Australian Government
Department of Defence
Defence Science and
Technology Organisation

Usability of a Battle Management System Under Simulated Vehicular Motion

Omio Abedin, Victor Demczuk and Gregory Judd

Land Operations Division
Defence Science and Technology Organisation

DSTO-TR-2762

ABSTRACT

Military personnel may be required to conduct command and control tasks whilst under various levels of motion. This study examined the usability of a Battle Management System under motion. Usability was assessed by examining performance degradations for typical Battle Management System tasks that a commander may be expected to complete whilst on the move. It was found that there were no differences in task performance between the static and mild levels of motion, but there were differences between the mild and high levels of motion. It was also found that participants performed better at tasks in which they were receiving information, rather than tasks they were in which they had to input information. There were also learning effects where participants performed better in their latter experiment sessions.

RELEASE LIMITATION

Approved for public release

Published by

Land Operations Division
DSTO Defence Science and Technology Organisation
PO Box 1500
Edinburgh South Australia 5111 Australia

Telephone: (08) 7389 5555
Fax: (08) 7389 6567

AR-015-436
October 2012

APPROVED FOR PUBLIC RELEASE

Usability of a Battle Management System Under Simulated Vehicular Motion

Executive Summary

Previous research has found that motion has an adverse effect on people's cognitive and psychomotor abilities. This has implications for military personnel operating computer based equipment in military vehicles. This report covers an experiment into the usability of a Battle Management System (BMS) under different levels of simulated vehicular motion in order to perform key command and control (C2) tasks.

The experiment simulated six different types of BMS tasks including reading text, reading an enemy unit's location, panning and zooming, creating text, creating a boundary line, and creating a new enemy unit. Participants were required to complete these tasks under static, mild and high motion conditions. They were also asked to provide a subjective rating of their workload and the difficulty of the task. A Simulator Sickness questionnaire was also completed by participants.

It was found that there was no performance difference between the static and mild motion conditions. However, there was a performance difference between the mild and high motion conditions. This was replicated in the subjective responses. No effect of simulator sickness was observed.

It was found that for the Pan and Zoom, Read Text, and Read Unit tasks, participants performed equally amongst the three motion conditions. However, for the Create Text, Create Line, and Create Unit tasks, performance degraded as the motion increased.

There were overall learning effects across the six experimental sessions and for particular tasks. There was no learning effect for the static experimental condition. This indicates that participants took some time to adjust to the motion. There was no learning effect for the Pan and Zoom, Create Unit, Read Text, and Read Unit tasks in any motion condition (i.e. static, mild or high). However, performance did improve over sessions for the Create Text and the Create Line tasks in the high motion condition. Furthermore, performance improved in the mild motion condition for the Create Text task.

Key conclusions:

- Under high motion there was greater difficulty in doing typing and drawing tasks than the Pan and Zoom, Read Unit, Read Text, Create Unit tasks.

- Subjects required a number of sessions to adjust to the motion. Thus training in the use of BMS in vehicles should include a motion condition.
- This experiment has identified that it is easier to read rather than enter information under motion.
- Further research is required using larger motion levels. These studies will be conducted with the completion of DSTO's Land Motion Platform (LAMP).

Authors

Omio Abedin
Land Operations Division

Omio Abedin is a human sciences analyst employed at the Defence Science and Technology Organisation's (DSTO) Land Operations Division. He has a Bachelor of Engineering (Aeronautical) degree and a Bachelor of Science (Psychology) degree from the University of Sydney. Omio has primarily worked with motion simulators to gain an understanding of how motion affects military personnel's performances. His main interests are evaluating as well as using simulator technologies, field trials, and human performance evaluations.

Victor Demczuk
Land Operations Division

Victor Demczuk is a Senior Defence Scientist with DSTO's Land Operations Division. He holds a Bachelor of Arts (Psychology) degree from Flinders University and a Master of Computer Science Degree from the University of South Australia. He has worked in the Human Factors area in DSTO for the last 30 years. His main interests are in Army Command and Control and in particular the Human Computer Interaction and human performance areas.

Gregory Judd
Land Operations Division

Greg Judd is a Systems scientist in Land Operations Division. He has a Masters degree in Computer Science from the University of South Australia. His interests include Command and Control Systems and Advanced Human-Computer Interfaces.

This page is intentionally blank

Contents

List of Abbreviations

ANOVA	Analysis of Variance
AS	Australian Standard
ASLAV	Australian Light Armoured Vehicle
BS 6841:1987	British Standards, titled, "Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock."
BMS	Battle Management System
BMSe	Battle Management System Emulator
C2	Command and Control
DSTO	Defence Science and Technology Organisation
HQ	Headquarters
Hz	Hertz
IMU	Inertial Measurement Unit
LAND 121	Project Overlander
LAMP	Land Motion Platform
LCD	Liquid Crystal Display
LOD	Land Operations Division
MSSQ	Motion Sickness Susceptibility Questionnaire
MUARC	Monash University Accident Research Centre
NASA	National Aeronautics and Space Agency
PMVL	Protected Mobility Vehicle – Light
RMS	Root mean square
RAR	Royal Australian Regiment
RTLX	Raw Task Load Index
SD	Standard Deviation
SE	Standard Error
TLX	Task Load Index
VGA	Video Graphics Array

Axis System

The following is the axis system used throughout this document.

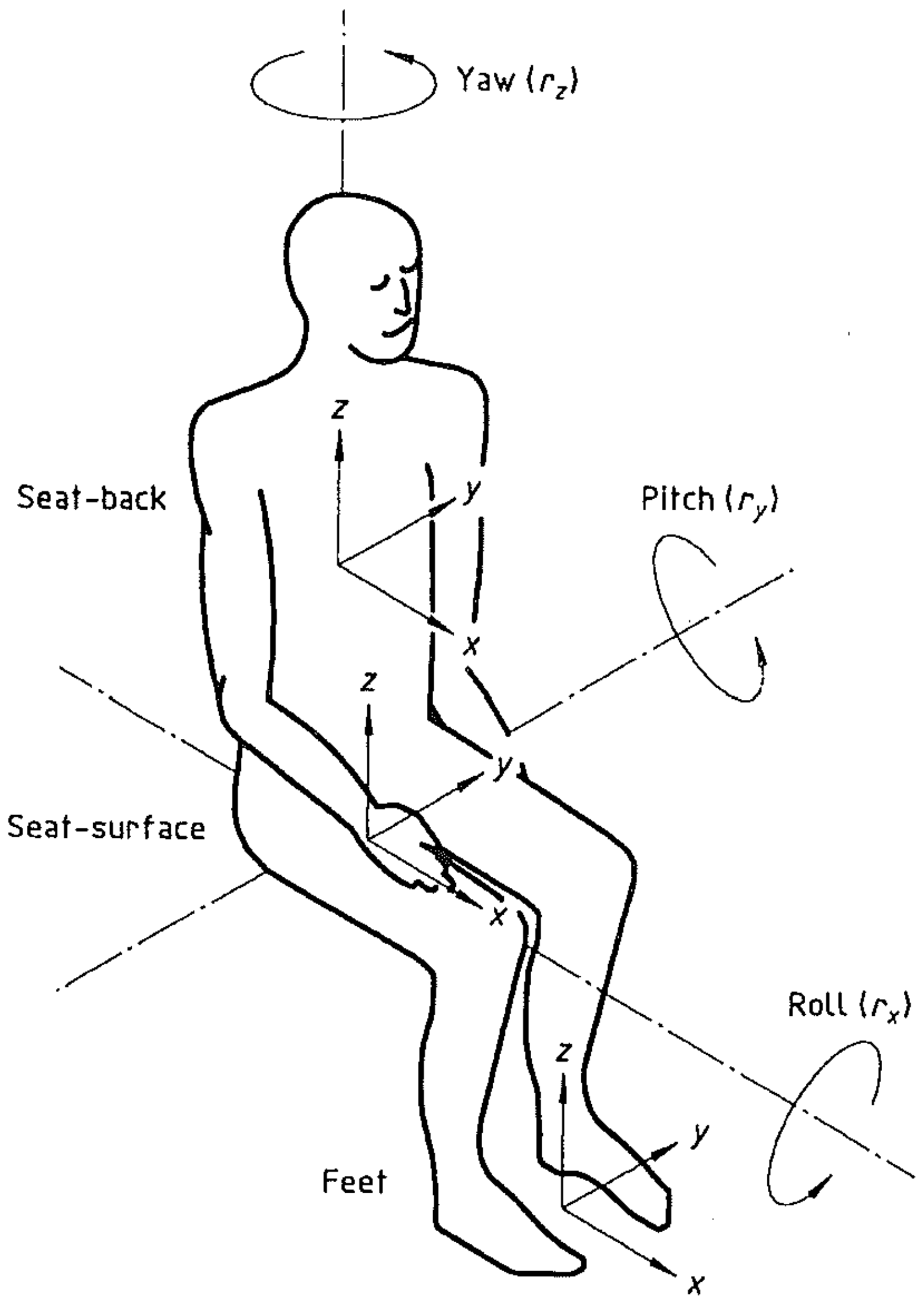


Image source: Standards Australia 2001.

1. Introduction

Cognitive and motor functions are a part of everyday life, and something which are performed countless times throughout one's life. However, performing these functions in a static versus moving situation is different and in the military context this difference has operational performance implications. This report outlines research into how motion affects human performance while carrying out standard military command and control tasks. It details the results of a series of experiments that investigated the effect of varying levels of motion on the typical tasks that the commander of a military vehicle would be expected to carry out using a command and control computer. Experiments were run using a three degree of freedom motion simulator, and data was collected and verified using a wide variety of technologies such as inertial measurement units, Matlab, a Battle Management System emulator (BMSe). Variables of interest were the accuracy of performing the tasks, as well as any learning effects associated with the tasks.

1.1 Military Context

The Australian Army is about to receive the first batch of a new digital Command and Control (C2) Battle Management Systems (BMS)[1]. As part of this roll-out, the system will initially be installed in 7 Brigade's Bushmaster vehicles followed by the 7 RAR's M113 fleet. Subsequent phases of this acquisition are likely to see the system installed into the Army's remaining combat vehicle's (i.e. ASLAVs and as a replacement for FBCB2 in the M1A1 tanks) as well as in current and future logistics vehicles acquired under LAND 121. Figure 1 below shows the system's vehicle mounted computer and display.

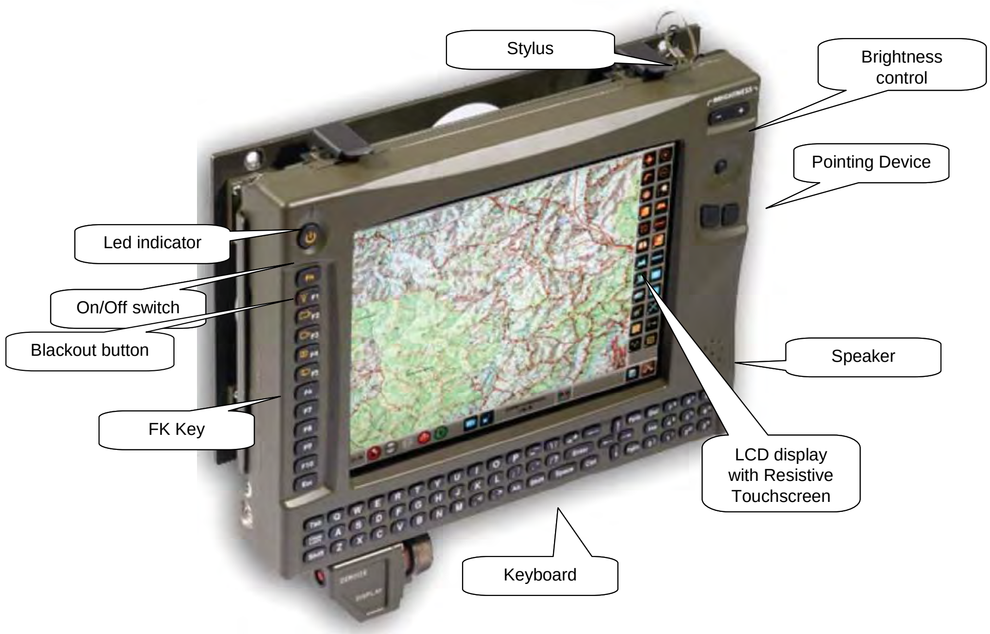


Figure 1: New BMS' vehicle mounted computer and user interface

[1] This acquisition, known as the Battle Group and Below Command, Control and Communications System, or BGC3 (but also known as BMS-C2) is a joint capability acquisition project between LAND 75 (Combat vehicles) LAND 125 (Dismounted Soldiers) and JP2072 (Land tactical Communications systems)

The new BMS is being rolled-out in order to increase Army's tempo of operations by decreasing the time taken to share key C2 information (i.e. plans, orders, reports and returns) and essential situation awareness information (friendly and enemy force locations, and current friendly force state). The extent to which the BMS is able to help achieve this goal of rapid information dissemination however, will partially depend on how easy it is to use while a vehicle is on the move.

1.2 Previous Motion Research

There has been a great deal of civilian and military research into the effect of motion on human performance. This research has generally found that motion tends to have a detrimental effect on task performance (Metcalfe et al 2008).

This research has also shown that it is difficult to predict the strength of the effect of different levels of motion on the performance of specific tasks performed in particular contexts. Seagull and Wickens (2006) for example, in their literature review of the effect of vibration on task performance in command and control vehicles, note that most previous research has investigated the effect of motion in only one axis (Vertical, i.e. up – down motion). They argue however, that these findings cannot (without further research) be used to predict the effect of complex multi-axis random motion (as experienced in military ground vehicles) on task performance. Salmon et al (2010) in their review of previous research into the effect of motion on the use of in-vehicle touch screens also conclude that the effect of different levels of motion, on different in-vehicle touch screen tasks, remains ambiguous.

This suggests that accurate measurement of the effect of motion on BMS task performance must use realistic tasks, equipment, and motion profiles. The best way to do this is to use real equipment and vehicles in real operating environments. To date however, there have been few such studies, with most military research investigating standard usability issues such as interface design by using static BMS systems outside of vehicles (i.e. Command HQs or in the laboratory) (for example see Stanton et al 2010).

Some limited research on vehicle mounted BMS usability in the field has been conducted. Many of the results from these studies however, are based on subjective assessments and not objective performance data (Seagull et al 2006). This is because it is difficult to control the field activity so that motion conditions are exactly replicated across multiple experimental runs for many different participants. Those studies that have attempted to collect objective data (see for example McDowell et al 2005, and Metcalfe et al 2008) have generally focussed on reach time and accuracy and not on the precise effect of motion on BMS information push tasks, such as text entry, drawing and icon placement, or information pull tasks, such as reading text messages; and icons and drawings on digital maps (Salmon 2010).

One way to gain enough control to accurately collect data on the effect of motion on task performance, is to use motion simulators within a laboratory environment[2]. Once again however, most of the studies using this method to date (see Zywiol et al, 2006, for

[2] These simulators can be made to partially look and feel like real vehicles by 'mocking up' crew cabin and equipment layouts.

example) have concentrated on identifying reach timing and accuracy in order to make recommendations about user interface design, not on assessing the effect of motion on BMS task performance (and therefore on operational performance).

Another area of interest is determining the best way to train users to use the BMS under motion. There is some evidence to suggest that, in general, tasks are best learnt in realistic conditions (Lenne et al 2010). This suggests that learning BMS tasks, in a static 'classroom' environment, may be less than optimal for use under motion. Again however, there is a lack of research into the effect of operator experience on BMS task performance under realistic motion conditions.

Finally, previous research has identified two key compounding factors that make it more difficult to accurately assess the effect of motion on task performance. The first factor is whether the user is suffering from motion sickness. Motion sickness, depending on its severity, also has an effect on physical and cognitive task performance under motion (Hill et al 2005) so it remains difficult to separate the direct effect of increases in motion on task performance from its indirect effect via induced motion sickness. This is further complicated by the fact that motion sickness tends to become less severe under higher workloads and after longer exposure (Seagull 2006). The second complicating factor is the effect of individual differences on task performance. In the case of performance under motion this is more than just differences between individuals' physical and cognitive abilities (e.g. typing speed). For example, individuals also vary in their susceptibility to motion sickness and more surprisingly the motion frequencies (resonances) most affecting individual task performance under motion vary according to anthropometric factors such as individual body mass, (Seagull 2006).

1.3 DSTO Motion Research Goals

As Army is acquiring the BMS system essentially off the shelf, the most pressing research need is not to determine the best user interface to support use under motion, but to determine the best way to use the purchased system under motion (i.e. identify the most effective standard operating procedures). DSTO's research program in this area therefore, aims to help Army maximise the overall operational impact of the new BMS by helping to identify the 'tipping point' when the loss of BMS task performance (i.e. time and accuracy) due to motion begins to outweigh the potential operational benefits provided by quicker information dissemination between friendly forces. Therefore, there will also be implications for the use of the BMS without motion.

Another research goal is to determine how long it takes to learn to perform a particular BMS task under motion and how much improvement does this practice bring? This has important implications for determining the amount of 'live' BMS practice versus 'classroom' BMS instruction needed to maximise performance. It is also hoped that the research (described below) will shed light on the extent to which motion simulation can be used to train commanders to use the BMS under motion, potentially reducing the time needed to practice in the field.

1.4 Previous LOD Motion Research

As mentioned above, the most objective and controlled way to determine the effects of different levels of motion on BMS task performance is to use laboratory based motion simulation with as realistic as possible: tasks, equipment and environments[3]. DSTO has been building up its ground vehicle motion simulation capability since 2009, starting with the small scale motion chair described in Section 3.3.1 below (also see Figure 2 below).

1.4.1 Initial DSTO Pilot Study

The motion chair was first used during a DSTO pilot study (Judd, Demczuk, and Jacques 2009) which looked at the effect of motion on the performance of six key BMS tasks. The goal of this study was to ensure that the procedures and BMS tasks used were appropriate for further use in a full experiment with more participants (described in the main report below). A purpose built mock up of a real BMS was used with the motion platform chair, a touch enabled 17-inch monitor and conventional keyboard.

Using a repeated measures design with motion as the independent variable, three conditions were simulated: no motion, mild motion (simulating driving on a sealed road) and high motion (simulating driving on an unsealed road). Participant task completion times and error rates were then measured during the following BMS tasks:

- reading text
- writing text
- reading a unit's location, type and size, on a digital map
- panning and zooming a digital map using digital buttons
- creating a military enemy unit on a digital map
- drawing a multi-segment control line on a digital map.

The pilot study's results suggested that motion is likely to affect task completion times only for the writing text task. Task error rates however, were higher during the writing text, creating unit and drawing line tasks, but only during the highest motion condition. Performance also improved considerable between all conditions across the three sessions of the experiment, suggesting that even more improvement might be possible with more practice.

1.4.2 MUARC Study

The pilot study's results justified further experimentation with larger numbers of participants in more realistic simulated environments. DSTO therefore commissioned the Monash University Accident Research Centre (MUARC) to use its advanced driving simulator capability to perform a further BMS motion task performance study (see Lenne et al 2010 and Salmon et al 2010). MUARC's simulator consists of a Holden passenger vehicle simulator cab, mounted on a motion platform that produces realistic road feel and

[3] DSTO is also supporting field evaluations of the BMS under motion as part of the acceptance and operational test and evaluations activities supporting the initial operating capability of the BMS. These evaluations however, will be more subjective than the studies described in this report and will be based on observations, surveys and subject mater expertise.

passenger vehicle dynamics. The external driving environment (of a rural sealed road and country side) was simulated using its six channel projection system (one displayed at the rear, two displayed as side mirrors and three at the front displayed on a curved screen). The same BMS emulator and set of six BMS tasks used in the DSTO pilot study (described above) was displayed on a ten inch LCD screen mounted on the vehicle's passenger-side dashboard. The 20 participants were required to complete the six tasks (during two repetitions each) while experiencing no-motion, on-road motion or off-road motion. The experiment also included a further visual task requiring the 20 participants to detect and report a particular type of object in the surrounding environment. Additional information about subjective workload was also collected using surveys but also by measuring the participant's eye fixation and blink rates (using an eye-tracking camera) as well as by measuring their heart-rates.

The study, which has since been published (Salmon et al 2011) found that the effects of high levels of motion on the speed and accuracy of information 'pull' tasks (e.g. reading, icon recognition) are marginal, but much higher on information 'push' tasks (e.g. text entry, boundary drawing). These findings were also consistent with the self reported and physiological measures of workload collected during the experiment. Task completion times however, were also found to be significantly shorter for the second drive in each motion condition, indicating a potentially significant learning effect, suggesting that more training under motion could significantly improve performance. Motion however, did not effect reaction times for the visual detection task, yet the percentage of time spent gazing at the BMS was found to be higher in the high motion condition (particularly for the first drive). During the experiment, it was also observed that reaching strategies changed under motion, with many participants using stabilising points for their hands (e.g. side of touch screen)[4]. The study's authors recommend that the issues relating to the use of reaching strategies be further examined. They also recommend that the results should be cross-checked by further studies measuring the effect of motion on BMS task performance in real vehicles, in real environments.

1.5 Report overview

The remainder of this report details the research goals, method and results of a more complete study into the effects of motion on BMS performance, recently completed in Land Operations Division. It concludes by outlining some on-going research into the use of the BMS under motion in realistic environments, collected during recent Land 121 Joint Protected Mobility Vehicle – Light (PMVL) trials in Puckapunyal. The report will finish by discussing some of the proposed future studies that will be conducted using LOD's LAnd Motion Platform (LAMP), which is soon to be commissioned.

---

[4] This tendency was also noted during the initial Pilot study, as well as during previous studies (McDowell et al, 2005 and Rider et al, 2003). This might explain why the writing task showed the worst performance, as stabilisation points for this task were hard to find and why scores on pan and zoom tasks were nearly 100% as these benefited most from stabilising on the side of the touch screen.

2. Rationale of Current Study

The current study aimed to extend the DSTO pilot study in several ways. Firstly, in the pilot study it was found that participants would easily learn the motion file sequence, and they would often wait for periods in the file with low motion to complete the tasks. With the current study, the motion profiles were more random, and participants could not anticipate periods of low amplitude motion in the file. The motion in the current study was also standardised according to British Standard BS 6841:1987, titled, "Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock." This ensured that the results of the study were easily comparable to real world scenarios, where the vibration in vehicles can be measured.

The current study employed the use of seat belts which the pilot study did not. This ensured that all participants were positioned with the same posture and had the same reach to the computer. This avoided the situation in the pilot study, where it was observed that participants were bracing the computer in different ways and each participant had different postures when seated.

There seemed to be a distinct difference between the information that was being "pushed" (i.e. given) to a commander and information that was being "pulled" (i.e. taken) from a commander. The pilot study showed that motion affected the information being pulled from the commander more adversely than information pushed to a commander. This study looked at whether degradation could eventually be found for the "push" tasks with higher amplitudes of motions. It also looked for the point in which the "pull" tasks became adversely affected by motion according to the British Standard.

The MUARC study and the DSTO pilot study only did two and three repeats respectively of the BMS tasks. Both previous studies had found some learning trends. However, neither had the repetitions required to do a proper learning effect analysis. The current study employed six repetitions of the BMS tasks as well as training of the BMS tasks before the experiments begun. It was able to do an analysis of learning effects of each task type over the various motion conditions.

2.1 Aims

There were several aims of the current study. Firstly, there is a need to determine how different levels of motion affect performance on C2 tasks. Three levels of motion were chosen for the study, static, mild and high. The mild motion was a "level two" (out of six) according to the British Standard, and the high motion was a "level four" according to the standard. The aim was to see at what level motion would have a significant effect on performance. The mild motion is typical of that experience on a bitumen road. The high level is typical of a rough dirt road.

Another aim of this study was to determine which types of C2 tasks are most adversely affected by motion. From the pilot studies, it would appear that it is easier for commanders to receive information, but much harder for them to give information. However, the results in the pilot study did not yield any significant effects, rather just trends were observed. Hence, this study aimed to further investigate this trend.

Lastly, the study looked at whether participants could 'learn' to cope with the motion at the various levels. If performance under motion can be improved by repeated exposure, then this could potentially alter commanders training regimes and plans. Commanders could be better prepared to perform BMS tasks under motion.

Based on previous literature, and past studies (the DSTO pilot study, and MUARC study), the following hypotheses were created:

2.2 Hypotheses

1. There will be differences in performance for the high versus static level of motion, but not for the mild versus static motion.

2. Participants will perform better on tasks in which they read information compared to tasks in which they have to enter information.

3. There will be learning effects based on type of task, and motion.

3. Research Method

3.1 Participants

There were 16 (13 male, three female) Defence Science and Technology Organisation (DSTO) employees who participated in the experiment. The average age of the participants was 32 years (SD = 8.02), with participant age ranging from 22 to 47 years. Nine of the participants had military experience, and seven participants also had some form of experience using command and control systems in the past. Two of the participants were left handed, and one participant had slight colour vision impairment. All participants willingly volunteered to take part in the study without any form of compensation.

3.2 Design

The study looked at two critical aspects of command and control tasks, which were, task performance and learning effects of doing tasks repeatedly over time. It employed a (3 × 6) repeated measures design that investigated three different levels of motion (static, mild, and high), and six task types (pan and zoom, reading text, reading unit icons, creating text, creating boundary lines, creating unit icons).

3.3 Materials

3.3.1 DBox motion chair

To simulate vehicle motion a D-BOX GP-PRO-200 'Gaming' motion platform, shown in Figure 2, which is a commercial product designed to replicate racing car motions while playing computer games was used. The D-BOX is capable of three types of motion; roll of approximately four degrees (left right rotational motion), pitch of four degrees (forward-backward rotational motion; and heave (vertical linear displacement or up down motion of up to 40mm). The chair can simulate accelerations of up to1g (i.e. 9.8 metres per sec^2).

Apart from the BMS screen there were no simulated external environment visuals. This was deliberately done to minimise simulator sickness due to visual cues/miscues.

Figure 2: DBox Motion Platform

3.3.2 XSens IMU

An XSens MTx inertial measurement unit (IMU) combined with the XSens Xbus Master was used to measure the vibrations that were being experienced by the participants, as shown in the Figure 3. Data was sampled at 120Hz at a baud rate of 921600. Further details on the sensor can be found at http://www.xsens.com/en/industrial-applications/mtx?tab=1.

Figure 3: XSens motion sensors

3.3.3 Panasonic Toughbook

The command and control tasks were installed on Panasonic Toughbook CF-19, which has a 10.4" 1024 × 768 VGA touchscreen. The computer was attached to the mount, which was available in front of the participant, as can be seen in Figure 1. For more information see http://www.buytough.com/tb_19.asp.

3.3.4 BMS emulator

The Battle Management System (BMS) emulator was produced to create a comparable replica of a real Battle Management System. It is capable of doing similar tasks such as reading, writing, pan and zoom, creating enemy units, creating boundary lines, and detecting enemy units on a fictitious map. A screenshot of the emulator can be seen below.

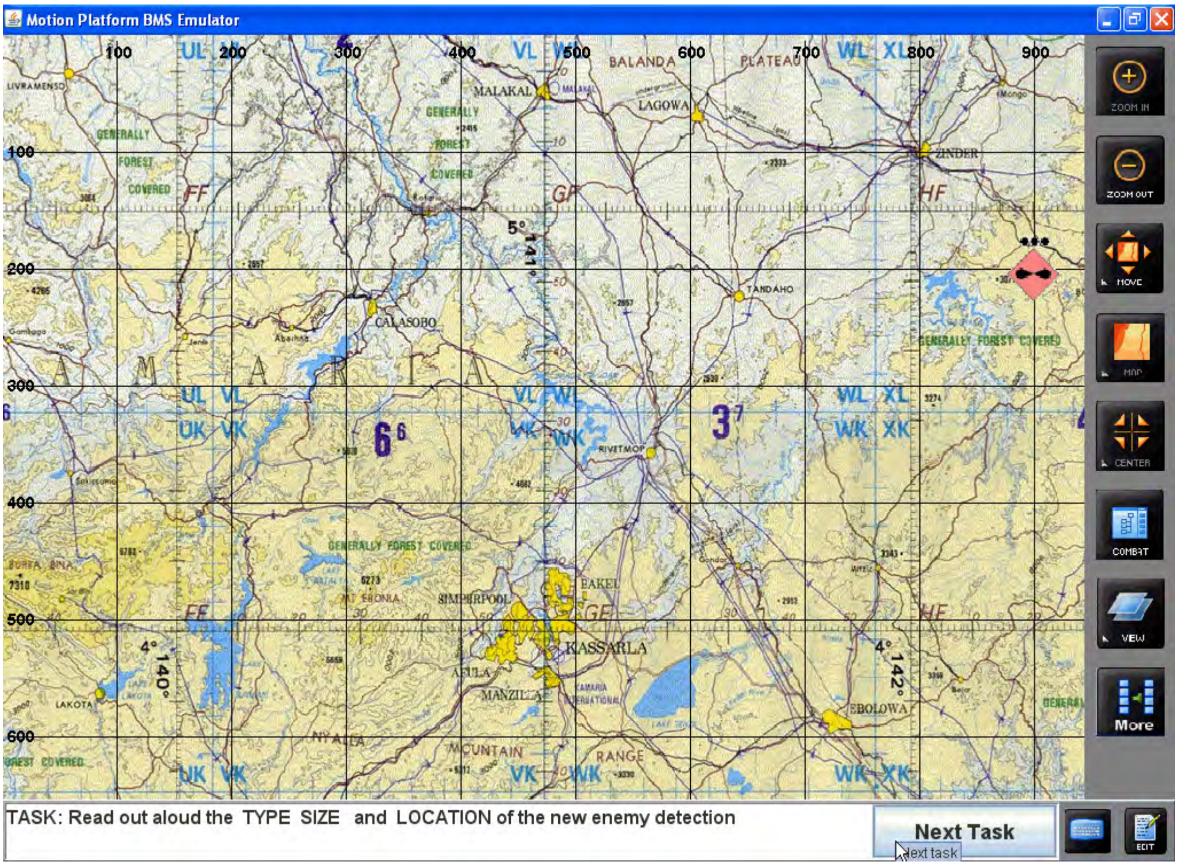


Figure 4. Screenshot of the BMS task emulator user interface.

3.3.5 Subjective Workload Measures

A series of subjective questionnaires were used for the experiment. These included a motion sickness susceptibility questionnaire, simulator sickness questionnaire, the NASA Task Load Index questionnaire, and a Task Difficulty questionnaire. A copy of the questionnaires can be seen in Appendices A, B, C, and D respectively. The motion sickness questionnaires were used to determine whether participants were susceptible to motion sickness or felt motion sick after simulation exposure. There was also a demographic questionnaire given before the start of the experiment which can be found in Appendix E.

3.3.6 Motion Sickness Questionnaires

3.3.6.1 Short Motion Sickness Susceptibility Questionnaire

An initial assessment of the participants' susceptibility to motion sickness was assessed by the Short Motion Sickness Susceptibility Questionnaire (Appendix A). If it was found that participants were susceptible to motion sickness, it would be recommended that they do not continue with the study.

3.3.6.2 Simulator Sickness Questionnaire

A questionnaire following motion stimulus was given to determine whether participants became ill as a result of being subjected to motion. The questionnaire can be found in Appendix B.

3.3.6.3 NASA Task Load Index

After completing each BMS condition, subjects filled in two workload assessment questionnaires. The NASA Task Load Index (TLX) was used to distinguish their subjective workload scores (Hart & Staveland, 1988). The TLX is a multi-dimensional rating assessment with six subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration. Each subscale is presented as a line divided into 20 equal intervals anchored by bipolar descriptors (e.g. High/Low). The questionnaire was presented after each condition.

The TLX was in the form of the Raw TLX (RTLX), a common modification to the original which eliminates the weighting process of the sub-scales. The ratings are simply averaged or added to create an estimate of overall workload. This method has been considered as equally sensitive to the original (Byers, Bittner & Hill, 1989). During the training session, discussion of the TLX was used to help subjects calibrate their understanding of the rating scales. The scores were either added or multiplied by 20 to obtain a normalised maximum score of 100. The Performance scale was excluded from Total RTLX % results as it was felt this was more indicative of mental load.

3.3.6.4 Task Difficulty Questionnaire

A Task Difficulty questionnaire was also completed by subjects after each BMS condition. Subjects scored difficulty for each of the six BMS tasks after each of the three motion conditions. A five point scale was used with subjects circling a number from one (not difficult) to five (extremely difficult). The scores were multiplied by 20 to obtain a normalised maximum score of 100.

3.4 Procedure

3.4.1 Creating Motion Profiles

The British Standards BS 6841:1987, titled, "Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock," was used to create motion profiles which simulated two particular levels of the Standards. Three random values (roll, pitch and heave) were inputted into the DBox using an executable file. The files were assessed using the XSens IMU and appropriate scaling was applied in order to gain the correct frequency magnitude of vibration in line with the Standards.

Three motion conditions were used for the experiment. One was static, the other was mild and lastly a high motion condition. The mild motion was a "level two" motion according to the standards, with a root mean square (RMS) value of $0.47 m/s^2$. The high motion was a "level four" motion, with an RMS value of $1.2 m/s^2$.

3.4.2 Participant Instructions

Participants were given instructions on how to complete the BMS tasks and they completed two training sessions to ensure that they fully understood all the instructions. They were informed of the voluntary nature of the experiment and advised to indicate whether they felt motion sick at any point. Participants were also shown the various questionnaires that they would be required to fill out throughout the experimental sessions. There were slightly different instructions for the first session compared to the subsequent experimental sessions.

At the start of each experimental session, participants were instructed to complete the SSQ, and then proceed to complete the first component of the experiment, which was either a static, mild or high level motion condition. The condition was completed, participants were asked to complete the NASA TLX and task ranking questionnaire. Furthermore, if participants just completed a motion condition, they were also asked to complete the SSQ. This procedure was repeated until all three condition for the session were completed. The complete script given to all participants can be found in Appendix F. Participants also observed the experimenter demonstrate how to do the tasks.

3.4.3 Scheduling and Capturing Data

Participants were scheduled to do one session per week. However, due to the participants' other work commitments, this was not always the case. At the beginning of each session a static training condition was administered. Following the training, each session consisted of a static, mild and high motion condition presented in random order. During each condition they completed the BMS tasks. Each set of the BMS tasks consisted of 24 items (four of each type: Pan and Zoom, Read Text, Read Unit, Create Text, Create Line, and Create Unit) presented in a random order. The training condition was provided to ensure no participants forgot how to complete a particular task.

A program was written to capture the data that was inputted by the participants. Each response given by the participant was recorded automatically in a '.csv' file format.

3.4.4 Task Types

There were six different tasks that the participants had to complete. Participants were asked to complete all tasks as quickly and accurately as possible. The Create Text task consisted of participants being presented five words, with each word being five characters long. They were asked to type the presented text into a box that appeared above the words. The Read Text tasks entailed participants to read ten words that appeared in a box. Each word was five characters in length. The Pan and Zoom tasks required the volunteers to navigate the touchscreen icons as per the requested instructions. Participants could Pan 'left', 'right', 'up' or 'down', and zoom either 'in' or 'out'.

The Read Unit tasks required participants to read out loud the type, size and location coordinates of a new enemy icon that appeared on the screen (Appendix G). There were five enemy types, and three sizes for the enemy units that could have appeared. The Create Unit tasks involved participants interacting with the touchscreen to place an icon at the instructed location. In the Create Line tasks participants needed to place their finger on the touchscreen at a specified grid location. They then needed to follow the instructions and move one grid unit either 'up', 'down', 'left', or 'right' and place their finger on that location. They were required to repeat this a further three times.

4. Results

4.1 Motion Sickness Questionnaires

4.1.1 Motion Sickness Susceptibility Questionnaire (MSSQ)

The motion sickness susceptibility questionnaire was administered to determine whether participants were susceptible to motion sickness. If participants were found to be susceptible to motion sickness, they were advised to re-consider participating in the experiment. The mean MSSQ score was 9.21 and the standard deviation was 9.20.

It is considered that MSSQ scores above 22.8 could indicate that a person is susceptible to motion sickness (Golding, 2006). One participant had scored above 22.8, however the participant was willing to continue with the experiment.

4.1.2 Simulator Sickness Questionnaire

The simulator sickness questionnaire was used to determine if participants became sick after being exposed to the simulator. Below is a chart of the responses of the questionnaire comparing pre-exposure to motion versus post "level two" and "level four" motion.

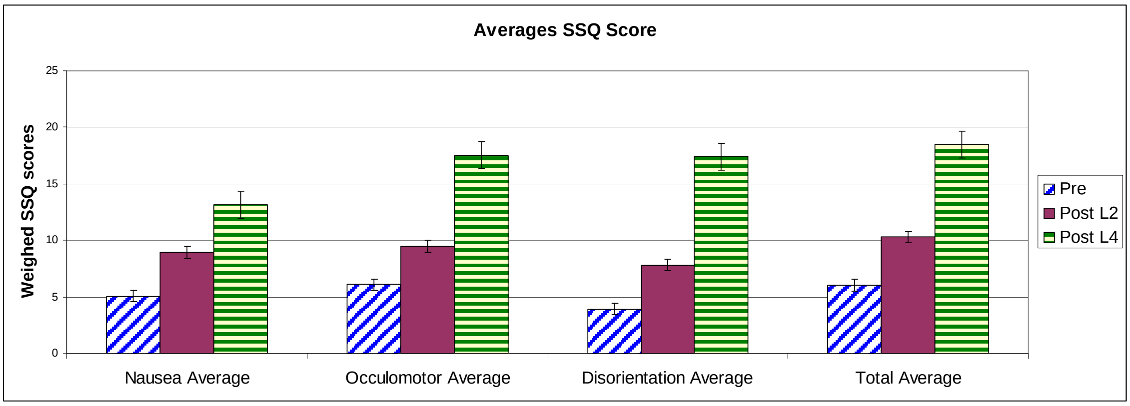


Figure 5: Average SSQ responses which include data for all sessions. Error bars represent +/- 1 standard error (SE).

Figure 5 shows that participants reported feeling worse after "level 4" motion exposure compared to before motion exposure (t_{15} = 3.112, p < .05), but they did not report feeling worse after "level 2" motion versus before motion exposure (t_{15} = .908, p > .05). However, no participants wished to discontinue as a result of simulator sickness.

Since participants reported being more sick after being exposed to the "level 4" motion, a regression analysis was done to see if this correlated with performance. It was found that there was no performance decrements due to increases in SSQ scores (R^2 = .006, $F_{1,30}$ = .190, p > .05).

4.2 BMS Performance

4.2.1 Overall Analyses Averaged Across Sessions

All scores were converted to percentages and inputted into the SPSS 18.0.0 statistical package. A (3 x 6) repeated measures analysis of variance (ANOVA) was conducted at the 0.05 level. Partial eta-squared values (ηp^2) are provided as estimators of effect sizes for the ANOVAs. The figure below shows this data graphically.

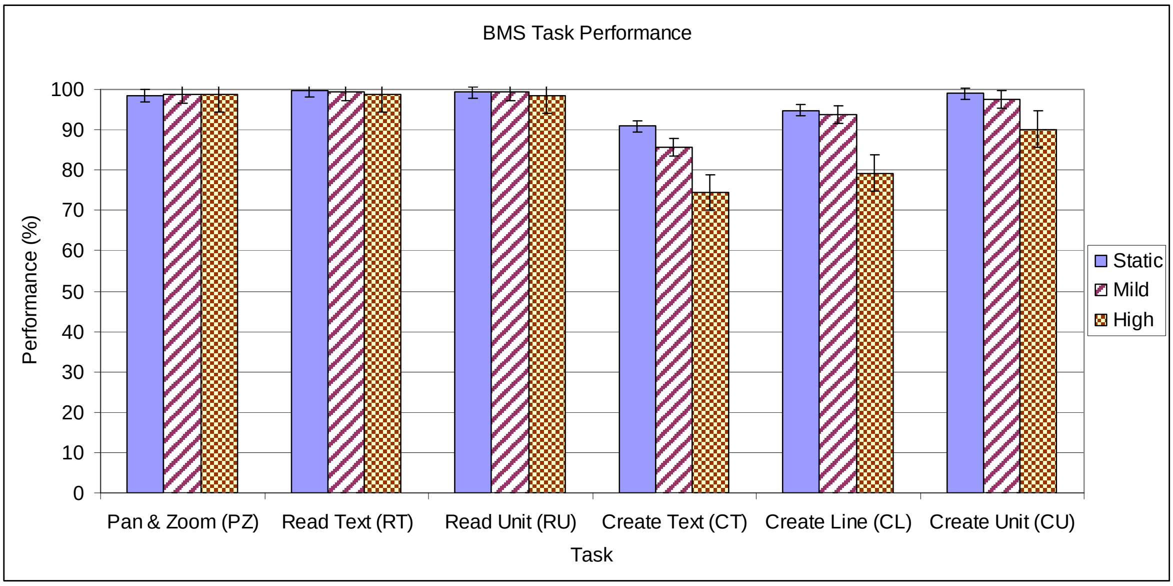


Figure 6: BMS Task Performance scores. Error bars represent +/- 1 standard error (SE).

As expected the two-way repeated measures ANOVA revealed significant main effects of motion ($F_{2,16}$ = 62.05, p < .05, ηp^2 = .81), and task type ($F_{5,16}$ = 35.71, p < .05, ηp^2 = .70). It also yielded significant interactions between motion and task type ($F_{10,16}$ = 15.51, p < .05, ηp^2 = .51).

4.2.2 Motion Condition

Further post hoc analyses were done using the Scheffe procedure. Due to the main effect of motion in the overall analysis, contrasts were conducted to see exactly where the differences in the motion conditions were. There was no difference between the static motion (M = 97.00, SD = 1.25) versus the mild motion (M = 95.79, SD = 1.73) conditions ($F_{1,16}$ = 6.17, p > .05, ηp^2 = .29). There was a statistically significant difference between the mild (M = 95.79, SD = 1.73) versus the high (M = 87.91, SD = 3.44) motion conditions ($F_{1,16}$

= 95.56, $p < .05$, $\eta p^2 = .86$). It was found that participant's performances were worse in the high versus the mild motion. This is depicted in the Figure 7.

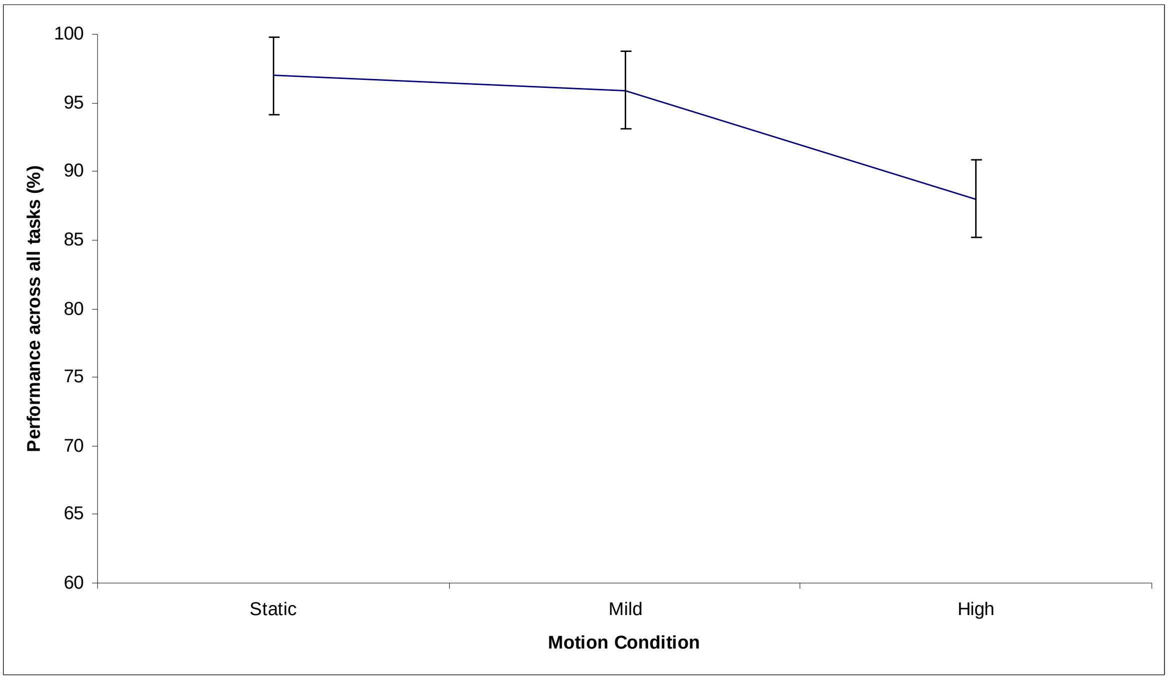


Figure 7. Performance scores of each motion condition averaged across all task types. Error bars represent +/- 1 standard error (SE).

4.2.3 Task Type

The significant main effect of task type was analysed further in a series of contrasts. This was to observe which tasks participants found easier than others. A bar chart of the task performances can be seen in Figure 8. Firstly a comparison between the visual tasks (Read Text and Read Unit) ($M = 99.24$, $SD = 1.16$) and non visual tasks (Pan and Zoom, Create Text, Create Unit, and Create Line) ($M = 91.89$, $SD = 10.19$) was done. Participants performed better in the visual tasks compared to the non visual tasks.

However, as shown in Figure 8, the Create Text, and Create Line scores were lower than all other tasks (Pan and Zoom, Read Text, Read Unit, and Create Unit). The difference between Create Text and Create Line ($M = 86.59$, $SD = 11.70$) versus the other tasks (Pan and Zoom, Read Text, Read Unit, Create Unit) ($M = 98.21$, $SD = 3.04$) was statistically significant ($F_{1,16} = 110.91$, $p < .05$, $\eta p^2 = .88$). Thus participants performed better in all other tasks compared to the Create Text and Create Line tasks. Furthermore, the difference between Create Text ($M = 83.85$, $SD = 13.09$) and Create Line ($M = 89.33$, $SD = 9.48$) task performance was not statistically significant ($F_{1,16} = 4.011$, $p > .05$, $\eta p^2 = .21$). Therefore the results show that the Create Text and Create Line tasks were equally difficult.

A comparison between Read Text and Read Unit ($M = 99.24$, $SD = 1.16$) versus Pan and Zoom ($M = 98.71$, $SD = 1.57$) showed no statistical difference ($F_{1,16} = 4.89$, $p > .05$, $\eta p^2 = .25$). Thus the performances in those three tasks were similar to each other. That is, participants performed equally well in the Pan and Zoom, Read Text and Read Unit tasks averaged across all three motion conditions.

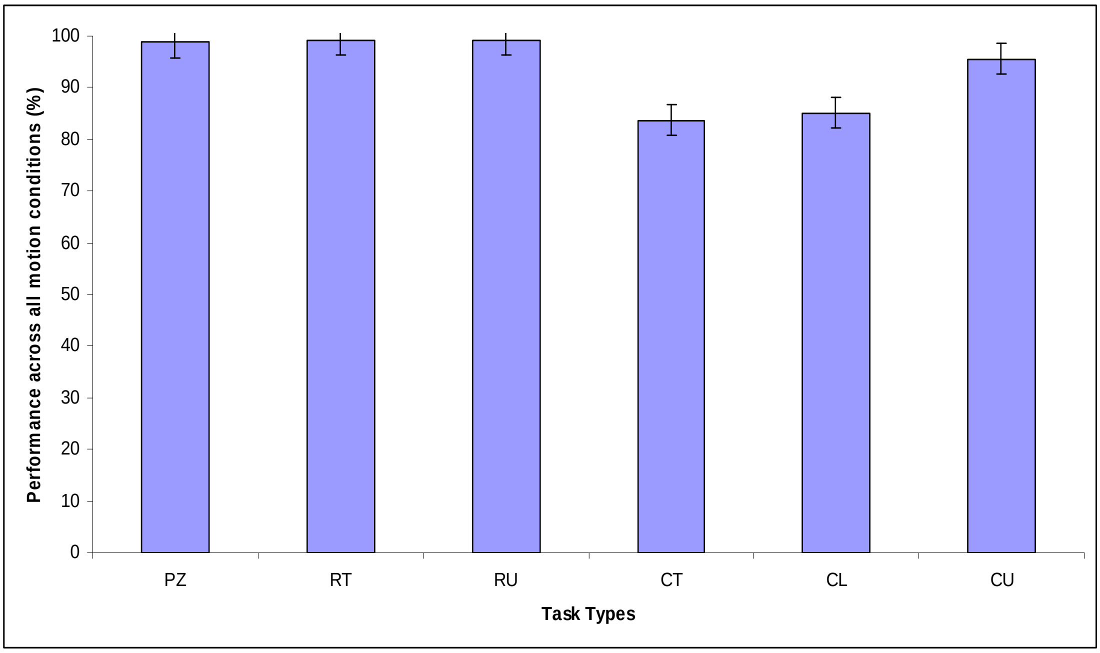


Figure 8. Performance scores of each task types averaged across all motion conditions. Error bars represent +/- 1 standard error (SE).

4.2.4 Interaction

The significant interaction found in the main ANOVA was further explored. No interaction between the static versus mild and tasks was found.

The difference between static Pan and Zoom (*M* = 98.44, *SD* = 1.61), mild Pan and Zoom (*M* = 98.83, *SD* = 1.86), and high Pan and Zoom (*M* = 98.68, *SD* = 1.50), performance scores were not statistically significant ($F_{2,16}$ = .20, p > .05, ηp^2 = .01). Similarly, no differences were found between static Read Text (*M* = 99.64, *SD* = .50), mild Read Text (*M* = 99.32, *SD* = .72), and high Read Text (*M* = 98.75, *SD* = .70) performances ($F_{2,16}$ = 13.36, p > .05, ηp^2 = .47), or static Read Unit (*M* = 99.29, *SD* = .90), mild Read Unit (*M* = 99.48, *SD* = .86), and high Read Unit (*M* = 98.44, *SD* = 1.82) performances ($F_{2,16}$ = 2.81, p > .05, ηp^2 = .16) tasks. Surprisingly, there was no statistical difference between the static Create Text (*M* = 90.94, *SD* = 4.33), mild Create Text (*M* = 85.75, *SD* = 8.46), and high Create Text (*M* = 74.45, *SD* = 17.22) performance scores ($F_{2,16}$ = 17.45, p > .05, ηp^2 = .54). The lack of statistical difference between motion conditions for the Create Text tasks was likely due to the high variability in the data.

There was a significant difference between the static Create Line (*M* = 94.81, *SD* = 4.41), mild Create Line (*M* = 93.82, *SD* = 4.19) and high Create Line (*M* = 79.25, *SD* = 9.01) scores ($F_{2,16}$ = 39.08, p < .05, ηp^2 = .72). There was also a significant difference between the static Create Unit (*M* = 98.96, *SD* = 1.52), mild Create Unit (*M* = 97.53, *SD* = 2.18), and high Create Unit (*M* = 90.18, *SD* = 4.50) scores ($F_{2,16}$ = 45.27, p < .05, ηp^2 = .75).

4.3 Learning Effects

A regression analysis was performed at the 0.05 level to determine if there were any learning effects throughout the six sessions for the different motion conditions. The figure below shows the average performances and trend lines for all tasks in the different motion conditions over the six sessions.

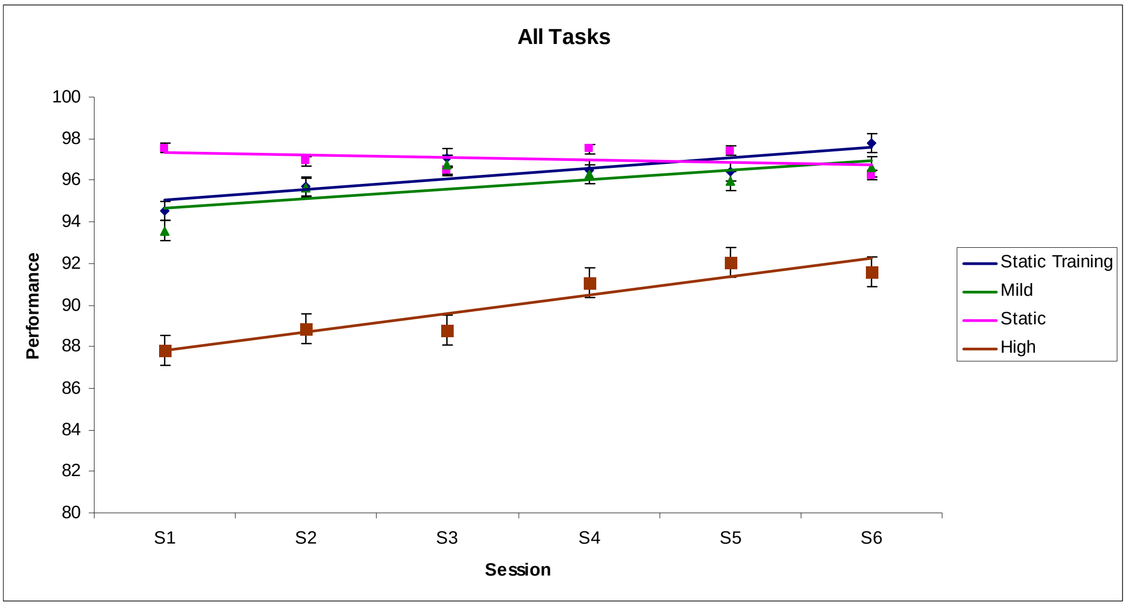


Figure 9. Average performance and trend line using all tasks for each session under the different motion conditions. Error bars represent +/- 1 standard error (SE).

It was found that participant performance improved during the initial training sessions ($R^2 = .013$, $F_{1,574} = 7.447$, $p < .05$). Once trained however, their performance during the static sessions remained the same ($R^2 = .001$, $F_{1,568} = .524$, $p > .05$). There continued to be an improvement for both the mild ($R^2 = .008$, $F_{1,568} = 4.450$, $p < .05$) and high ($R^2 = .009$, $F_{1,568} = 5.342$, $p < .05$) motion conditions across the six sessions.

4.3.1 Individual Tasks

Since there were differences between the performances for the task types, further analysis was done to determine if participants learnt the tasks differently.

4.3.1.1 Pan and Zoom

There was no difference in performance between the training ($R^2 = .004$, $F_{1,94} = .424$, $p > .05$), static ($R^2 = .003$, $F_{1,93} = .003$, $p > .05$), mild ($R^2 = .000$, $F_{1,93} = .003$, $p > .05$) or high motion conditions ($R^2 = .011$, $F_{1,93} = 1.033$, $p > .05$). That is, participants performed just as well across all the motion conditions for the Pan and Zoom task. This can be seen in the figure below.

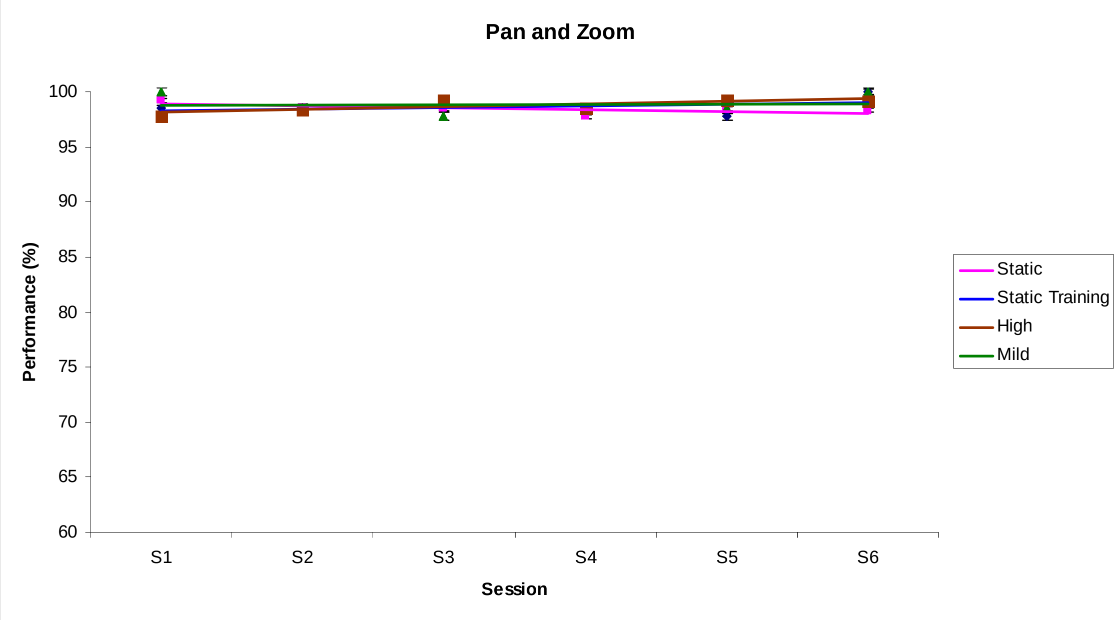


Figure 10. Average performance and regression line for the Pan and zoom task across the six sessions. Error bars represent +/- 1 standard error (SE).

4.3.1.2 Read Text

Performance in the Read Text task statistically improved for the training sessions (R^2 = .009, $F_{1,94}$ = .841, p > .05), however, this improvement would be considered operationally insignificant. Performance did not change across the sessions for the other conditions, static (R^2 = .009, $F_{1,93}$ = .841, p > .05), mild (R^2 = .026, $F_{1,93}$ = 2.486, p > .05) or high sessions (R^2 = .000, $F_{1,93}$ = .005, p > .05). This is shown in the figure below.

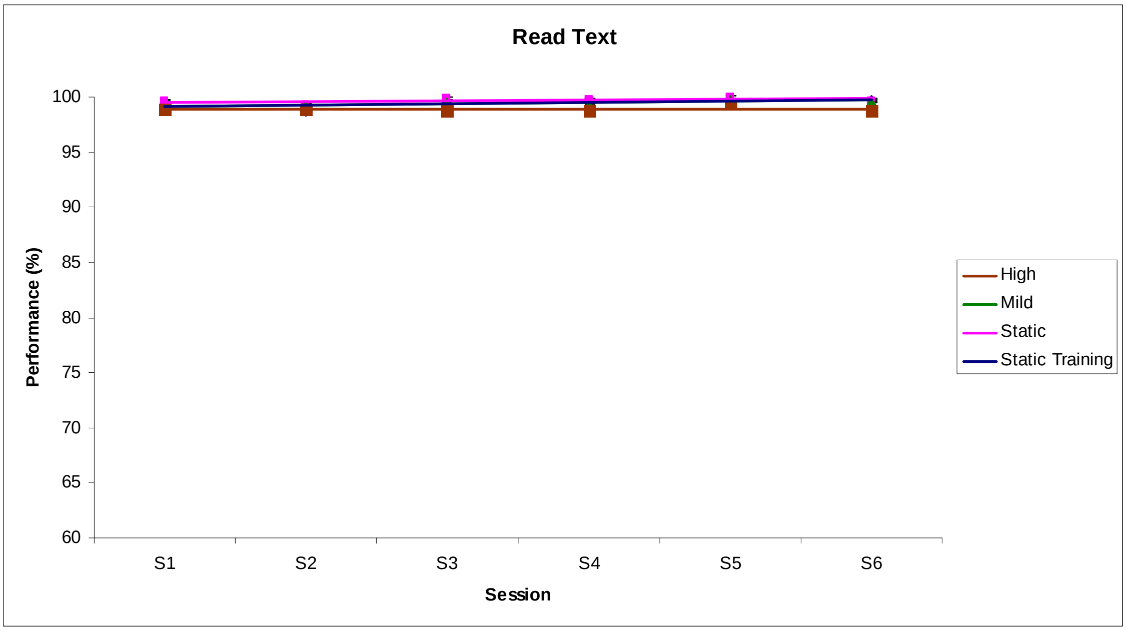


Figure 11. Performance and regression lines across the six sessions for the training, static, mild and high conditions. Error bars represent +/- 1 standard error (SE).

4.3.1.3 Read Unit

Performance in the Read Unit task statistically improved for the training sessions (R^2 = .050, $F_{1,94}$ = 4.913, $p < .05$), however, this improvement would be considered operationally insignificant. Performance did not improve for the other conditions, static (R^2 = .007, $F_{1,93}$ = .671, $p > .05$), mild (R^2 = .017, $F_{1,93}$ = 1.637, $p > .05$) and high (R^2 = .003, $F_{1,93}$ = .256, $p > .05$), across the sessions. This is depicted in the figure below.

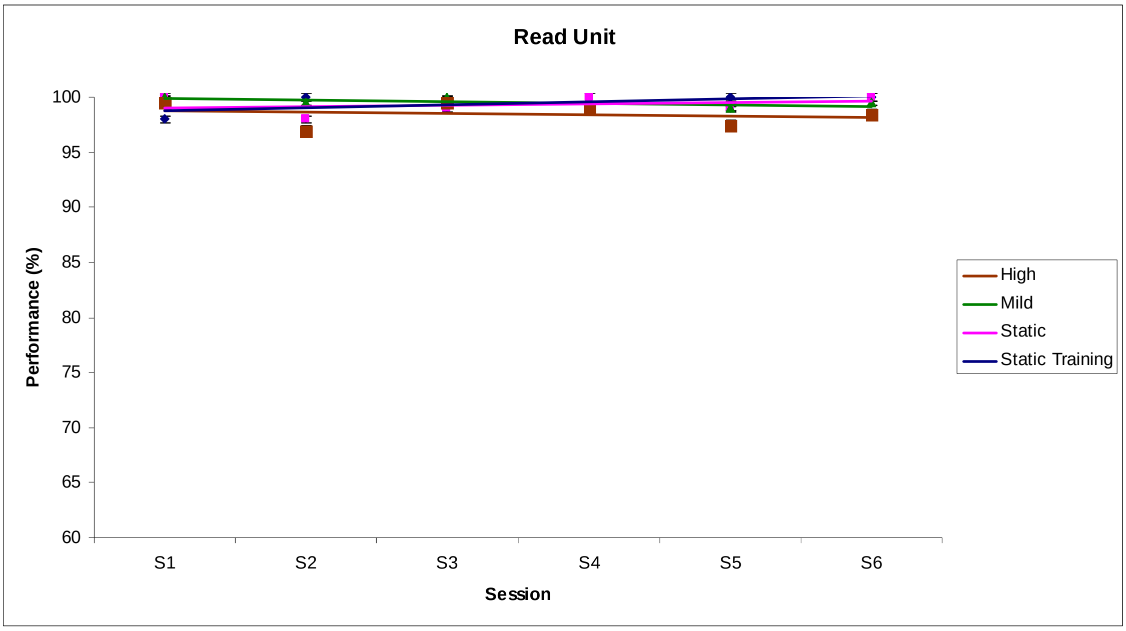


Figure 12. Regression lines and average performance for the Read Unit task over the six sessions. Error bars represent +/- 1 standard error (SE).

4.3.1.4 Create Text

Participants showed no significant improvement for the Create Text task for either the training (R^2 = .030, $F_{1,94}$ = .841, $p > .05$) or the static (R^2 = .001, $F_{1,93}$ = .086, $p > .05$) conditions. However, the performance in the Create Text task did improve for the mild (R^2 = .089, $F_{1,93}$ = 9.063, $p < .05$) and high (R^2 = .040, $F_{1,93}$ = 3.888, $p < .05$) conditions over the six sessions.

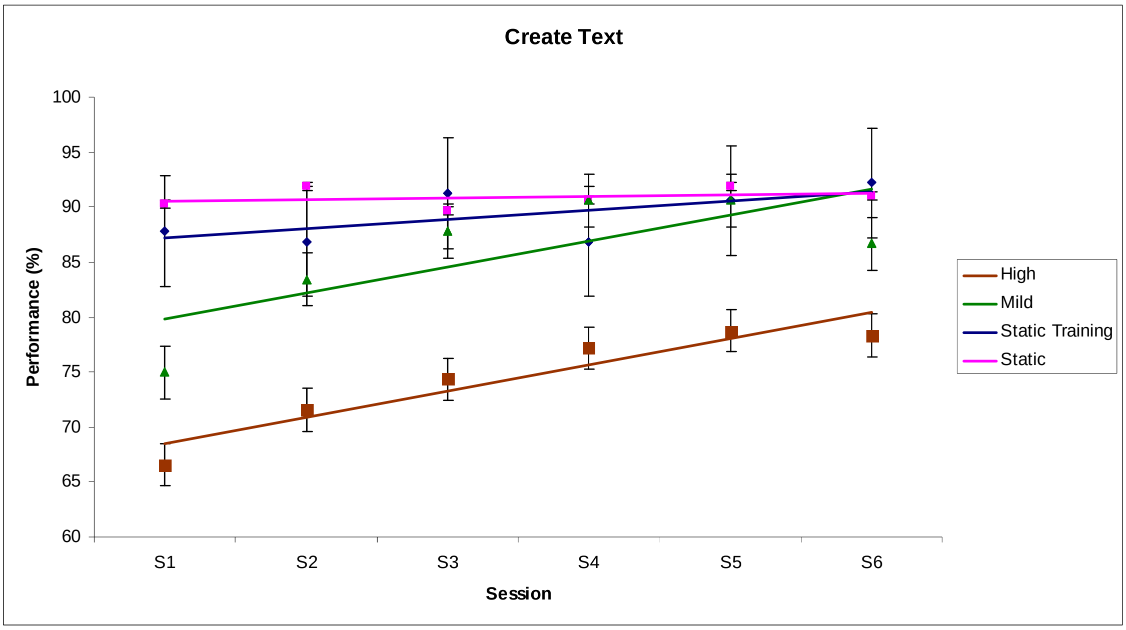


Figure 13. Create Text average performance and regression lines for the six sessions. Error bars represent +/- 1 standard error (SE).

4.3.1.5 Create Line

The only statistically significant performance improvement for the Create Line task across the different sessions was for the high motion condition (R^2 = .043, $F_{1,93}$ = 4.162, p < .05). None of the other conditions training (R^2 = .014, $F_{1,94}$ = 1.364, p > .05), static (R^2 = .009, $F_{1,93}$ = .886, p > .05) or mild (R^2 = .005, $F_{1,93}$ = .470, p > .05) yielded performance improvements over the sessions.

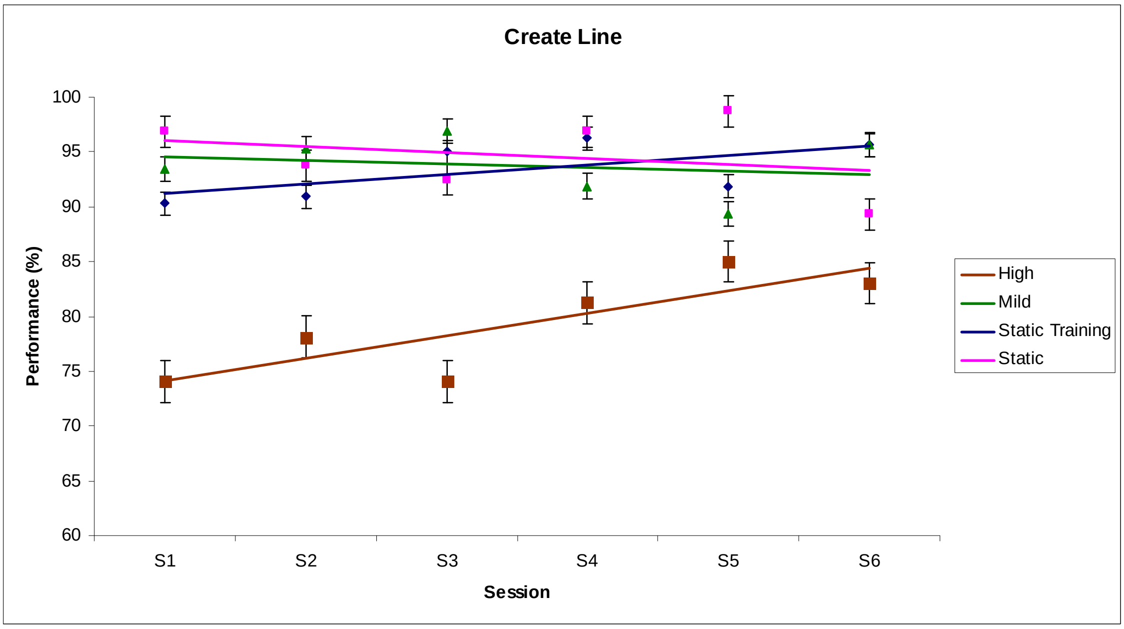


Figure 14. Average performance and regression lines for the Create Line tasks across the six sessions. Error bars represent +/- 1 standard error (SE).

4.3.1.6 Create Unit

The only condition is which performance improved over the six sessions for the Create Unit task was during the training (R^2 = .062, $F_{1,94}$ = .841, $p < .05$). In all other conditions, static (R^2 = .026, $F_{1,93}$ = 2.476, $p > .05$), mild (R^2 = .040, $F_{1,93}$ = 3.855, $p > .05$), and high (R^2 = .012, $F_{1,93}$ = 1.083, $p > .05$), the performance did not improve over the sessions.

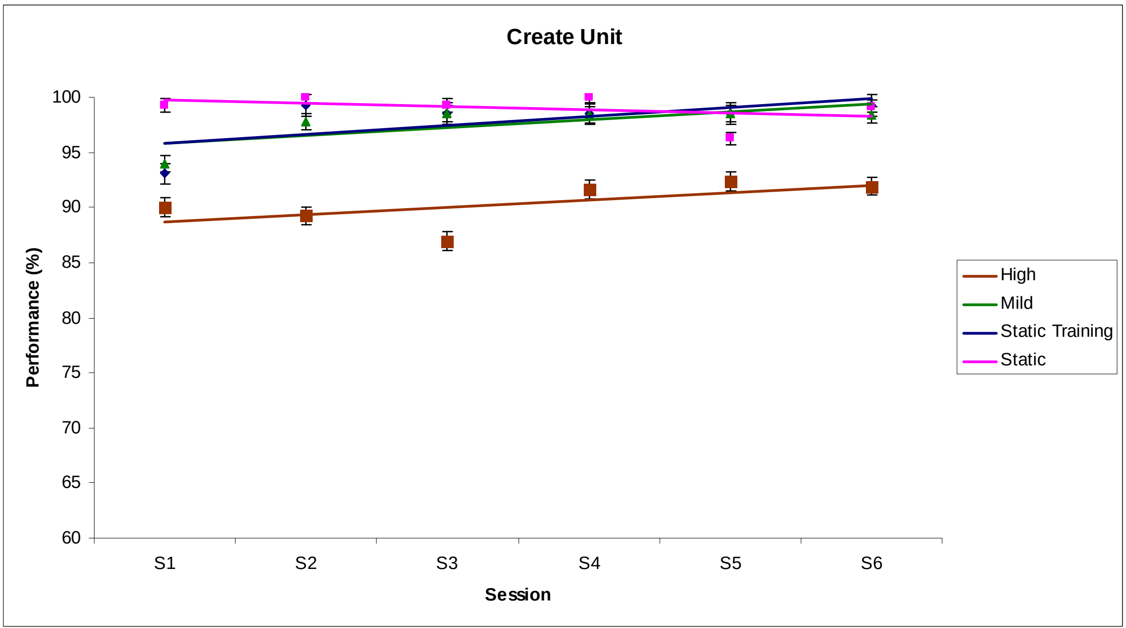


Figure 15. Regression lines and average performance for the Create Unit task over the six sessions. Error bars represent +/- 1 standard error (SE).

4.4 Subjective assessments

4.4.1 NASA Raw Task Load Index

Figure 16 shows the overall RTLX responses for each motion condition. The chart shows a box plot where the central line indicates the median value, the inner box indicates the +/- 25% values, and the outer whiskers indicate the outer +/- 25% values. The difference between the mean and median for the static condition shows the data being skewed. There was no significant difference between the static (mean=26, SD=16) and motion "Level two" (mean=32, SD=16), and a significant difference between the static and motion "Level four" (mean=56, SD=20), as well as between motion "Level two" and "Level four". Thus both the static and "Level two" conditions were rated as "low" workload and "Level four" as half way between "low" and "high".

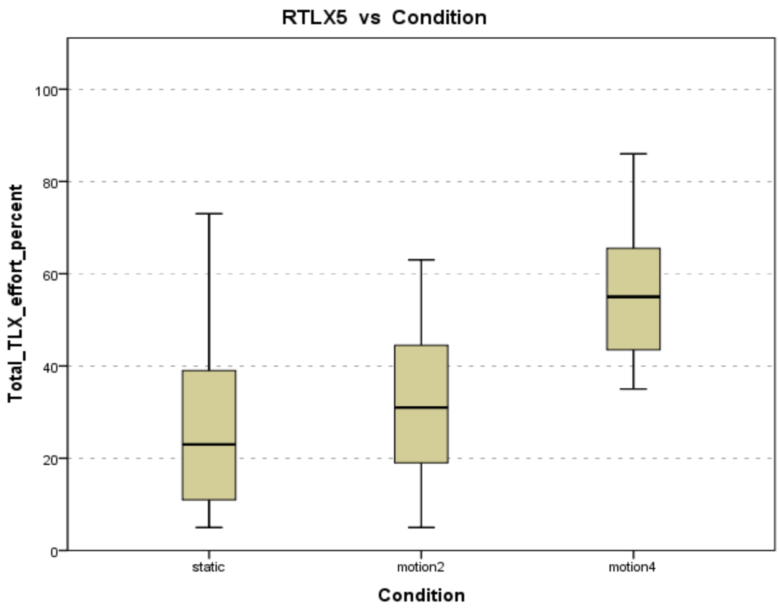


Figure 16: Subjective RTLX_Mental Demand% vs Motion Level

Figure 17 shows the subjective Raw Task Load Index (RTLX) responses for all sessions vs the motion conditions.

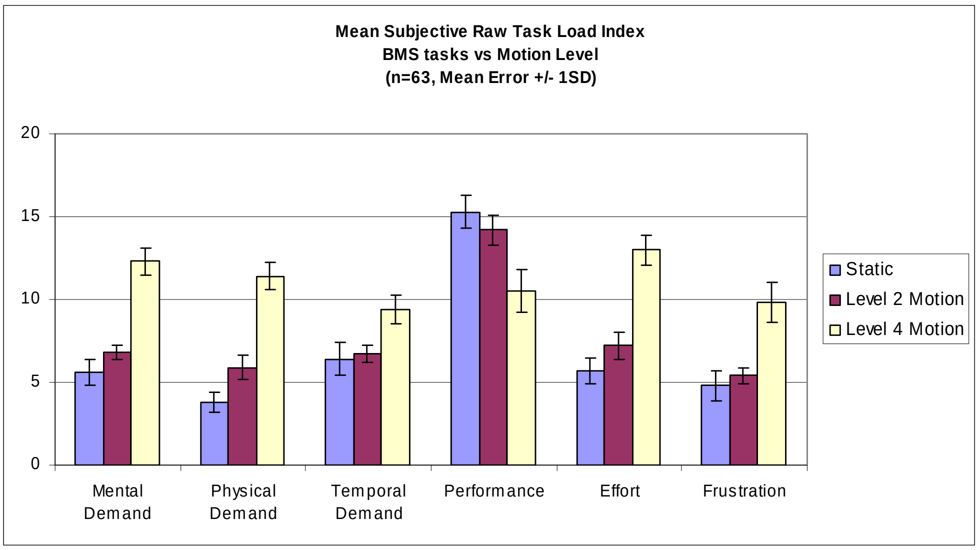


Figure 17: Subjective RTLX vs motion level +/- 1 standard error (SE).

4.4.2 BMS Task Difficulty

Figure 18 shows the overall (normalised) subjective BMS Task Difficulty for the three motion conditions. The value 20 represents the minimum value of "not difficult". The value of 100 represents the maximum value of "extremely difficult". The value of 60 represents the half-way value. The chart shows a box plot where the central line indicates the median value, the inner box indicates the +/- 25% values, and the outer whiskers indicate the outer +/- 25% values. In the motion2 condition there are three outlier values. The difference between the mean and median for the "level four" condition shows the data being skewed. There was a significant difference between the static (mean=28, SD=7) and "Level two" motion (mean=34, SD=8), and a significant difference between the static and "Level four" motion (mean=63, SD=15). There was also a significant difference between "Level two" and "Level four" motions. Note that the normalised subjective difficulty average of 63 for the "Level four" motion is half way between "not difficult " and "extremely difficult".

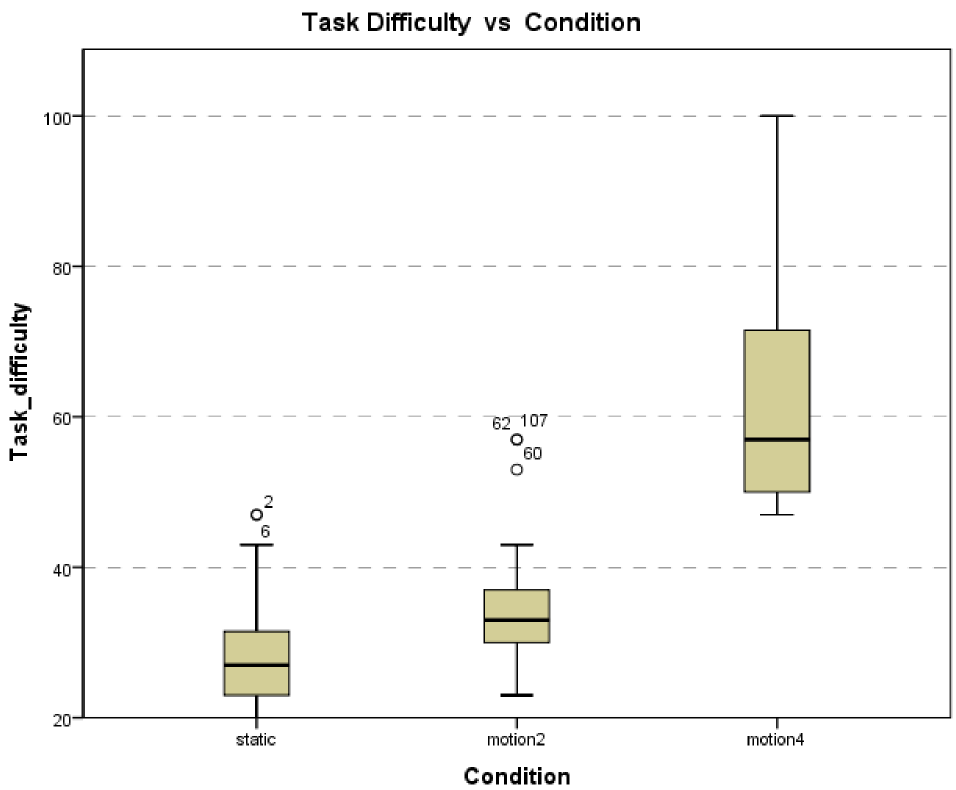


Figure 18: Task Difficulty vs. Motion Condition

Figure 19 shows the BMS Task Difficulty vs Motion Level for the individual tasks. Note that the normalised means for Static: Pan_Zoom, Read_Unit, and Reading tasks were 20 and thus are difficult to see in the figure.

It is interesting to note that the reading task under "Level four" motion was considered to be almost as difficult as the creating text, units and lines tasks, but this was not reflected in actual performance.

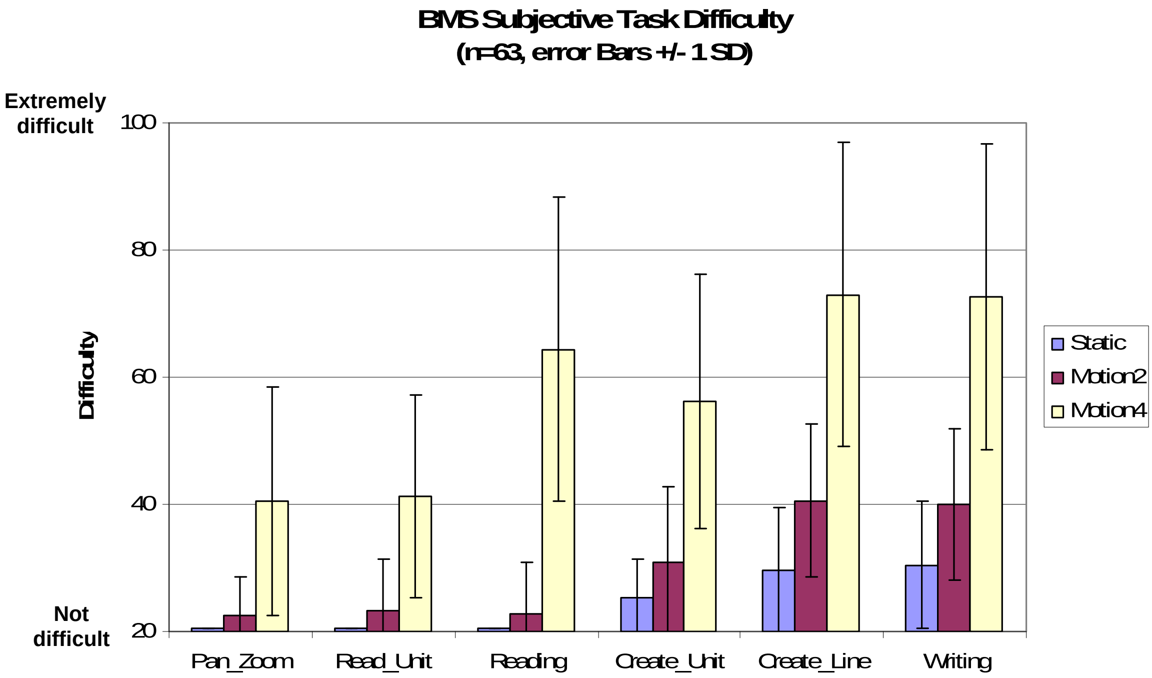


Figure 19: BMS Subjective Task Difficulty vs Motion Level

5. Discussion

5.1 Motion Condition

The results of this experiment support the first hypothesis as no overall difference between the static and mild motion conditions were observed. However there was a difference between the mild and high motions (as shown in Figure 8). Therefore, commanders could be expected to relay information through the BMS as well as receive information from the BMS "on the move" if the motion is relatively small. More specifically, if the motion is lower than an RMS value of $0.47m/s^2$, commanders should not have problems entering as well as reading information through the BMS.

However, if the motion is high, then commanders would be able to receive information, but it would be a lot more difficult to send (input) information. This study showed that for an RMS value above $1.2m/s^2$, commanders could not send information through the BMS as well as during the mild motion conditions. Further research is needed to ascertain what motion level between $0.47m/s^2$ and $1.2m/s^2$, is likely to lead to a statistically different result from the mild motion condition. This issue can be further investigated with DSTO's new LAMP capability described below.

The experiment also supports previous studies' findings (e.g. Metcalfe et al 2008) that performance degrades with higher levels of motion. However, this study extends previous literature as it has used a three degree of freedom (multi-axis) simulator to generate the motion. As Seagull & Wickens' (2006) review of the literature had shown, most studies simply used z-axis (vertical, heave) motion to evaluate task performance. Salmon et al (2010) also comments on the ambiguity of such studies when trying to evaluate the effect of different motion levels on BMS performance. The three degree of freedom simulator added two other axes of motion than a simple up and down motion simulation and arguably, this is more realistic of what military crew would experience. Therefore, a more applicable motion profile was used to validate the results.

5.2 BMS Performance

These results also support hypothesis two, as there is a clear difference in performance based on the type of task that was performed, and it also extends previous literature in this area. As Salmon (2010) noted, previous field research using a BMS system under motion has not measured specific task related performance. Rather, it has focused on issues such as reach timing and accuracy. This study shows that even after a person has 'reached' the BMS system, there will be differences in accuracy depending on the type of task at hand. Furthermore, as Zywiol et al (2006) has shown, lab experiments in this area have also concentrated on issues such as reach timing and accuracy, and were concerned with making user interface recommendations. Furthermore, previous laboratory based studies did not focus on the operational performance of BMS tasks under motion, as this study has.

Figure 6 shows that participants found the Read Text, Read Unit and Pan and Zoom tasks are relatively easy, as they performed above 98% even in the high motion condition. However, the Create Text, Create Unit and Create Line task performances show that they are clearly more difficult than the other three tasks. Furthermore, the performance for the Create Text, Create Unit and Create Line tasks degraded as the motion level increased. Thus there is a clear distinction between the reading and simple button pressing tasks versus the creating tasks. The reading task is a type of task which feeds information to a commander. The creating tasks occur when a commander gives information to others. It can therefore be inferred that, under high motion conditions, it would be appropriate to give information to a commander and ask them to perform very simple button presses (Pan and Zoom), rather than enter more difficult textual or graphical information.

5.3 Learning Effects

The study supported the third hypothesis that there is a learning effect depending on the type of task as well as the type of motion. Performance improved across the training, mild and high sessions, but not fore the static condition. Noting that the training was under no motion, this result indicates that participants had to mitigate against the new motion stimuli. Essentially participants appeared to be learning how to cope with the motion. Hence, performance in the mild and high conditions improved over the sessions.

Performance in the training sessions only improved for the Read Text, Read Unit and Create Unit tasks. Performance did not improve in the training session for the Pan and Zoom, Create Text, and Create Line tasks. This shows that some tasks do not need as much training. In particular, in the Pan and Zoom, Create Unit, Read Text, and Read Unit tasks there was no learning effect for the static, mild or high motion conditions. That is, performance remained the same across the six experimental sessions across each of the motion conditions. However, performance did improve for the Create Text and the Create Line tasks in the high motion condition. Furthermore, performance improved in the mild motion condition for the Create Text task.

This shows that it would be valuable to train crew under motion, especially for the more difficult output tasks such as creating text or creating line type of tasks. Lenne et al (2010) suggested that, in general, tasks are best learnt in realistic conditions. This study has reinforced that suggestion.

5.4 Subjective Assessments

Subjects generally rated the “Level four” motion as requiring high effort and difficult. There was little difference between ratings for the Static and “Level two” motion.

The SSQ scores were higher for the “Level four” motion compared to the pre motion condition. However, this did not lead to performance decrements. Therefore, the performance decrements found above were due to increases in motion magnitude, rather than simulator sickness.

The subjective questionnaire responses presented in Appendix I provide information about learning effects. Subjects found Reading and Pan-Zoom particularly easy with no learning curve. Writing, Create-Line, and Create-Unit appeared to require learning time across a number of sessions.

5.5 Limitations

Despite best efforts, participant scheduling was not consistent throughout the whole experiment. This was because unforseen events or meetings continuously came up over the six weeks, which participants could not avoid. However, there was always a minimum of three days in between sessions and a maximum of ten days.

Also, the relatively small number of participants means that the results have to be taken with certain caution. For instance, some participants may have accidentally pressed the touchscreen in the ‘Create Line’ task in an unintended location, leading to an exaggerated decrease in performance. With a small number of participants, these errors become amplified, which may lead to inaccurate results.

The limited displacement of the three degree of freedom motion platform limited the type of motion that could be subjected to the participants. Although the produced level of vibrations used for the experiment aligned with the “level two” and “level four” ranges according the standards, it is not indicative of the type of motion that might occur in the real world. A simulator with larger actuator arms may have been able to produce more realistic motion profiles.

5.6 Future and Other Research

A field study was also carried out with light armoured field vehicles. The vehicles were driven over various terrains, and the vibration measurements were taken for each drive. There were three main types of road that the vehicles were driving over, smooth paved roads, gravel road and rough cross country roads. The participant sitting in the commander position completed the BMS tasks as described above. Analyses of the road vibrations have been done. The maximum frequency weighted acceleration attained from all the drives was $1.42m/s^2$. The results of the BMS tasks will be matched against the frequency weighted accelerations in order to determine performance at the different vibration levels.

The field study also showed that the maximum frequency weighted acceleration was higher than the one used in the lab study. This means that military drivers often exceed the highest vibration level than given in this lab study. The field study also had large crest factors, indicating that there were more dynamic motion profiles. Future studies, with larger motion capabilities will need to incorporate higher levels of motion as one of its conditions.

DSTO's motion platform simulation capability program will culminate with the commissioning of DSTO's six degree of freedom LAMP later this year. The LAMP will allow research into the effect of much greater ranges of motion on BMS performance. It is anticipated that with a greater range on motion simulation capability, there will be a greater ability to re-create more realistic and ecologically valid simulations. However, this is to be verified through validation exercises and experiments. The current experiment will be replicated using the LAMP, in order to verify the current results and also to rectify some of the limitations of the current study. This will be followed by further experiments aimed to identify the levels of motion beyond which even pull tasks (i.e. reading text and icons) becomes difficult.

6. Conclusion

The study found that participants could cope with a mild level of motion, but performance degraded when the motion was high. More specifically, participants showed no difference in performance between motions less than $0.47m/s^2$ and a static motion situation. However, there was a difference between the mild and high motion condition. It also found that there was a difference in performance depending on the type of tasks the participants were performing. In particular, it was more difficult to enter information compared to reading information. It appears easier to 'push' information to participants, rather than 'pull' information from them. Lastly, there were learning effects found for both motion and task type. There was no learning effect for the static condition, but there were learning effects for both the mild and high conditions. Learning effects were apparent during the Create Line and Create Text tasks in the high motion condition. The Create Text tasks also showed learning effects in the mild motion. None of the other tasks showed learning effects in the experimental conditions (static, mild or high). This implies that BMS training for use in vehicles should include motion conditions so users learn how to adapt to vehicle motion.

This study improved upon previous research looking at performance degradation due to motion. It used technology which has not been used widely before, by employing a three degree of freedom motion simulator. By employing such methods, it created a more realistic motion cue, closer to what military personnel might experience in the field. This gives the results more ecological validity. However, further research needs to be done in this area, to fully understand how larger motion affects performance in a military context. DSTO’s new LAMP capability will aid in exploring further research questions in this area.

7. References

Cowings, P. S., Toscano, W. B., DeRoshina, C., & Tauson, R. A. (1999). *The effects of the command and control vehicle (C2V) operational environment on soldier health and performance.* (No. ARL-MR-468). Aberdeen Proving Ground: Army Research Laboratory.

Golding, J. F. (2006). Prediction individual differences in motion sickness susceptibility by questionnaire. *Personality and Individual differences, 41*, 237-248.

Hill, S. G., & Tauson, R. A. (2005). *Soldier performance issues in C2 "on the move"*. Paper presented at the International Command and Control Research and Technology Symposium (ICCRTS), Virginia beach.

Judd, G., Demczuk, V., & Jacques, P. (2009). *An investigation into the effect of simulated ground vehicle motion on the performance of C2 tasks using an in-vehicle Battle Management System (BMS).* Paper presented at the Defence Human Sciences Symposium (DHSS), Melbourne.

Lenne, M., Cornelissen, M., Salmon, P., Tomasevic, N., Willamson, A., Reid, N., & Triggs, T. (2010). *The Influences of Motion On Task Performance and Workload In a Driving Simulator (Report prepared for Land Operations Division DSTO)* Monash University Accident Research Centre.

McDowell, K., Rider, K., Truong, N., & Paul, V. (2005). *Effects of ride motion on reaction times for reaching tasks*. Paper presented at the SAE World Congres.

Metcalfe, J. S., James A. Davis, J., Tauson, R. A., & McDowell, K. (2008). *Assessing constraints on soldier cognitive and perceptual motor performance during vehicle motion* (No. ARL-TR-4461). Aberdeen Proving Ground, MD: Army Research Laboratory.

Rider, K. A., Mikol, K. J., Chaffin, D. B., Reed, M. P., & Nebel, K. J. (2003). *A pilot study of the effects of vertical ride motion on reach kinematics* (No. 2003-01-0589). Detroit: SAE World Congress.

Salmon, P., Lenne, M., Triggs, T., Cornelissen, M., Tomasevic, N., & V., Demczuk (2010). *The effects of Motion On Task In-Vehicle Touch Screen System Operation: A Battle Management System Case Study (Report prepared for Land Operations Division DSTO)* Monash University Accident Research Centre

Salmon, P., Lenne, M., Triggs, T., Cornelissen, M., Tomasevic, N., & V., Demczuk (2011). The effects of motion on in-vehicle touch screen system operation: A battle management system case study. *Transportation Research Part F, 14F*(6), 494–503.

Seagull, F. J., & Wickens, C. D. (2006). *Vibration in Command and Control Vehicles: Visual Performance, Manual Performance, and Motion Sickness: A Review of the Literature* (Technical Report: HFD-06-07/FEDLAB-06-01) Human Factors Disision, Institute of Aviation: University of Illinois at Urbana-Champaign

Standards Australia (2001). Evaluation of human exposure to whole-body vibration. Part1: General requirements. (AS 2670.1–2001). Standards Australia International Ltd.

Stanton, N. A., Jenkins, D. P., Salmon, P. M., Walker, G. H., Rafferty, L., & Revell, K. (2010). Digitising command and control: a human factors and ergonomics analysis of mission planning and battlespace management. Ashgate, Aldershot, UK.

Zywiol, H., Gorsich, D., McDowell, K., & Hill, S. (2006). *Using motion-base simulation to guide future force systems design* (No. 15506). Warren: USA TACOM Lenne et al 2010

Appendix A: Motion Sickness Susceptibility Questionnaire

Short Motion Sickness Susceptibility Questionnaire

PARTICPANT ID: ______________

Please give your answers on the dotted lines, or encircle one of the printed options

Have you ever had any medical conditions involving your ears? Yes No

- If yes, what conditions did you have?……………………………………..
- And how old were you? ……………. years

Do you suffer from headaches? Never / seldom / sometimes / often

- If yes, did your doctor characterise this as migraine? Yes No

The next questions refer to your sensitivity to motion sickness in the past and to the kind of motions that you dislike most. Here, motion sickness refers to a clear feeling of discomfort, nausea, or vomiting due to motion.

How often did you feel sick as a child (below the age of 12 years) in

cars	n.a / never / seldom / sometimes / often
busses	n.a / never / seldom / sometimes / often
trains	n.a / never / seldom / sometimes / often
aircraft	n.a / never / seldom / sometimes / often
small boats	n.a / never / seldom / sometimes / often
large ships	n.a / never / seldom / sometimes / often
swings	n.a / never / seldom / sometimes / often
merry-go-rounds	n.a / never / seldom / sometimes / often
fair ground attractions	n.a / never / seldom / sometimes / often

Did you ever have to throw up because of motion sickness **<u>as a child</u>**?

Yes No

How often did you feel sick in the past 12 years in

cars	n.a / never / seldom / sometimes / often
busses	n.a / never / seldom / sometimes / often
trains	n.a / never / seldom / sometimes / often
aircraft	n.a / never / seldom / sometimes / often
small boats	n.a / never / seldom / sometimes / often
large ships	n.a / never / seldom / sometimes / often
swings	n.a / never / seldom / sometimes / often
merry-go-rounds	n.a / never / seldom / sometimes / often
fair ground attractions	n.a / never / seldom / sometimes / often

Did you ever have to throw up because of motion sickness **<u>in the past 12 years</u>**

Yes No

Appendix B: Simulator Sickness Questionnaire

Simulator Sickness Questionnaire
Symptom Checklist

PARTICPANT ID: ________ CONDITION: ____________ SESSION: _________

PRE-Simulator				
Circle below if any of the symptoms apply to you now				
1. General discomfort	*none*	*slight*	*moderate*	*severe*
2. Fatigue	*none*	*slight*	*moderate*	*severe*
3. Headache	*none*	*slight*	*moderate*	*severe*
4. Eyestrain	*none*	*slight*	*moderate*	*severe*
5. Difficulty focusing	*none*	*slight*	*moderate*	*severe*
6. Increased salivation	*none*	*slight*	*moderate*	*severe*
7. Sweating	*none*	*slight*	*moderate*	*severe*
8. Nausea	*none*	*slight*	*moderate*	*severe*
9. Difficulty concentrating	*none*	*slight*	*moderate*	*severe*
10. Fullness of the head	*none*	*slight*	*moderate*	*severe*
11. Blurred vision	*none*	*slight*	*moderate*	*severe*

Please stand up when assessing for symptoms 12 - 14

12. Dizziness (eyes open)	*none*	*slight*	*moderate*	*severe*
13. Dizziness (eyes closed)	*none*	*slight*	*moderate*	*severe*
14. Vertigo	*none*	*slight*	*moderate*	*severe*

15. Stomach awareness	*none*	*slight*	*moderate*	*severe*
16. Burping	*none*	*slight*	*moderate*	*severe*

Simulator Sickness Questionnaire
Symptom Checklist

PARTICPANT ID: ________ CONDITION: ____________ SESSION: _______

POST-Simulator				
Circle below if any of the symptoms apply to you now				
1. General discomfort	*none*	*slight*	*moderate*	*severe*
2. Fatigue	*none*	*slight*	*moderate*	*severe*
3. Headache	*none*	*slight*	*moderate*	*severe*
4. Eyestrain	*none*	*slight*	*moderate*	*severe*
5. Difficulty focusing	*none*	*slight*	*moderate*	*severe*
6. Increased salivation	*none*	*slight*	*moderate*	*severe*
7. Sweating	*none*	*slight*	*moderate*	*severe*
8. Nausea	*none*	*slight*	*moderate*	*severe*
9. Difficulty concentrating	*none*	*slight*	*moderate*	*severe*
10. Fullness of the head	*none*	*slight*	*moderate*	*severe*
11. Blurred vision	*none*	*slight*	*moderate*	*severe*

Please stand up when assessing for symptoms 12 - 14

12. Dizziness (eyes open)	*none*	*slight*	*moderate*	*severe*
13. Dizziness (eyes closed)	*none*	*slight*	*moderate*	*severe*
14. Vertigo	*none*	*slight*	*moderate*	*severe*

15. Stomach awareness	*none*	*slight*	*moderate*	*severe*
16. Burping	*none*	*slight*	*moderate*	*severe*

Appendix C: NASA-TLX

NASA-Task Load Index

PARTICPANT ID: ________ **CONDITION:** ____________ **SESSION:** _________

Please rate your workload by marking a box on each of the seven scales, which matches your experience.

Mental Demand

Low High

Physical Demand

Low High

Temporal Demand

Low High

Performance

Good Poor

Effort

Low High

Frustration

Low High

NASA-Task Load Index Rating Scale Definitions

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix D: BMS Task Difficulty Questionnaire

Task Difficulty Questionnaire

Please indicate how difficult you found the tasks you have just performed by circling a number.
1 = not difficult. 5 = extremely difficult

Participant ID
Session
Date
Condition

Writing text	1	2	3	4	5
Reading Text	1	2	3	4	5
Pan and Zoom	1	2	3	4	5
Create boundary	1	2	3	4	5
Read Unit	1	2	3	4	5
Create unit	1	2	3	4	5

Appendix E: Demographic Questionnaire

Demographic & Military Experience Questionnaire

PARTICPANT ID: ______________________

Please give your answers on the dotted lines, or encircle one of the printed options

1. Age: …………………… years old
2. Gender: Male Female
3. Which is your dominant hand? Right Left
4. Do you wear glasses when working on the computer? Yes No
5. Do you have impairment to your colour vision?) Yes No
   - If yes, what type of impairment (if known)?

     ………………………………………………………………………………………

6. Have you any experience with the military unit icons used by the Australian Army?

   Yes No

   - If yes, what experience do you have?

     ……………………………………………………………………………………………

     ……………………………………………………………………………………………

     ……………………………………………………………………………………………

7. Have you ever used a digital command and control system?

   Yes No

   - If yes, what type of command and control system have you used and what experience have you had?

     ……………………………………………………………………………………………

     ……………………………………………………………………………………………

Appendix F: Participant Instructions.

Intro Script

- *Explain study* – Thanks for coming in today. Firstly, have a read through the **Information Sheet** for this study and the **Guidelines for Volunteers**, and then I will give you a demonstration of the tasks and the motion. [SHOW TRAINING OF TASKS, NOT IN DETAIL/GIVE MOTION DEMO]
- *Data collection* – Data will be recorded in the following ways:
    - Most data on the speed and accuracy of your performance of the 6 BMS tasks will be recorded automatically by the BMS software. Some tasks however require verbal responses from you and these will be recorded manually by the experimenter.
- If you agree to participate in this experiment you will be asked to attend up to another 7, approximately half hour, experimental sessions. If you also agree to take part in the EEG testing, it will require an extra half hour per session. Today and in the next session, you will be required to complete 3, 5-10 minute practice trials where you will complete 24 randomly assigned Battle Management System tasks without any motion. In the six subsequent trials, you will complete the tasks with and without motion. There are two levels of motion, excluding the static trails. One will simulate moderate vehicle motion and in other will emulate the motions experienced when driving on a relatively rough road.
- *Show SSQ* – Before beginning each motion session, you will be required to complete a Simulator Sickness Questionnaire, which will ask you about your current physical state. At the end of each group of tasks, you will again need to complete the Simulator Sickness Questionnaire. This is done to assess whether the simulator has any affect on your physical state. If you begin feeling sick during your time on the simulator however, it is important that you let me know so we can stop the session immediately.
- *Show NASA-TLX* – After you complete each experimental condition, you will be required to complete the NASA Task Load Index, which asks you to rate the workload experienced during each experimental condition.
- Show Questionnaire – You will be asked to complete a questionnaire asking you to rank how hard you felt each task was to complete.

- Do you agree to take art in this study? To take part in this study, you will need to sign the **Consent Form**.
- *Complete the* ***Demographic & Military Experience questionnaire*** – Could you please complete this questionnaire asking some demographic questions about you as well as any military experience you might have
- *Complete the* ***Motion Sickness Susceptibility questionnaire.*** Could you also please complete this questionnaire about your past history with motion sickness? This information will help us determine whether past history is a good predictor of the risk of participants experiencing motion sickness using this experimental equipment.

Training Session Script

- Show visual icon information sheet: Here is a sheet describing the icons that will be used throughout the experiment. [SHOW READ ICON DESCRIP DOC] The icons have been modified for non-military personnel. Have a read of this sheet explaining how the information about enemy detections is represented visually using icons displayed on the map.
- Train participants in the 6 Tasks now I will train you to perform the 6 Battle Management System tasks that will be used throughout this experiment. You are to observe while I demonstrate a mock up of a BMS on the touch screen in front of me. My task instructions are written at the top of the screen. Once I have completed the task I will press the next button at the top right of the screen. Note you will always be strapped in whilst doing the tasks. Also you are allowed to brace yourself on the laptop mount if you wish.
    - ***Pan and Zoom*** (5 minutes) - In this task the written instructions at the top of the screen will ask you to pan and zoom the map display. You should select the pan button, which is the third button down on the right hand side of the screen and then select the arrow button in the resulting dialog that matches the instruction. Then, based on the written instruction, you should then select either the zoom in button (top button) or the zoom out button (second from top) according to the text presented at the top of the screen. You should do this as quickly and as accurately as possible. Once you have finished please press the next button.
    - ***Write Text*** (5 minutes) - In this task you should type the text presented at the top of the screen into the message text box presented in the middle of the screen. You should do this as quickly and as accurately as possible. However, if you make a mistake, please continue on without trying to correct for the error. Once you have finished typing the words please press the next button.
    - ***Read Type, Size and location of an enemy Unit*** (5 minutes) - In this task the written instructions at the bottom of the screen will ask you to locate a new red enemy icon on the screen and read out aloud its type size and location. You should read out the location from the x axis numbers at the top of the map and then from the y-axis numbers running down the left hand side of the map. I will manually record your

responses. You should do this as quickly and as accurately as possible. Once you have finished reading out the details please press the next button.

- ***Draw a new Unit Movement Boundary (****5 minutes)* – In this task the written instructions at the top of the screen will ask you to create a series of joined lines on the map representing a unit's movement boundary.(this is a line the unit should not cross during an operation). To start the line press down on the specified map location. This should create a blue point. Then press down exactly one grid form that point in the direction indicated in the instructions. This will create a new line. Then press down one grid away in the next direction indicated until you have created four joined lines. You should do this as quickly and as accurately as possible. Note the lines do not have to join up to form a square. Once you have finished creating the lines please press the next button.
- ***Create a new Unit Icon (****5 minutes)* – In this task the written instructions at the top of the screen will ask you to create a particular type of new red enemy icon at a certain X Y location on the screen. To do this you should hold your figure down on the screen at the specified location for 2 seconds. This will then bring up a popup menu allowing you to select the required type of enemy unit. In the popup menu select "Contact Reports" and then select the appropriate icon. You should do this as quickly and as accurately as possible. Once you have finished creating the unit please press the next button.
- ***Read Text*** (5 minutes). – In this task you should read out aloud the text presented at the bottom of the screen. I will record your responses manually. You should do this as quickly, clearly and as accurately as possible. Once you have finished reading please press the next button.

First/Second Session Script

- Now we are going to perform the first/second session of the experiment where data will be collected. In this session I will ask you to perform the tasks you just observed under a no motion condition. These static only session are to familiarise you with all the tasks. There will be three sets of 24 tasks, and a 5-10minute break in between each, where you will be asked walk outside the room.
- *Show NASA-TLX* – After you complete each trial, you will be required to complete the NASA Task Load Index, which asks you to rate the workload of each trial according to your experienced mental demand, physical demand, temporal demand, performance, effort, and frustration level. Please read the definitions of each scale on this definition sheet (hand sheet)
- *Show Questionnaire* – I will also ask you to complete this questionnaire after each trial. It asks you to rate each of the 6 different tasks in terms of difficulty on a five point scale.
- *Give Motion Sickness Susceptibility Questionnaire* – Please complete the motion sickness susceptibility questionnaire.

You will now start the experimental sessions proper.

- *For Static Trials* –In this trial you will be presented with 24 tasks presented in random order. You will not experience any motion. You should complete the trials as quickly and accurately as possible. (on completion)…… Please get out of the motion simulator (sit them at desk)
  - Please complete this **Simulator Sickness Questionnaire** remembering to stand for questions 12-14
  - Now please complete the **NASA Task Load Index** by marking a square on the scale rating the workload you experienced during this trial

Thank you for completing this session

Following Session Scripts

- Today we are going to perform the next session of the experiment. Just as during the previous session I will ask you to perform 24 randomly assigned tasks during three different simulated driving conditions.
- Show Simulator Sickness Questionnaire – Once again please complete this **Simulator Sickness Questionnaire** to assess your physical state, remembering to stand when assessing for symptoms 12 to 14. (Completes questionnaire). Also please remember that you should let me know immediately if you begin feeling sick during your time on the simulator. At the end of each trial I will also ask you complete the **Simulator Sickness Questionnaire** once again**.**
- Remind about Forms – After you complete each trial, I will also ask you to complete the **Simulator Sickness Questionnaire** once again as well as the **NASA Task Load Index** and the **task ranking questionnaire**.

- Static Trial –For this trial you will be presented with 24 tasks presented in random order. You will not experience any motion. You should complete the trials as quickly and accurately as possible. (on completion)…… Please get out of the motion simulator (sit them at desk)
  - Please complete this **Simulator Sickness Questionnaire** remembering to stand for questions 12-14
  - Now please complete the **NASA Task Load Index** by marking a square on the scale rating the workload you experienced during this trial
  - Finally please complete this questionnaire by ranking each of the 6 different tasks in order of difficulty. If you wish, please also provide any other comments about the difficulty of each task.

- Mild Motion Trial – In this trial you will once again be presented with 24 tasks presented in random order. This time however, the motion chair will simulate the vibrations you might experience while driving on a relatively good sealed road. You should complete the trails as quickly and accurately as possible. During the typing trial you should try and correct any typing mistakes made, but if this proves too difficult just leave that word as it is and try and type the next word in the list. (on completion)…… Please get out of the motion simulator (sit them at desk)

- Please complete this **Simulator Sickness Questionnaire** remembering to stand for questions 12-14
- Now please complete the **NASA Task Load Index** by marking a square on the scale rating the workload you experienced during this trial
- Finally please complete this questionnaire by ranking each of the 6 different tasks in order of difficulty. If you wish, please also provide any other comments about the difficulty of each task.

- Rough Motion Trial –for this trial you will once again be presented with 24 tasks presented in random order. This time however, the motion chair will simulate the vibrations you might experience while driving on a relatively rough dirt road. You should complete the trails as quickly and accurately as possible. During the typing trial you should try and correct any typing mistakes made' but if this proves too difficult just leave that word as it is and try and type the next word in the list. (on completion)…… Please get out of the motion simulator (sit them at desk)
    - Please complete this **Simulator Sickness Questionnaire** remembering to stand for questions 12-14
    - Now please complete the **NASA Task Load Index** by marking a square on the scale rating the workload you experienced during this trial
    - Finally please complete this questionnaire by ranking each of the 6 different tasks in order of difficulty. If you wish, please also provide any other comments about the difficulty of each task.

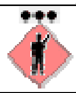
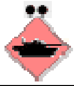
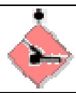
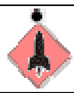
Thank you for completing this session

- (**At end Might want to offer them the opportunity to come back and play the racing simulation in the chair as a reward one lunch time)**

Appendix G: Create Unit Task

Visual Information about an Enemy Detection

1. The *type* of enemy unit detected is represented by a Military Icon

Infantry:	Tank	Artillery	Helicopter	Missile
				

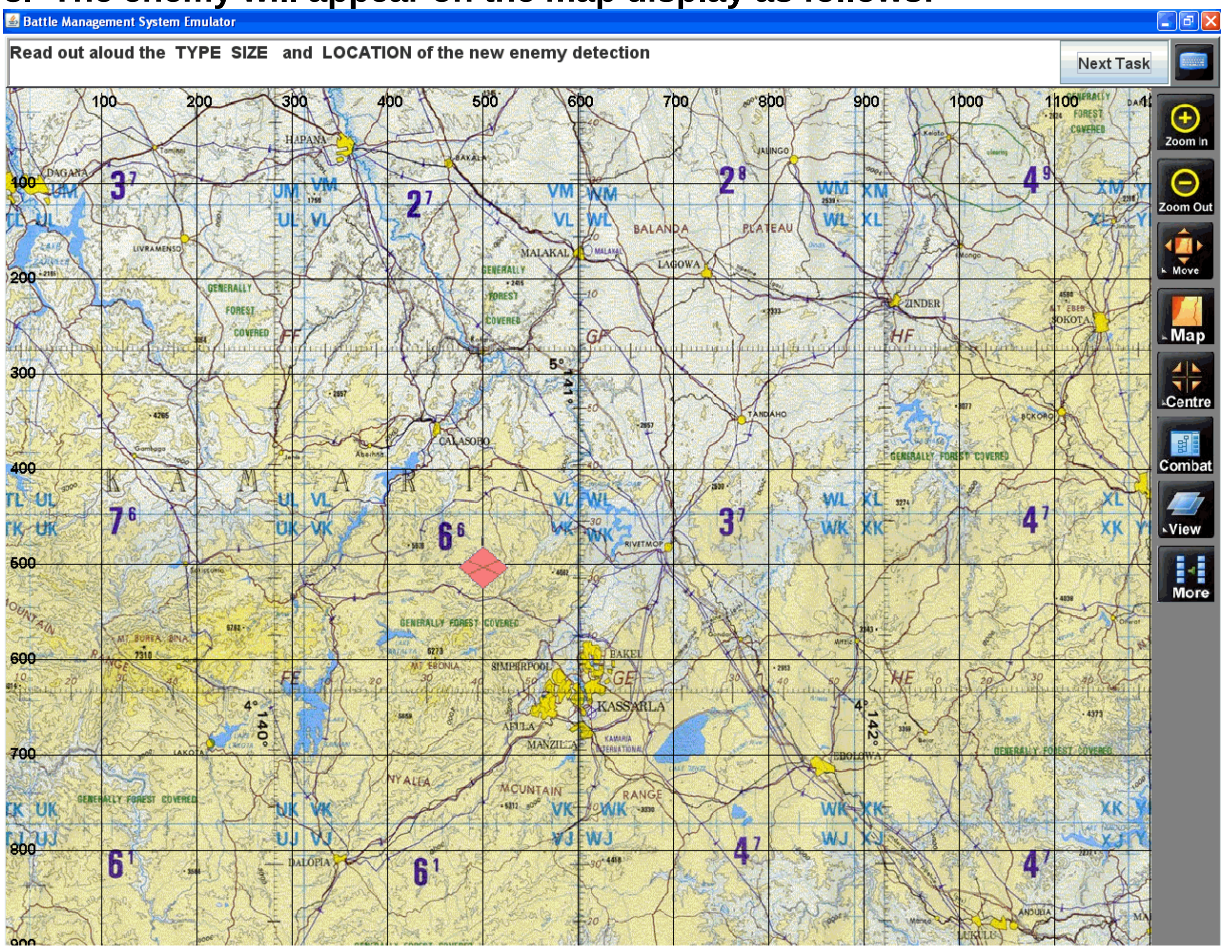
2. The *Number* of detected enemy is indicated by the symbol displayed on top of the red diamond

One enemy: • that is a single black dot

Two enemies: •• that is two black dots in a row

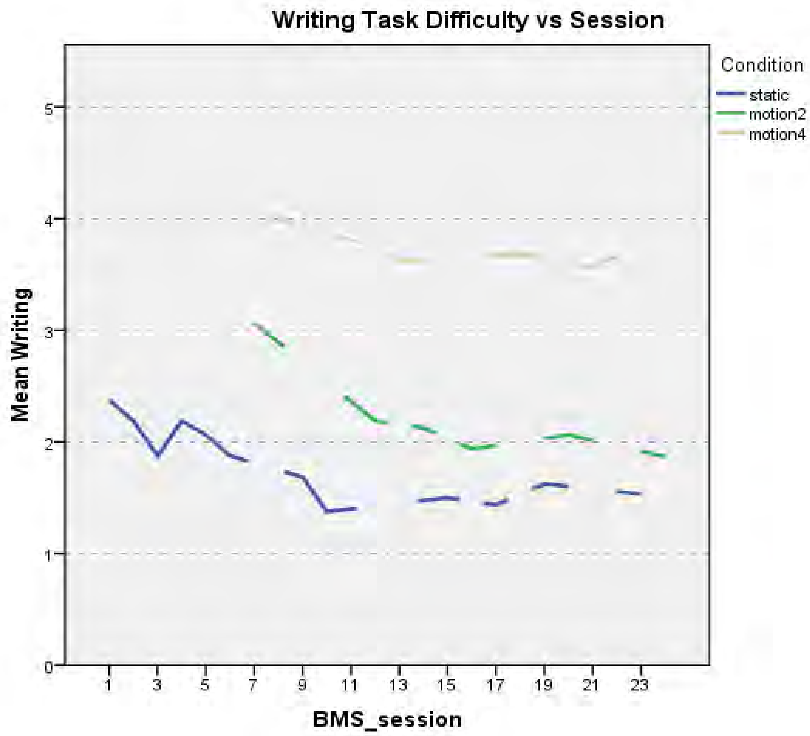
Three enemies: ••• that is three black dots in a row

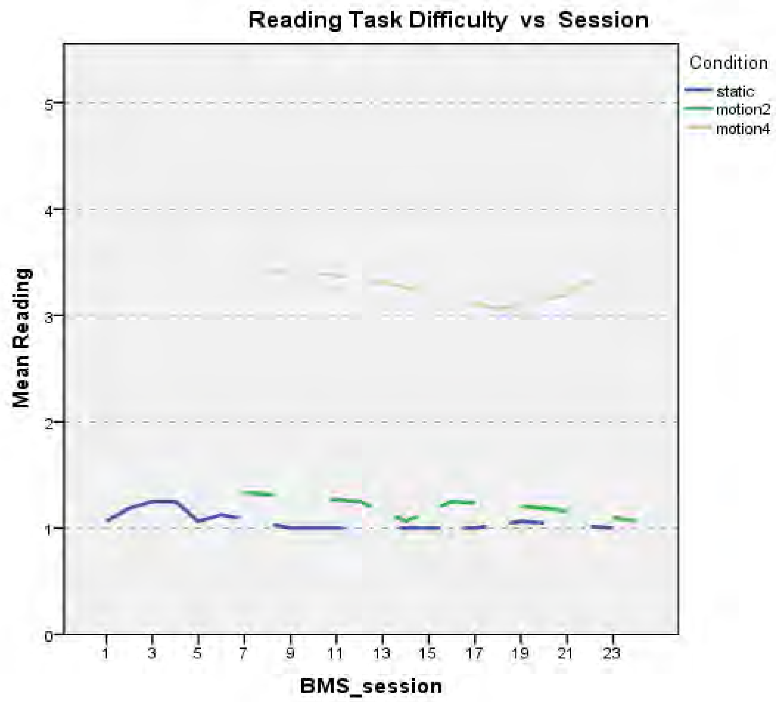
3. The enemy will appear on the map display as follows:

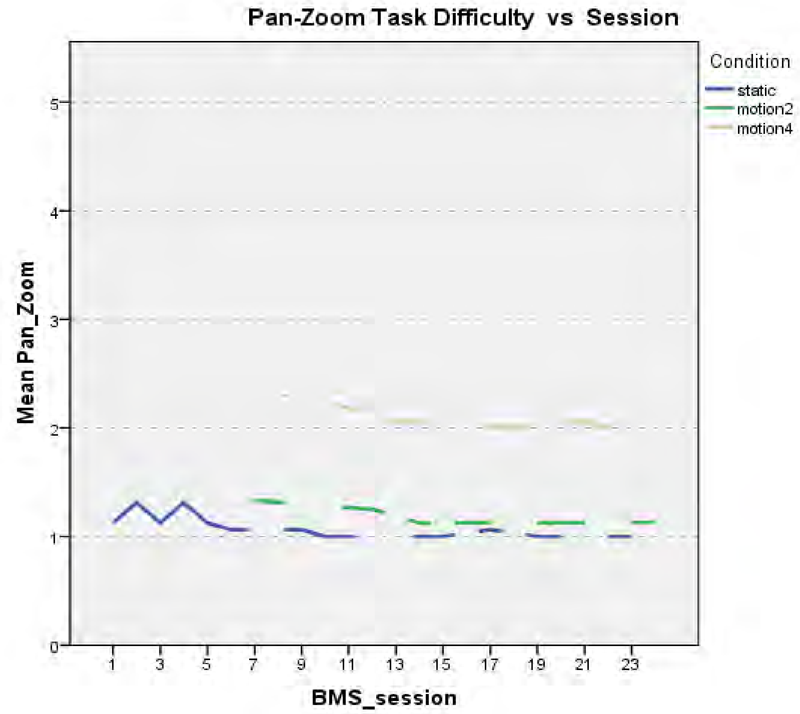


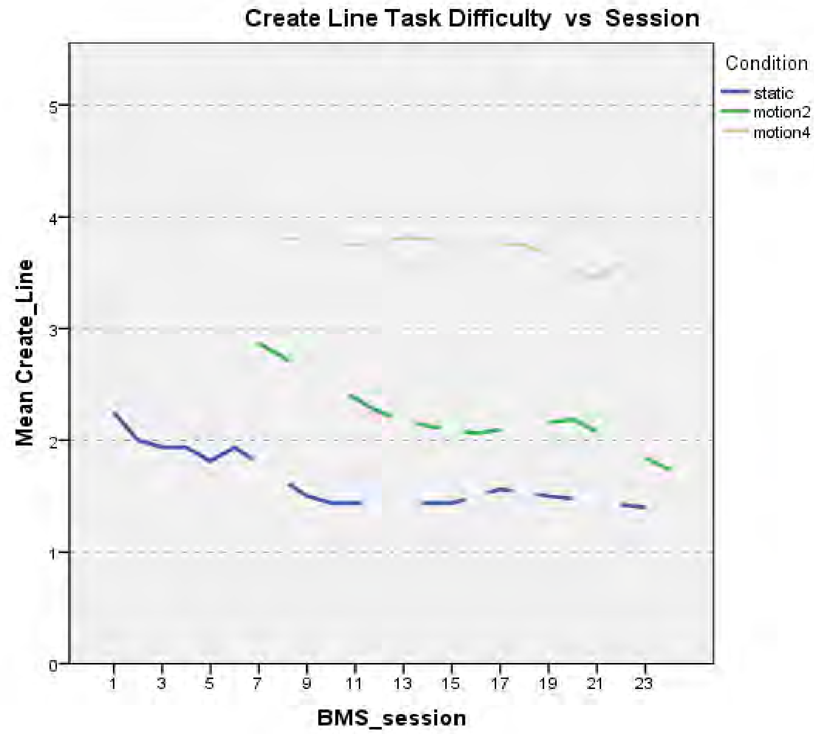
Appendix H: BMS Task Difficulty vs Sessions – Learning Effects

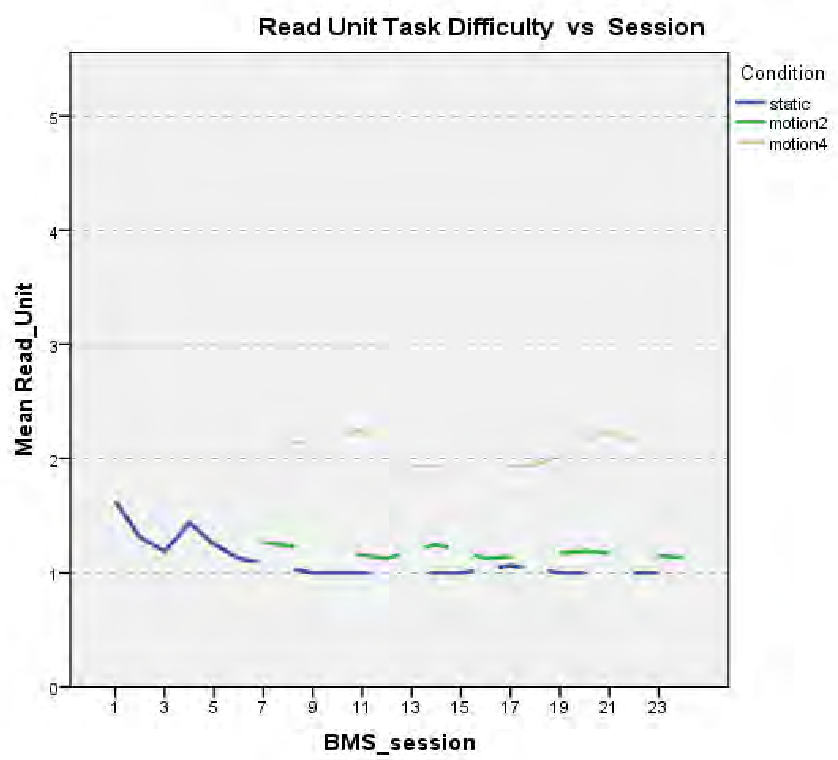
The BMS Task Difficulty Questionnaires, may also give insight into learning effects. The following are graphs of how difficult participants rated the task over the six sessions.

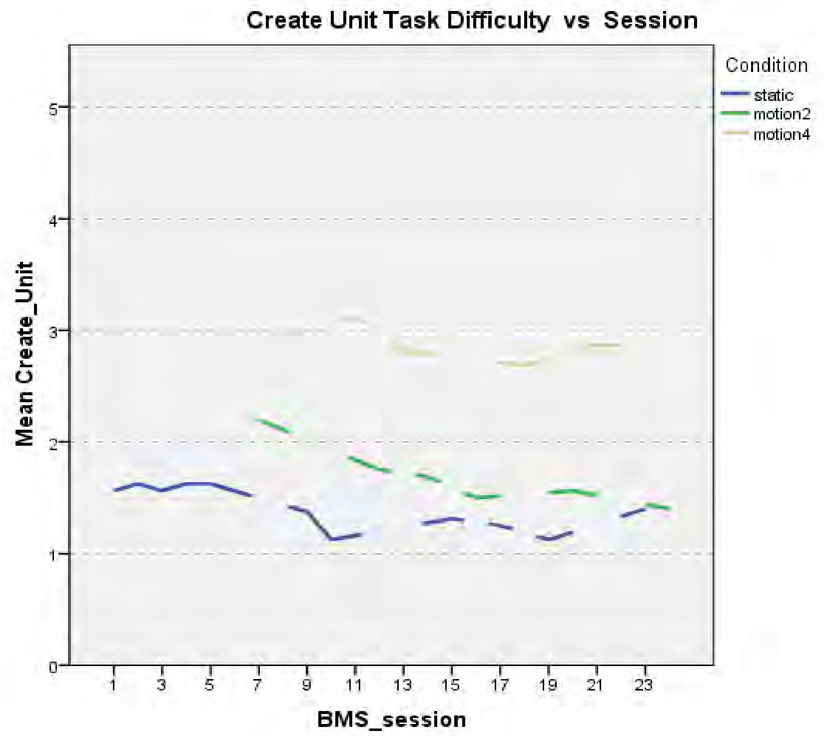





Pan-Zoom Task Difficulty vs Session
Mean Pan_Zoom
BMS_session
Condition
static
motion2
motion4
0
1
2
3
4
5
1
3
5
7
9
11
13
15
17
19
21
23


Create Line Task Difficulty vs Session
Mean Create_Line
BMS_session
Condition
static
motion2
motion4
0
1
2
3
4
5
1
3
5
7
9
11
13
15
17
19
21
23


Read Unit Task Difficulty vs Session
Condition
static
motion2
motion4
Mean Read_Unit
BMS_session
0
1
2
3
4
5
1
3
5
7
9
11
13
15
17
19
21
23


Create Unit Task Difficulty vs Session
Condition
static
motion2
motion4
Mean Create_Unit
BMS_session
0
1
2
3
4
5
1
3
5
7
9
11
13
15
17
19
21
23

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE Usability of a Battle Management System Under Simulated Vehicular Motion	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) Omio Abedin Victor Demczuk Gregory Judd	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation PO Box 1500 Edinburgh South Australia 5111 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-2762	AR-015-436	Technical Report	October 2012

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2012/1095218	Task Number	DGLD	59	14

13. DOWNGRADING/DELIMITING INSTRUCTIONS	14. RELEASE AUTHORITY
To be reviewed three years after date of publication	Chief, Land Operations Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

18. DSTO RESEARCH LIBRARY THESAURUS

Battle Management Systems, Motion, Simulators

19. ABSTRACT

Military personnel may be required to conduct command and control tasks whilst under various levels of motion. This study examined whether there were performance degradations for typical tasks that commanders may be expected to complete whilst on the move. It was found that there were no differences in task performance between the static and mild levels of motion, but there were differences between the mild and high levels of motion. It was also found that participants performed better at tasks in which they were receiving information, rather than tasks they were in which they had to input information. There were also learning effects were participants performed better in their latter experiment sessions.