ASSESSING THE EFFECTS OF MOTION ON TOUCH SCREEN BMS OPERATION: A COMPARISON OF ON-ROAD AND SIMULATION STUDY DATA

Natassia Goode¹, Michael G. Lenné² and Paul M. Salmon¹

Abstract. Vehicle motion is one of the key human factors problems associated with the implementation of advanced technologies in mobile command and control units [1,2]. This paper compares results from a simulator [3] and an on-road [4] study to investigate whether motion simulation is a behaviourally valid tool for studying the impact of vehicle motion of the use of touch screen BMS. The studies examined the impact of “normal” and “high” levels of vehicle motion across a range of touch screen Battle Management System (BMS) task types (such as reading, writing, panning and zooming, and drawing). The current study compared completion task times and accuracy in the simulator and on-road study for each task type. Overall, the results suggest that simulated motion is appropriate for studying the direction of effects on BMS touch screen tasks, but not the magnitude of those effects. The findings suggest that the behavioural validity of simulators may be highly task specific, as the magnitude of observed effects varied across BMS task types. Challenges for using simulators to investigate the human factors problems associated with C2 on the move are discussed.

INTRODUCTION

The Australian Defence Force (ADF) is currently undertaking significant capability projects to enable mobile command and control (C2) centres. Touch-screen Battle Management Systems (BMS) are intended to play a key role in these mobile command centres, replacing paper maps and acetate-based mission planning, and battle management processes [3]. One of the key human factors problems associated with the implementation of advanced technologies in mobile surface units is vehicle motion and its effects on performance with in-vehicle technologies [1,2]. Vehicle simulators offer one possible avenue for studying this problem, as it is now possible to simulate many aspects of vehicle motion, including pitch, roll, and yaw rotations; sway, surge, and heave movements; and noise and vibration [4]. However, whether or not simulators are appropriate for studying this issue is dependent on the correspondence between human behaviour in the simulator and the real vehicle. That is, does simulated vehicle motion have the same impact on human performance as real vehicle motion?

The distinction between physical fidelity and behavioural validity is critical to the appropriate use of simulators as human factors research tools. Physical fidelity, sometimes referred to as physical validity, refers to the extent to which the simulator’s components, layout, and dynamics mirror the real world counterpart ([5,6]). Behavioural validity refers to the extent to which human behaviour in the simulator mirrors behaviour in the real world counterpart ([6,7]). Like physical fidelity, behavioural validity is not a unitary construct: a simulator may be valid for studying one behaviour or task, but not another [8].

Godley et al [7] distinguish between two types of behavioural validity: absolute validity (identical numerical values) and relative validity (differences found between experimental conditions are in the same direction and of similar magnitude). The type of behavioural validity that is required in a simulator depends on the research question of interest. For example, absolute validity is critical for researchers wishing to determine whether simulated training produces similar, worse or better learning outcomes than the real environment (although note Boldovic’s [9] warnings that null results should not be taken as evidence of equal training effectiveness). Similarly, researchers wishing to establish when performance on in-vehicle interfaces degrades beyond a certain point will also require absolute validity. In contrast, researchers who are primarily interested in the direction and magnitude of the effects of independent variables on dependent variables, rather than numerical measurements, may only require relative validity [7,10]. If relative validity is established, then the researcher can conclude that the simulation provides a relatively useful model of the real world for this type of experimental research [11].

There are relatively little data available on whether simulated vehicle motion has a similar effect on human performance to real vehicle motion. Findings show that drivers tend to make less lane violations and drive closer to the speed limit in motion-based compared to fixed-based simulators [12–15]. Comparisons between driver behaviour in fixed-based simulators and real vehicles show similar inconsistencies in speed and lateral position [11,16]. These results suggest that simulated motion enhances the correspondence between driving performance under simulated and real conditions. However, this only supports the claim that motion-based simulators may be more appropriate for studying vehicle control than fixed-based simulator; it says nothing about whether motion-based simulators are appropriate for studying touch screen interactions.

To the authors’ knowledge, no research is available that compares touch screen in-vehicle task performance under simulated and real vehicle motion conditions. In fixed-based simulators and real vehicles task accuracy and completion times for touch screen in-vehicle tasks are similar, although not identical [11,15,16]. Based on these results, Wang et al [11] conclude that fixed-based simulators are valid for

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studying interactions with in-vehicle technologies; however, this research was only concerned with civilian drivers, who are unlikely to encounter extreme terrains.

This paper compares results from a motion-based simulator [17] and an on-road [18] study to investigate whether motion simulation is a valid tool for studying the impact of vehicle motion of the use of touch screen BMS. Both studies examined the impact of different levels (“high” or “normal”) of (simulated or real) vehicle motion on the use of a touch screen BMS. The experimental protocol across the studies was identical, allowing for comparisons of BMS task completion times and accuracy. Moreover, a range of different BMS tasks were utilized (such as reading, writing, zooming, and drawing) allowing for a detailed examination of which tasks can be validly studied under simulated motion conditions.

This study is limited to assessing relative validity, as the motion profiles across the two studies were not identical. Vehicle motion was measured using an Xsens MTx IMU combined with the Xsens Xbus Master in both studies. Table 1 presents the average acceleration across the x, y and z axes (m/s²) and overall values for each condition. Focussing on the overall values, according to the British Standard [19], the normal condition in both studies is rated a level 0, “not uncomfortable”. In the simulator study, the high condition is rated a 1, “a little uncomfortable”. In the on-road study, the high condition is rated a 3, “uncomfortable”.

Based on these motion profile ratings, it is hypothesized that: 1) BMS task completion times and accuracy will be worse in the high compared to the normal motion condition across studies; 2) on average performance will be worse in the on-road than in the simulator study, as the motion profiles for the on-road study conditions were more extreme than in the simulator study and, 3) the decrement in performance from normal to high motion will be greater in the on-road study than in the simulator study, again due to the more extreme motion profiles in the on-road study.

**METHOD**

**Recruitment**

The recruitment protocol for both studies was identical: participants were recruited through newsletters and flyers at Monash University. In both studies, participants had to fulfil the following criteria to be eligible to participate: aged between 18 and 65 years; hold a current full car driver’s licence; and be proficient in the use of English. Both studies were approved by the Monash University Human Ethics Committee.

**Design**

A 2 x (2) x (2) mixed design was used. The between-subjects factor was study type (simulator, on-road). The within-subjects factors were motion (high, normal) and drive number (1,2). Vehicle motion was counterbalanced so that equal numbers of participants experienced high and normal levels of motion first. The dependent variables were mean task completion time and accuracy on six BMS tasks (described below). To ensure that valid comparisons could be made between studies, the experimental protocol and BMS tasks were identical across studies.

**Materials**

The studies utilised the on-road test vehicle and advanced driving simulator at the Monash University Accident Research Centre. The on-road test vehicle is a VE Holden Commodore. The advanced driving simulator (Figure 1) consists of a Holden simulator cab, computer hardware and specialised software. The cab was mounted on a motion platform allowing up/down movements and pitch/roll rotations. Maximum ranges of the motion base are: ±50mm (heave); ±2.12° (pitch); and ±4.84° (roll). A 3D sound system provided driving sounds, engine noises, environmental sounds and low frequency vibrations.

Both the on-road routes and simulator scenarios involved the manipulation of the levels of motion, achieved through the selection of different road surface conditions. An effort was made to try and match the levels of motion experienced across the two studies; however, this was limited by the driving scenarios available in the simulator. In the simulator, the normal motion scenario was selected to achieve the smoothest ride possible (a simulated rural road) and the high motion scenario was selected to achieve the bumpiest ride possible (simulated driving alongside the road shoulder). An effort was then made to select on-road conditions that matched the levels of motion experienced in the simulator. A sealed freeway was selected to match the normal road condition and an unsealed dirt road was selected to match the high motion condition. As discussed in the introduction, it should be noted that the overall level of motion experienced in the on-road study in both conditions was “higher” than the simulator study.

In both studies, the BMS was displayed on a 10-inch touch screen with a standard keyboard attached. The BMS was mounted on the dashboard in front of the passenger seat in the simulator and on the headrest of the front passenger seat in the on-road test vehicle. The different configurations were due to safety concerns in the on-road vehicle.

The BMS user-interface (Figure 2) consisted of a window displaying a map marked with gridlines. A vertical menu bar displayed icons for performing different tasks. Text boxes displayed the instructions for each task.

The BMS simulated two types of information extraction tasks (tasks that require the user to retrieve information from the system):

- Reading: Ten pseudo randomly selected five letter words were presented in a dialogue box. Participants were instructed to read them aloud.

- Read unit: A red diamond icon was presented on the map (see Figure 1). Participants were prompted to read aloud the type, size and map co-ordinates of the diamond.
The BMS simulated four types of information input tasks (tasks that require the user to enter information in the system):

- Writing: Five, five-letter words were displayed in a dialogue box. Participants were prompted to type them into a text box using the keyboard.
- Panning and zooming: Participants were instructed to pan the map left, right, up or down, and zoom in or out.
- Create unit: Participants were instructed to add a military symbol to location on the map by pressing their finger down at the desired location and selecting the appropriate military symbol.
- Draw unit boundary: Participants were instructed to draw a boundary on the map by pressing their finger at the desired starting location, and then at each desired location on the map. A line was activated which joined the locations together.

BMS interactions and latencies were recorded to a .csv file. Verbal responses were recorded using a Dictaphone.

Procedure
In both studies, upon arrival, participants completed a consent form and a demographics questionnaire. They were then briefed about the session and provided with a short BMS training session. This involved familiarisation with the BMS and symbols involved, and practice performing the BMS tasks.

Participants were then seated in the vehicle appropriate to the study type (that is, on-road or simulator). The participant performed the BMS tasks while the on-road vehicle or simulator was “driven” along the route by a researcher (Drive 1, either normal or high motion depending on counterbalancing). This was repeated for the second drive on the same route (Drive 2, alternative motion condition to drive 1). For the on-road study the experimenter then drove the car to the alternative route and the procedure was repeated. Overall, participants completed the BMS tasks four times; twice under normal motion conditions and twice under high motion conditions.

RESULTS

Sample
Twenty participants (12 males, 8 females) with a mean age of 33.70 years (SD = 6.25, range 25–44) participated in the simulator study. Twenty-two participants (10 males, 12 females) with a mean age of 26.05 years (SD = 7.77, range 20–56) participated in the on-road study.

Task Completion Times and Accuracy
Task completion times for the on-road and simulator studies are presented in Table 2 by condition; task accuracy is presented in Table 3.

To determine whether task completion times and accuracy differed according to study type, motion and drive number, a mixed design Analysis of Variance (ANOVA) was conducted for each BMS task (12 analyses in total). A summary of the ANOVA results for task completion time and accuracy is presented in Tables 4 and 5, respectively. In the following sections, the results relating to each BMS task are presented.

Reading
For reading tasks, in both studies, task completion time was significantly slower under high motion compared to the normal motion conditions; F(1, 37) = 8.57, p = .006. Task completion times did not differ by study type or drive number. The interaction terms were not significant.

Task accuracy did not differ by motion, study type, or drive number. The interaction terms were not significant.

Read Unit
For read unit tasks, in both studies, task completion time was significantly slower under high motion compared to the normal motion conditions, and in the first in comparison to the second drives; F(1, 34) = 9.25, p = .005 and F(1, 34) = 15.35, p < .001, respectively. Task completion times did not differ significantly by study type, and the interaction terms were not significant.

Task accuracy did not significantly differ by motion, study type, or drive number. There was a significant interaction between motion and drive number, such that task accuracy improved from drive 1 to drive 2 under normal motion conditions, but decreased under high motion conditions; F(1, 37) = 4.16, p = .049. The other interaction terms were not significant.

Writing
For writing tasks, task completion times were significantly slower under high motion compared to the normal motion conditions, in the simulator compared to the on-road study and in drive 1 in comparison to drive 2; F(1, 36) = 15.51, p < .001, F(1, 36) = 46.51, p < .001, and F(1, 36) = 15.90, p < .001, respectively. There was a significant interaction between motion and study type, such that increasing motion had a greater impact in the simulator compared to the on-road study; F(1, 36) = 8.57, p = .006. The other interaction terms were not significant.

Task accuracy was significantly worse under high motion compared to normal motion conditions F(1, 37) = 39.34, p < .001, in the simulator in comparison to the on-road study (F(1, 37) = 9.14, p = .005), and in drive 1 in comparison to drive 2; F(1, 37) = 39.34, p < .001, F(1, 37) = 9.14, p = .005, and F(1, 37) = 9.15, p = .005, respectively. There was a significant interaction between motion and study type, such that increasing motion had a greater impact in the simulator compared to the on-road study; F(1, 37) = 4.62, p = .038.
Panning and Zooming

For panning and zooming tasks, task completion times were significantly slower under high motion compared to the normal motion conditions, in the simulator compared to the on-road study, and in drive 1 in comparison to drive 2; \( F(1, 34) = 3.81, p = .05, F(1, 34) = 6.77, p = .014 \), and \( F(1, 34) = 14.03, p = .001 \), respectively. The interaction terms were not significant.

Task accuracy was significantly worse in the simulator in comparison to the on-road study; \( F(1, 37) = 7.15, p = .011 \). Task accuracy did not differ significantly by motion or drive number, and the interaction terms were not significant.

Create Unit

For create unit tasks, task completion times were significantly slower under high motion compared to the normal motion conditions, in the simulator compared to the on-road study, and in drive 1 in comparison to drive 2; \( F(1, 34) = 17.99, p < .001, F(1, 34) = 5.22, p = .03 \) and \( F(1, 34) = 18.50, p < .001 \), respectively. There was a significant interaction effect between motion and study type, such that increasing motion had a greater impact in the simulator compared to the on-road study; \( F(1, 34) = 4.66, p = .04 \).

Task accuracy was significantly worse under high motion compared to normal motion conditions and in the on-road compared to the simulator study; \( F(1, 37) = 15.99, p < .001 \) and \( F(1, 37) = 6.05, p = .019 \), respectively. Task accuracy did not differ significantly by drive number. The interaction terms were not significant.

Draw Unit Boundary

For draw unit boundary tasks, task completion times were significantly slower under high motion compared to the normal motion conditions and in drive 1 in comparison to drive 2; \( F(1, 33) = 34.99, p < .001 \) and \( F(1, 33) = 10.65, p = .003 \), respectively. Task completion times did not differ significantly by study type. There was a significant interaction effect between motion and study type, such that increasing motion had a greater impact in the simulator compared to the on-road study; \( F(1, 34) = 4.66, p = .04 \).

Task accuracy was significantly worse under high motion compared to normal motion conditions \( (F(1, 37) = 69.56, p < .001) \) and in the on-road compared to the simulator study; \( F(1, 37) = 69.56, p < .001 \) and \( F(1, 37) = 45.28, p < .001 \), respectively. Task accuracy did not differ significantly by drive number. The interaction terms were not significant.

**DISCUSSION**

Overall, the results suggest that simulated motion is appropriate for studying the direction of effects on BMS touch screen tasks, but not the magnitude of those effects. In support of Hypothesis 1, in the simulator and on-road studies increasing levels of vehicle motion had a detrimental impact on task completion times for all BMS task types. Task accuracy was also negatively impacted for most information input tasks; the effect was in the predicted direction but not significant for information extraction tasks. However, it was predicted that on average performance would be worse in the on-road study than in the simulator, as the motion profiles for the on-road study conditions were more extreme than in the simulator study (Hypothesis 2). The opposite effect was found across many BMS tasks. Task completion times tended to be worse in the simulator study than the on-road study for all information input tasks, with the exception of draw unit boundary tasks. Task accuracy was worse in the simulator study than the on-road study for writing and panning and zooming. Only the results for create unit and draw unit boundary task accuracies followed the predicted pattern. It was also predicted that the effect of motion on performance would be greater in the on-road study than in the simulator study, again due to the more extreme motion profiles in the on-road study (Hypothesis 3). However, the effect of motion was more pronounced in the simulator than the on-road study for writing, panning and zooming, and drawing unit boundary task completion times; writing task accuracy was also more diminished in the simulator than the on-road study.

Although increasing levels of vehicle motion had a detrimental effect in both studies, the results suggest that simulated motion (as operationalised in the current study) is in some ways qualitatively different to real vehicle motion. Regardless of the level of motion, the simulator appeared to be a more challenging environment for participants on almost all BMS tasks. Potentially, this may be because of unintended conflicts between experienced and visual motion cues. It is very difficult to exactly synchronise the visual and motion systems in a simulator and this may have had an impact on performance. This problem is widely acknowledged as the source of “simulator sickness”, and poses a significant challenge for research and training involving simulators [8]. In addition, Table 1 illustrates that the distribution of motion across the axes were quite different in the two studies; simulated motion may have posed more of a challenge to participants because of these novel characteristics. Overall, these issues suggest that the British Standard [19] may not be a reliable predictor of performance impairment in the simulator, because it does not take these challenges into account.

The findings suggest that the behavioural validity of simulators may be highly task specific, as the magnitude of observed effects varied across BMS task types. In particular, while task completion times tended to be longer in the simulator than on-road study, this pattern was reversed for create unit and draw unit boundary task accuracies. In addition, task completion times for panning and zooming tasks were almost ten times longer in the simulator than in the on-road study. Writing accuracy in the simulator in the high motion conditions was 53–66% compared to over 80% for the comparable conditions in the on-road condition. There is no clear explanation for these findings. However, it suggests that human factors researchers interested in
predicting the magnitude of performance degradations due to motion should be cautious when generalising from the results of simulator studies. As a corollary, this also suggests that simulated motion is not an appropriate tool for predicting when operator performance might degrade beyond acceptable boundaries.

Although not directly relevant to the hypotheses of the current study, it is notable that for most BMS tasks there was a predictable learning effect on task completion times. Task completion time improved from drive 1 to drive 2 for all tasks except reading, which was already at a close to ceiling level of performance. This suggests that in field settings, some of the detrimental effects of vehicle motion are likely to be overcome through practice. As the learning effect was observed in both studies, this suggests that it may be appropriate to use vehicle simulators to train operators to overcome the effects of motion on performance. Further research is required to determine whether the effects observed in the current study will be completely ameliorated with practice.

Finally, the limitations of the present study should be acknowledged. Firstly, the motion profiles utilised in both studies were not direct correlates, so it was only possible to assess relative, rather than absolute, behavioural validity. Secondly, the BMS was placed at slightly different heights across the two studies: on the front dashboard in the simulator study and on the head rest of the passenger seat. However, this was not expected to impact the results as the reach distance in the two studies was approximately equivalent. Thirdly, participants in both studies experienced only a limited range of vehicle motion. The terrain encountered in military field operations is likely to be even more variable; this raises some concerns about what could happen in more severe off-road conditions and heightened states due to operational demands. Finally, the sample consisted of university students, rather than the intended military end users of the BMS. As a civilian sample is unlikely to have had prior experience utilising a touch screen in a high motion environment, their performance can be said to approximate the novice military end user of the BMS. As the findings show that there is a significant learning effect with the BMS, different results may be obtained with military personnel that have extensive experience working with in-vehicle interfaces in high motion environments (such as in mobile C2 centres).

In conclusion, the results of the present study illustrate that motion simulators are valid tools for studying some of the human factors issues associated with C2 on the move. In particular, the results suggest that simulated motion is appropriate for studying the direction of effects of motion on the use of in-vehicle technologies, but not the magnitude of those effects. The results offer a further warning against the usual focus on physical fidelity over behavioural validity. Researchers wishing to employ simulation must first demonstrate it is appropriate for the question of interest. The current study provides an evidence-base for those wishing to use simulation to study the human factors problems associated with the implementation of advanced technologies in mobile surface units.

REFERENCES


Dr Natassia Goode is a research fellow within the University of the Sunshine Coast Accident Research team.

Associate Professor Paul Salmon is a senior research fellow and the leader of the University of the Sunshine Coast Accident Research team. He currently holds an Australian National Health Medical Research Council post-doctoral training fellowship.

Associate Professor Michael Lenné is a senior research fellow and is leader of the Human Factors team at the Monash University Injury Research Institute.

Figure 1. The Monash University Accident Research Centre’s Advanced Driving Simulator.

Figure 2. Example of a BMS Read Unit Task.
Table 1. **Average acceleration across x, y, and z axes (m/s²) for each condition.**

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Motion condition</th>
<th>x (m/s²)</th>
<th>y (m/s²)</th>
<th>z (m/s²)</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-road</td>
<td>Normal</td>
<td>0.096</td>
<td>0.077</td>
<td>0.207</td>
<td>0.241</td>
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<tr>
<td></td>
<td>High</td>
<td>0.639</td>
<td>0.297</td>
<td>0.918</td>
<td>1.157</td>
</tr>
<tr>
<td>Simulator</td>
<td>Normal</td>
<td>0.119</td>
<td>0.086</td>
<td>0.059</td>
<td>0.158</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0.328</td>
<td>0.318</td>
<td>0.184</td>
<td>0.493</td>
</tr>
</tbody>
</table>

Table 2. **Summary of information input and extraction task completion times (seconds) by condition.**

<table>
<thead>
<tr>
<th>Task</th>
<th>Normal, Drive 1, On-road</th>
<th>Normal, Drive 1, Simulator</th>
<th>Normal, Drive 2, On-road</th>
<th>Normal, Drive 2, Simulator</th>
<th>High, Drive 1, On-road</th>
<th>High, Drive 1, Simulator</th>
<th>High, Drive 2, On-road</th>
<th>High, Drive 2, Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information extraction</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Reading</td>
<td>10.26 (1.95)</td>
<td>10.89 (2.07)</td>
<td>10.00 (1.65)</td>
<td>10.74 (2.15)</td>
<td>10.96 (2.46)</td>
<td>11.84 (2.28)</td>
<td>9.98 (1.80)</td>
<td>11.97 (2.52)</td>
</tr>
<tr>
<td>Read unit</td>
<td>10.04 (2.57)</td>
<td>10.09 (1.54)</td>
<td>8.53 (2.22)</td>
<td>8.99 (1.78)</td>
<td>11.34 (4.19)</td>
<td>10.96 (2.47)</td>
<td>9.05 (2.12)</td>
<td>10.09 (2.16)</td>
</tr>
<tr>
<td>Information input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing</td>
<td>16.84 (3.77)</td>
<td>27.75 (8.78)</td>
<td>15.15 (4.80)</td>
<td>24.39 (6.94)</td>
<td>18.07 (4.97)</td>
<td>34.47 (11.25)</td>
<td>15.67 (3.82)</td>
<td>29.65 (8.55)</td>
</tr>
<tr>
<td>Panning &amp; zooming</td>
<td>7.36 (2.03)</td>
<td>89.95 (25.55)</td>
<td>6.93 (2.44)</td>
<td>93.35 (17.44)</td>
<td>7.62 (1.96)</td>
<td>88.40 (19.52)</td>
<td>7.10 (2.11)</td>
<td>95.05 (12.09)</td>
</tr>
<tr>
<td>Create unit</td>
<td>11.18 (2.72)</td>
<td>11.75 (2.34)</td>
<td>10.04 (1.81)</td>
<td>11.13 (2.04)</td>
<td>12.01 (3.37)</td>
<td>14.34 (2.49)</td>
<td>10.67 (2.40)</td>
<td>13.05 (3.09)</td>
</tr>
<tr>
<td>Draw unit boundary</td>
<td>12.24 (2.82)</td>
<td>12.53 (1.78)</td>
<td>11.46 (2.57)</td>
<td>12.52 (3.74)</td>
<td>13.10 (3.40)</td>
<td>16.11 (3.32)</td>
<td>11.87 (2.67)</td>
<td>14.67 (3.64)</td>
</tr>
</tbody>
</table>

Table 3. **Summary of information extraction and input task accuracy by condition.**

<table>
<thead>
<tr>
<th>Task</th>
<th>Normal, Drive 1, On-road</th>
<th>Normal, Drive 1, Simulator</th>
<th>Normal, Drive 2, On-road</th>
<th>Normal, Drive 2, Simulator</th>
<th>High, Drive 1, On-road</th>
<th>High, Drive 1, Simulator</th>
<th>High, Drive 2, On-road</th>
<th>High, Drive 2, Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information extraction</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Reading (% correct)</td>
<td>100.00 (.00)</td>
<td>99.20 (1.82)</td>
<td>100.00 (.00)</td>
<td>98.75 (1.94)</td>
<td>98.25 (7.65)</td>
<td>98.15 (3.21)</td>
<td>98.25 (7.65)</td>
<td>98.90 (1.92)</td>
</tr>
<tr>
<td>Read unit (% correct)</td>
<td>90.64 (11.27)</td>
<td>87.87 (10.72)</td>
<td>89.47 (11.40)</td>
<td>85.07 (9.75)</td>
<td>90.06 (12.22)</td>
<td>86.20 (10.10)</td>
<td>93.57 (11.30)</td>
<td>91.70 (8.73)</td>
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<tr>
<td>Information input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing (% correct)</td>
<td>94.74 (12.49)</td>
<td>79.05 (25.36)</td>
<td>94.74 (12.49)</td>
<td>82.95 (24.28)</td>
<td>80.70 (23.08)</td>
<td>53.00 (29.23)</td>
<td>87.72 (25.36)</td>
<td>66.00 (30.41)</td>
</tr>
<tr>
<td>Panning &amp; zooming (% correct)</td>
<td>100.00 (.00)</td>
<td>89.98 (24.54)</td>
<td>98.24 (5.26)</td>
<td>93.35 (17.44)</td>
<td>96.49 (8.92)</td>
<td>88.40 (19.52)</td>
<td>100.00 (.00)</td>
<td>95.05 (12.09)</td>
</tr>
<tr>
<td>Create unit (pixel error)</td>
<td>18.48 (7.20)</td>
<td>14.05 (19.00)</td>
<td>16.68 (6.29)</td>
<td>11.68 (15.48)</td>
<td>27.74 (7.27)</td>
<td>16.12 (5.18)</td>
<td>25.28 (16.91)</td>
<td>23.47 (19.28)</td>
</tr>
<tr>
<td>Draw unit boundary (pixel error)</td>
<td>14.38 (3.12)</td>
<td>8.73 (1.62)</td>
<td>13.87 (3.16)</td>
<td>9.17 (1.73)</td>
<td>16.79 (3.39)</td>
<td>12.34 (1.94)</td>
<td>16.49 (14.38)</td>
<td>12.53 (3.29)</td>
</tr>
</tbody>
</table>
### Table 4. Summary of ANOVA results for task completion times for each BMS task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Motion</th>
<th>Study type</th>
<th>Drive number</th>
<th>Motion x Study type</th>
<th>Motion x Drive number</th>
<th>Condition x Drive number</th>
<th>Motion x Study type x Drive number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading</td>
<td>High normal**</td>
<td>&gt; ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Read unit</td>
<td>High normal**</td>
<td>&gt; ns</td>
<td>Drive 1</td>
<td>Drive 2**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Writing</td>
<td>High normal**</td>
<td>&gt; Simulator &gt; on-road**</td>
<td>Drive 1</td>
<td>Drive 2**</td>
<td>Effect of motion &gt; in simulator**</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Panning &amp; zooming</td>
<td>High normal*</td>
<td>&gt; Simulator &gt; on-road**</td>
<td>Drive 1</td>
<td>Drive 2**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Create unit</td>
<td>High normal**</td>
<td>&gt; Simulator &gt; on-road*</td>
<td>Drive 1</td>
<td>Drive 2**</td>
<td>Effect of motion &gt; in simulator*</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Draw unit boundary</td>
<td>High normal**</td>
<td>&gt; ns</td>
<td>Drive 1</td>
<td>Drive 2**</td>
<td>Effect of motion &gt; in simulator**</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Note: ns = non-significant result, *p < .05, **p < .01

### Table 5. Summary of the ANOVA results for task accuracy for each BMS task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Motion</th>
<th>Study type</th>
<th>Drive number</th>
<th>Motion x Study type</th>
<th>Motion x Drive number</th>
<th>Condition x Drive number</th>
<th>Motion x Study type x Drive number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Read unit</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>Effect of time differs by motion*</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Writing</td>
<td>High normal**</td>
<td>&lt; Simulator &lt; on-road**</td>
<td>Drive 1</td>
<td>Drive 2**</td>
<td>Effect of motion &gt; in simulator**</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Panning &amp; zooming</td>
<td>ns</td>
<td>Simulator &lt; on-road**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Create unit</td>
<td>High normal**</td>
<td>&lt; On-road simulator*</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Draw unit boundary</td>
<td>High normal**</td>
<td>&lt; On-road simulator**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Note: ns = non-significant result, *p < .05, **p < .01