of the consumer to buy and use such equipment and if this reluctance is not addressed, the future potential of VR to have a beneficial effect on our lives may be diminished.

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