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Habituation to the side effects of immersion in a virtual environment

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Abstract

When people are exposed to movement within a virtual environment, they experience symptoms, such as nausea, which are similar to those of motion sickness. True motion sickness is reduced or eliminated by repeated exposure to motion, and we examined whether people also habituate to the visual appearance of motion. Nineteen subjects used a non-tracked Head-Mounted Display (a 'personal display system') to view the game 'Wipeout' for 20 min on five consecutive days. On average, they reported significantly less nausea and a delayed nausea onset on the fifth day compared with that reported on the first day. Thus, we conclude that habituation did occur. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Virtual reality; Adaptation; Vision; Motion sickness; Nausea

1. Introduction

The rapid development and increasing popularity of Virtual Reality (VR) headsets, incorporating Head-Mounted Displays (HMDs), has raised questions about their effects on the health and safety of VR participants. In particular, there is concern over the nature of some of the side effects caused by immersion in a Virtual Environment (VE), including nausea, eyestrain and general visual discomfort. There are potentially considerable advantages to be gained by using VR in industry, medicine and education, especially in the areas of training and the evaluation of equipment [1]. Similarly, there are applications in the entertainment industry, where VEs may be viewed using 'personal viewing systems' consisting of untracked HMDs and low-cost computing hardware. However, if the VR technology is to become widely accepted, any questions surrounding issues of health and safety must be answered satisfactorily, and any side effects must not be detrimental to users.

Concern over the health and safety aspects of VR led the UK Health and Safety Executive (HSE) to launch a two-year study in 1994 into the potential visual and psychological effects of VR. The study, completed in 1996 [2], highlighted such side effects as simulator sickness, disorientation and physical discomfort. All these symptoms have been noted the first time people use an HMD and it is possible that some effects may change with additional exposures. Regan [3] reported that repeated immersion in a Virtual Environment produces small amounts of habituation and that over time side effects such as nausea and eyestrain become less pronounced and even disappear in some participants. However, as will be seen, the interpretation of these results is difficult because of the long periods between immersions.

The malaise experienced during immersion in a VE appears to be polygenic and polysymptomatic and has been termed Virtual Simulator Sickness (VSS) to distinguish it from simulator sickness caused by mechanical simulators, and from other, more desirable, side effects of immersion, such as pleasure [4,5]. When an HMD is worn, these adverse side effects are found both when the head is tracked and when it is not [5]. The symptoms of VSS, such as nausea and dizziness, mimic some of those reported during motion sickness, simulator sickness and space sickness [3–7]. However, even though the symptoms may be similar, their genesis is not necessarily the same. Generally, the VSS symptoms caused by immersion in the VEs are induced visually, whereas those caused by actual motion may not be.

In some simulations, such as those used in driving simulators, and in many films, changes in the visual world (the 'optic flow') lead to the feeling that the body is moving. This information is different to that provided by proprioceptors and the vestibular system, which reports that the body is stationary. It is this form of sensory conflict that is normally

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experienced in Virtual Environments [5] and people do not suffer from motion sickness in a VE if they close their eyes, whereas closing the eyes is no protection against conventional motion sickness.

People are known to habituate to motion [8–11], but it remains to be seen precisely how they habituate to the *appearance* of motion. In a recent study of repeated exposure to a VE [12], it was found that participants immersed for ten consecutive trials reported significantly lower malaise ratings on the last trial than on the first and the suggestion was made that habituation to the appearance of motion caused this reduction. However, the problem with interpreting the results of this study, and those of Regan [3], is that there are a number of potential causes of the change:

- Behavioural adaptation—people could reduce the amount of head movement during immersion in the VE, which would result in both a reduction in sensory conflict (whether the head was tracked or not) and a reduction in muscular tension and strain, resulting in a reduction in nausea.
- Practice—people may improve, with practice, at the task performed in the VE and so the visual stimulus would change, possibly becoming more stable.
- A change in a subject's criteria as a consequence of the questioning—participants may be cued to report sensations of nausea as a result of the questions asked by the investigator [13].
- Physiological adaptation—habituation takes place as a result of a reduction in sensory conflict. This is similar to the habituation seen in motion sickness [8–11].

In the light of these various potential reasons for changes in reported nausea, the current study had two aims. The first was to confirm that habituation does take place with repeated exposure to the VE, and the second was to examine whether an increase in visual stimulation alone is accompanied by an increase in habituation. This increase is predicted from Sensory Conflict theory, because the visual sense reports self-motion, but the vestibular system reports that the head and body are stationary [5,9,10,14].

Two groups of participants played a computer driving game in an immersive VE, on five consecutive days. During the immersion, their subjective feelings of malaise were recorded at one minute intervals. One group underwent a further immersion using the HMD after each trial. In this second immersion it was the experimenter who controlled the vehicle and the participant adopted the role of passenger. Both groups, therefore, had the same amount of practice at the computer game, but had different amounts of exposure to the visual stimulus. If neural changes occur as a consequence of visual stimulation, we would expect members of the second group to show greater habituation than those in the first. This habituation could manifest itself in two ways, either as a reduction in the severity of a symptom after exposure for a given period of time or as an increase in the time taken to reach a particular severity.

2. Method

2.1. Participants

Of the twenty-six people who started the experiment, nineteen (six female and thirteen male, mean age 29 years) completed it. These were mainly undergraduates, postgraduates and teaching staff of Loughborough University. All were unpaid volunteers replying to advertisements placed around the campus of Loughborough University, apart from three who had been told of the experiment by friends who were participants themselves. All participants reported that they were healthy, were not suffering from any vestibular dysfunction, and were not taking any medication during the experiment. Only one person had ever used an HMD before, and this was over six months before the start of the experiment. The true purpose of the experiment was withheld from the participants, who were told that the aim was to measure driving performance during immersion.

2.2. Apparatus

The bi-ocular (non-stereoscopic) visual stimulus was presented with a Virtuality Dynovisor HMD. This HMD does not track the head position, and thus the system can be considered to be a personal viewing system similar to the one used by Howarth and Costello [5]. The visual stimulus was a CD driving game called Wipeout, which was run on a Sony PlayStation® incorporating a 'Power Pad' controller. Wipeout is a game in which competitors race a hovercraft around a futuristic circuit against seven other racers and this task was chosen to maintain the participants' interest during the experiment. The hovercraft can move in a number of ways—left, right, up, down and in a rolling motion—and we have found the game to be a particularly powerful nauseogenic stimulus. The PlayStation was also connected to a monitor so that the experimenter could view the image seen by participants through the HMDs, and thus could record performance times.

2.3. Procedure

Each participant took part in five trials in total, being immersed for five consecutive days, beginning on a Monday. For some people (the 'control' group) this trial consisted of a single twenty-minute exposure to the VE, during which time they played the game by controlling the vehicle themselves. For the others (the 'experimental' group) a second immersion of fifteen minutes followed the first immersion and the completion of some questionnaires. During this second immersion, participants simply viewed the game (through the HMDs) whilst the experimenter controlled the vehicle.

Before the commencement of the experiment each person filled in a consent form and a motion sickness history questionnaire, and before and after immersion on each day participants completed additional questionnaires (which have

Table 1
The Malaise Rating (MR) Scale

Malaise rating	Verbal report
1	No symptoms
2	Some symptoms, no nausea
3	Mild nausea
4	Moderate nausea

been analysed separately [15]). During each trial, participants were asked to rate themselves on the four point malaise scale (Table 1), as commonly used in motion sickness studies [16,17] at one minute intervals. The metric of interest was the malaise reported during immersion and it is these changes alone that are reported here.

Following each immersion, participants continued to rate themselves on the malaise scale at one minute intervals for the first five minutes post immersion so that their recovery could be evaluated. When they had reached baseline levels they were asked to sign the post immersion consent form and they were then free to leave.

2.4. Data analysis

For the first analysis, to determine whether participants had habituated during the course of the experiment, the highest malaise ratings each person reported during trials 1 and 5 were compared using a Binomial Sign Test [18]. It was expected that the former would be higher than the latter if habituation had occurred.

A different metric was needed to allow comparison between the two groups, however, and the one chosen was the time taken for each person to first report an increase on the malaise scale. A different technique was required for this second analysis as, although a matching process had been employed initially in the assignment of participants to each group, there was no way of knowing at the outset which participants would not complete the full five days. As a consequence of subjects dropping out, we were unable to achieve a totally satisfactory match between the groups at the end of the experiment and our analysis procedure needed to take this into account.

First, the nineteen participants were ranked within the sample according to the time taken to report an increase in malaise on the first day. This process was repeated for the last day; if there had been no increase then a time of 21 min was recorded. The change in the rank order of the two groups between trials 1 and 5 was then analysed using the Mann–Whitney *U* test for Unrelated Data. If the groups did not differ, then, on average, the rank of each participant would be unchanged between trials 1 and 5. However, if the groups differed as a consequence of the different exposure then the rank of each participant would change and the direction of their change would depend upon their group.

Performance at the racing task was evaluated by recording the fastest lap that the participant achieved each day. In order to compare the practice effect (and consequent change in visual stimulus) for each group, the same analysis procedure was performed: subjects were ranked according to their performance on both the first and the last day and the change in rank over the week for each group was compared.

3. Results

3.1. Subjects

Of the nineteen people who completed the experiment, eight had been placed in the control group at the outset and eleven in the experimental group. The large number (seven) of people who declined to complete the study is testament to the nauseogenicity of the stimulus. The average age of each group was 29 years and both groups contained three females.

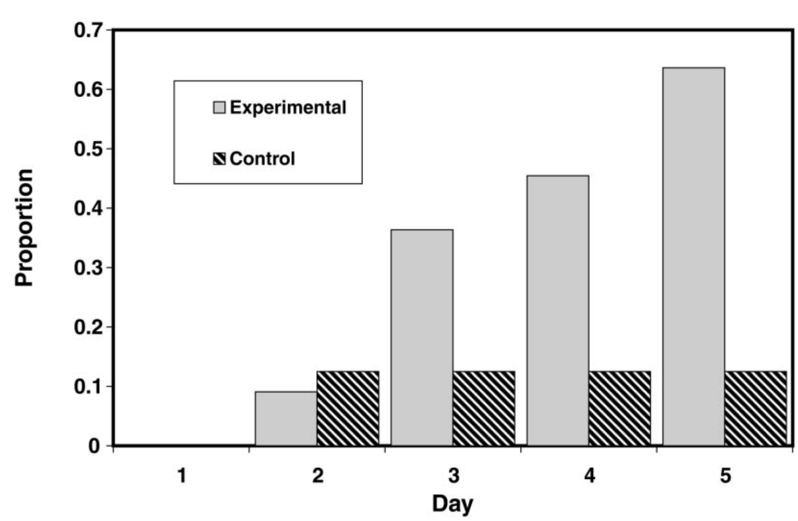

Fig. 1. The proportion of subjects who reported no symptoms during each trial.

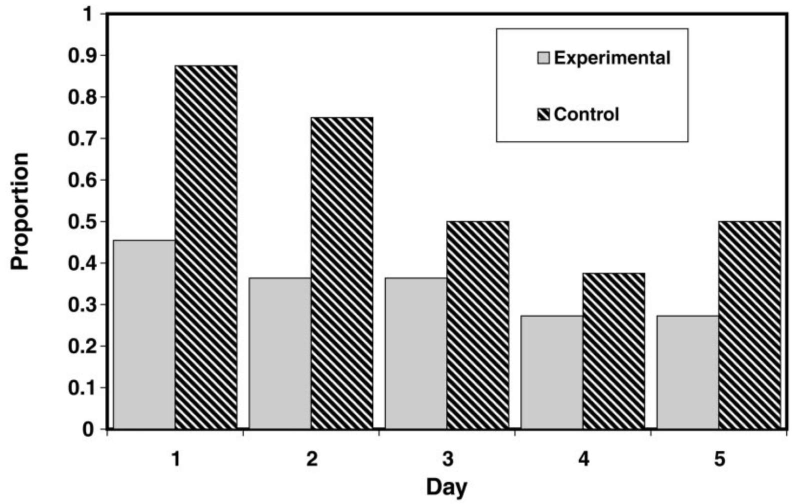

Fig. 2. The proportion of subjects who reported mild nausea (SR3) or worse, on each day.

3.2. Change in malaise over the week

Fig. 1 shows the number of participants who remained at MR1 (no symptoms) during each of the five trials. In trial 1, none of the participants remained symptom-free, as reporting some malaise was a requirement to participate in the experiment. On the second day, two participants remained at MR1 for the entire 20 min immersion in the VE and by the end of the week eight participants failed to report any symptoms by the end of the immersion period. There appeared to be a difference between the groups, as there was a daily increase in the proportion of people who failed to report experiencing any symptoms during immersion in the experimental group, whereas all but one of the control subjects experienced some symptoms every day of the week.

Turning to the proportion of subjects who had reached MR3 (mild nausea) by the end of the immersion period, we now see clear evidence of habituation in the control group as well as in the experimental group (Fig. 2) and both groups showed a steady decline over the week. For the sample as a whole, twelve of the nineteen participants reported feelings of mild nausea at some time during trial 1, compared with only seven by trial 5.

A third way of examining the changes over the week is to consider the time that participants took to first report an increase on the malaise rating scale. There was a steady daily increase in this measure over the week and during trial 5 the mean time before an increase occurred was 12.53 min compared with 4.58 min in trial 1.

Finally, as a computational confirmation of the changes over the week, a comparison was made between the highest rating each participant reported on the first and fifth trial. Fourteen participants reported a lower rating on day 5 than day 1 and the other five reported the same rating ($p < 0.001$). No one reported a higher rating at the end of the week than at the beginning.

3.3. Comparison between groups

Unfortunately, the ratings of the two groups differed

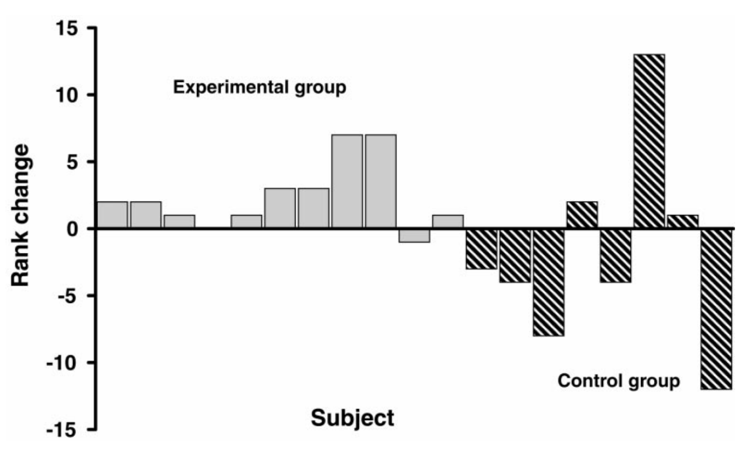

Fig. 3. The change in overall rank for each subject, within the whole sample, between the first and fifth days.

slightly at the end of the first day (before the experimental group had been re-immersed). This difference can be seen by comparing the proportion of each group who reached MR3 on the first day (Fig. 2). The control group, on average, reported a rating 0.5 higher than the experimental group and this difference led to the adoption of the ranking analysis used.

Fig. 3 shows the rank change for each subject between the first and fifth days. The groups differed in this change ($p < 0.024$) with the experimental group showing the greater habituation.

As a consequence of the concern over the initial difference between the groups, a further analysis was performed. The data from those participants in the experimental group who had shown little change in rating on the first day was removed. When this was done, the groups were exactly matched on their initial rating. When the ratings on the final day were compared, the experimental group again showed significantly lower ratings than the control group.

3.4. Performance

No significant difference was found between the groups in the improvement of performance of the game over the week ($n = 19,\ U = 23;$ n.s.).

4. Discussion

The study had two aims. The first was to confirm the occurrence of habituation to the symptoms of malaise brought about by immersion in a Virtual Environment using an HMD over five consecutive trials [12]. The second was to investigate whether participants exposed to a visual stimulus for longer would habituate to a greater extent than those who had less exposure, and this was found to happen. There were four possible reasons suggested earlier to explain any changes that might occur and each of these needs to be examined now in the light of the differences found between the two groups.

First, practice at the driving game would have altered the visual stimulus for all of the participants over the week. A reduction in the number of crashes, as participants became more skilled at driving the hovercraft, could have made the overall movement of the visual stimulus smoother and this could have altered the nauseogenicity of the stimulus. On the other hand, the increased skill could have allowed participants to drive around the course faster, increasing the nauseogenicity of the stimulus. Although the existence of practice effects cannot be discounted, they cannot account for the differences seen between the two groups. This is because the groups did not differ significantly in the amount of performance improvement, and any practice effects that did occur would have affected both groups equally.

Second, subjects could have been 'primed' to expect the occurrence of unpleasant symptoms, although whether this would have made people more likely (suggestibility, [13]) or less likely (a 'macho' effect [2]) to report them is unclear. A comparison between the groups again allows us to reject this explanation as accounting for all of the changes seen. Although one might expect any 'priming' to be constant for an individual over the week, criterion changes could have taken place once the subjects had experienced the symptoms. However, there is no reason to suppose that these changes would be greater for one group than for the other.

Third, behavioural changes such as reduced head movements may have altered the nauseogenicity of the stimulus. Such head movements have been implicated in the generation of adverse symptoms when an HMD, devoid of head tracking, was worn to play chess [5]. Here, small head movements would have altered the position of both the head and the screen. Although the vestibular system would record the head movement, the lack of movement in the visual stimulus (relative to the head) would provide conflicting information, namely that the head was still. According to sensory conflict theory [14,19], adverse symptoms would be expected to follow—which is what Howarth and Costello [5] found. Behavioural changes could also account for the results of Regan's [3] study. In her experiment there was a four-month period between the first and the second immersions and the same time between the second and the third immersions, and if the stimulus had been real motion, rather than the appearance of motion, one would not expect any habituation to have remained. It is generally accepted that long-term physiological adaptation does not occur when exposures to nauseogenic motion are more than a week apart [20] and a similar finding has been reported for habituation to vection-induced nausea [21]. Regan [3] reported a small reduction in symptoms after the second immersion, but no further reduction after the third, and it is possible that during the first immersion people simply learned not to move their head. This suggestion was made in an unpublished study by Ramsey [22] who exposed subjects on three occasions, each a week apart, and saw a decrease in nausea between the first two immersions, but not between the second and third. Behavioural changes could well account for some of the changes seen in the current study, but it seems unlikely that such changes would consistently reduce the symptoms on a daily basis (Figs. 1 and 2). Also, there is, again, no reason why these changes should have been different for the two groups. Observation of the participants revealed that different people moved their head by different amounts, but no consistent changes were seen over the week as a whole.

Thus we are left with the conclusion that there must have been physiological habituation to the appearance of motion, and that this habituation was greater in the experimental group than in the control group. The groups differed slightly in the symptom report on the first day, in that a greater proportion of the control group reached MR3, and hence could be said to be more susceptible to VSS than the experimental group. However, this difference cannot account for the different habituation seen between the groups. One would expect the group with the greater initial symptoms to show the greater habituation, as they had more scope to change, but in fact the *opposite* result was seen and it was the experimental group that showed the greater change in rank.

In summary, although it is not possible to say with certainty that all of the change in reported malaise was as a consequence of habituation, it seems likely that at least part of it had this cause. This finding supports the idea that much of the nausea that is a component of VSS is a consequence of the appearance of motion in the VE, leading to a form of vection-induced motion sickness resulting from the feeling of self-motion. Given the current trend to improve the fidelity of Virtual Environments, it is somewhat ironic that the increased feeling of self-motion associated with this fidelity improvement could both increase the participants' feeling of 'presence' in the VE and increase the side effects of the immersion.

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