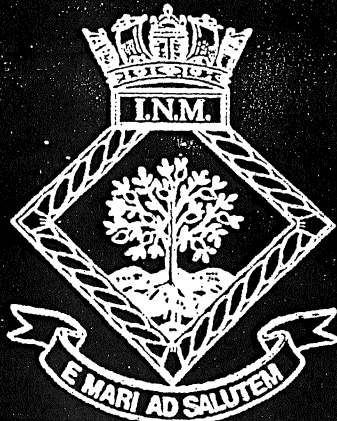# UNITED KINGDOM INFORMAL GROUP MEETING ON

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AN INVESTIGATION OF THE EFFECTS OF LAGS ON MOTION SICKNESS WITH A HEAD-COUPLED VISUAL DISPLAY

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Abstract

Display lags within head-coupled displays impair the ability to change the orientation of displayed images according to head movement. It is hypothesised that the discrepancy between head motion and the delayed response of a head-coupled display will cause motion sickness. Effects of a 280 ms lag and head movement on motion sickness is studied.

Forty-eight male subjects participated in the experiment. Nausea ratings increased significantly after five minutes of simulation. In this study, neither head movement nor the additional 280 ms lag had a significant effect on the severity of the reported nausea symptoms.

About 60% of the subjects suffered 'general discomfort' after the experiment and 'eye-strain' was the most frequently reported symptom. Four subjects withdrew from the experiment after suffering 'moderate nausea'. Nausea symptoms after the simulation were found to correlate with the rated level of realism of the simulation. Possible causes of motion sickness by visual stimuli are discussed.

1.0 INTRODUCTION

People can normally select their field-of-view using rotational head movements. Such ability is inhibited when viewing images presented on a display monitor: the monitor is only visible with certain head angles. With a head-coupled visual display, the field-of-view can be selected by head movement: it is continuously updated according to the head orientation. In recent years, this type of display has been referred to as a virtual reality display.

A head-coupled visual display consists of a helmet-mounted display and a helmet-pointing system (Figure 1). The former presents an image to an operator regardless of the head orientation and the latter measures the head orientation. Inevitable lags occur between the moment at which the head orientation is sampled and the moment the image is presented. Such lags have been referred to as 'display lags' (So and Griffin, 1993, 1994). In the context of this paper, the display lags are pure time delays.

Movement of a large visual scene gives the illusion of self-motion in the opposite direction (vection). This experience can be nauseogenic (visually-induced motion sickness, Griffin, 1991). When visual stimuli are perceived in the absence of expected signals from the vestibular receptors, 'sensory conflict' may be produced (Reason and Brand, 1975). The sensory conflict theory provides a qualitative explanation of the cause of motion sickness. However, the theory does not indicate how sensory conflict can be measured and, therefore, succeeds more in post-hoc explanation than in prediction (McCauley and Sharkey, 1992). In order to determine quantitative relationships between stimuli (in this case, visual scene movements) and symptoms of sickness, experimental studies are needed. Griffin (1991) summarised various experiments concerning motion sickness with specific types of motion and stimuli.

McCauley and Sharkey (1992) predicted that when head-coupled displays are used to present simulation with rich scene content, the viewer may experience a strong sense of self-motion (vection) and, hence, visually-induced motion sickness. Based on studies concerning motion sickness with fixed-based simulators, Hettinger and Riccio (1992) hypothesised that (i) simulation with head-coupled visual displays would induce vection-related visually-induced motion sickness; and (ii) detectable display lags would also induce sickness. Pausch *et al.* (1992) reported a literature survey of flight simulator sickness
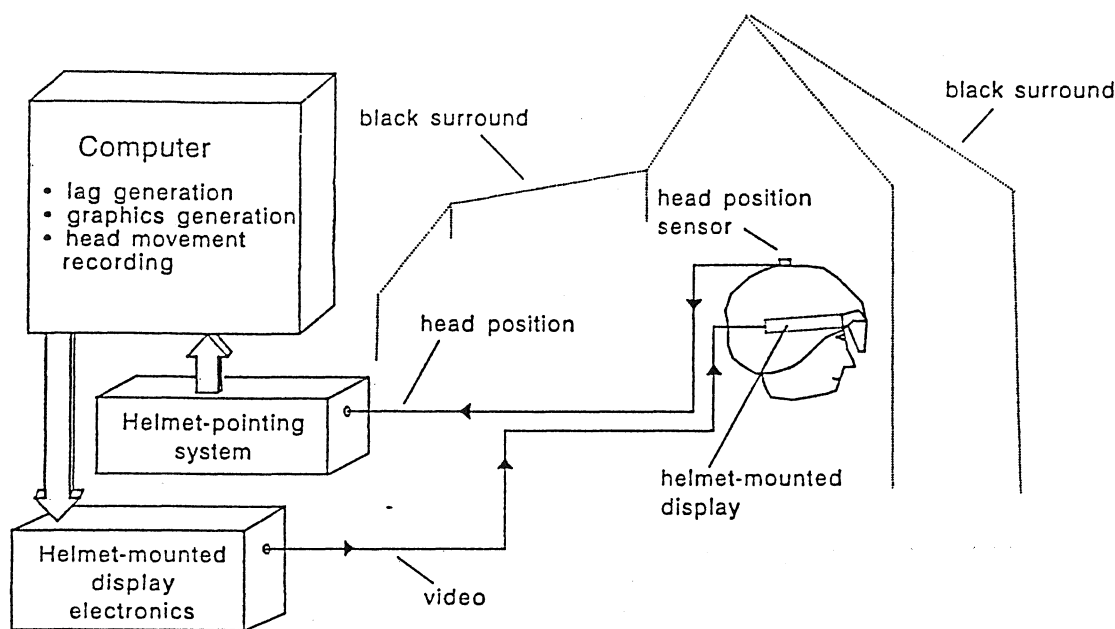
Figure 1   The head-coupled visual display used in the experiment.

studies with specific emphasis on virtual reality displays. Effects of lags in updating a visual scene according to a manual control signal were discussed. However, an effect of display lag on motion sickness was not reported because 'display lags' are unique to head-coupled displays.

Regan and Price (1993a) reported that after a 20 minute simulation with a virtual reality display, 61% of the subjects reported symptoms of malaise. The symptoms ranged from 'headaches' and 'eye-strain' to 'severe nausea'. A total of 150 subjects were used and 5% of the subjects had to withdraw from the experiment due to 'severe dizziness'. Equipment and display related symptoms such as 'helmet pressure', 'display resolution' and 'display lag' were also investigated. Among the 30% of the subjects who reported disturbance during head movement, 42% specified 'lag' as the cause of their disturbance. The system had a display lag in the order of 300 ms (Regan and Price, 1993b). In another experiment with 44 subjects, Regan and Price (1993c) reported that there was no significant difference between the malaise ratings of standing and seating subjects. Subjects were instructed to glide rapidly through a simulated environment with pronounced head movements. The speed and the direction of gliding were controlled manually by the subjects.

2.0   AIM AND HYPOTHESES

The objective of the study was to investigate the effect of display lag on sickness caused by head-coupled simulation. It was hypothesised that:

(i)   the perception of a moving visual scene without corresponding movement of the body would cause motion sickness; and

(ii)   the discrepancy between head motion and the delayed response of a head-coupled display would increase sickness.

3.0   MATERIALS AND METHODS

3.1   Apparatus

The general arrangement of experimental apparatus is summarized in Figure 1. The helmet-pointing system (HPS) was a Polhemus 3-SPACE magnetic head tracker capable of detecting helmet orientation in the pitch, yaw and roll axes. Helmet orientation was sampled at 60 samples per second. The sensor was mounted on a purpose-built helmet housing a GEC binocular monochrome helmet-mounted display (50° diameter optics model). The field-of-view of the visual simulation was 40° horizontal by 30° vertical per each eye. The visual scenes presented to the two eyes completely overlaid each other and images were focused at 2 metres in front of the display. The weight of the helmet-mounted display was 2.5 kg, symmetrically loaded.

The flight simulation was generated by a 4D-50G Silicon Graphics workstation and the view of the computer-generated scene changed according to the helmet orientation. The scene was in colour but only the green channel was presented on the helmet-mounted display. Both eyes perceived the same image and the pixel resolution of the view was 780 x 575. The simulation was presented at 25 samples per second and the inherent system display lag was approximately 75 ms. This system lag included: (i) 40 ms computation time; (ii) 0 to 20 ms delay due to the asynchronisation between the raster scan running at 50 Hz and the simulation program running at 25 Hz, (iii) 17 ms frame delay of the helmet-pointing system and (iv) 0 to 17 ms delay due to the asynchronisation between the helmet-pointing system

running at 60 Hz and the simulation program running at 25 Hz. Additional display lags could be generated through a data buffer implemented with the simulation software.

3.2   Methods and Design

3.2.1   Procedure and measurements

At the start of the experiment, subjects were asked to complete a 'motion sickness history questionnaire' and a 'symptom checklist'. They were then asked to put on the helmet-mounted display and sit inside a dark environment.

A one minute simulation was presented during which the subjects were asked to familiarize themselves with the head-coupled display. This was followed by a twenty minute simulated view from an aircraft that was following another aircraft, the target. During the twenty minutes, subjects were asked to move their heads to keep the target in the centre of their field-of-view. At the start of the simulation, subjects were instructed to orientate their heads so that the Frankfort plane was horizontal to the laboratory.

At five minute intervals from the start of the simulation until ten minutes after the simulation, subjects were asked verbally to rate their symptoms of nausea on a 7 point scale (Table 1). During the last ten minutes, the simulation was turned off and the subjects were asked to remain seated with the helmet on. After the last verbal rating, the helmet was removed and subjects were asked to complete a 'symptom checklist' and a 'simulation assessment questionnaire'. The r.m.s. head movements in the pitch, yaw and roll axes during the simulation were measured.

3.2.2   Visual content of the simulation

During the twenty minute simulation, the target aircraft manoeuvres included: (i) alternate nose dive and climb at an angle of about 20°; (ii) a 180° left or right turn once every minute and (iii) two 60° roll oscillations per minute. The subjects viewed the target aircraft from its position 20 samples (0.8 seconds) earlier. In this way, the subjects always saw the target flying approximately in front of them.

Table 1   Seven point nausea scale (adapted from Golding and Kerguelen, 1992)

1	No symptoms
2	Any symptoms, however slight
3	Mild symptoms, e.g. stomach awareness but no nausea
4	Mild nausea
5	Mild to moderate nausea
6	Moderate nausea but can continue
7	Moderate nausea, want to stop

During the aircraft manoeuvres, the target would remain approximately at the centre of the display while the background scene would move relative to the target aircraft and the subject.   The background scene consisted of an airfield with a single runway, some buildings, some pyramid-shaped mountains, a dark coloured ground with square grids and a light coloured sky.   During the simulated nose dive and climb movements, the 180° left or right turn and the roll movements of the aircraft, the visual scene would appear to oscillate in the pitch axis, scroll downwards and rotate in roll respectively (Figure 2).

3.2.3   Subject details and simulation conditions

Forty-eight male subjects participated in the experiment; their ages ranged from 17 to 37 years. Thirty-seven subjects were University researchers and students and eleven subjects were members of the general public. Subjects were assigned randomly into three groups.   Each group received one of the three simulation conditions: C1: no imposed display lag and no additional target offset; C2: no imposed display lag but with an addition target offset; C3: 280 ms imposed display lag with the same additional target offset. When the additional target offset was applied, the target aircraft would appear to oscillate horizontally to the laboratory.   The oscillation was the sum of a 0.015 Hz and 0.025 Hz sinusoidal motions, both with the same amplitude. This produced head yaw movement with an amplitude of approximately 24° r.m.s.

The experiment reported in this paper was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research. All subjects were

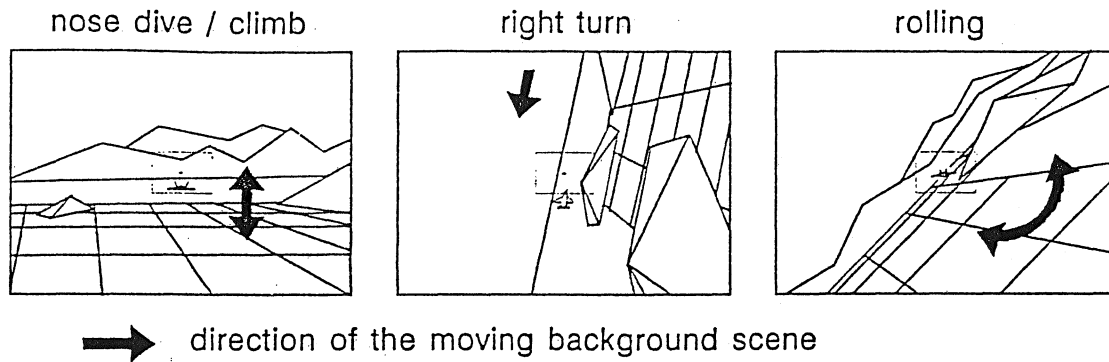| nose dive / climb	right turn	rolling

→ direction of the moving background scene

Figure 2   Illustration of the movements of the background scene during aircraft manoeuvres.

fully informed about the experiment and their right to withdraw at any time without prejudice during the experiment.

3.3   Dependent Variables

3.3.1   Motion sickness history questionnaire

A self-rated susceptibility to motion sickness was obtained from answers to the following question:

> Which of the following best indicates your present susceptibility to motion sickness relative to others of the same age?
>
> | Much less than average | Less than average | Average | More than average | Much more than average |
> |---|---|---|---|---|

A numeric weighting of 1 to 5 was assigned to each answer with 1 representing the answer 'Much less than average'.   This weighting will be referred to as the rated 'sickness susceptibility'.   In addition, subjects were asked about their experience with computer games:

> In the past 12 months how many times have you played computer games?
> Never   1   2-4   5-16   17-64   65-256   257 or more

A numeric weighting of 0 to 6 was assigned to each answer with 0 representing the answer 'never'. This weighting will be referred to as the rated 'experience with computer games'.

3.3.2 Symptom checklist

This checklist consisted of six symptoms extracted from the Simulator Sickness Questionnaire reported by Kennedy *et al.*, 1992. They are: 'general discomfort'; 'fatigue'; 'drowsiness'; 'headache'; 'eyestrain' and 'sweating'. Subjects were encouraged to mention additional symptoms if necessary. For each symptom, there were four levels of severity: (i) none; (ii) slight; (iii) moderate and (iv) severe.

3.3.3 Nausea rating scale

The seven point nausea rating scale reported by Golding and Kerguelen (1992) was used (Table 1).

3.3.4 Simulation assessment questionnaire

This questionnaire was adapted from Regan and Price (1993a). It assesses the realism of the simulated images and the level of involvement of the subjects. The level of the realism of the simulation was indicated by the answer to the following question:

How completely did you believe you were flying in an aircraft?

Totally   A lot   Somewhat   A little   Not at all

A numeric weighting of 1 to 5 was assigned to each answer with 1 representing the answer 'Not at all'. This weighting will be referred to as the rated 'level of realism' of the simulation. The quality of the simulated three dimensional images was assessed with the following question:

How flat and missing in depth did the world appear?

Totally   A lot   Somewhat   A little   Not at all

Similarly, a numeric weighting of 1 to 5 was obtained and will be referred to as the rated

level of 'missing in depth'.

4.0   RESULTS AND DISCUSSION

4.1   Symptoms

The percentages of subjects who indicated any symptom before and after the experiment are shown in Figure 3. Data were obtained from the 'symptom checklist'. Inspection of Figure 3 shows that about an additional 60% of the subjects suffered signs of 'general discomfort' after the experiment. Among the seven symptoms, 'eye-strain' was most frequently reported. Such a finding is common in literature concerning simulator sickness (e.g., McCauley *et al.*, 1990; Kennedy *et al.*, 1989). McCauley *et al.*, 1990 reported that the 'eye-strain' symptom is one of the unique features with simulator sickness. During the simulation, the images presented on the helmet-mounted display were focused at 2 m, this might have contributed to the 'eye-strain'. With Condition C3, eight out of the sixteen subjects reported slight 'fatigue' before the experiment. After the experiment, seven subjects reported slight 'fatigue' and one subject reported moderate 'fatigue'.
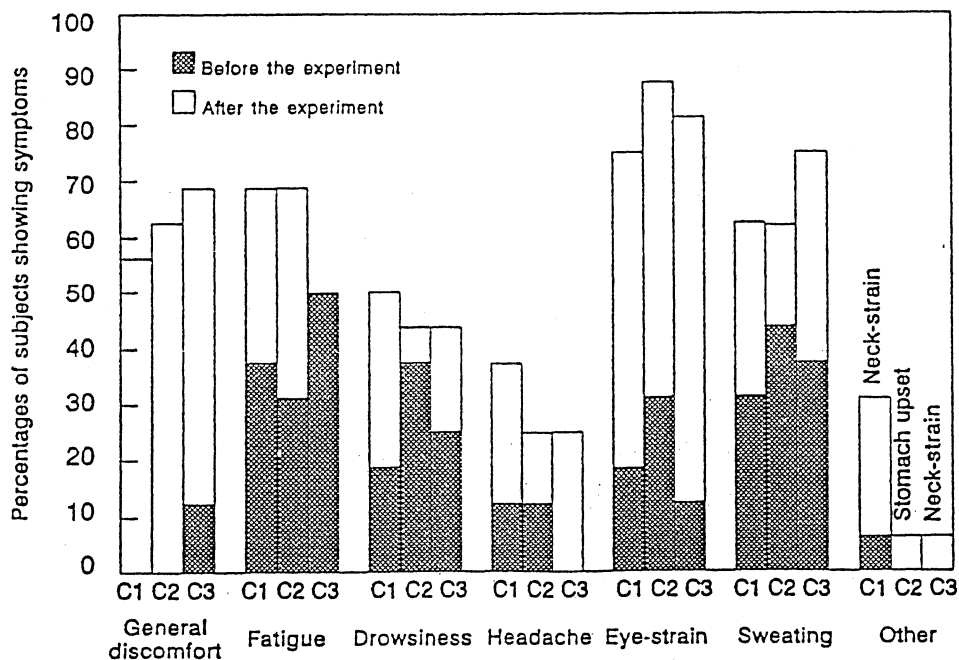

Figure 3   Percentages of subjects showing sickness symptoms before and after the experiment.

Nausea ratings with the three simulation conditions are shown in Figure 4 as functions of simulation duration. The total duration of the experiment was 30 minutes but the simulation was turned off during the last 10 minutes. Four out of the forty-eight subjects withdrew from the experiment because they suffered from 'moderate nausea' (7 on the scale, Table 1). However, the median nausea rating only reached a maximum of 2 on the scale which is 'any symptoms, however slight'. This suggests that the simulation was not very nauseogenic to most subjects. For the purpose of data analysis, after a subject withdrew from the experiment, a rating of 7 was assigned until the simulation was turned off. At 5 and 10 minutes after the simulation, missing values were reported.
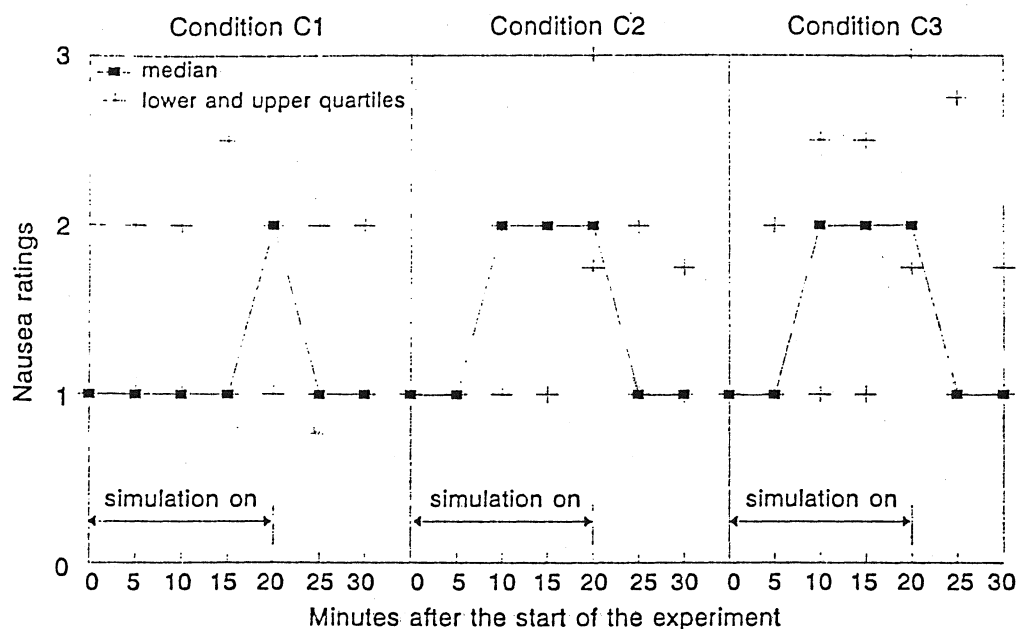
4.2 Effects of target offset and simulation duration

Without the target offset (Condition C1), subjects' heads were approximately stationary (Table 2) and the visual stimuli from the simulation were perceived in the absence of an expected vestibular signal. With the target offset (Condition C2), the subjects had to oscillate their heads horizontally at 0.015 Hz and 0.025 Hz. Such head oscillations in the yaw axis were uncorrelated with the apparent movement of the visual scene in the pitch and roll axes. Nausea ratings are shown in Figure 4. There was no significant difference between the ratings with and without the target offset at all time intervals ($p > 0.15$, Mann-Whitney U test).

Due to gravitational force, head pitch movement may introduce a stronger stimulus to the vestibular system (otolith) than head yaw movement; this may enhance any visual-vestibular conflict (Griffin, 1991). Future studies investigating the effects of head pitch movement during simulation with head-coupled displays are desirable.

Table 2   Rotational head movement during the simulation (median r.m.s. angular displacements of 16 subjects).

Axis of head movement	Condition C1	Condition C2	Condition C3
pitch (r.m.s.)	1.85°	1.65°	1.90°
yaw (r.m.s.)	0.80°	24.2°	23.7°
roll (r.m.s.)	2.15°	3.95°	5.15°

Figure 4   Nausea ratings at different times during the experiment (3 conditions).

Note: due to withdrawal of subjects, median data at 25 and 30 minutes for C1, C2, and C2 are calculated from 15, 14 and 15 subjects respectively.

During the first 20 minutes of the simulation, the nausea ratings increased with duration and the increases were significant after five minutes with Conditions C1 and C3 and after ten minutes with C2 ($p < 0.05$, Wilcoxon matched-pairs signed-ranks test). Ratings taken after 25 and 30 minutes were less than those taken after 20 minutes ($p < 0.01$, Wilcoxon, data taken from all three conditions excluding the four cases in which the subjects withdrew before completing the experiment). This indicates that the visual stimuli from the head-coupled display may have caused the reported symptoms. The simulation was turned off after 20 minutes from the start of the experiment.

4.3   Effects of display lag

Inspection of Figure 4 shows that at 5, 10 and 15 minutes after the start of the simulation, the upper quartile ratings with Condition C3 are slightly higher than those with C2. However, there is no significant difference between the two ratings ($p > 0.2$, Mann-Whitney U test performed with ratings at all exposure times). This indicates that the 280 ms imposed display lag had no significant effect on the nausea rating. A possible reason for the absence of any significant effect of lags is the absence of rapid head movements. The sums-of-sine head oscillations generated by the target offset had frequencies at 0.015 Hz

and 0.025 Hz. With such head movements, the 280 ms imposed display lag would introduce an image position error of 0.9° r.m.s. This might have been too slow to generate any visible discrepancy between head movement and the head-coupled visual scene.

4.4   Other effects

4.3.1   Helmet weight

Inspection of Figure 3 shows that Condition C1 gave the highest incidence of 'other' symptoms after the experiment. With this condition, all five subjects who reported the 'other' symptom specified 'neck-strain'. No subject reported 'neck-strain' in Condition C2 and only one subject reported 'neck-strain' in Condition C3. A possible reason for the reported 'neck-strain' may be the weight of the helmet. In Condition C1, subjects were required to keep their heads stationary, therefore the 2.5 kg helmet weight was supported by the same neck muscles throughout the experiment. In Conditions C2 and C3, subjects were required to oscillate their heads horizontally and, therefore, the 2.5 kg weight was distributed among different neck muscles.

4.3.2   Realism of the simulation and visual cues

Kendall's tau-b correlation tests were performed among the variables listed in Table 3. These correlation tests were performed with data from all the 48 subjects. The 'nausea rating after 20 minutes', the rated 'level of realism' of the simulation and the 'r.m.s. head roll' movement have significant positive correlations with each other ($p < 0.05$, Kendall). First-order partial correlation test was carried out with these three variables and significant correlation was found only between the 'nausea rating after 20 minutes' and the rated 'level of realism' of the simulation (Table 4). This suggests that the realism of the simulation was an important factor in causing visually-induced motion sickness.

Head movements in the roll and pitch axes were significantly correlated ($p < 0.05$, Kendall). This suggests that subjects might have tilted their heads when following the horizontal oscillation of the target.

Table 3   Kendall correlation coefficients and two-tailed significant levels indicating the correlation between the following variables (data from all three conditions were used, N=48).

Variables	Level of realism	Missing in depth	Nausea rating (20 mins)	Head pitch (r.m.s.)	Head yaw (r.m.s.)	Head roll (r.m.s.)	Age	Experience with computer games	Sickness susceptibility
Level of realism	1.00 (p=0.000)	-	-	-	-	-	-	-	-
Missing in depth	-0.23 (p=0.072)	1.00 (p=0.000)	-	-	-	-	-	-	-
Nausea rating (20 mins)	0.36 (p=0.003) **	-0.09 (p=0.470)	1.00 (p=0.000)	-	-	-	-	-	-
Head pitch (r.m.s.)	0.02 (p=0.878)	0.05 (p=0.693)	-0.03 (p=0.794)	1.00 (p=0.000)	-	-	-	-	-
Head yaw (r.m.s.)	-0.06 (p=0.627)	0.12 (p=0.31)	0.01 (p=0.941)	0.02 (p=0.850)	1.00 (p=0.000)	-	-	-	-
Head roll (r.m.s.)	0.27 (p=0.016) *	0.04 (p=0.718)	0.32 (p=0.004) **	0.13 (p=0.212)	0.23 (p=0.023) *	1.00 (p=0.000)	-	-	-
Age	-0.13 (p=0.256)	0.04 (p=0.716)	-0.21 (p=0.067)	0.04 (p=0.685)	-0.01 (p=0.950)	-0.14 (p=0.18)	1.00 (p=0.000)	-	-
Experience with computer games	0.23 (p=0.056)	-0.22 (p=0.079)	0.25 (p=0.033) *	-0.15 (p=0.181)	-0.13 (p=0.215)	0.20 (p=0.062)	-0.21 (p=0.062)	1.00 (p=0.000)	-
Sickness susceptibility	-0.11 (p=0.389)	-0.05 (p=0.680)	0.16 (p=0.195)	-0.14 (p=0.230)	-0.09 (p=0.441)	-0.13 (p=0.256)	0.17 (p=0.137)	-0.19 (p=0.112)	1.00 (p=0.000)

Key: * $p < 0.05$,   ** $p < 0.01$

Table 4 Two-tailed significant levels of partial correlation test with the following variables.

Variables pair	Control variable	Significant level
Rating v. head roll	Level of realism	p>0.1
Rating v. level of realism	Head roll	p<0.005
Level of realism v. head roll	Rating	p>0.1
Rating v. experience with computer games	Level of realism	p>0.1

During the simulation, subjects did not need to roll their heads in order to follow the target aircraft. The measured r.m.s. head roll movement might have been a response to the rotating background scene. However, because the head movement time history in the roll axis was not measured, the specific cause of such head roll movements could not be identified. Recording of head orientation in future studies is desirable.

5.0 CONCLUSIONS AND RECOMMENDATIONS

With a flight simulation presented on a head-coupled display, nausea ratings increased with the duration. The simulation contained a moving background scene in the pitch and roll axes. After 20 minutes of simulation, the most frequently reported symptom was 'eye-strain'. This agrees with published literature concerning simulator sickness.

With head oscillation in the yaw axis at 0.015 Hz and 0.025 Hz during the simulation, no significant effect was found on nausea ratings.

An imposed 280 ms display lag did not significantly increase the nausea ratings. The absence of an effect of lag on nausea may be due to the lack of rapid head movements in the simulation. Further studies with more rapid head movements are desirable.

A subjective rating of the realism of the simulation significantly correlated with symptoms of nausea. Further studies to identify the factors affecting the rated level of realism are desirable.

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