Optimising Operator Performance by Reducing Seasickness with an Artificial 3D Earth-fixed Visual Reference

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ABSTRACT

Operator performance has been shown to be negatively correlated with seasickness. As an alternative to medication we created an artificial Earth-fixed matrix of 3D crosses on a display, possibly augmented with a track showing the (predicted) way ahead. To test this display we performed two experiments on a motion platform, one showing instantaneous ship motion only, the other showing both instantaneous and coming aircraft motion. Sickness decreased with visual feedback of instantaneous motion in both experiments up to a factor of two, where added anticipatory motion reduced sickness to over a factor of four.

KEYWORDS

Motion sickness; seasickness; airsickness; visual display, artificial horizon; human performance; operator performance.

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.

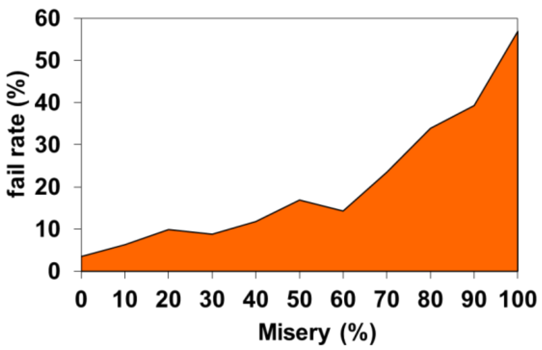

Figure 1. Percentage of tasks failing due to seasickness (0 = no problems at all ... 100 = vomiting) in adapted naval crew (Bos, 2004).

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 or in an enclosed aircraft cabin. Two 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, and is an adaptation of Bos et al. (2012).

METHODS

Extended artificial horizon

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 different matrices of 3D crosses 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, zoom factor, and minimum distance at which objects are displayed were chosen such that a natural imagery with smoothly moving objects was the result.

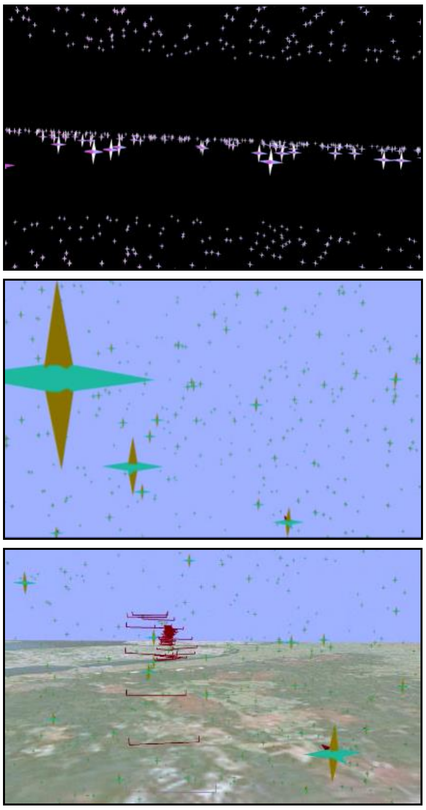

Figure 2. Visual displays used for reducing seasickness (top) and airsickness (middle and bottom). In addition to showing instantaneous motion only, the bottom display also showed the trajectory ahead.

In Experiment 1, the background was black to allow a task being presented on top, and the crosses were ordered in layers so as to mimic air, water and bottom surfaces. To study the effect of anticipation (see, e.g., Rolnick & Lubow, 1991 and Bos et al., 2008) we added a rollercoaster like track showing the trajectory to be flown in Experiment 2. To improve the realism of the imagery in this experiment, the background was coloured bluish and a ground pattern was added. Here the displays were only projected on a central screen.

The imagery was always moving opposite the platform motion (see below) such that it effectively suggested an Earth-fixed frame of reference.

Simulated motion

To simulate ship motion (Experiment 1), time histories were calculated of a 108 m Holland Class Patrol Vessel of the Royal Netherlands Navy. 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. One time history lasted five minutes and was played back four times consecutively.

To simulate aircraft motion (Experiment 2), a flight profile 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 slightly adapted to fit within the motion envelope of TNO's Desdemona motion platform in Soesterberg, the Netherlands. 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. Desdemona motion platform.

Note that the 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 experiments can therefore be considered to be veridical anti motion sickness experiments, and not concerning 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 more or less constant forward velocity having been shown to optimise the sense of being in a moving ship or aircraft, but not physically applied, because the human vestibular and somatosensory systems cannot discriminate between conditions of different constant velocity.

Task performance

Only in Experiment 1 with ship motion, a task was added to rate human task performance. To that end we used the Multi-Attribute Task (MAT) developed by NASA (Comstock & Arnegard, 1992). 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.

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, shown in the background of this task on the same computer screen, or projected on the central screen of the Desdemona cabin right above and behind the computer screen.

Misery ratings

Prior to, repeatedly during, and right after each experimental session, 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

Subjects

Fourteen subjects, 7 males and 7 females between 20 and 47 years of age completed all sessions of Experiment 1.

Eleven subjects, 2 females and 9 males with an average age of 43 with a standard deviation of 17 years took part Experiment 2.

In both experiments, 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, and written informed consent was obtained from all subjects.

Experimental designs

In Experiment 1 we tested two ways of presenting the 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 as further explicated below.

Table 2. Overview of experimental conditions in Experiment 1. M = physical motion, C = anti-sickness display on computer screen, P = anti-sickness display on projection screen.

Cond.	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.

In Experiment 2 we tested the two bluish display configurations against a condition with no visual display, thus resulting in three conditions to be tested as listed in Table 3. In the control condition the projector was just switched off, while ambient lighting was present allowing the subject to see the inside of the cabin.

In both experiments, the subjects participated in all conditions, allowing within-subjects designs. Each condition was realised on a separate day. All conditions were 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).

Table 3. Overview of experimental conditions in Experiment 2. M = physical motion, C = anti-sickness display showing crosses only, A = anti-sickness display showing anticipatory data in addition.

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

RESULTS

Figure 4 shows the statistics of the observed increases in sickness relative to the control condition 1A for Experiment 1, where no physical motion and no anti sickness display were used.

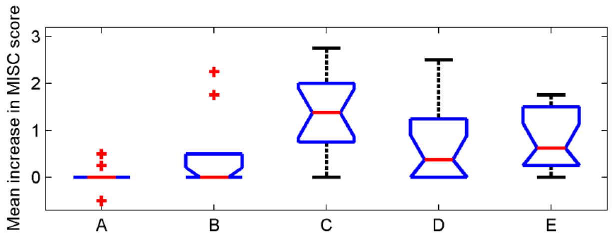

Figure 5. Box and whisker plot of mean MISC differences per condition (1A – 1E according Table 2), boxes showing lower, median and upper quartile values, whiskers showing the most extreme values within 1.5 times the interquartile ranges. Data outside the whisker range are plotted as red plus markers.

Given the experimental design, a number of comparisons could be 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).

The performance data did not reveal any clear trend 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.

In Experiment 2, 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). Figure 6 shows the average MISC ratings of those subjects who were susceptible to airsickness, resulting in a reduction of a factor of almost two when using the crosses only (2B versus 2A), and a reduction of almost a factor of five 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 ($p \leq 0.01$).

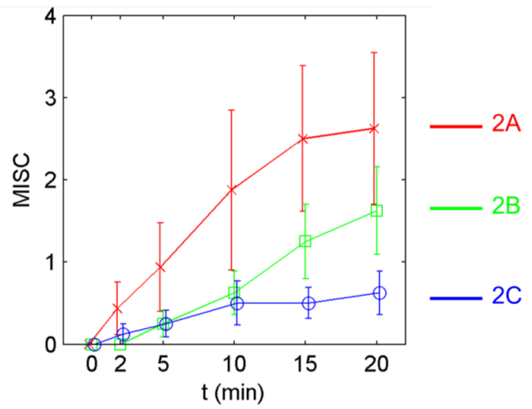

Figure 6. Average MISC values over the 20 minute motion exposure for the three conditions 2A - 2C listed in Table 3. Error bars show the standard errors of the means.

DISCUSSION AND CONCLUSIONS

Given these data, we conclude that the anti-motion sickness displays tested here are of benefit with respect to feelings of misery. Although no matching effects on task performance were observed in Experiment 1, 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.

We furthermore conclude that the effect of showing an imagery that only responds instantaneously to the vehicle motion can be considerably enlarged by adding an anticipatory trajectory. This effect 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.

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REFERENCES

Bos JE (2004) How motions make people sick such that they perform less: a model based approach. NATO RTO/AVT-110 Symp. Habitability of Combat and Transport Vehicles Noise, Vibration and Motion. Prague, CZ, 4-7 October:27.1-11.

Bos JE (2008). A theory on visually induced motion sickness. Displays 29:47-57.

Bos JE, Hogervorst MA, Munnoch K, Perrault D (2008). Human performance at sea assessed by dynamic visual acuity. Proc. ABCD Symposium "Human Performance in the Maritime Environment", Pacific 2008 International Maritime Conference, 29 January - 1 February

Bos JE, Houben MMJ, Lindenberg J. (2012) Optimising human performance by reducing motion sickness and enhancing situation awareness with an intuitive artificial 3D Earth-fixed visual reference. Maritime Systems and Technology Conference (MASTEurope), Malmo Sweden, 11-13 September:1-10.

Bos, J.E., MacKinnon, S.N. and Patterson, A (2005). Motion sickness symptoms in a ship motion simulator: effects of inside, outside, and no view', Aviat Space Environ Med 76:1111-1118.

Colwell JL. (2000) NATO Questionnaire: correlation between ship motions, fatigue, easickness and naval task performance. RINA Conference Proceedings, Human Factors in Ship Design and Operation, 27-29 September 2000, London.

Colwell JL, Allen N, Bos J, Bridger R, Duncan C, Elischer P, Grech M, Green A, Hogervorst MA, MacKinnon SN, Munnoch K, Perrault D, Roger W, Schwartz R, Valk P, Wright D (2008). Human performance sea trial QUEST Q-303. Proc. ABCD Symposium "Human Performance in the Maritime Environment", Pacific 2008 International Maritime Conference, Sydney, Australia, 29 January - 1 February pp 1-10.

Comstock, J.R., & Arnegard, R.J. (1992) The Multi-Attribute Task battery for human operator workload and strategic behaviour research. NASA TM-104174, National Aeronautics and Space Administration, Langley Research Center, 1992.

Feenstra PJ, Bos JE, Gent RNHW van (2011). A visual display enhancing comfort by counteracting airsickness. Displays 32:194-200.

Houben MMJ, Bos JE. (2010) Reduced seasickness by an artificial 3D Earth-fixed visual reference. In: Proc. Int. Conf. on Human Performance at Sea, HPAS2010, Glasgow, UK, 16-18 June. Turan O, Bos J, Stark J, Colwell JL (eds) Univ. Strathclyde, Glasgow, UK. pp. 263-270.

McCauley ME, Pierce E, Price B. (2006) High speed vessel operations and human performance. ABCD Symposium on Human Performance at Sea, Panama City, FL, 25-26 April.

Reason JT, Brand JJ (1975). Motion sickness. Academic Press, London.

Rolnick A, Lubow RE (1991). Why is the driver rarely motion sick? The role of controllability in motion sickness. Ergonomics 34:867–879.