OPTIMISING HUMAN PERFORMANCE BY REDUCING MOTION SICKNESS AND ENHANCING SITUATION AWARENESS WITH AN INTUITIVE ARTIFICIAL 3D EARTH-FIXED VISUAL REFERENCE.

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ABSTRACT

Human performance has been shown to be negatively correlated with seasickness. By reducing crew, ship size, and hence redundancy, sickness induced risks increase exponentially. Although medication is effective, it also causes drowsiness. Non-pharmacological countermeasures are scarce, the most popular one being to look at the horizon.

We exploited the latter by creating an artificial Earth-fixed matrix of 3D crosses, that can be used wherever outside views are scarce and visual displays are available. To test such a display we performed two experiments. In Experiment 1, 14 subjects completed a number of 20-minute trials in TNO's Desdemona motion simulator reproducing a ship motion. The crosses were presented on a computer screen in the background of a demanding task, and on a projection screen in front of the participant. Sickness severity was rated at fixed intervals. In Experiment 2, 11 subjects completed a number of 20-minute trials in the same simulator, now reproducing an aircraft motion. No task was used in Experiment 2, but the display was extended by including a roller-coaster like track showing the trajectory to be followed ahead.

Results of Experiment 1 showed that the anti-seasickness display did not interfere with the computer task *per se*, while it did reduce sickness due to ship motion, whether presented on the computer monitor or on the projection screen. In Experiment 2, sickness was further reduced from somewhat less than a factor of 2 when only showing the crosses (with respect to a control condition without any display), by over a factor of 4 when adding an anticipatory trajectory. These results allow for optimising operator performance and situation awareness at sea, as well as in the air and on land, as well as the performance of, e.g., troops having to perform right after a sickening transport.

Keywords: human performance, operator performance, seasickness, airsickness, motion sickness, artificial horizon, visual display.

1. INTRODUCTION

Human performance has been shown to suffer from motion sickness. McCauley et al. (2006), for example, estimated 90% of unadapted Utah Marine Reservists aboard HSV-2 Swift during African Lion in April 2005 to suffer from seasickness. Considering that these troops would yet have to perform after their transport, their capabilities to do so can seriously be doubted. Colwell (2000) and Bos (2004) showed that also in adapted crew, i.e., having been at sea already for two weeks, the number of failing tasks increased with their feelings of sickness as shown in Figure 2. In yet another study with the Canadian research vessel Quest (Colwell et al., 2008), crew cognitive and visual performance even showed to suffer more from seasickness than from the motions causing the sickness *per se* (Bos et al., 2008). Hence, counteracting seasickness, and likewise any form of motion sickness, pays.

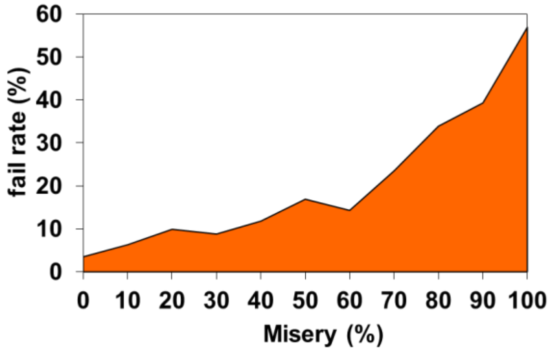

Figure 1. Percentage of tasks failing due to seasickness (0 = no problems at all ... 100 = vomiting) in adapted naval crew (Bos, 2004).

The most popular countermeasure against motion sickness seems to be the use of medication. Medication, however, needs to be taken well in advance to be effective and is associated with a decreased appetite, increased respiration, hyperthermia, euphoria, irritability, insomnia, confusion, tremors, convulsions, anxiety, paranoia, aggressiveness, loss of self-criticism, hot flashes, dry mouth, tachycardia, chest pain, hypertension, reduced mood, blurred vision, reduced (muscle) coordination, and/or a lack of memory. Most importantly, the majority of all medication are sedative, which is probably the most undesirable side-effect opposing their use by professionals performing critical tasks, such as flying an aircraft and operating a ship. Moreover, they require a certain time to wash out, why these side effects may still persist after cessation of the motion exposure when troops/marines typically have to do their job.

More sophisticated instruments to counter motion sickness consist of reducing vehicle motion by, e.g., optimising (ship) hull form and (the location of) crew habitats, and adding appropriate ride control systems and/or anti-roll devices. Selection of unsusceptible crew or habituation training are yet another category of countermeasures. Incited by the general assumed positive effect of looking at the horizon when suffering from seasickness, we here report on the positive effect of providing an artificial Earth-fixed frame of reference when on a moving platform deprived from a natural view on the outside world, such as below deck on a ship (Experiment 1) or in an enclosed aircraft cabin (Experiment 2). Both experiments were performed in a laboratory setting using a motion platform to simulate the ship (Experiment 1) and aircraft (Experiment 2) motion, with the advantage of being able to reproduce exactly the same motion using different visual conditions. Although both experiments have been described separately before by Houben et al. (2010, Experiment 1) and Feenstra et al. (2011, Experiment 2), the current paper combines the two experiments, drawing additional conclusions based on the combined results.

2. EXPERIMENT 1

To study the effect of an Earth fixed frame of reference on seasickness, subjects were exposed to 20 minutes of simulated ship motion in several conditions with and without the artificial display. Subjects were in addition required to perform a task, so also the effect of sickness and the effect of the display thereupon could be studied in addition. More details are given by Houben et al. (2010).

2.1 Methods

2.1.1 Artificial display

It was considered essential to visualise six degrees of freedom, i.e., not restricting to an artificial horizon. If a horizon would be presented in the frontal plane, only two degrees of freedom are visible: heave and roll, heave being confounded by pitch. To avoid such ambiguities we created layers of 3D crosses of equal size, suggesting water and air surfaces as shown in Figure 2. The tips of the crosses in the horizontal plane were given different colours allowing an increased situation awareness. The size of the objects and zoom factor was chosen such that a natural imagery with smoothly moving objects was the result. Although roll, pitch and yaw could be inferred in an absolute sense (i.e. in degrees), surge, sway and heave could only be inferred relatively.

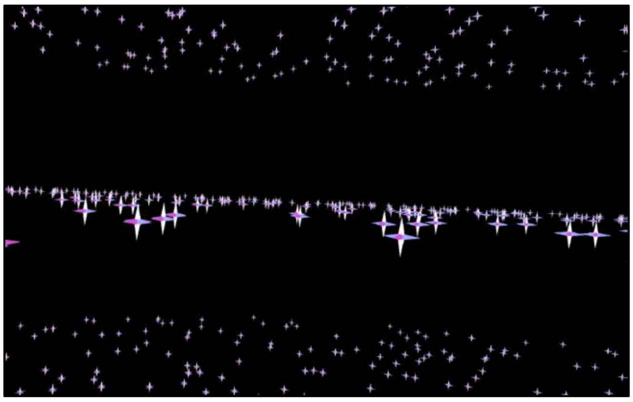

Figure 2. Artificial image with 3D objects moving opposite the ship.

This imagery was always moving opposite the ship/simulator motion (see below) such that it effectively suggested an Earth-fixed frame of reference. It was either shown on a computer monitor or projected on a screen using a beamer as further explicated below as well.

2.1.2 Simulated ship motion

Motions were calculated of a recently acquired ship of the Royal Netherlands Navy, a 108 m Holland Class Patrol Vessel (see Figure 3 left). Hydrodynamic code was available to calculate ship motion depending on wave and wind conditions. For the present study a significant wave height Hs of 2.5 m, an average period T1 of 6.8 s was chosen, typical for sea state 4. The ship sailed with 12 kts 120^{o} relative to the waves.

The resulting six degrees of motion freedom were next slightly adapted to fit within the motion envelope of TNO's Desdemona motion platform in Soesterberg, the Netherlands, used in this experiment. The main adaptation concerned filtering out the constant part of the forward velocity. The Desdemona motion platform as shown in Figure 3 consists of a cabin with a diameter of approximately 2 m, equipped with a safety chair, a modular instrument console and a three channel 120 x 40^{o} visual of which only the centre screen was used in the current experiment. This cabin is fully gimballed allowing for unlimited angular motion about its yaw, pitch and roll axes. These gimbals can next move up and down with a stroke of 2 m, which device can bodily move over a horizontal sled of 8 m long. This sled, lastly can be rotated about a central Earth vertical axis so as to induce a sixth degree of freedom also allowing for centrifugation when the cabin is positioned off-axis. All degrees of freedom can be controlled dynamically and simultaneously. More information on this platform can be found at www.desdemona.eu.

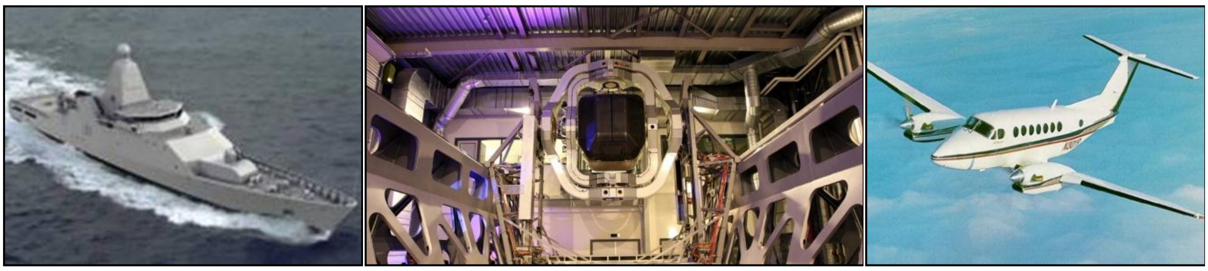

Figure 3. TNO's Desdemona motion platform (centre), capable of simulating ship (Holland Patrol Vessel left) and aircraft (right) motion.

Note that the anti-seasickness display was driven by the simulated motion, rather than the actual calculated ship motion, so as to realise a true Earth-fixed frame of reference. The current experiment can therefore be considered to be a veridical anti motion sickness experiment, and not one dealing with simulator sickness. Here, simulator sickness may be defined as sickness occurring in a simulator when it does not occur in the condition that is simulated. This reasoning still holds despite the forward velocity having been shown to optimise the sense of being on a moving ship, because the human vestibular and somatosensory systems cannot discriminate between conditions of different constant velocity.

2.1.3 Multi-attribute task

To realise some sort of navy realistic environment with crew operating computer consoles, also allowing the quantification of operator performance, we used the Multi-Attribute Task (MAT) developed by NASA (Comstock & Arnegard, 1992). Its basic layout is shown in Figure 4, left. Features of this task include a system monitoring task, a tracking task, and a resource management task, all tasks having to be performed simultaneously. Performance measures include tracking error, missed alarms, tank fuel level variations, and reaction times.

Figure 4. Multi-Attribute Task (MAT, left), projected on top of the anti-sickness display on a computer monotor (centre) or on a screen above the computer displaying the MAT (right).

This task was performed using a laptop mounted right in front of the subjects and used in all conditions to be discussed below. The anti-seasickness display was either not shown (Figure 4, left), shown in the background of this task on the same computer screen (Figure 4, centre), or projected on the central screen right above and behind the computer screen (Figure 4, right). For practical reasons, each 20 minute session was divided into four equal five minute intervals. The MAT was initialised before each interval and its results stored at the end thereof.

2.1.4 Misery ratings

Prior to each experimental session and after every five-minute interval during the experiment, the subjects rated their sickness severity on a single value 11-point misery scale (MISC, see Table 1). The MISC has been validated before (e.g., Bos et al., 2005). The rationale behind the MISC is the observation that nausea is generally preceded by other symptoms like dizziness, headache, (cold) sweat and stomach awareness (Reason & Brand, 1975], the latter symptoms varying among people in order of appearance and severity. Whenever nausea is felt, sickness is rated from 6 and up. Once subjects are familiar with this scale, its rating, i.e. asking for a single number only, takes only a few seconds. It can therefore easily be applied repeatedly, still giving some reference to sickness symptoms. A trial was stopped whenever a MISC of 7 or higher was scored.

Table 1. MIsery SCale (MISC)

Symptoms		MISC
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, headache, stomach / throat awareness, sweating, blurred vision, yawning, burping, tiredness, salivation, … but no nausea	vague	2
	little	3
	rather	4
	severe	5
Nausea	little	6
	rather	7
	severe	8
	retching	9
Vomiting		10

2.1.5 Subjects

Fourteen subjects, 7 males and 7 females between 20 and 47 years of age (median of 27) completed all sessions of Experiment 1. Subjects were paid with an additional bonus when starting the last session (see next section). All participants confirmed having had a normal night's rest, not having consumed more than two alcoholic beverages and not taken any drugs twelve hours prior to each session. The experiment was approved by the local ethical committee (Toetsingscommissie Proefpersoonexperimenten, TCPE) and written informed consent was obtained from all subjects.

2.1.6 Experimental design

In Experiment 1 we tested two ways of presenting the anti-seasickness display to the subjects: 1) in the background of the MAT on a computer screen, and 2) projected on a screen above a person doing the same computer task. A number of control conditions without motion were added. To limit the number of conditions to be realized we restricted to those listed in Table 2 and further explicated below.

Table 2. Overview of experimental conditions. M = physical motion, C = anti-sickness display on computer screen, P = anti-sickness display on projection screen.

Condition	M	C	P	Measurement
1A	–	–	–	Control: task performance *per se*
1B	–	+	–	Control: effect of anti-sickness display on task *per se*
1C	+	–	–	Control: task performance during motion *per se*
1D	+	+	–	Task performance during motion + anti-sickness display on computer screen
1E	+	–	+	Task performance during motion + anti-sickness display on projection screen

Condition 1A (no motion and no anti-sickness display) is essential as a baseline measurement of task performance. By comparing the results thereof with those of condition 1B (no physical motion but with the anti-sickness display on the computer screen) the possible (negative) effect of a moving visual background on task performance *per se* could be tested. In this case, the motion of the anti-sickness display moved as it did on the motion platform. Note that in this case the motion pattern may cause sickness instead of counteracting it, then called visually induced motion sickness, or cybersickness (Bos, 2008). To test the effect of the anti-seasickness display, it is essential to test it against a condition without the display, why condition 1C has been added. Conditions 1D and 1E, lastly comprise the actual test conditions of interest in Experiment 1.

Each subject participated in all conditions, allowing a within-subjects design. Each condition was realised on a separate day. For practical and financial reasons, conditions 1A and 1B were realised on a single day using a desktop setup outside the Desdemona gondola. All conditions were further presented to the subjects in a random order to avoid learning or order effects. No further instructions were given to the subjects with respect to what to look at, nor about the exact nature of the imagery (i.e. being Earth fixed).

2.2 Results

2.2.1 Misery

Overall misery levels were low, i.e., 0.5 on average with a maximum of 4. Most likely this can be ascribed to the moderate motion used here, both with respect to its amplitude(s) and duration. Yet, highly significant effects were observed. Figure 5 shows the statistics of the observed increases in sickness relative to the control condition 1A where no physical motion and no anti sickness display were used.

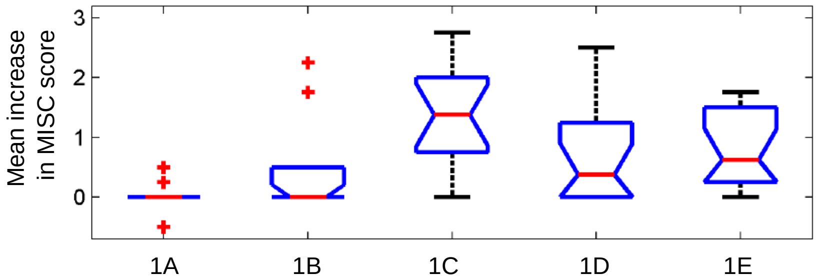

Figure 5. Box and whisker plot of mean MISC differences per condition (1A – 1E according Table 2), boxes showing lower, median and upper quartile values, whiskers showingthe most extreme values within 1.5 times the interquartile ranges. Data outside the whisker range are plotted as red plus markers.

Given the experimental design, a number of comparisons could and were made, ANOVA's yielding the following results. By comparing conditions 1A and 1B), some (cyber)sickness was observed, although the difference was not significant. The physical motion was found to be sickening (by comparing 1A and 1C), which effect was cancelled by the anti-sickness using the computer screen (1B and 1D did not differ, while 1C and 1D did differ). Although slightly less significant, the same conclusion could be drawn for the anti-sickness display projected on the screen above the computer task (1C and 1E did differ, be it marginally, while 1D and 1E did not differ at all).

2.2.2 Task performance

The MAT data did not reveal any clear cut and/or statistically significant differences between conditions. Importantly, this includes the observation that in condition 1B the crosses moving in the background of the computer task did not interfere with the task *per se*.

2.3 Conclusions

Given the data of Experiment 1, we conclude that the anti-seasickness display tested is of benefit with respect to feelings of misery. Although no matching effects on task performance were observed in the current setup, we yet assume that due to the clear relationship between task performance (or fail rate) and misery as shown in Figure 1, longer lasting and more vigorous motion will increase the effect of the display on sickness, and will manifest an effect on task performance as well.

3. EXPERIMENT 2

To study the effect of an Earth fixed frame of reference on airsickness, subjects were exposed to 20 minutes of simulated aircraft motion using two adapted versions of the anti-seasickness display as described above (section 2.1.1). One essential adaptation concerned the addition of a sort of highway-in-the-sky showing the trajectory to be flown, thus allowing anticipation. In this experiment no task was applied and we merely focussed on wellbeing. More details on Experiment 2 are given by Feenstra et al. (2011).

3.1 Methods

3.1.1 Artificial display

To study the effect of an artificial Earth-fixed frame of reference on airsickness, we created two alternative versions of the display described in Experiment 1. A first adaptation concerned placing the same 3D crosses at random throughout in space around the aircraft (see Figure 6, left). Because in this case we did not add a task, the background was coloured bluish. A second adaptation concerns the observation that car drivers and pilots generally do not get sick (Rolnick & Lubow, 1991), it is common knowledge that looking forward in this respect is better than looking backward, and also from a theoretical point of view anticipation seems to be at issue (Bos et al., 2008). For the second adaptation we therefore added a rollercoaster like track showing the subject the trajectory to be flown.

Opposite to real-time flight, we used a pre-recorded flight path in the laboratory trial, allowing an exact predictive flight path to be shown. To further improve the realism of the imagery, we also added a ground pattern in this case (see Figure 6, right). Both displays were projected on the central screen of the Desdemona cabin extending approximately 40 x 40 degrees.

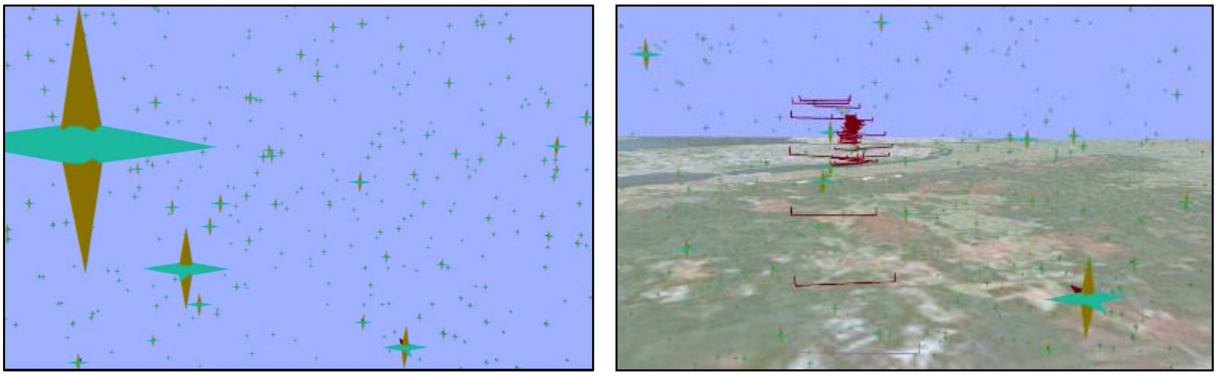

Figure 6. Anti-airsickness displays using a 3D matrix of randomly positioned crosses only (left) and one with an added anticipatory trajectory and ground pattern (right).

3.1.2 Simulated aircraft motion

The flight profile used was created by a certified pilot flying a figure-8 trajectory on a pc-based flight simulator (X-Plane, Laminar Research, Radcliffe, USA). The chosen aircraft model was a small dual prop business aircraft (see Figure 3, right). The trajectory was flown at a low speed and a low altitude to enlarge the effect of turbulence on the aircraft motion. One trajectory lasted 10 min, and was played back during the experiment twice. The resulting six degrees of motion freedom were again slightly adapted to fit within the motion envelope of the Desdemona motion platform, and again the main adaptation consisted of filtering out the constant part of the forward velocity. Note that also this anti-airsickness display was driven by the simulated motion, rather than the actual flown aircraft motion, so as to realise a true Earth-fixed frame of reference, again resulting in a veridical anti motion sickness experiment, and not one dealing with simulator sickness. Here too the forward velocity was made visible.

3.1.3 Misery ratings

As in Experiment 1, the MISC was used to rate symptoms and severity of motion sickness. In this case, the MISC was taken at t = 0, 2, 5, 10, 15 and 20 minutes.

3.1.4 Subjects

Eleven subjects, 2 females and 9 males with an average age of 43 with a standard deviation of 17 years took part Experiment 2. As in Experiment 1, also these subjects were paid with an additional bonus when starting the last session (see next section). All participants confirmed having had a normal night's rest, not having consumed more than two alcoholic beverages and not taken any drugs twelve hours prior to each session. The experiment was approved by the local ethical committee (Toetsingscommissie Proefpersoonexperimenten, TCPE) and written informed consent was obtained from all subjects.

3.1.5 Experimental design

In this experiment we tested the two display configurations against a condition with no visual display, thus resulting in three conditions to be tested as listed in Table 3. In that control condition the projector was just switched off, while ambient lighting was present allowing the subject to see the inside of the cabin. No further instructions were given with respect to what to look at, nor to the exact nature of the imagery (i.e. being Earth fixed nor that the trajectory was the one to be flown). Each participant took part in the experiment three days in a row, every day at the same time. The conditions were presented to the subjects in a randomised but balanced order.

Table 3. Overview of experimental conditions. M = physical motion, C = anti-sickness display showing crosses only, A = anti-sickness display showing anticipatory data in addition.

Condition	M	C	A	Measurement
2A	+	–	–	Control: baseline values
2B	+	+	–	Effect of anti-sickness display showing crosses only
2C	+	–	+	Effect of anti-sicknes diplay showing anticipatory data in addition

Results

Three participants (27%) appeared to be insensitive for any of the conditions (i.e., rated MISC = 0 only). The remaining eight participants (73%) rated any discomfort (i.e., MISC > 0 at any time). One participant scored a MISC = 8 (severely nauseated), thus putting an end to that condition (2A). The data set for this participant was completed with his last score (MISC = 8, giving a conservative estimate where vomiting might have been anticipated when the motion would have lasted). Fig. 7 shows the average MISC ratings of those subjects who were susceptible to airsickness, resulting in a reduction of a factor of almost 2 when using the crosses only (2B versus 2A), and a reduction of almost a factor of 5 when using the anticipatory trajectory in addition (2C versus 2A). As described by Feenstra et al. (2011) inclusion of the three subjects who were unsusceptible to the motion used here, these factors were almost 2 and somewhat over 4, respectively. These effects were all (highly) significant ($p \leq 0.01$).

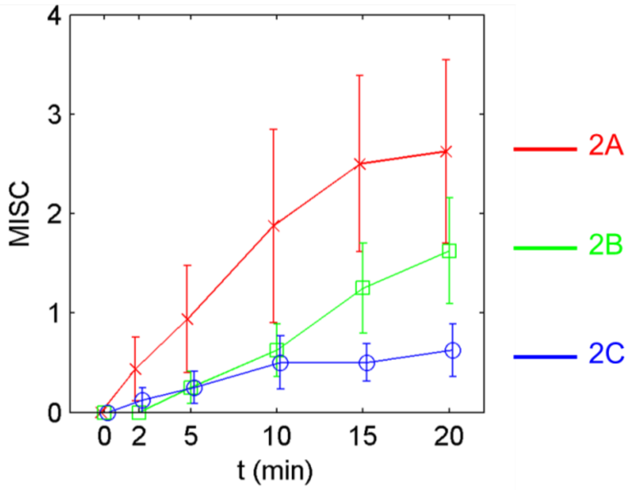

Figure 7. Average MISC values over the 20 minute motion exposure for the three conditions 2A - 2C listed in Table 3. Error bars show the standard errors of the means.

Conclusions

Given the data of Experiment 2, we conclude that the anti-airsickness display tested is of even more benefit with respect to feelings of misery than the anti-seasickness display, which especially holds for the display including the anticipatory trajectory.

GENERAL DISCUSSION AND CONCLUSIONS

Overall, we conclude that an artificial Earth-fixed frame of reference can be effective in abating the negative effects of motion sickness, both from a subjective point of view, i.e. regarding passenger and crew discomfort, and from an objective point of view regarding crew task performance. Interestingly, the display with the anticipatory trajectory did show a rather large effect, that may even outperform the use of medication, however, without any side effect, thus keeping crew fit for the (critical) tasks they are supposed to perform. Note that these considerations not only hold for crew operating during the motion exposure. Also troops (marines) having endured a sickening voyage as passengers will generally perform worse right after the transport due to a lasting effect of sickness after cessation of the provocative stimulus (see e.g., Bos et al., 2005). Here it does not matter whether these troops are transported by aircraft, ships or (armoured) land vehicles, where military vehicles are general less abundantly supplied with views on the outside world than civil vehicles are. Due to the mentioned side-effects of medication, including their persistence due to slow wash out, a remedy lacking these disadvantages is desirable, and the anti-motion sickness display seems favourable regarding all these aspects.

In addition to the observed reduction in sickness, the display presented here may also be of benefit to increase situation (or spatial) awareness. This holds for crew on ships' bridges and command centres (typically located below deck without further reference to the outside world they aim to control), of pilots and crew aboard enclosed armoured land vehicles. Implementation of a display as described here furthermore seems straightforward. The amount of displays available already in these environments is still increasing, and the moving crosses shown in the background of the presently applied computer task did not interfere with that task.

When using the crosses only, implementation is straightforward, for it only requires instantaneous motion information easily available through on-board equipment or separate commercial off-the-shelf inertial motion and GPS sensors. Although inclusion of an anticipatory trajectory seems impractical in aviation (yet), at sea it is feasible already using wave radar and an appropriate model calculating ship motion given the wave data. For that purpose we assume that showing the motions for some 20 seconds in advance will suffice. Note that apart from the technical aspects of the motion feedback *per se*, further improvements on the content and way of presentation of the imagery may be possible as well.

A final point of interest discussed here concerns the intuitive nature of the display. Subjects were not informed about the details and use of the display, while they yet did clearly showed to benefit from it. Therefore no training is required. Moreover, different from medication, it does not need to be applied well in advance of the provocative stimulus, which makes the method readily applicable, which in turn is of special interest with respect to rapid deployments typical for military operation.

ACKNOWLEDGEMENTS

The Dutch Ministry of Defence supported Experiment 1 through the project "NTP Enhanced SA displays", and facilitated this publication through the programme V937 "Improved Performance at Motion".

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