

Psychophysiological Effects of Large Moving 3D Displays

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Abstract

Large wide screen displays are increasingly being used to provide information for situation awareness. They may employ virtual reality (VR) technology for moving displays that are immersive and interactive. Yet such displays have potential to cause psychophysiological side effects, including symptoms of nausea, instability and eyestrain. Symptoms may occur while viewing and may also persist for a time afterwards, raising health and safety concerns and reducing effectiveness. The incidence and severity of side effects differ between displays and VR systems, so that empirical studies are needed to develop guidelines for use of a new facility.

FOCAL (the Future Operations Centre Analysis Laboratory) at DSTO Edinburgh has been used to explore new paradigms for future command environments. It employs VR technology with a large 3.6 metre radius, 150° wide field-of-view curved screen, and projectors that display mono or stereo graphics. Previous research in the VR field found field-of-view and visual flow rate to influence the occurrence and severity of side effects from large displays, so an experimental study examined the effects of these two factors with moving 3D displays in FOCAL. Results found both incidence and overall severity of psychophysiological side effects to be high. Of the 20 participants, six experienced moderate nausea in at least one of the four experimental sessions, while only two participants consistently reported having no symptoms. Viewing the display on the full screen resulted in more severe symptoms than viewing it with the field-of-view restricted to one-third of the screen. There was no clear effect of visual flow rate. The pattern of results was complicated by order effects, where viewing the display on the full screen in the first session resulted in higher levels of side effects overall. This finding has implications for a desensitisation regime for naïve or unadapted participants before they view similar displays.

Vection and sense of presence were also measured, and both correlated with severity of psychophysiological side effects, consistent with the greater symptomatology associated with greater realism found in flight simulator studies. This has implications for the degree of realism desirable in a large moving display.

1 Introduction

Rapid advances in the technologies that support network-centric warfare have greatly increased the amount and richness of information that can be delivered to a command centre. As a result, commanders and their staff may spend long, continuous periods of time in a command centre where they view displays designed to support situation awareness and decision-making. Large screens for the provision of a diverse range of displays are becoming increasingly common, which raises questions of how these technologies may be used both safely and most effectively. Many human factors issues are involved, ranging through cognitive, psychophysiological, ergonomic, organisational and social. There are particular issues when a screen is used for the projection of a moving display, which might represent a flyover, remote video or a display designed to support course-of-action (COA) decisions. The moving display has the potential to induce unwanted psychophysiological side effects that may impact on health and safety, reduce the display effectiveness and adversely affect the performance of those using it. This paper is concerned specifically with the psychophysiological issues involved in the use of moving displays, and presents the results of an experimental study assessing the psychophysiological side effects of viewing a large moving 3D display.

FOCAL (the Future Operations Centre Analysis Laboratory) at DSTO Edinburgh employs virtual reality (VR) technology, using a large 3.6 metre radius curved screen with 150° wide field-of-view, and six projectors that display either mono or stereo graphics. This provides for collaborative semi-immersive viewing and interaction (see Figure 1). FOCAL has been used to explore new paradigms for future command environments. Displays that have

been developed include virtual representations of the battlespace and interactive, immersive tools for (COA) visualisation. While moving displays and moving interactive environments can enhance the provision of information and assist analysis, planning and decision making, if they are not appropriately implemented they may easily induce unwanted psychophysiological side effects. These are most commonly symptoms resembling those of motion sickness, but with 3D displays may also include symptoms of eyestrain. Such symptoms have been well recognised as occurring in flight simulators (as simulator sickness) since the 1950s, and have been increasingly observed in the use of VR technologies. It was therefore considered important to identify and understand factors that could induce or exacerbate such side effects in FOCAL, to avoid or minimise adverse consequences for users' health and safety and safeguard the overall effectiveness of the system.



Figure 1. The Future Operations Centre Analysis Laboratory (FOCAL)

2 Cybersickness

Psychophysiological side effects of VR displays (frequently termed cybersickness) can be experienced as symptoms of gastrointestinal distress, postural instability or disorientation, and/or visual symptoms of eyestrain or eye fatigue. These groups of symptoms have been identified as the three dimensions of simulator sickness or cybersickness (Kennedy, Lane, Berbaum & Lilienthal, 1993). The first two dimensions resemble motion sickness symptoms, while the visual symptoms are usually related to the properties of the visual display. Symptoms may be only mild, such as a mild headache or drowsiness, or they may be much more pronounced, such as severe nausea or dizziness. The symptoms most commonly occur while viewing, and may be transient or may also persist for a time afterwards. In some cases, insidious symptoms like instability may occur only after viewing.

While there are individual differences in susceptibility, the incidence of symptoms does depend strongly on the VR system used and on the type of display. For example, in a survey of ten US Navy flight simulators the incidence of sickness varied from 10 to 60% depending on the particular simulator surveyed (Kennedy, Hettinger & Lilienthal, 1990). Incidence in the general population and with untested displays could be expected to be even higher, and indeed Regan and Price (1994) found that among a group comprising civilians, military personnel and fire-fighters, more than 60% experienced symptoms following only a 10-minute immersion in a VR-generated environment using a head-mounted display.

There is a considerable research literature relevant to the problem. This derives from the extensive investigations of simulator sickness, a smaller but increasing number of studies of cybersickness, and studies of other visually induced motion sickness (VIMS). However, because side effects can vary greatly between systems and between different environments displayed on a given system, it is very difficult to provide specific guidelines for design of displays and use of a new system. To do this generally requires empirical investigations using the new system. In particular for FOCAL, there are very few studies of side effects induced by a VR system using a large screen display. Most existing cybersickness studies have employed the more immersive HMDs, so that findings may not generalise to large screens. However, empirical studies using the large FOCAL screen could be expected to have implications for similar usage of other large screen systems.

In a study of the side effects of a new VR display system, it is particularly useful to investigate factors that could be expected to induce or exacerbate symptoms. A number of studies have shown wide field-of-view displays to be associated with a greater incidence of symptoms than are restricted field-of-view displays (Pausch, Crea, & Conway 1992). There are several possible reasons for this. A wide field-of-view is capable of producing a more compelling simulation of motion and thus inducing strongervection, the perception of self-motion. Vection has been associated with increased side effects and may precede the development of actual symptoms (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan 1990). Flicker of the display is more detectable in peripheral than in foveal (central) vision, particularly with a bright display, so that a wide field-of-view may thus indirectly aggravate symptoms (Pausch et al. 1992). The sense of presence, the perception of “being in the virtual environment”, may be increased by the wide field-of-view, although researchers have disagreed as to the relationship between presence and cybersickness symptoms. Some have found increased symptoms with increased presence (eg Wilson, Nichols, & Haldane 1997), while others have found a negative relationship (eg Witmer & Singer 1998). Because the wide screen is a major feature of FOCAL, and it can be used to produce compelling moving displays, field-of-view is one of the factors investigated in this study.

Global visual flow, the rate at which objects flow through the visual scene displayed, has been shown to influence sickness, with faster rates associated with more symptoms (McCauley & Sharkey 1992). A substantial rate of global visual flow would be associated with a display representing a fly-through, which might be used for operational planning as well as mission rehearsal. Effects of fast rate of flow are well understood in flight simulators, which has led to procedural recommendations to avoid rapid gain or loss of altitude, high rates of acceleration, unusual or aggressive manoeuvres, abrupt freezing of the display, and abrupt changing of observer position (Kennedy, Hettinger, et al. 1990). Interactive displays designed for other tasks and purposes in FOCAL would be capable of moving at an appreciable flow rate, and may need to be subject to similar restrictions. Thus rate of visual flow is the second factor that is investigated in this study.

3 The Experiment

The experiment was designed to investigate the psychophysiological side effects of viewing a large moving display projected onto the FOCAL screen, with the main focus on motion-sickness-like symptoms. The main aims of the study were to assess the incidence of symptoms, and to test the effects of two display design attributes that could affect the incidence of symptoms; namely, field-of-view and rate of visual flow. It was considered possible that the two factors could have a synergistic effect in increasing symptoms, and this could also be tested in the factorial design. Controls also allowed for the testing of any order effects in the presentation of conditions to participants.

The study described in this paper obtained approval from ADHREC (ADHREC Protocol 317/03).

4 Method

4.1 Participants

Twenty participants, 18 male and 2 female, were recruited from the civilian staff at DSTO Edinburgh. All were naïve (and therefore unadapted) to the display used. At the time of recruitment, all participants were screened to establish that they were in good health, were briefed on the experimental procedures and possible side effects, and given information sheets before being asked to give signed consent.

4.2 Materials and Apparatus

4.2.1 Forms and Questionnaires

Subjective measures of cybersickness were assessed pre- and post-exposure using the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, et al. 1993), with the four point rating scale for each item as used by Regan and Price (1994). While the SSQ Total Score was the main focus of the assessment, the component dimension scales of Nausea, Oculomotor (visual symptoms) and Disorientation (or Instability) were also assessed.

During the experimental session, the experimenter recorded the participant's malaise ratings based on the four point rating scale of Golding and Stott (1997). Following the experimental session, participants completed the Vection Rating Scale of Hettinger et al. (1990) and the Short Presence Questionnaire, consisting of relevant items taken from the Presence Questionnaire of Witmer and Singer (1998). Participants were asked during initial screening whether they considered themselves to be susceptible to motion sickness, and a Susceptibility Checklist recorded whether the participant had experienced motion sickness as a child or in the last five years.

4.2.2 The Display

The display was required to simulate the continuous movement of the participant through an environment for a period of 20 minutes. It had to be capable of being displayed in 3D with two different fields-of-view (either the full FOCAL screen or a one-third centred section of the screen), and at two different rates of visual flow (fast and slow). The display was also required to contain features that the participant could identify and report, thus ensuring that the participant was attending to the display throughout.

CAVE Quake III was chosen, as it could be used to construct a display to meet the requirements and used software freely available on the Internet. A custom designed CAVE Quake environment was constructed, and a path selected to simulate travelling passively along a predetermined path through the environment. This path could be traversed at either of two simulated speeds of travel: 2.54m/sec (~9.1km/h) for the fast rate, and 1.27m/sec (~4.6km/h) for the slow rate. At intervals along the path of travel, pictures of simple objects were set into shallow alcoves in the walls. Some of these objects could not be identified until the participant appeared to reach them during virtual travel, and some required the participant actively to look to the sides of the screen to identify them.

While the content of the display may not initially appear to be representative for the intended use of large screen displays, it does in fact share flow rates, fields-of-view and the compelling sense of immersion with displays that could be used in a future command centre. It is not extreme in the sense that as a game environment it is widely used, and it was hoped that for this reason it would hold the interest of participants. The CAVE Quake environment is shown in Figure 2.



Figure 2. Participant viewing the CAVE Quake III experimental display

4.3 Experimental Design

To assess both the incidence of cybersickness and the effects of the two display factors, the repeated measures design employed three within-subjects factors each with two levels. These were Pre/Post Exposure, Field-of-View (Full FOCAL Screen vs. Centred one-third of the FOCAL Screen), and Flow Rate (Fast Rate vs. Slow Rate, which was one-half of the Fast Rate). The factors Field-of-View and Flow Rate were fully crossed, so that each participant took part in all four conditions, with testing sessions for the conditions separated by at least one full day. The order of the four conditions was counterbalanced using a Latin Square, to control for any potential order effects. Although order effects were not anticipated, predictions regarding possible adaptation or sensitisation effects could not be made, as there is little existing research on the side effects of large screen 3D displays. The four testing sequences used were:

- 1: Full / Fast, Full / Slow, Centred / Fast, Centred / Slow
- 2: Centred / Fast, Full / Fast, Centred / Slow, Full / Slow
- 3: Full / Slow, Centred / Slow, Full / Fast, Centred / Fast
- 4: Centred / Slow, Centred / Fast, Full / Slow, Full / Fast

The dependent variables were the symptoms of cybersickness, assessed by the following measures. Subjective measures of the three dimensions of cybersickness, namely nausea, instability or disorientation, and oculomotor symptoms, were assessed both pre- and post-exposure using the SSQ (Simulator Sickness Questionnaire) [Kennedy, Lane, et al. 1993], with the four point rating scale for each item. Subjective ratings of malaise were recorded at five-minute intervals during exposure to the VE, using the four point rating scale of Golding and Stott [1997]. This also served to monitor the level of the participant's symptoms while viewing, as if the maximum malaise rating was reached the participant ceased viewing and the length of the viewing time was recorded.

A number of other factors identified in the literature as potentially affecting the incidence and severity of symptoms were controlled. These factors included duration/exposure time, which was fixed at 20 minutes unless the participant experienced symptoms of malaise at the maximum rating and terminated the session. There were no breaks in viewing during the experimental session. Although individual susceptibility was not controlled, possible predictor variables (history of motion sickness) were recorded. Some attempt was made to control for circadian variation by having each of a given participant's sessions at approximately the same time of day. Two other variables that may be associated with motion-sickness-like side effects were recorded; namely vection and presence.

4.4 Procedures

Each participant took part in each of the four experimental conditions, in the order determined by the Latin square sequence to which they had been randomly assigned. Before each experimental session participants were screened to ensure they were in their usual state of health and fitness. The participant completed the pre-session SSQ, and proceeded with the experimenter to the FOCAL Operations Room for the experimental session. Instructions for the session were given. Participants were asked to identify and report each of the objects appearing in the picture alcoves along the path of virtual travel, were reminded of the ratings on the Malaise Rating Scale and that they should call for a halt if symptoms reached the maximum rating on the scale (i.e. moderate nausea with or without other symptoms).

The participant stood in position in the centre of the viewing region (see Figure 2), while the experimenter sat a few metres behind and slightly to the side of them throughout the session. Malaise Ratings were recorded before the display started to move and every five minutes thereafter, unless malaise at the maximum rating was experienced, in which case the participant reported it so that the display could be stopped, the viewing session terminated and the viewing time recorded. Otherwise the display ran for the full 20 minutes. The pictures of objects were visible at regular intervals along the path of virtual travel, and the experimenter recorded each one as it was identified. Participants were not informed of the purpose of the picture object identification, which was merely to ensure that they attended to the display at all times. Some objects were placed to the side of the screen, which meant that participants needed to turn their heads to identify them.

When the viewing session was completed, participants completed the post-session SSQ, the Vection Rating Scale, and the Short Presence Questionnaire. If the participant had experienced any symptoms, they were asked to rest until they recovered, and were reminded to be aware of the risk of poor balance.

A period of at least one full day was allowed between the experimental sessions for each participant, to allow time for full recovery from any symptoms experienced.

5 Results

Results presented here for the Simulator Sickness Questionnaire (SSQ) focus principally on those for the SSQ Total Score. The scores for the three dimensional subscales (Nausea, Oculomotor and Disorientation) that contribute to the Total Score are not independent of each other, and their individual results are only quoted when relevant to illustrate a particular result. In general, results for the subscale scores reflected the same pattern of results as did the Total Scores.

5.1 Occurrence and Severity of Symptoms

Both the incidence and overall level of self-reported symptoms were high. Indeed, they were much higher than anticipated at the time of planning the experimental study. This was reflected in the time the participants were able to spend viewing without experiencing appreciable symptoms, as well as in the self-report symptom measures of the Malaise Scale ratings given throughout the session, and the post-session SSQ scores.

Six of the 20 participants terminated at least one experimental session before the scheduled 20 minutes had elapsed. That is, they reported the maximum rating on the Malaise Rating Scale, indicating that they were experiencing moderate nausea with or without other symptoms. Of the sessions terminated prematurely, the time spent in the VE ranged from 5½ to 16½ minutes. Thus some participants developed marked symptoms in a very short time spent viewing the moving display.

The malaise ratings recorded each 5 minutes during exposure reflected the high symptomatology. Only two participants gave consistent ratings of 0 (no symptoms) for all four sessions. Eleven of the participants reported at least mild nausea for at least one session. Mean and maximum malaise ratings were both strongly correlated with post-session SSQ Total Scores (both Spearman $\rho(80) = 0.8, p < .001$), and negatively correlated with time spent viewing the display (Spearman $\rho(80) = -0.6$ and -0.7 respectively, both $p < .001$).

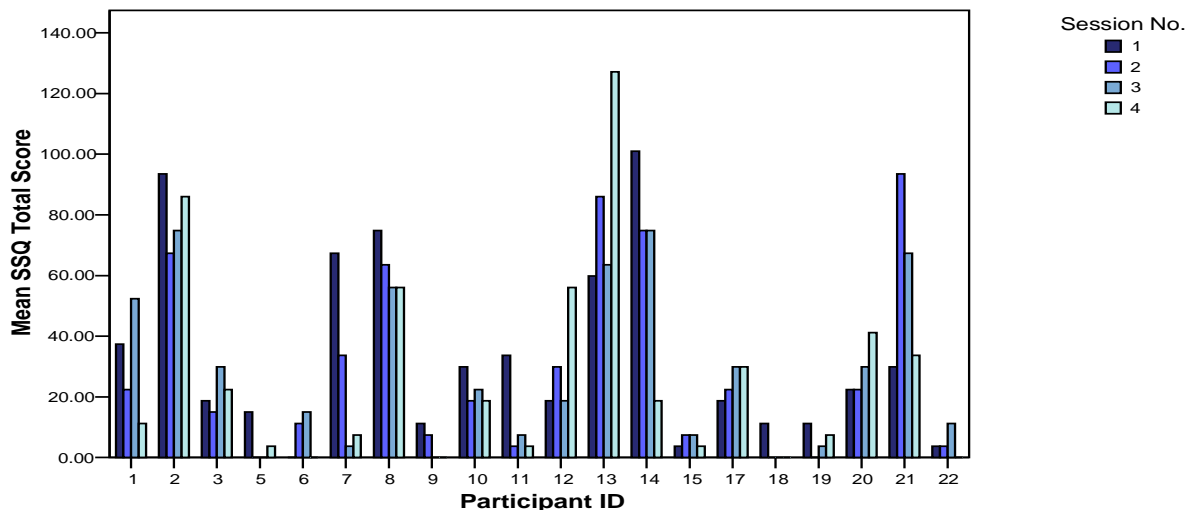


Figure 3. Simulator Sickness Questionnaire (SSQ) Total Scores for individual participants in each experimental session, presented in the order the sessions were experienced (without specifying the condition for each session).

The post-session SSQ Total Scores for the individual participants are shown in Figure 3, and indicate the severity of symptoms induced. As an indication, an SSQ Total Score of 15 represents feeling slightly fatigued with perhaps a slight headache and slight difficulty concentrating. A score below 15 is consistent with being fit for work. Yet as Figure 3 illustrates, most participants had scores considerably above this level. A score of 60, achieved by several participants, represents symptoms of moderate to severe nausea or a moderately severe headache, with dizziness or eyestrain, usually associated with sweating, considerable discomfort and difficulty concentrating. For scores above this level the symptoms were more severe. Clearly viewing the display could induce considerable symptomatology.

5.2 Predicting Individual Susceptibility

While the results indicate differences in individual susceptibility, this could not be predicted either by the participants themselves or by a past history of motion sickness. Each of the following differences was tested using the Mann-Whitney U test. At the time of recruitment, participants were asked if they considered themselves susceptible to motion sickness. This pre-participation estimate was not predictive of whether the participant experienced symptoms, as indexed by their SSQ Total Scores ($U(4, 16) = 24.0, p > .4$). Anecdotally, many of those who experienced side effects expressed their surprise that they did so. History of motion sickness was likewise not predictive of side effects from viewing the display. There was no difference in overall symptoms between those who had experienced motion sickness as a child ($U(8, 12) = 43.5, p > .7$), nor any significant difference between those who had experienced motion sickness in the last five years and those who had not ($U(10, 10) = 44.0, p > .6$). Participants were also asked whether they had previously played the computer game of Quake on a PC. Previous experience with the game also failed to distinguish between those who did and those who did not experience side effects ($U(4, 16) = 17.5, p > .17$).

5.3 Factors influencing Psychophysiological Side Effects

The SSQ scores were analysed to determine the effects of the factors to be investigated (field-of-view, rate of visual flow). Before analysing for these effects, preliminary investigations were carried out to determine whether there were any carry-over effects. This could be either a practice or adaptation effect resulting from repeated experimental sessions, or an effect of the order of presentation of the four conditions.

5.3.1 Carry-over Effects: General Adaptation

Although the research literature might suggest the possibility of adaptation, or the overall reduction of symptoms with repeated sessions, there was very little evidence to suggest a generalised adaptation effect across all conditions. For the post-exposure scores, the overall effect of the number of experimental sessions already experienced on the participants' total SSQ symptom score appeared to be small, and the apparent trend seen in Figure 4 was not significant.

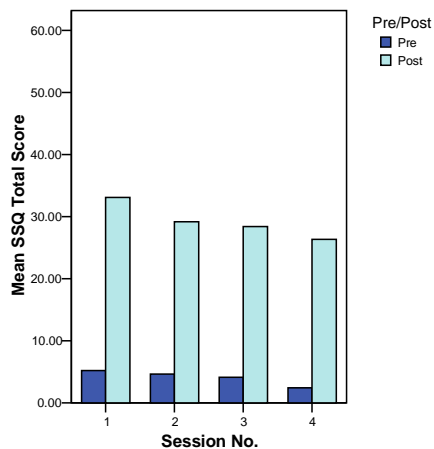


Figure 4. SSQ Total Score for the successive experimental sessions, averaged across conditions.

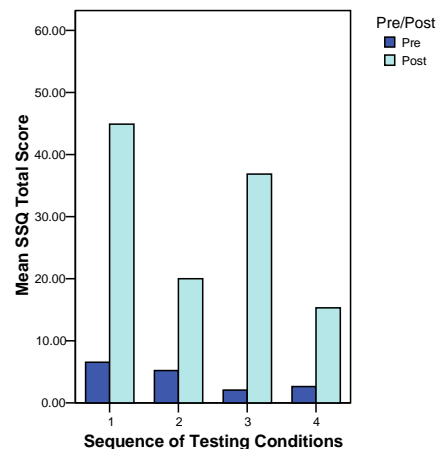


Figure 5. SSQ Total Score for each testing sequence, averaged across experimental conditions.

5.3.2 Carry-over Effects: Order of Conditions

In contrast to the lack of overall influence of repeated viewing of the display, there was evidence of a marked carry-over effect of the presentation order for the experimental conditions. This can clearly be seen in Figure 5, which shows the much higher mean scores for participants assigned to the two sequences in which the full screen field-of-view was presented first (testing sequences 1 and 3). There is also the suggestion in Figure 5 of an effect of order of presentation of visual flow rate (sequences 1 and 2 for fast rate versus sequences 3 and 4 for slow rate). Although these apparent order effects were not predicted or expected, the counterbalancing of condition order did control for such effects. This made analysis of the order effects possible by including field-of-view and flow rate presentation orders as factors in the overall analysis.

5.3.3 Overall analysis of SSQ Scores

The SSQ Total Scores were analysed as a five-way mixed ANOVA, with the between subjects factors of Order of Field-of-View and Order of Flow Rate, and the within subjects factors of Pre/Post Exposure, Field-of-View and Flow Rate. The distributions of scores showed a positive skew, so the ANOVA was carried out on a log transform of the scores. Results of the analysis showed a highly significant effect of the pre/post factor, with the mean post-exposure SSQ Total Score substantially higher than the mean pre-exposure SSQ Total Score ($F(1, 16) = 43.4, p < .001$). This effect was very strong, with a Partial Eta Squared of 0.73. There was a significant interaction between Pre/Post and Field-of-View ($F(1, 16) = 5.3, p < .05$), where there was no difference between the Field-of-View conditions in the pre-exposure scores, but the post-exposure scores were higher for the full screen than for the centred screen. Partial Eta Squared for this effect was 0.25. The interaction between Pre/Post and the Order of Field-of-View approached significance ($F(1, 16) = 3.3, p = .087$), again with no pre-exposure difference between Field-of-View order conditions but higher post-exposure scores when the full screen conditions were presented in the first session. It is perhaps worth mentioning that for the three component scales of the SSQ, the Disorientation (or Postural Instability) scale did show a significant Pre/Post by Order of Field-of-View interaction ($F(1, 16) = 5.0, p < .05$). A significant interaction between Field-of-View and Order of Field-of-View presentation suggested that the effect of the full screen was greater when it was presented first, although this effect was not an interaction with Pre/Post. There was a significant three-way interaction between Pre/Post, Field-of-View and Order of Flow Rate ($F(1, 16) = 4.6, p < .05$), and a statistical trend to a three-way interaction between Pre/Post, Field-of-View and Order of Field-of-View ($F(1, 16) = 3.2, p = .095$). These indications of order effects are followed up below. There were no significant higher order interactions, and no evidence of effects of either flow rate or order of presentation of flow rate.

5.3.4 Effect of Field-of-View

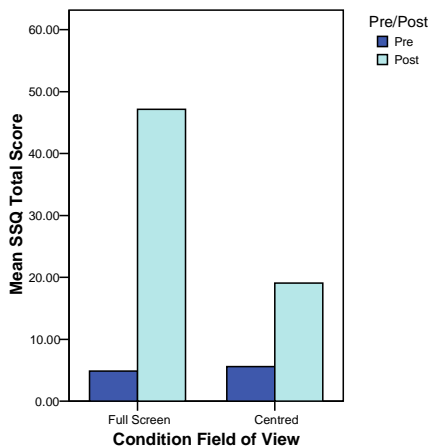


Figure 6. First session SSQ Total Scores showing levels for the two field-of-view conditions.

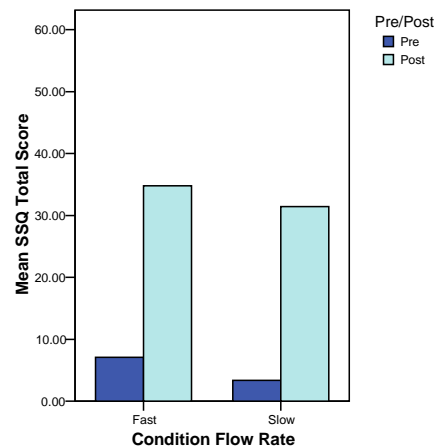


Figure 7. First session SSQ Total Scores showing levels for the two flow rate conditions.

Due to the presence of carry-over order effects, the SSQ Total Scores for the first session were analysed separately as a three-way repeated measures ANOVA, with the factors Pre/Post Exposure, Field-of-View and Flow Rate. Scores for the first session are uncontaminated by any carry-over effects, so this represents an unbiased test of both field-of-view and flow rate. This analysis also showed the highly significant pre/post effect ($F(1, 16) = 26.2, p < .001$), again a strong effect with a Partial Eta Squared of 0.62. The Pre/Post by Field-of-View interaction was also significant in this analysis ($F(1, 16) = 4.8, p < 0.05$) with a Partial Eta Squared of 0.23, again showing no difference between conditions for the pre-exposure scores, but higher post-exposure scores for the full screen than for the centred screen. There was no significant effect of flow rate, and no significant interaction between the two display factors. This result for the first session provides compelling evidence that viewing the full screen field-of-view induces greater symptoms than viewing the centred screen. Figure 6 illustrates the differing levels of symptoms for the two field-of-view conditions, while the comparison Figure 7 for the two flow rate conditions shows no similar effect.

5.3.5 Condition Order Effects

The apparent effects on symptom scores of the order of conditions, and their interactions with display field-of-view, found in the full five-way ANOVA were followed up by two four-way ANOVAs. The first of these analyses combined the pairs of testing sequences having the same order of testing field-of-view conditions and tested the order of flow rate and its interactions (Pre/Post X Order of Flow Rate X Field-of-View X Flow Rate). The second combined the pairs of sequences having the same order for flow rates and tested field-of-view order and its interactions (Pre/Post X Order of Field-of-View X Field-of-View X Flow Rate).

In the first of these ANOVAs, the strong pre/post effect ($F(1, 18) = 48.5, p < .001$) and the significant interaction between pre/post and field-of-view ($F(1, 18) = 4.6, p < .05$) were again found, along with the significant interaction between field-of-view and the order of field-of-view conditions ($F(1, 18) = 11.6, p < .01$). The interaction between Pre/Post and Order of Field-of-View approached significance at the 0.05 level ($F(1, 18) = 3.7, p = .070$), again with no pre-exposure difference between the field-of-view orders but higher post-exposure scores when the full screen conditions were presented in the first session. The Disorientation (or Postural Instability) scale showed a significant Pre/Post by Order of Field-of-View interaction for this effect ($F(1, 18) = 5.5, p < .05$). This trend for the SSQ Total Scores, and the significant effect for the Disorientation/Postural Instability scale, has been consistent throughout the analyses. The experimental design was not constructed to test for the effect, but the result does suggest that side effects may be increased by presenting viewers with the full screen on the first session, and reduced by first presenting them with the smaller display, and this may provide a useful clue for developing a desensitisation procedure. An illustration of the influence of field-of-view presentation order is given in Figure 8, which suggests that even though the difference in symptom levels between the two groups decreases across sessions they experience other conditions, scores for those viewing the full screen first may remain higher.

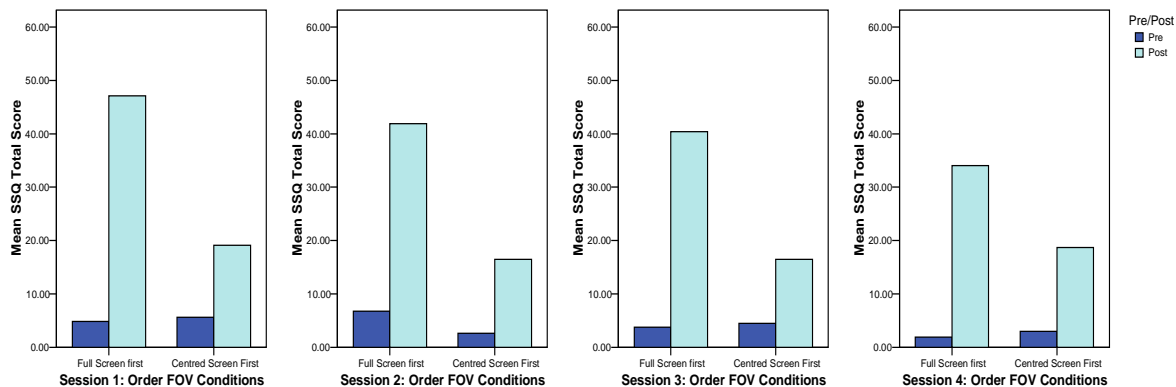


Figure 8. Comparison of the SSQ Total Scores for successive testing sessions without regard to experimental condition, but comparing those who viewed the full screen in the first session with those who viewed the centred screen first.

The second of the two ANOVAs also found the strong pre/post effect ($F(1, 18) = 40.4, p < .001$) and the significant Pre/Post by Field-of-View interaction ($F(1, 18) = 4.9, p < .05$). The Pre/Post by Field-of-View by Order of Flow Rate interaction fell just short of statistical significance ($F(1, 18) = 4.3, p = .053$). This trend was due to a tendency for the full screen to induce higher symptom scores when the slow rate was presented first. Again, this may provide a clue when designing a future desensitisation procedure for testing.

5.4 Vection and Presence

Ratings for vection, the perception of self-motion as opposed to the perception that one is merely viewing a moving display, were significantly higher for the full screen display than for the centred screen (Wilcoxon Signed Ranks test) ($Z = 3.1, n = 40, p < .01$). Vection ratings were also significantly correlated with the SSQ Total Scores ($\rho(80) = 0.23, p < .05, 2$ -tailed).

Scores on the Short Presence Questionnaire, representing the perception of actually being in the environment of the display, were significantly higher for the full screen display than for the centred screen (Wilcoxon Signed Ranks test) ($Z = 5.0, n = 40, p < .001$), and also higher for the faster flow rate ($Z = 2.5, n = 40, p < .05$). Scores for presence were positively correlated with both SSQ Total Scores ($\rho(80) = 0.23, p < .05, 2$ -tailed) and with vection ratings ($\rho(80) = 0.34, p < .01, 2$ -tailed).

6 Discussion

The high level of psychophysiological side effects experienced and the number of participants affected indicate a definite problem with viewing moving displays on the FOCAL screen. A substantial number of the participants reported moderate to severe symptoms, and this was not limited to those who were susceptible to motion sickness. The fact that the participants themselves could not reliably predict whether they would experience symptoms, and the lack of predictive value of a past history of motion sickness, means that any naïve viewer is potentially at risk of side effects. The display was certainly a compelling depiction of being in the CAVE Quake environment, but it is a display familiar to many people, particularly young game players who frequently play first-person shooter computer games. The display used the wide screen in a way that is not inconsistent with providing situation awareness displays (see Figure 1), and the two flow rates used were not depicting particularly rapid, erratic or violent motion. The display in the study was projected in 3D, but the stereo projection would not be sufficient to explain the motion-sickness-like symptoms experienced by the participants. Thus the experiment revealed a problem that needs to be addressed.

The experiment demonstrated that use of the full screen to view a moving display induced greater symptoms than having the display confined to only the centred one-third of the screen. This result was found in both the overall analysis, and the analysis of data from the first session, which was uncontaminated by carry-over effects. It was also a relatively strong effect, though less so than the dramatically strong pre/post difference in reported symptoms. This means that side effects can be reduced by restricting moving displays to a smaller section of the large screen.

Vection, the perception of self-motion, and presence, the degree to which the participant perceives themselves as actually being in the depicted environment, were both correlated positively with cybersickness symptoms. This is consistent with findings from flight simulators in which a greater degree of realism induces a higher level of simulator sickness. It is notable that both vection and presence were greater for the full screen display than for the centred screen. This may suggest that a high degree of realism is not desirable in a large moving display. According to the sensory conflict theory of motion sickness (Reason & Brand, 1975), in which conflicting cues from the various senses induce the symptoms, greater realism of the display would make the conflicting cues more subtly different and therefore harder to resolve, thus increasing symptoms. Thus while the relationship shown here between vection, presence and cybersickness symptoms is only correlational, it may be wise to limit the degree of realism in large displays.

The order effects were an unexpected finding. Although the experimental design did control for such effects, it was not set up to test for them fully. Yet there were good indications that viewing the display on the full screen in the first session resulted in a higher level of symptoms not only for that first session, but also across subsequent sessions. This effect can be seen in Figure 8. Analysis of the SSQ Total Score showed a statistical trend in this

direction that almost reached significance. For the dimension of disorientation, or postural instability, viewing the display on the full screen first did result in significantly greater symptoms overall across sessions. One interpretation of this result is that the higher symptomatology induced by the first viewing on the full screen sensitised the participants to a greater response of symptoms in subsequent sessions. The results do suggest that it may be possible to desensitise naïve or unadapted viewers by designing a schedule in which participants are presented first with a small display, and then by displays of increasing size. Thus the unexpected finding may give a valuable clue to overcoming the problem of side effects. This remains to be tested in a follow-up experiment.

While the experiment reported here was run on the large FOCAL screen, the results may well apply to other moving displays on large screens. Thus the findings have implications beyond the FOCAL facility.

7 Conclusions

The experiment demonstrated that moving displays on the FOCAL screen can induce a considerable level of psychophysiological side effects. It is suggested that this effect would be shown with any large screen and a moving display. Consistent with previous research, the study found that symptoms were greater for displays shown on the full screen as compared to a centred one-third section of the screen. A greater perception of realism of the display could be associated with a higher level of symptoms. An effect of order of field-of-view presentation was found, so that viewing the display on the full field-of-view screen first could lead to higher levels of symptoms on subsequent viewings. This unexpected finding provides a useful clue as to how the side effects might be reduced, by designing a desensitisation schedule for naïve and unadapted viewers. This should be tested in a follow-up experiment.

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