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TNO report

TNO-DV 2008 A267

TNO contribution to the Quest 303 trial - Human performance assessed by a Vigilance and Tracking Test, a Multi-Attribute Task, and by Dynamic Visual Acuity

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TNO bijdrage aan het quest 303 onderzoek

Alertheid, complexe taakprestatie en het gezichtsvermogen bepalen mee het presteren van mensen. Op zee wordt dit ook nog eens beïnvloed door scheepsbewegingen. Dat laatste is met een studie gedurende twee weken op het Canadese onderzoeksschip Quest aangetoond. Interessant genoeg lijkt het er op dat hierbij zeeziekte een grotere rol speelt dan de bewegingen op zich.

Probleemstelling

Waar mens en machine samen een prestatie moeten neerzetten kan de mens een beperkende factor zijn. Bij missies op zee wordt dat mee bepaald door de scheepsbewegingen. Vraag hierbij is hoe je deze beperking kunt vastleggen, met als doel waar mogelijk daar dan ook verbetering in aan te brengen.

Vanuit de *ABCD Working Group on Human Performance at Sea* werd de mogelijkheid geboden experimenten te doen met proefpersonen gedurende twee weken op de Atlantische Oceaan bij Canada op het onderzoeksschip Quest. Schip, proefpersonen en begeleiding zijn betaald door *Defence Research & Development Canada.*

TNO Human Factors heeft in opdracht van de DMO/KM hierbij drie experimenten gedaan.

Beschrijving van de werkzaamheden

In overleg met de Koninklijke Marine is voor de volgende experimenten gekozen:

1 Onderzoek naar verminderd cognitief presteren met behulp van een *Vigilance and Tracking Task* en een *Multi Attribute Task.* Beide tests geven een getal voor alertheid en voor hoe goed meerdere taken tegelijk uitgevoerd kunnen worden.

2 Onderzoek naar het gezichtsvermogen met behulp van een voor de Luchtmacht ontwikkelde *Dynamic Visual Acuity* test. Alle tests konden door de proefpersonen zelf aan boord met een computer worden gedaan.

Resultaten en conclusies

Het onderzoek heeft laten zien dat zowel complexe taakprestatie, als het gezichtsvermogen achteruit gaan bij het toenemen van de scheepsbewegingen. Interessant hierbij was dat deze achteruitgang meer veroorzaakt lijkt te zijn door zeeziekte dan door de bewegingen op zich.

Toepasbaarheid

De uitgevoerde tests geven de mogelijkheid op een relatief eenvoudige manier onder operationele omstandigheden alertheid, taakprestatie en het gezichtsvermogen te kwantificeren. Dat zeeziekte hierbij een grotere rol kan spelen dan de bewegingen op zich geeft de mogelijkheid hier gericht oplossingen voor te zoeken.

Daarnaast heeft dit onderzoek ook laten zien dat de dynamische visustest een rol kan spelen bij een algemeen, op locatie toepasbare *fit-to-perform* screentest.

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Samenvatting

Er is een multinationaal onderzoek gedaan naar het menselijk presteren op zee met het Canadese onderzoeksschip Quest op de Atlantische Oceaan bij Nova Scotia in februari en maart 2007. Het hoofddoel van dit onderzoek was om zowel subjectieve als objectieve maten voor taakprestatie te verzamelen onder invloed van echte scheepsbewegingen. In opdracht van de Nederlandse marine heeft TNO aan dit onderzoek meegedaan met drie tests: een *Vigilance and Tracking Test*, een *Multi-Attribute Task* en een *Dynamic Visual Acuity* test. Twaalf proefpersonen van de Canadese marine (in actieve dienst en als reservist) hebben meegedaan. Er is vooraf geoefend met de tests toen het schip nog in de haven lag, waarbij ook basismetingen gedaan zijn. Op zee is op acht dagen lang gemeten tot en met *sea state* 6, en weer na afloop voor anker in rustig kustwater. In dit rapport wordt het protocol beschreven, de bewegingscondities, en de resultaten van de Nederlandse tests.

De resultaten laten zien dat cognitief presteren en het gezichtsvermogen verminderen wanneer de scheepsbewegingen toenemen. Interessant genoeg is daarbij gevonden dat het er op lijkt dat dit meer veroorzaakt wordt door zeeziekte dan door de bewegingen op zich. Daarbij was een tracking-taak alleen beïnvloed door zeeziekte, en niet door de beweging zelf. Daarnaast geven de DVA-resultaten aan dat, naast dat deze kunnen bijdragen aan het kwantificeren van het menselijk presteren, de test zelf ook gebruikt zou kunnen worden als een algemeen, op locatie toepasbare *fit-to-function* screentest.

Summary

A multi-national sea trial on the effects of ship motions on human performance was performed on Canadian Forces Auxiliary Vessel Quest, off the coast of Nova Scotia, Canada, in February and March of 2007. The primary goal of these experiments was to obtain subjective and objective measures for human task performance, possibly affected by real ship motion. On behalf of the Royal Netherlands Navy, TNO participated with three tests: a Vigilance and Tracking Test, a Multi-Attribute Task, and a Dynamic Visual Acuity test. Twelve volunteer subjects were recruited from Canadian Forces regular navy and naval reserve. The experiment was conducted in three phases: a pre-exposure phase of four days with the ship alongside in harbour, used for learning and to establish baseline performance; an exposure phase of eight days at sea, with sea conditions varying from calm to low sea state six; and a one day post-exposure phase with the ship at anchor in sheltered waters to re-examine baseline performance. Experiment schedule and protocol are described, motions and wave conditions encountered during the trial, and the results of the Dutch tests are presented.

Results show that cognitive performance and visual acuity are impaired by ship motion. Interestingly, this seems to be caused by seasickness in particular, possibly even more so than by ship motion *per se*. Tracking was affected only by sickness, and not by the motion itself. Apart from showing that DVA is of value to further quantify human performance, these data also support the development of an onsite fit-to-perform screening tool based on DVA.

Contents

1 Introduction

Human performance in operational environments is affected by the degree of the adverse effects of these environments. For human performance at sea one of the major disturbing factors is the movements of the ship. These movements may affect the execution of the task itself directly by means of postural instabilities or manual task performance, but also indirectly by means of sleep disturbance or deprivation and seasickness (see e.g. Bittner & Guignard, 1985). To further investigate these effects, a human performance sea trial, denoted Quest Trial Q-303, was performed in February and March of 2007 as a collaborative effort of the *ABCD Working Group on Human Performance at Sea*. This ABCD group is an informal association of American, Australian, British, Canadian and Dutch ship and human research agencies. The experiment was led by Defence R&D Canada - Atlantic. Australia participated through the Defence Science and Technology Organisation (DSTO), Britain through the Institute for Naval Medicine, Canada by the Memorial University of Newfoundland, the University of New Brunswick, DRDC Toronto and DRDC Atlantic, and the Netherlands through TNO Defence, Security and Safety. The primary goal of these experiments was to obtain subjective and objective measures for human task performance, possibly affected by real ship motion.

On behalf of the Royal Netherlands Navy, TNO Human Factors contributed with three tests:

1 A Vigilance and Tracking Test (VigTrack).
2 A Multi-Attribute Task (MAT).
3 A Dynamic Visual Acuity (DVA) test.

The experiment protocol, designated Protocol # L-585, was approved by the Human Research Ethics Committee, DRDC Toronto. Results have been presented to the Pacific 2008 International Maritime Conference, held from 29-31 January 2008 in Sydney, Australia (see Colwell et al, 2008; Valk et al., 2008, and Bos et al., 2008).
Chapter 2 will give details about the Q-303 trial as a whole, presenting wave, motion and sickness data. Chapter 3 will next describe the VigTrack and MAT tests and results. Chapter 4 will then describe the DVA test and results. Chapter 5 will present some concluding remarks.

2 Q-303 trial generic data

2.1 The Ship: CFAV Quest

The experiment was performed on Canadian Forces Auxiliary Vessel (CFAV) Quest, which is a civilian-crewed ship owned and operated by the Canadian Department of National Defence for DRDC. Quest has a full load displacement of 2200 tonnes, overall length 76 metres, and midships beam of 12.6 metres. Quest has accommodations for approximately 20 scientific personnel (including the volunteer subjects), and a ship's complement of 20 officers and crew. A total scientific complement of ten personnel was embarked on CFAV Quest for conducting this experiment.

The experiments performed by TNO were conducted in the Quest 'Dry Lab', located on the main deck in the after part of the superstructure, immediately forward of the ship's open quarter deck. This lab was arranged as generic office space with heating, ventilation, good illumination, and all port holes with external views of the outdoors were covered. The Dry Lab has approximate floor dimensions of 14 metres by 6 metres, had twelve individual computer workplaces, laid out in three rows, in the forward two-thirds of the lab space. Each workstation seat had a computer notebook and input peripherals. Mrs Munnoch from the Institute of Naval Medicine, Alverstoke, UK, administered the tests each day to the subjects. She was supported by Mr Perrault from DRDC Atlantic during the trial. The experimental setup and data analyses were realised by TNO.

2.2 The experiment protocol

CFAV Quest was dedicated to this experiment from 19 February through 9 March of 2007. The first two days of 19 and 20 February were used for installing and testing ship and environmental measurement systems, and for preparing the experiment spaces. February 21 was the first day that subjects were brought aboard the Quest, and this is designated as Day 1 of the trial.

The experiment was separated into three phases; pre-exposure, exposure and post-exposure, where 'exposure' refers to the time when the ship is at sea and the subjects are exposed to the resulting ship motions. The pre-exposure phase lasted four days with the ship tied up at the wharf in Halifax Harbour, from 21 to 23 February, and on 26 February (the ship was originally scheduled to sail on 26 February, but the departure was delayed one day due to matters unrelated to the experiment). The exposure phase with the ship at sea lasted a total of eight days, from 27 February (Day 5) to 6 March (Day 12). The post-exposure phase lasted one day, beginning on the evening of 6 March when the ship entered the sheltered waters of St. Margarets Bay, and ended in the evening of 7 March, after which Quest returned to Halifax.

During the pre-exposure phase of the experiment, subjects had an opportunity to become familiar with the tests, questionnaires, and activities used for the experiment. On the first and second days, only parts of the full protocol were accomplished, but the entire protocol was performed on each of the last two days of the pre-exposure phase.
Thus, the pre-exposure phase provided for 'learning effects', and also established calm-water or 'baseline' results. On these four days, the subjects slept ashore in their usual

accommodations, and only reported to the ship on a '9 to 5' basis. The weekend of 24 and 25 February was 'time off' for all involved.

The meal schedule on Quest began with breakfast from 07:00 to 08:00, followed by lunch from 11:30 to 12:30, and dinner from 16:30 to 17:30. The experiment daily schedule had subjects completing computer-based test batteries and questionnaires in four sessions of 90 minutes duration each, as follows: Session A, from 08:00 to 09:30; Session B, from 10:00 to 11:30; Session C, from 13:00 to 14:30; and, Session D, from 15:00 to 16:30. During the 30 minute breaks between Sessions AB and Sessions CD, and during the 90 minute lunch break, subjects were free to spend their time as they chose.

The twelve subjects were arranged in three groups of four people; Teams ALPHA, BRAVO and CHARLIE, corresponding to the Dry Lab seating arrangement with three groups of four workstations. Each group of four workstations was configured to perform a different set of activities, and so the three teams 'rotated' seating between workstations during each of the sessions.

This 'day shift' schedule does not represent the typical '4 on, 8 off' watch rotation schedule followed by most personnel on modern naval ships, and so it restricts the potential generalization of results from this experiment directly to naval operations; however, this does not reduce the value of the experiment.

The vigilance, complex task performance, and dynamic visual acuity tests were part of a larger test battery as summarised by Colwell et al. (2008).

2.3 The waves

Figure 1 shows the variation of significant wave height from three different wave buoys; C44150 and C44258 are permanently moored Environment Canada wave buoys, and DREA is one of two DRDC Atlantic directional wave buoys deployed from Quest during the trial.

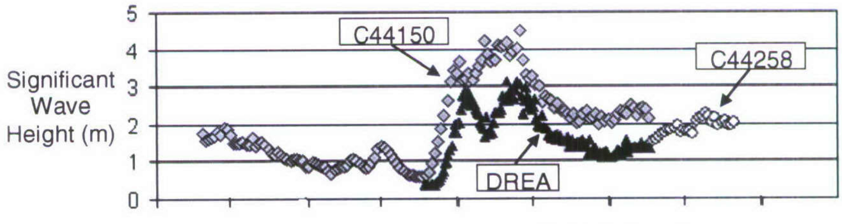

Figure 1 Significant wave height, RMS roll angle, and RMS pitch angle.

Buoy C44150 is located on La Have Bank, at the southern-most part of the trials area, about 200 nautical miles south of Halifax, buoy DREA was located at the northern-most part of the trials area, about 100 miles south of Halifax, and buoy C44258 is located in the approaches to Halifax Harbour. On the first four days at sea, only data for buoy C44150 are shown, as data from ship-launched wave buoys DREA and DRDC (not shown here) are very similar and overlap to a great extent. The data for buoy DREA ends mid-way through Day 11, as the ship had to recover the buoy on the way in towards shore. Most of the time, Quest was located between buoys C44150 and DREA, and the variation in wave height between these two buoys reflects the variation in wave height due to sheltering effects of land for the northern-most position at buoy DREA's location. The wave data shown for Days 11 and 12 shows wave data are from buoy C44258, which is likely more representative of conditions at Quest's location, as the ship moved close inshore, due to forecasts of extreme freezing spray warnings for late on Day 12. Day 13 was spent in the shelter of St. Margarets Bay. A significant wave height of 4 to 6 metres corresponds to Sea State 6, and so the conditions experienced by Quest on Day 9 were relatively rough.

2.4 The motions

To relate the human performance data to ship motion, roll and pitch angle, roll, pitch and yaw rate, and heave, surge, and sway acceleration were quantified by their RMS-value determined over the 1.5 hour intervals of the sessions performed. For all sessions from day 4 onwards, motion data were available. Figure 2 shows the data for all sessions as scatter plots against each other. From these data it can be concluded that roll angle is highly correlated with roll rate and lateral acceleration. Lateral acceleration may therefore be taken into account while ignoring roll and roll rate. Pitch similarly correlates highly with pitch rate and vertical acceleration. Vertical acceleration may therefore be taken into account while ignoring pitch and pitch rate. Of all angular rates, yaw rate is the smallest and does correlate somewhat with lateral acceleration. We will therefore also ignore yaw rate in the further analyses. Longitudinal acceleration, lastly, is very small (as compared to lateral and vertical acceleration), and correlates highly with vertical acceleration, so we will also ignore longitudinal acceleration. Further analyses will consequently be limited to lateral and vertical accelerations (i.e., sway and heave).

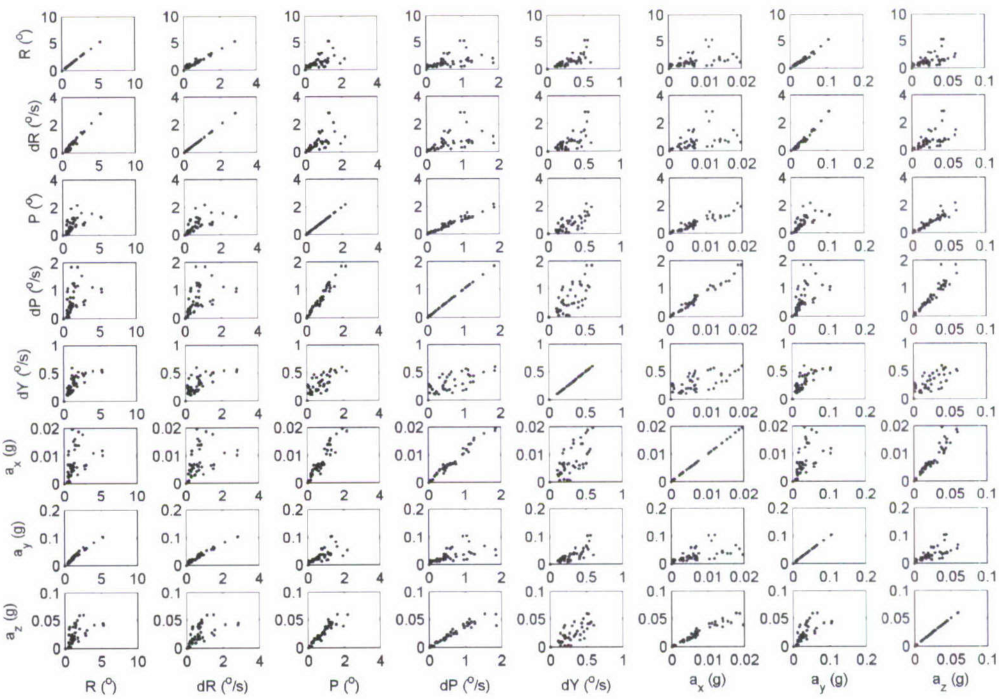

Figure 2 Scatter plots of all motion parameters for all sessions against each other. R = roll angle, dR = roll rate, P = pitch angle, dP = pitch rate, dY = yaw rate, a_x, a_y, a_z = surge, sway, and heave acceleration respectively.

For statistical testing, all test sessions have been divided into groups with smaller and larger than average lateral acceleration and smaller and larger than average vertical acceleration.

2.5 The subjects

A total of twelve volunteer subjects, nine male and three female with ages from 18 to 44, were recruited from the Canadian Forces navy and naval reserve. All subjects possessed valid Canadian Forces Medical Certificates with no employment restrictions. Potential subjects were excluded for the following reasons: females who were pregnant, individuals with heart or respiratory illness, individuals with vestibular system problems, and individuals with past serious head injuries. The original intent was to exclude individuals who are highly resistant to motion sickness by using a motion sickness susceptibility questionnaire (Golding 1998); however, this was not used as a total of only twelve eligible volunteers were located. The ship was not alcohol-free, but neither was there an open bar service; during the experiment, subjects were requested to follow normal Canadian Forces on-duty Standard Operating Procedures for alcohol and medication, for which healthy moderation is a key consideration.

2.6 The sickness

To relate the human performance data to sickness, subjects rated their well being on a well-validated, 11-point misery scale (MISC) according the symptoms listed in Table 1, taken from Bos et al. (2005). The advantage of using this scale instead of counting the number of subjects that reach the limit of vomiting is that it also rates more subtle symptoms, thus showing misery even if none of the subjects would reach the ultimate limit at all.

Table 1 Misery scale (MISC).

Symptom		score
No problems		0
Uneasiness (no typical symptoms)		1
Dizziness, warmth, headache, stomach awareness, sweating, ...	vague	2
	slight	3
	fairly	4
	severe	5
Nausea	slight	6
	fairly	7
	severe	8
	(near) retching	9
Vomiting		10

Of all possible sickness ratings 6% were missing. For the other 94% Figure 3 shows the average and peak MISC data (black) as well as the sway (red) and heave (blue) motions for all successive session intervals. This figure shows that, on average, sickness was minimal to mild. There were only a few exceptions on days 5 and 9, day 5 being the first day at sea, and day 9 the first day with bad weather. This figure also shows a faster decrease of sickness severity (black lines) than of the motions (red/dashed and blue / dotted lines), indicating that during lasting motion habituation was almost complete in these subjects within one day. This also indicates that the motion and sickness data should be treated independently.

Because the vast majority of sickness data was 0, the most (if not only) obvious division for statistical testing was between 0 and 1 or higher.

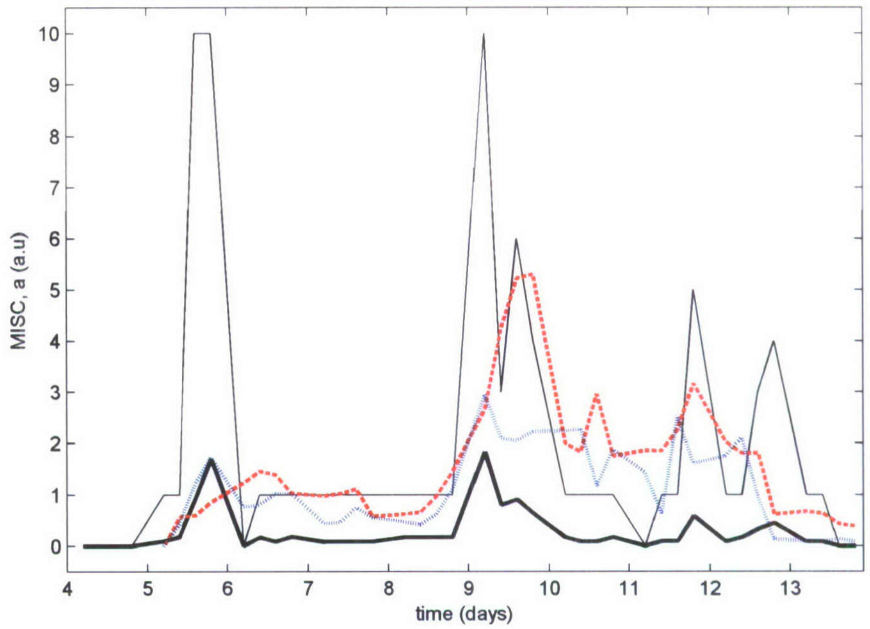

Figure 3 The black bold line gives the MISC-data averaged over all subjects, the thin black line the peak values. In addition, the red (dashed) and blue (dotted) lines give the RMS sway and heave accelerations (a scale value of 5 corresponds to an acceleration of 0.1 m/s²).

3 Vigilance and complex task performance

3.1 Introduction

As stated in the introduction, movements not only have effects on the execution of a task itself, but also other factors such as sleep disturbance and sleep deprivation may impair human performance. In this respect, Motion Induced Fatigue (MIF) and Motion Induced Loss of Sleep (MILoS) are the descriptors applied by the scientific community. Smith (1999) uses these terms to describe peripheral and central fatigue, where peripheral fatigue induced by motion is likely to have a large impact on many aspects of physical performance (Wertheim et al., 1993). Central fatigue (Davis, 1995) is rather related to reduced alertness and cognitive impairment.

Most of the research on the effects of motion on cognitive performance has been done in laboratory studies. Studies in a ship motion simulator (Helsdingen, 1996; Wertheim & Kistemaker, 1997) showed a reduction of information transfer on complex task performance. However, this result could not be explained as motion-induced interference with any one particular human skill (Wertheim, 1998). Therefore, it was suggested to distinguish the underlying skill components:
1 Cognitive tasks.
2 Motor tasks.
3 Perceptual tasks.

Investigating the literature, Wertheim (1998) concludes that motion-induced performance decrements only can be expected to occur when motion creates general artifacts such as reduced motivation, balance problems, or increased fatigue.

As most of the studies mentioned in literature were rather short (minutes to a few hours), real fatigue problems may not have occurred. The Quest trial thus offered a good opportunity to provide relevant information on the effects of motion on cognitive performance for several days.

This chapter describes the experiment that has been done on two types of cognitive performance, vigilance and complex task performance. Several studies have shown that vigilance is impaired when people are fatigued (Valk & Simons, 1996). On the other hand, complex task performance seems to be better maintained when fatigued or drowsy, due to the intrinsic arousing aspects of complex tasks (Valk, Simons, Struijvenberg, Kruit & Smits van Oyen, 1998).

3.2 Method

3.2.1 *Assessments*

The Vigilance and Tracking Test (VigTrack, Valk et al. 1997) and the Multi-Attribute Task battery (MAT, Comstock, 1992) were used to investigate cognitive performance. The VigTrack was performed on a Psion-3a hand held computer (see Figure 4).
The VigTrack task is a dual-task measuring vigilance performance under the continuous load of a compensatory tracking task. The task has been developed on a Psion 3a palmtop computer and is successfully applied in field studies concerning effects of fatigue and

sleepiness (Valk & Simons, 1996), laboratory studies on sedative effects of antihistamines (Valk et al., 1998; Valk, Van Roon, Simons, Rikken, 2004), and residual effects of alcohol (Valk, Van Roon & Simons, 1999). During the tracking task, subjects have to steer a cursor-block, using the arrow-keys, so that it is kept between two markers in the centre of the display. The cursor-block is programmed to move continuously from these two markers. While tracking, subjects have to perform the vigilance task. During this task a moving dot leaps between two horizontal lines on top of the computer screen. Most of the leaps are equidistant, however some of them are twice the normal size. If the latter is the case, subjects have to respond as quickly as possible by pressing a response button (bottom left key in Figure 4). The duration of this test was 10 minutes and performance measures include root mean square tracking error, percentage omissions and number of false reactions.

Figure 4 Psion based Vigilance and Tracking Task (VigTrack). See text for further explanation.

The Multi-Attribute Task (MAT) was performed on a personal computer.
The MAT-battery provides a benchmark set of tasks for use in a wide range of laboratory studies of operator performance and workload. The MAT was developed by NASA / Langley Research Center (Arnegard, 1991; Comstock & Arnegard, 1992; see also Figure 5). Features include a system monitoring task, a tracking task, and a resource management task. Subjects have to perform these tasks simultaneously during 10 minutes total test time. The system monitoring task, demands the subject to monitor gauges and warning lights. Monitoring performance measures include number of false reactions, number of omissions, and mean response time. During the tracking task the subject has to keep the target symbol in the centre of the window by compensatory tracking with a track ball. Tracking performance is defined as the root mean square tracking error. The demands of fuel management are simulated by the resource management task. Subjects have to maintain the level of fuel in both tanks A and B at 2500 units each (see Figure 5). In order to maintain this level, subjects must transfer fuel from the lower supply tanks by switching pumps 'on' and 'off'. The task is complicated by programmed pump failures. Resource management performance measures include the mean absolute deviation of fuel tanks A and B from the target of 2500 units.

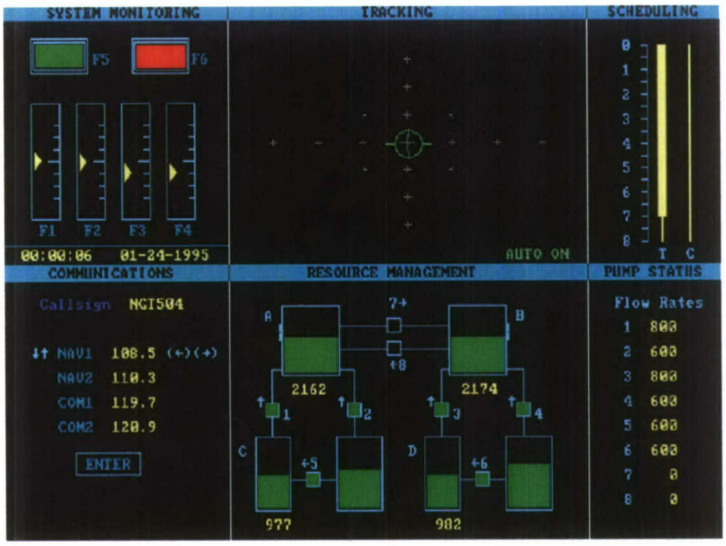

Figure 5 Computer based Multi Attribute Task. See text for further explanation.

3.2.2 *Design and Procedure*

Subjects were trained on the performance tests on 3 separate days within one week before the vessel Quest left the harbor of Halifax (study days 1-4). On 'sea-days' (study days 5-13) subjects were tested 3 times a day, in the morning, about noon and in the afternoon.

3.2.3 *Data analysis*

All performance variables were tested using a repeated measures ANOVA. Significance level was set to an alpha of 0.05. If the analysis revealed a significant effect, post-hoc analysis was performed (Tuckey HSD). Comparisons between acceleration groups and MISC groups were performed by using Student's *t*-tests for independent samples.

3.3 Results

Results are given for 'sea days' (5-13) and only reflect performance scores on the VigTrack and the MAT, and their relationship with ship motion. The influence of other variables such as sleep quality and sleep duration and subjective ratings of fatigue and alertness has not been analyzed yet.

3.3.1 *Vigilance and Tracking Task*

Figure 6 depicts the results on tracking RMS and % omitted targets, separated out for subjects not suffering from sickness at all and those who did. A significant day-effect was found for the % omissions indicating that performance impaired during the days at sea (p<0.01). Post-hoc analysis revealed a significant difference between day 7 and day 12.

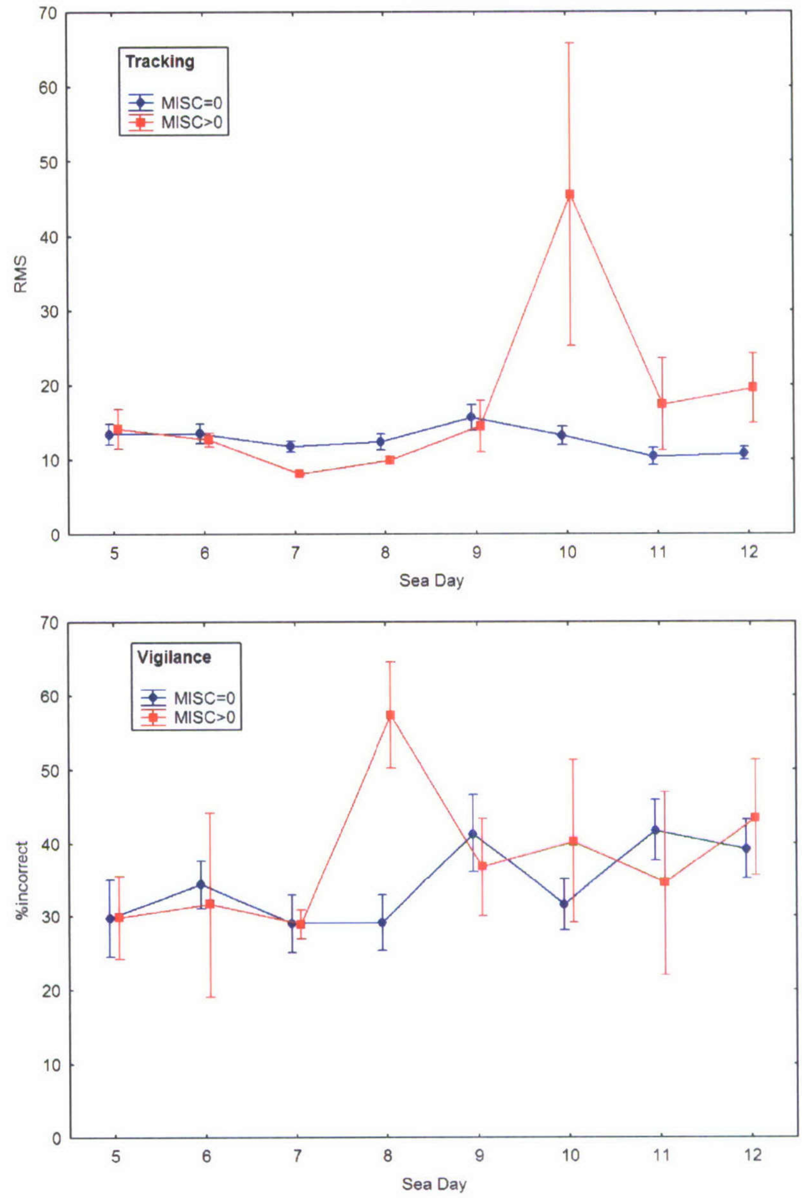

Figure 6 Tracking (RMS, top) and vigilance performance (% omissions, bottom) for the VigTrack task during sea-days. Error bars indicate standard error of the mean.

With respect to ship motion none of the parameters did reveal significant differences for both lateral and vertical accelerations.

Related to subjective ratings on the misery scale (MISC), significant effects on tracking performance were found. Comparing groups with (*MISC*>0) and without (*MISC*=0) misery feelings it was found that this last group performed significantly better on the tracking task ($p < 0.01$, see Figure 6).

3.3.2 *Multi-Attribute Task battery*

Subjects showed significant performance improvement over days for monitoring response time ($p < 0.001$), monitoring omissions ($p < 0.05$) and tracking RMS ($p < 0.01$).

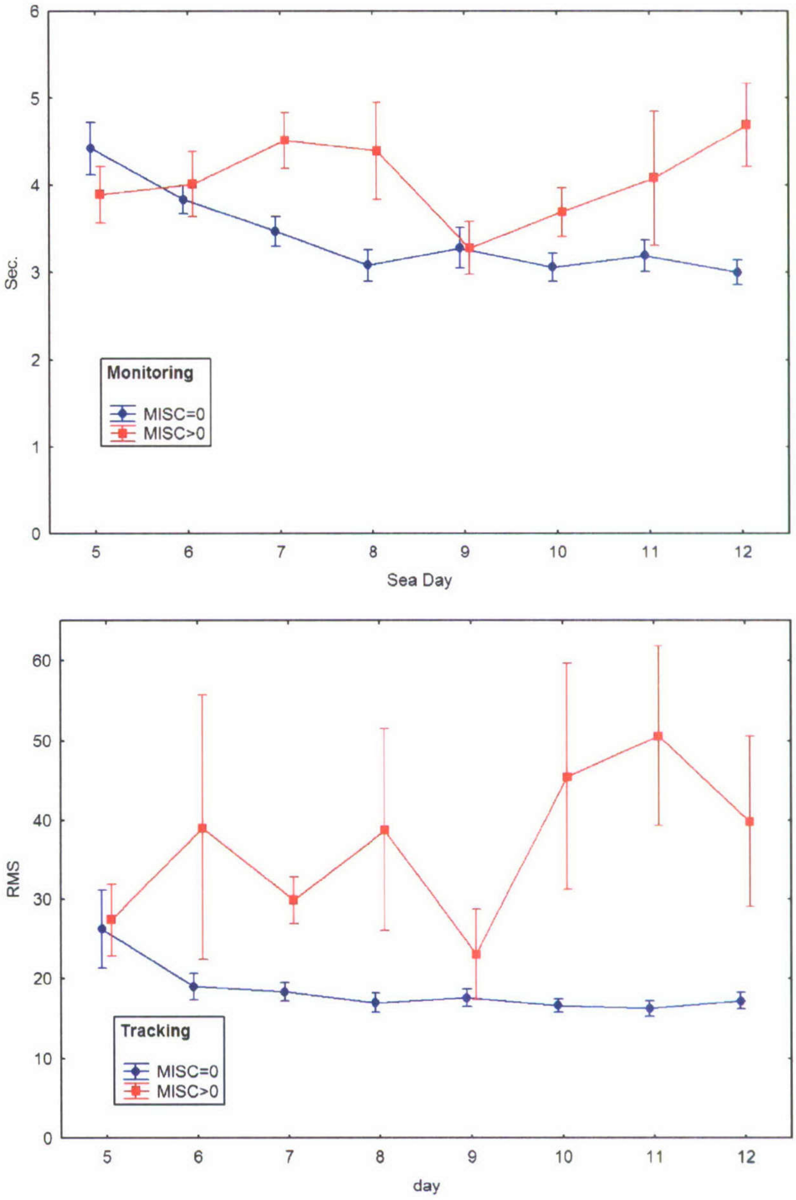

Figure 7 Monitoring (response time, sec. top) and tracking (RMS, bottom) performance for the Multi-Attribute Task battery during sea days. Error bars indicate standard error of the mean.

With respect to ship motion significantly less false reactions ($p < 0.05$) and shorter response times ($p < 0.01$) were produced on the monitoring task during high lateral acceleration conditions. This same significant effect was found during high vertical acceleration conditions ($p < 0.05$ for both parameters).

Related to subjective ratings on the MISC significant effects for monitoring response time and tracking performance were found. For both parameters the group having misery scores greater than 0 performed significantly worse ($p < 0.001$).

3.4 Discussion and conclusions

The purpose of this part of the study was to investigate the effects of ship motion on cognitive performance, assuming that increased ship motion would negatively affect cognitive performance. Two different types of performance tasks were used, the Vigilance and Tracking dual Task and the more complex Multi-Attribute Task battery.

During the first 4 days the weather on the North-Atlantic Ocean was very calm. This resulted in very smooth ship motions. This was followed by a period of about 4 days showing more rough weather.

Performance scores showed ambiguous results. Tracking and vigilance performance on the VigTrack task did not show effects that were related to ship motion.
Tracking performance did, however, show relationships with feelings of misery (MISC scale). Performance appeared to be deteriorated in subjects not feeling well (35% performance decrement).

Scores on the Multi-Attribute Task battery improved over days. This effect could possibly be explained by the fact that subjects did not reach a performance plateau during the training sessions. It is known that this, as well as other complex tasks, needs sufficient training to exclude learning effects during the real experiment. Furthermore, during high acceleration conditions (lateral and vertical) performance on the monitoring component of the MAT was improved in terms of faster response times (10%) and less false reactions (40%). These unexpected effects are probably the result of the combination of learning effect appearing during the first, calm sea, days and the performance plateau effect appearing during the last, rough sea, days.
On the other hand, monitoring response time and tracking performance did show ‘normal’ relationships with feelings of misery. Performance appeared to be deteriorated in subjects not feeling well (20% slower response time and 100% worse tracking performance).

So, there are indications that specific parameters of both tasks are sensitive to pick up possible detrimental effects of ship motion and feelings of sickness. This effect might be caused by the motion itself, or the sea sickness as a result of this. Besides, especially on the vigilance part of the Vigilance and Tracking Task, we found some indications that performance is impairing during the trip at sea. This might reflect the accumulation of fatigue, probably due to less sleep or worsened sleep quality. As data on subjective ratings on fatigue and alertness and sleep quality and sleep duration are not available yet, we were not able to control for these factors.

Furthermore, data showed considerable large variability. One way of reducing this variability could be to look at difference scores. Data gathered during training could serve as reference or baseline data. These analyses should be considered.

4 Dynamic Visual Acuity

4.1 Introduction

Another aspect of human performance that may be sensitive to ship motions is the ability to visually discern small objects, such as characters presented on TV or computer displays. Because of the increasing importance of information presented by computer aids, the ability to read this information has become more important. In general, character sizes are determined by the acuity of an average population assessed under static conditions. Here, visual acuity refers to a certain minimum angle that can still be resolved (Minimum Angle Resolved, or Minimum Angle of Resolution, MAR). Under normal conditions, i.e., for healthy subjects and with appropriate lighting, this angle is about 1 minute of arc. There is, however, ample evidence that under moving conditions, the visual acuity gets worse (see for a review Toet & Bos, 2002). Moreover, acuity measured under static conditions does not necessarily correlate with the acuity measured under dynamic conditions (Toet & Bos, 2002).

A variety of reasons may cause these discrepancies between visual acuity in static and dynamic conditions. First, there are differences in the objects that are moving. Only one object may be moving in an otherwise static background, the background may be moving too, the observer may be moving, the eyes in the head of the observer may be moving, and all combinations thereof may be at issue too. Another reason why static and dynamic vision may be different is due to the different neuro-physiological processes involved. Rods and cones within the retina of the eye have to convert light quanta into neural action potentials by means of relatively slow electro-chemical processes.
These action potentials have subsequently to be transported by neurons to the visual cortex in the back of our brain to be processed, finally resulting in visual perception. But - and this may be the most important part regarding dynamic vision - the highest spatial resolution in the retina is only obtained in a narrow central part called the fovea. Signals generated by the visual cortex are therefore used to move the eyes such that the foveae remain focused onto the object of interest if this is moving. If the head, and hence each eye, is moving too, matters may become even more complicated.
The organs of balance within the inner ears are sensitive to head motion as well, and redirect the eyes opposite to head rotation by means of a relatively fast reflex arc.
This vestibulo-ocular reflex, however, does have a certain frequency dependency, which is why not all head motions are adequately compensated for. All these reasons together may result in a degraded performance when objects of interest and/or observers themselves are moving. In aviation these effects have been studied to some extent already (e.g. Kruk at al., 1981, 1983), but at sea, these phenomena have not been studied systematically yet.

In this respect, we were fortunate to have the opportunity to study dynamic visual acuity (DVA) in a realistic operational setting at sea during the Canadian Q-303 sea trial.
To that end, we used a novel dynamic acuity test and a subset of motion conditions used before (Toet & Bos, 2002; Bos et al., 2003, 2005).

4.2 Methods

4.2.1 *DVA test*

Visual acuity can be assessed by means of so-called optotypes. These optotypes generally consist of simple images for use with children, characters as proposed by Snellen, or circles with a gap either up, down, left or right as proposed by Landolt (called Landolt-C optotypes; see e.g., Davson, 1990). An essential part of optotypes is the presence of high contrast unambiguous gaps between a minimum of parts of the 'image' of known size. Visual acuity is generally defined in one of two ways.
Most often it is given by the reciprocal of the minimum angle resolved (1/MAR) in arcmin^{-1}. This measure indicates how *well* we can see, with an acuity of 1 for normal vision. Alternatively, the $\log_{10}$ of the MAR itself (logMAR) gives a scale that indicates how *poorly* we can see, with a logMAR of 0 for normal vision. The advantage of the logMAR is that it represents equal ratios in the sequence of optotype sizes used in standard testing. Here we will use the logMAR.

To measure the logMAR, we used an optotype consisting of two rectangular digits of different sizes but known gap angles. Masking 'H'-characters were added to impede readability and thus increase the differentiating power of the test (see Figure 8).

Figure 8 Two-digit optotype masked by 10 'H'-characters.

These optotypes were presented on 20" computer screens viewed from 2 m distance. To prevent smear inherent to LCD screens, we used CRT screens for this purpose. Subjects indicated the numbers discerned by means of a separate keypad.

A sequence of maximum 20 optotypes with different digits was presented in a staircase way with increasing and decreasing optotype sizes depending on the correctness of the answers given by the subject. The data were finally fitted to a psychometric function in addition allowing further refinement of the estimation of the actual minimum angle resolved.

To control for eye movements, we used a small but clearly visible fixation dot that either stood still, or moved from the left to the right with a predefined velocity. When this fixation dot was in the centre of the screen, it was replaced by the optotype for 200 ms. The optotype could also be standing still or moving with a predefined velocity.
We always used the highest contrast black optotypes on an otherwise white screen. The experimental room was normally lit.

4.2.2 *Dynamic conditions*

Though more combinations were possible, the scope of dynamic conditions was limited in the present study to those listed in Table 2 for practical reasons (most importantly the time available).

Table 2 Dynamic conditions.

Test		Fixation dot (°/s)	Optotype (°/s)
Static	static	0	0
Retinal Slip	RS-3	0	3
	RS-6	0	6
Smooth Pursuit	SP-15	15	15
	SP-30	30	30

In the Static test the stationary fixation dot was only interrupted for 200 ms by the stationary optotype. Because of the contour interaction induced by the masking characters and the short duration available to discern the optotype, this test will result in a logMAR larger (i.e. worse or >0) than obtained normally with a standard Snellen or Landolt-C test.

In the Retinal Slip conditions, the fixation dot was standing still, while the optotype was moving from left to right. Because visually induced eye movements typically show a latency of 200 ms or more, the optotype was assumed to be moving with the predefined velocity over the retina.

In the Smooth Pursuit condition the fixation dot was moving with the predefined velocities from left to right, interrupted in the screen centre by the optotype moving at the same velocity. If the subject was smoothly following the optotype, no retinal slip should be present giving no reduction of acuity. A worse acuity may be expected when the subject is fatigued or under the influence of drugs (including alcohol), because smooth pursuit is known to be affected by these influences due to the occurrence of step-wise eye movements called saccades where the foveae only fixate on the target for brief periods.

These five tests took about 15 minutes altogether. They were performed by all 12 subjects available in the Q-303 trial two times a day, typically during the first session after breakfast, and the first session after lunch.

In each test we looked for a worse visual performance caused either directly by ship motion, or indirectly by fatigue or motion sickness.

4.2.3 *Data analysis*

DVA data have been excluded for which the tests did not converge within the maximum number of repetitions allowed, that suffered from erroneously set screen resolutions and frame rates (after incidental PC crashes), and/or larger values were obtained than what could be expected based on the actual angle resolvable. Because there were many missing data, the final matrix of data was incomplete, impeding a concise analysis of variance. We therefore only drew conclusions on possible effects by using Student's t-tests for two independent samples.

4.3 Results

Of all possible DVA data, 39% was missing. For the remaining 61%, it was found that only the RS-6 test on the first day was significantly different from the last day ($p < 0.02$), indicating a learning effect, with a marginally significant peek on day 10, likely due to the bad weather. An equal difference (learning effect) was observed in the SP-30 test ($p < 0.05$).

Figure 9 shows the average logMAR values. Here, the DVA data have been separated out for the two motion parameters and for the MISC data.

It appeared that motion did not systematically discriminate between low and high logMAR values. Only the SP-30 difference between small and large lateral motion was significant ($p < 0.05$). For vertical motion this difference was only marginally significant ($p < 0.1$). Both differences were opposite to what was expected, but this may be attributed to the fact that this condition was the most difficult one giving the worst acuities anyway.

When looking at the DVA data separately when subjects were not sick or were sick, the data do show a consistent behaviour: in all tests sick subjects showed worse acuities. Of these the RS-3 condition gave a significant difference ($p < 0.05$), and both SP conditions gave a marginally significant effect ($p < 0.1$).

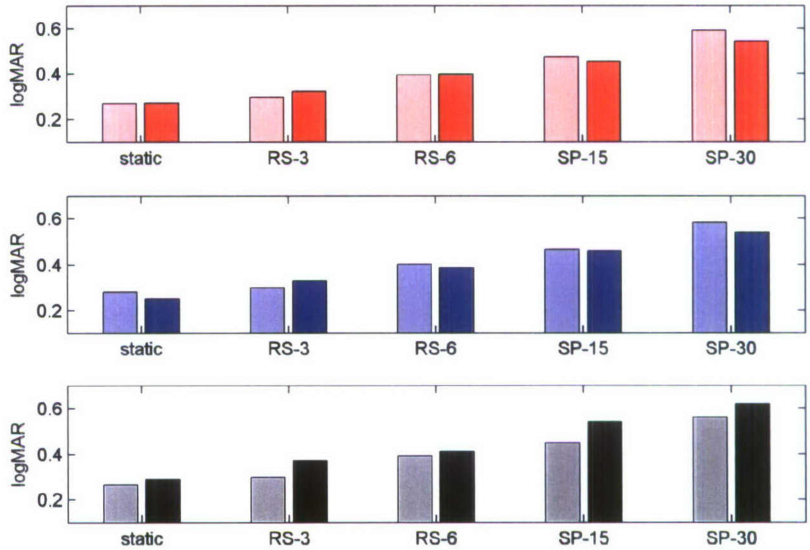

Figure 9 DVA test results separated out for lateral motion (top, red), vertical motion (centre, blue), and sickness severity (bottom, black). The light red and blue represent DVA results when the ship motions were less than average, while the darker colours represent DVA results when the motions were greater then average. The light grey represents DVA results when no sickness symptoms were reported, while the black represents DVA results when at least some discomfort was reported.

To take all tests into account simultaneously, average results per test have been subtracted from the individual data, giving plots as shown in Figure 10. Then the differences become even more obvious, and a *t*-test performed over the pooled data did not show an effect for different motions, but a highly significant effect for differences in sickness ($p < 0.006$).

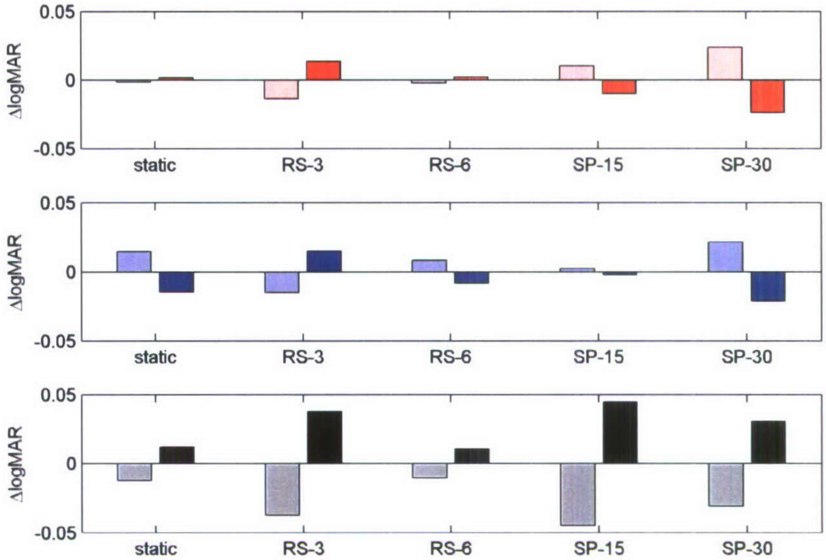

Figure 10 DVA test results presented analoguous to Figure 4, but with the average per test subtracted and plotted on a different scale.

4.4 Discussion and conclusions

With this part of the study we made an effort to quantify one aspect of human performance with a focus on crew working on a moving ship at sea, assuming an acuity degradation with increasing ship motion.

To that end, a newly developed test to specifically assess visual acuity under a wide range of dynamic conditions was applied. This test consisted of a possibly moving fixation dot, to control for eye movements, interrupted for 200 ms by a possibly moving optotype. Our main conclusion is that even though ship motion does not appear to directly affect visual acuity significantly, there is a noticeable and consistent affect from motion-induced sickness: visual acuity of subjects not feeling well was worse than those who did feel well. In addition we conclude that although some differences between the different tests have been found, the current data do not allow for further conclusions on the usability of these tests to discern between different causes, likely due to a large variability in measured acuities.

The current data did show a considerable larger variability as compared to previous results obtained in an Earth fixed laboratory (Bos & Hogervorst, 2006). Based on these previous experiences, we had anticipated larger effect sizes than measured in the current study, and/or larger differences between the different test conditions. One reason why we currently only found a clear over-all effect instead of more individual differences may be that the subjects considered this task to be one of the most boring ones, and moreover, they had to performed it over and over again without any incentive. In future studies this aspect should therefore be considered seriously. In addition to financial incentives, one could also think of implementing these tests within the framework of a computer game.

Apart from showing the possibility to (further) quantify human performance in general, the current DVA test was originally developed as a selection tool, more specifically a fit-to-fly test. The idea was that with a short on-site, preferably laptop based screening

tool, task-critical abnormalities in visual function could easily be assessed.
Dynamic visual acuity is promising in that respect, because it is assumed (and in some cases proven) to be dependent on fatigue, drug abuse, as well as several diseases. In that respect it may also be noted that the natural incentive to perform well in these tests would be clearance to do the task (e.g. the pilot not being grounded). The currently reported data further supports this idea.

5 General Discussion and Conclusions

With the cognitive and visual test results described in this report, another few pieces of the puzzle of discerning and quantifying human performance have been put in place. Though the variability in data were rather large, yet a complex monitoring task, and visual acuity were affected by ship motion, but even more so by seasickness. Tracking was even only affected by sickness and not by the ship motion itself. Apart from the significance of these data regarding their respective theoretical backgrounds, this also shows that seasickness may be a larger problem for human performance than the motions *per se*.

Because many more data have been gathered during the Q-303 trial, it can be anticipated that more insight can be obtained in the underlying mechanisms by combining all these data into one meta-analysis. Also because the Dutch have contributed to the application of a postural stability test, a sleep quality and fatigue questionnaire, and the use of so called actiwatches, it is recommended to further invest in such a meta-analysis within the framework of the *ABCD Working Group on Human Performance at Sea*.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

A multi-national sea trial on the effects of ship motions on human performance was performed off the coast of Canada, in early 2007. Primary goal: To obtain subjective and objective measures for human task performance, possibly affected by real ship motion. TNO participated with a Vigilance and Tracking Test, a Multi-Attribute Task, and a Dynamic Visual Acuity test. The experiment was conducted in three phases: a pre-exposure phase in harbour, an exposure phase at sea, (sea conditions varying from calm to low sea state six) and a post-exposure phase in sheltered waters to re-examine baseline performance. Experiment schedule and protocol are described, motions and wave conditions encountered during the trial, and the results of the Dutch tests are presented. Results: Cognitive performance and visual acuity are impaired by ship motion. This seems to be caused by seasickness in particular, possibly even more so than by ship motion per se. Tracking was affected only by sickness, and not by motion itself. Apart from showing that DVA is of value to further quantify human performance, these data also support the development of an onsite fit-to-perform screening tool based on DVA.

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