Effects of Mobile Map Orientation and Tactile Feedback on Navigation Speed and Situation Awareness

Nanja J.J.M. Smets
TNO Human Factors and Delft
University of Technology
kampweg 5, 3769ZG
Soesterberg
+31346356279

Nanja.smets@tno.nl

Guido M. te Brake
TNO Human Factors
kampweg 5, 3769ZG
Soesterberg
+31346356253

Guido.tebrake@tno.nl

Jasper Lindenberg
TNO Human Factors
kampweg 5, 3769ZG
Soesterberg
+31346356264

Jasper.lindenberg@tno.nl

Mark A. Neerincx
TNO Human Factors and Delft
University of Technology
kampweg 5, 3769ZG
Soesterberg
+31346356298

Mark.neerincx@tno.nl

ABSTRACT

Mobile information systems aid first responders in their tasks. Support is often based on mobile maps. People have different preferences for map orientations (heading-up or north-up), but map orientations also have different advantages and disadvantages. In general north-up maps are good for building up situation awareness and heading-up maps are better for navigational tasks. Because of heavily loaded visual modalities, we expect that tactile waypoint information can enhance navigation speed and situation awareness. In this paper we describe an experiment conducted in a synthetic task environment, in which we examined the effect of heading-up and north-up displays on search and rescue performance of first responders, and if adding the tactile display improves performance.

Categories and Subject Descriptors

H.5.2 **[Information Interfaces and Presentation]**: User Interfaces - *Evaluation/methodology, Graphical user interfaces (GUI), Haptic I/O, Prototyping.*

General Terms

Measurement, Performance, Design, Experimentation, Human Factors.

Keywords

1. INTRODUCTION

A toxic cloud is threatening the life of inhabitants of a small urban area. First responders are the first to arrive at the scene of the crisis. In this dangerous, dynamic and chaotic environment, their task is to do surveillance and reconnaissance, bring victims to safety, provide first aid, and establish a good understanding of the situation and possible developments to inform other crisis response personnel and commanders. In this ambiguous and unclear situation they have to think fast and take important decisions.

Mobile information systems are being developed to aid them with these tasks. Support of this type is often based on maps for information presentation and interaction. However, people have different preferences when using maps. Some prefer the map to be aligned with their orientation (heading-up), others prefer that the map always shows north up (north-up). It is also important to take into account the relative advantages of north-up and heading-up maps for different tasks. Heading-up maps have been shown to be more effective for navigational tasks [3, 20, 21]. Using a heading-up map, no mental rotation is required to align the position of one self to the map, reduce cognitive efforts. North-up maps depict the world always the same, thus making it easier for the user to develop situation awareness (SA). In the case of first responders both north-up and heading-up maps can be beneficial, because important tasks of first responders include targeted search (e.g. rescuing of victims) and building up SA (e.g. for communication, finding the way out of dangerous areas).

Audio and visual modalities of the first responders are heavily loaded by tasks such as communication, navigation, coordination, and updating SA. An additional modality that is not yet used by first responders is tactile feedback by means of a mobile tactile display. We expect that providing waypoint information (a vibrating signal in the direction of a destination, for example a reported victim requiring help) may improve navigation speed.

In this paper we examine if the choice between heading-up and north-up displays effects search and rescue performance of first responders, and if adding the tactile display improves performance. We distinguish four research questions:

1. Will victims be rescued faster when participants use a heading-up map instead of a north-up map?

2. Will victims be rescued faster when in addition to a map participants are given tactile waypoint feedback?

3. Does map orientation affect participants' SA?

4. Does tactile waypoint information affect participants' SA?

We expect that victims will be rescued faster when heading-up maps are used. However, this map may hamper the development of SA, because the north-up map does not move with the heading of the participant and, consequently, the visual and tactile displays are incompatible. On the other hand, when tactile information is combined with the heading-up display, the information provided may be redundant. Tactile information may induce that the first responders do not pay attention to the environment, because they just follow the tactile signal, and hence have less SA. On the other hand, they have more time to pay attention to the environment while walking, because it is less important to watch the map, hence SA could also improve.

Recently, game-based simulation has become popular in the scientific community, because of the possibilities and control it provides [11, 8, 19]. Logging data for analysis is one of the other advantages of experimenting in simulated environments. In this experiment we used a synthetic task environment (STE) based on the Unreal Tournament game-engine, which has proven its worth in previous studies [2, 18].

In this paper we will first give some background of recent literature on the topic of mobile maps and tactile feedback for navigation tasks. Next the experiment is described and results are presented. We end with a discussion of the results and draw conclusions.

2. BACKGROUND

A number of studies have shown that maps aligned to the orientation of the user are read more easily and can improve task performance [15, 1]. Most of this work has been done for in-vehicle navigation systems, but some more recent work has focused on pedestrians [17, 9]. Typically, two types are distinguished. North-up maps are similar to the well-known paper maps in that north is always at the top. The alternative, in this paper called heading-up, but sometimes also called head-up, forward-up, track-up, or simply rotating, adapts to the movement and orientation of the user, rotating the map such that the heading of the user is at the top of the map. Heading-up maps are favored when rapid decisions are required regarding lateral turns or while performing a targeted search [3, 20, 21]. Using a heading-up map, no mental rotation is required to align the position of oneself to the map, thus targets are generally found more quickly than with a

north-up map and less cognitive effort is required. North-up maps depict the world always in the same way, thus making it easier for the user to develop situation awareness (SA). It is easier to keep an overview of the situation, for example when keeping track of the movements of other people. This could be an important consideration when the mobile support is used in a collaboration task where keeping track of colleagues is important, such as the crisis response domain.

Hermann, Bieber, and Duesterhoeft compared automatic map rotation with physical rotation and a north-up condition [9]. Three different conditions were compared: north-up, north-up but participants were allowed to rotate the map physically, and heading-up. In the heading-up condition (Wizard of Oz style, this part was non-functional but controlled by the experimenter) participants were able to navigate more successfully than in the other conditions. Manual rotation was better than fixed north-up. Seager and Fraser [17] found different results. They distinguished four conditions: north-up, physical rotation, automatic rotation (heading-up), and manual rotation (the user was able to rotate the map digitally). They conclude that most people prefer physical rotation over heading-up map, north-up map and manual rotation respectively. The same order was found for the number of errors and disorientations. They suggest that the differences found compared to the study of Hermann et al can be contributed to differences in information presentation on the map. Hermann's visualization was rather simple and was single-turn based, whereas Seager's task was more complex and open. Different cognitive processes may be required for these tasks [17].

Prison and Porathe found that heading-up proved better than north-up and paper maps when navigating in a maze [14]. Their other alternative, a 3D projection, gave even better results. Providing a 3D representation is also one of the design solutions suggested by Sas et al. [16]. However, because egocentric 3D projections have the major drawback that information at your back is not visible, they are not suited for the type of tasks first responders have to conduct.

Presenting waypoint navigation on a visual display is not suited to all situations. It has been investigated if it is feasible to present the navigation information on a tactile display [6]. An important design issue of the display is how direction and distance information must be coded. Tactile displays have been successfully used for soldiers' navigation in forested areas by day as well as by night [7]. The day experiment consisted of an experiment with soldiers who had to navigate 1800 meters in a densely forested terrain. Each participant navigated a similar route three times with different support (compass, GPS and a tactile belt). This experiment showed that participants had a higher walking speed and reached more targets using tactile feedback compared to a GPS compass system.

The experiment by night examined soldiers' navigation performance with a focus on target detections and SA. The tactile display is expected to be beneficial on the visual, mental workload and degraded vision. This is why the experiments were performed by nights, with off-limit areas and object negotiation on the route. In this experiment the tactile belt, a handheld visual support and a helmet mounted display were compared. The night-time experiment showed that the tactile information decreased visual load and there was an increase in targets that were detected along the routes. The tactile display enabled the soldiers to have

their eyes free for the task of scanning the area for targets. It became harder to build up global SA of the environment when using the tactile display, however, due to a lack of information on their position and distance to waypoints when using the tactile display [4].

3. METHOD

3.1 Task

Participants had to rescue victims in an STE. The participant's task was to rescue a specific victim as quickly as possible. The player started somewhere in the urban environment and had to go to the victim, whose location was indicated on the map, as quickly as possible. In conditions with tactile feedback, the tactors indicated the relative direction of the victim. After rescuing the victim the participant had to return to the starting point, this time without any form of navigation support. This task was repeated ten times with different starting positions and victims. If the participant took longer than 40 seconds to return to the starting point, the next trial was started.

The participant moved through the environment using a game controller. They could move forward, backward, sideways, and turn. When the participant walked through the environment the map screen turned black. This was to prevent participants from walking solely by looking at the map. Victims in the game were rescued by just walking up to them. When the participant was sufficiently close, the victim disappeared from the STE and the map.

3.2 Design

In the experiment two independent variables were examined: map orientation and tactile feedback. Map view could be north-up or heading-up, tactile feedback could be available or not. Tactile feedback was given by means of a suit that participants wore on top of their clothing, as shown in Figure 3. Each participant conducted the task in two of the four conditions, making the experiment partly between and partly in-between subjects. The map view remained the same for each participant, but the tactile condition would change (with or without tactile feedback), hence each participant would either do condition one and two or condition three and four, as shown in Table 1. To prevent practice effects, two different urban environments with similar look and feel and complexity were used.

Table 1. Design of the experiment, with the independent variables map size and tactile feedback

	Map orientation	Tactile feedback
1	North-up	With tactile waypoint feedback
2	North-up	Without tactile waypoint feedback
3	Heading-up	With tactile waypoint feedback
4	Heading-up	Without tactile waypoint feedback

3.3 Variables

The dependent variables that were measured in the experiment are listed below:

- Performance data. The performance consisted of time required to walk from the starting point to the victim. Also the number of starting points found was recorded.

- Situation awareness. SA was measured by a subjective questionnaire after each trial and by performance measures. The subjective questionnaire examined whether the participant changed their strategy during the experiment and if they were aware what their position was with respect to the starting point and the victim. Performance measures for SA consisted of the number of times the starting point was found and the time it took to walk from victim to starting point without a map or tactile support. It was assumed that better SA would lead to more effective and efficient returns.

- Satisfaction. Subjective data on satisfaction was gathered in questionnaires.

3.4 Material

An STE suited to our experiments was built using Unreal Tournament, which is very popular in the academic community [12]. Besides the quality of the engine, attractiveness lies in the modification called Gamebots [10], which allows external software to communicate with the game engine. Gamebots was developed at the University of Southern California for artificial intelligence research and provides two application programming interfaces (APIs). The first API allows controlling virtual characters in the game, the second pipes information out of the game.

The main component of the architecture is the Unreal Tournament 2004 server that hosts the game. A player, playing the role of a first responder, has the synthetic world at their disposal via the replication mechanism of Unreal Tournament 2004. All types of scenes can be created varying from simple block worlds to very realistic urban areas using the Unreal Level Editor UnrealEd 3.0 that comes with Unreal Tournament 2004. The Gamebots script was slightly changed and recompiled using the Unreal Tournament 2004 compiler to enable transfer from additional information from the game to the support tool, such as the participant's location. The basic support tool is created using Microsoft's Visual Studio's C# language and communicates with the Unreal Tournament server using a TCP/IP channel.

Figure 1: Set-up of the experiment.

In the experiment each participant used two computers, both with a 17 inch computer screen. Figure 1 shows the set-up of the experiment. The support screen was situated on the left in front of the participant and displayed a map of the environment, either head-up or north-up. The environment screen was situated on the right, in front of the participant, and showed the synthetic task environment from a person's perspective. Screenshots of both screens are shown in Figure 2 and Figure 3. To navigate in the virtual environment the participants used a Logitech game controller. The experiment was modeled in Unreal Tournament 2004 editor and additional programming was done in C#. The tactile suit that was used is developed by TNO and consists of a vest with pager-motors also found in mobile phones [5]. Pictures of the vest are shown in Figure 4. The tactors vibrated with a frequency of 200 Hz. The tactors were on for one second and then off for one second. One horizontal circle of tactors was used to indicate the location of the victim.

Figure 2: The support screen in north-up condition.

Figure 3: The synthetic environment.

Figure 4: Pictures of the tactile vest that the participant used, left is the front of the vest and right the back.

A spatial ability test was conducted. In another project a software application has been developed for assessing mental spatial ability [13], which has been used in many subsequent experiments. A test was conducted with this mental spatial ability test to investigate its correlation with navigation performance. We assumed that people who showed worse spatial ability would also show worse navigation. These people may need more or different navigation support. Participants received a sequence of forty screens (such as shown in Figure 5) in a fixed (but adjustable) time schedule. A reasonable time (15 seconds) was determined by means of a pilot experiment. Within these 15 seconds, a participant had to determine which of the four peripheral images was identical to the central image (by clicking on the image) or had to decide that no image was identical (by clicking on the none or 'geen' button). It was possible to switch between answers during the 15-second interval. When the subject had not chosen an answer after 12 seconds an alarm beep was given.
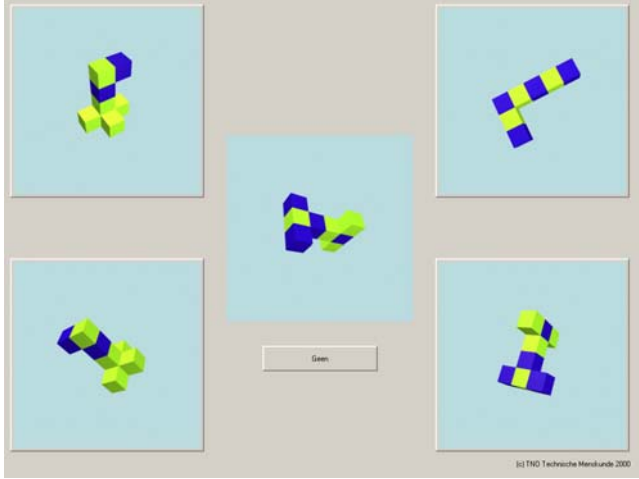
Figure 5: Screenshot of the test that was conducted to estimate the participant's spatial ability.

3.5 Participants

Forty-two participants were used in the experiment as paid volunteers, twenty-two male and twenty female. The average age of the participants was 22 (range 18-30), and they were all college students. None of the participants had any previous experience with search and rescue tasks. All participants had sufficient computer experience to be able to perform the task in the STE.

3.6 Procedure

At the beginning participants were given a general, written instruction about the experiment. Then participants had to fill in a general questionnaire about their background, computer and game experience, and sensitivity to motion sickness. Then the spatial ability test was conducted. The experiment consisted of two trials. Before the trial started, the participants got a general instruction of the task and modalities (map view, tactile feedback) in this trial. A trial consisted of conducting the search and rescue task ten times, of which the first two were considered practice runs to account for learning effects. After each trial the participant had to fill in a questionnaire.

4. RESULTS

4.1 Performance data

T-tests were conducted on the time it took to get from the starting point to the victim. Table 2 shows the time required to rescue eight victims (the first two times from each trial were not used in order to remove practice effects). The time to rescue victims with and without tactile feedback was significantly shorter when participants used a heading-up map, than when they used a north-up map, $t(39) = 2.32$, $p < 0.05$. When there was no tactile feedback, participants rescued the victims significantly faster with a heading-up map, than with a north-up map, $t(39) = 2.60$, $p < 0.05$. For the heading up condition, no significant differences were found. When the map view was north-up, participants got to the victim significantly faster with tactile feedback than without tactile feedback, $t(19) = -2.44$, $p < 0.05$. When participants had a

heading-up map no significant changes were found when tactile feedback was added.

Table 2: Total time required to reach eight victims (seconds).

	Tactile	No tactile
North-up	404	491
Heading-up	367	377

A multiple linear regression analysis was performed to predict performance measures based on predictor variables: spatial ability, age, and computer gaming per week. First, we performed this analysis separately for the conditions with and without tactile feedback.

Table 3 shows that spatial ability explains most of the variance in the data for the conditions with and without tactile suit. In the regression it explains the largest part of the variance percentage-wise for four out of six performance variables (namely number of starting points found and time to walk from victim to start, with and without tactile feedback). Furthermore we can see that spatial ability is more important for the condition with tactile feedback than without tactile feedback.

Age explains most of the variance for two out of four criterion variables (namely time to walk from starting point to the victim in both conditions, with and without tactile suit)

Hours of gaming per week explains only part of the variance of the number of starting points found without the tactile suit.

Table 3: The percentage of explained variance the different predictor variables add for the different criterion variables, for the conditions with and without tactile suit.

Criterion variable	Explained variance R2 (%) by the three predictor variables
Number of starting points found, with tactile suit	Spatial ability = 31 % *
Start to victim time, with tactile suit	Age = 17 % * Add spatial ability = 30 % *
Victim to start time, with tactile suit	Spatial ability = 26 % * Add hour of games = 29 %
Number of starting points found, without tactile suit	Spatial ability = 10 % * Add hour of games = 14 % Add age = 18 %
Start to victim time, without tactile suit	Age = 6% Add spatial ability = 12 %
Victim to start time, without tactile suit	Spatial ability = 11 % *

* Significant at level $p < 0.05$

We performed the same multiple linear regression analysis for the conditions with north-up and heading-up support.

Table 4 shows that spatial ability explains most of the variance in the performance data with north-up and heading-up support. In the regression analysis it explains the largest part of the variance for four out of six criterion variables (namely number of starting points found for north-up and heading-up map, time to walk from starting point to victim in the north up map and time to walk from victim to start in condition with the north-up map).

Age explains most of the variance for two out of four dependent performance variables (namely time to walk from start to victim with a heading up map and time to return from victim to starting point with a heading up map).

Table 4: The percentage of explained variance the different predictor variables add for the different criterion variables, for the conditions with north-up and heading-up map support.

Criterion variable	Explained variance R2 (%) by the three predictor variables
Number of starting points found, north-up	Spatial ability = 41 % *
Start to victim time, north-up	Spatial ability = 19 %
Victim to start time, north-up	Spatial ability = 47 % *
Number of starting points found, heading-up	Spatial ability = 24 % * Add age = 32 %
Start to victim time, heading-up	Age = 56 % * Add spatial ability = 63 %
Victim to start time, heading--up	Age = 19 % Add spatial ability = 29 %

* Significant at level $p < 0.05$

4.2 Situation awareness

T-tests were conducted on the time to walk back from the victim to the starting point and the number of starting points found. Table 5 shows the number of times the participant returned to the starting point in time in the four conditions. No significant differences were found, although the data suggests that adding tactile information may lower SA. No significant differences were found for the return times.

Table 5: Average number of times a participant returned to the starting point in time (out of eight runs).

	Tactile	No tactile
North-up	6,45	7,00
Heading-up	6,66	6,85

After each trial the participant filled in a questionnaire. To the question whether they changed their strategy during the experiment, 21 participants answered yes in the condition with the tactile suit. Participants that changed their strategy during the experiment indicated that they first started walking based solely on information from the tactile suit. However, they noticed that they did not know how to walk back to the starting point and they found they did not know the most efficient route to the victim when using the tactile suit alone. They would then change their strategy to looking at the map for a global overview and start walking to the victim by means of the tactile vest. In the condition without the tactile suit only four indicated that they changed their strategy. They indicated that they changed their strategy and looked more on the map, because they were sometimes unable to find the way back.

Participants were asked if they knew their location with respect to the starting point and victim. They had to fill this in on a five-point scale (1 = no, 5 = yes). The mean answers did not differ for the conditions, the participants indicated that they knew where the starting point and victim were during the search and rescue task (mean answer = 4.0). Apparently, for some this required a change in strategy.

4.3 Satisfaction

The following questions were answered on a five-point scale (1 = no and 5 = yes) in the condition where participants used both maps and tactile feedback:

1. Did you find the tactile suit hard to use?

   Did you find the map hard to use?

2. Did you find the tactile suit comfortable to use?

   Did you find the map comfortable to use?

3. Did you find the tactile suit useful?

   Did you find the map useful?

Figure 6 shows the results. The questions were compared using a Wilcoxon matched pairs test. Results indicated that the map was more useful to the participant and more comfortable to use than the tactile vest, $p < 0.01$.
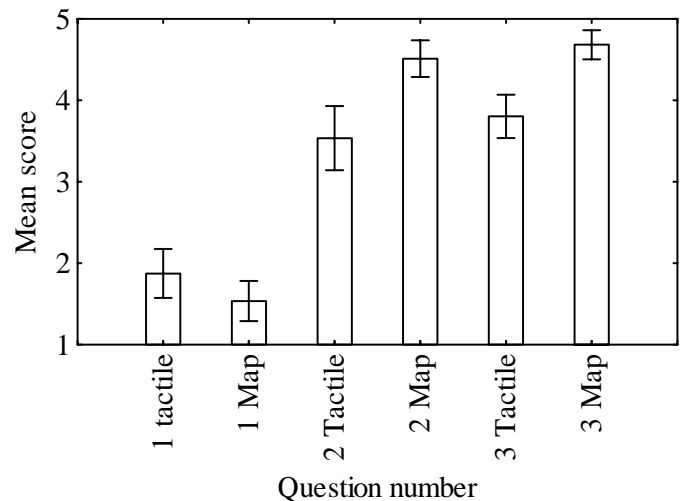

Figure 6: mean score to three questions about the usability of the tactile suit and the map, error bars denote 95% confidence interval.

Figure 7 shows the routes one participant walked during the experiment with a north-up mobile map and tactile feedback. The routes depicted here are displayed in different colors for each search and rescue run. Rescues that went very well are for instance the rescue of victims seven and eight. The participant starts for instance at starting point seven (S7) rescues victim seven (V7) and ends again at starting point seven. Cases where the participant did not make it back to the starting point were the rescue of victims three and nine. In both rescues the participants made a wrong turn on the way back after rescuing the victim.
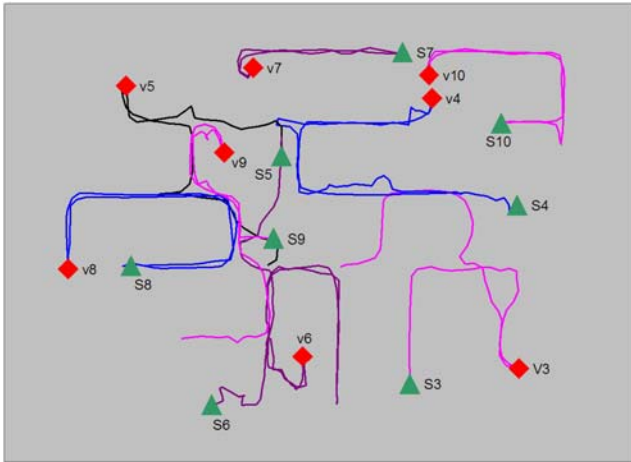

Figure 7: The routes one of the participants walked in the virtual environment with a mobile map and tactile feedback support. The green triangles with the S stands for starting point, the red diamonds with the V stands for victim.

5. DISCUSSION

Results showed that the time to walk from the starting point to the victim was shorter with a heading-up display than with a north-up display. Spatial ability was an important indicator for the time to walk from starting point to victim when using a north-up map. This was as we expected it to be, since it is easier to make quick navigation decisions and lateral turns using a north up map. When tactile feedback is added to the north-up map support, victims were rescued significantly faster. Adding tactile feedback to the condition where a heading-up map was available did not lead to a significant improvement in performance. The difference in time it took to rescue a victim with a north-up map with tactile feedback was not significantly different from the time it took to rescue a victim with a heading-up map (both with and without tactile feedback). Spatial ability was an important predictor for locating starting points and time to walk from victim to start with and without the tactile vest. These results suggest that tactile feedback may take away or reduce the disadvantages of using a north-up map in a targeted search.

Participants indicated that they found the map more useful for their task than the tactile feedback. This makes sense, because the map shows that sometimes the most direct street does not lead to the victim but a detour is required. Maybe if tactile feedback would be provided as route-based information instead of simple waypoint-based, the participants would have found it equally useful.

The T-tests that were conducted on the time that participants took to return from the victim to the starting point and from the number of found starting points produced no significant results. We hoped that the time required to return to the starting point without he support of maps or tactile information would be an indicator of the participant's SA. Although also for the tactile conditions no differences were found for the return time to the starting point, subjective data showed that participants had the feeling that the tactile suit had an impact on situation awareness. More than half of the participants changed their strategy during the trial with the tactile suit. Participants that changed their strategy indicated that at first they relied too much on the tactile feedback and were unable to (or found it hard) to return to the starting points. This indicates that a learning effect occurred when using the tactile suit. Maybe if participants were able to use the tactile suit longer, the positive effects would have been more obvious.

6. CONCLUSION

Heading-up maps significantly outperform north-up maps in our search and rescue task. Adding a tactile display to a heading-up map does not improve performance, but when added to a north-up map performance was improved significantly. Hence, for tasks where having proper SA is important, north-up maps in combination with tactile waypoint information may be a good design alternative.

Map orientation significantly improved the performance. Victims were rescued faster with a heading-up map than with a north-up map. But no significant effects were found in the time needed to walk back to the starting point.

Whether adding tactile information affects SA or not is hard to say based on our results. No significant effect was found in the measurements, although a trend seems to suggest that tactile feedback lowers SA. Subjective data also showed that participants had the feeling that the tactile suit had an impact on the situation awareness. However, to determine whether SA is really lowered by adding tactile information requires furthers study.

7. ACKNOWLEDGMENTS

8. REFERENCES

[1] Aretz, A.J. and Wickens, C.D. 1992. The mental rotation of map displays. Human Performance, 5, 4, 303-328. Lawrence Erlbaum Associates, Inc., Philadelphia, PA, USA.

[2] Brake, G., te, Greef, T., de, Lindenberg, J., Rypkema, J., Smets, N. 2006. Developing Adaptive User Interfaces Using a Game-based Simulation Environment. In Proceedings of the 3rd International ISCRAM Conference. (Newark, NJ, USA, May 15 – 17, 2006). ISCRAM 2006. Springerlink, Heidelberg, Germany, 510- 519.

[3] Darken, R.P. and Cevik, H. 1999. Map Usage in Virtual Environments: Orientation Issues. In proceedings of the IEEE Virtual Reality, (Houston, TX, USA, Mar. 13-17, 1999). VR 1999. 133- 140.

[4] Duistermaat, M., Elliot, L.R., van Erp, J.B.F., and Redden E.S. 2007. Tactile land navigation for dismounted soldiers. In Human factor issues in complex system performance, de Waard, D. Hockey, B. Nickel, P. Brookhuis, K. Ed. Shaker publishing, Maastricht, The Netherlands, 43–53.

[5] Van Erp, J.B.F. 2002. Guidelines for the use of vibro-tactile displays in Human Computer Interaction. In proceedings of Eurohaptics, S.A. Wall, B. Riedel, Crossan, A. & McGee, M.R. Ed. (Edingurgh, July 8- 10, 2002). ACM press, New York, NY, 18-22.

[6] Van Erp, J.B.F., Van Veen, H.A.H.C., Jansen, C., and Dobbins, T. 2005. Waypoint Navigation with a Vibrotactile Waist Belt. In transactions on Applied Perception. ACM press, New York, NY, 2 (2), 106-117.

[7] Van Erp, J.B.F. and Duistermaat, M. 2005. Tactile guidance for land navigation. Technical report: TNO-DV3 2005-C 013 Soesterberg, The Netherlands: TNO Human Factors Research Institute.

[8] Frey, A., Hartig, J., Ketzel, A., Zinkernagel, A., and Moosbrugger, H. 2007 The use of virtual environments based on a modification of the computer game Quake III Arena ® in psychological experimenting. Computers in Human Behavior. Elsevier, Oxford, England, 23, 2026-2039.

[9] Hermann, F., Bieber, G. and Duesterhoeft, A. 2003. Egocentric maps on mobile devices. In proceedings of 4th International Workshop on Mobile Computing. (Providence, RI, USA, May 19- 22) ICDS 2003. IRB Verlag, Stuttgart, Germany, 141- 158.

[10] Kaminka, G.A., Veloso, M.M., Schaffer, S., Sollito, C., Adobbati, R., Marshall, A.N., Scholer, A. and Tejada, S. 2002. GameBots: a flexible test bed for multiagent team research. Communications of the ACM. ACM Press, New York, NY, 45, 1, 43-45

[11] Lewis, M., and Jacobson, J. 2002. Game Engines in Scientific Research. Communications of the ACM. ACM Press, New York, NY, 45, 1, 27-31

[12] McGrath, D. and McGrath, S.P. 2005. Simulation and Network-Centric Emergency Response. Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC).

[13] Neerincx, M.A., Pemberton, S., and Lindenberg, J. 1999. U-WISH Web usability: methods, guidelines and support interfaces. Technical report: Report TM-99-D005 Soesterberg, The Netherlands: TNO Human Factors Research Institute.

[14] Prison, J. and Porathe, T. 2007. Navigation with 2-D and 3-D Maps: A Comparative Study with Maritime Personnel In the Proceedings of the 39th Nordic Ergonomics Society Conference (Lysekil, Sweden, Oct 1- 3, 2007)

[15] Rossano, M. J., and Warren, D.H. 1989. Misaligned maps lead to predictable errors. In Perception. Pion Ltd. London, England, 18, 215-229

[16] Sas, C., O'Grady, M., and O'Hare, G. 2003. Electronic navigation – some design issues. In proceedings of Mobile HCI (Udine, Italy, Sept 8- 11, 2003). MobileHCI03. Springer, Heidelberg, Germany , 471-475.

[17] Seager, W. and Stanton-Fraser, D. 2007. Comparing Physical, Automatic and Manual Map Rotation for Pedestrian Navigation. In ACM SIGCHI Conference on Computer-Human Interaction. (San Jose, CA, USA, April 28- May 3, 2007) CHI 2007. ACM Press, New York, NY, 767 – 776.

[18] Smets, N.J.J.M., te Brake, G.M., Lindenberg, J., Neerincx, M.A. 2007. Influence of mobile map size and user capacities on situation awareness tested in a virtual environment. In proceedings of the 4th International ISCRAM Conference B. Van de Walle, P. Burghardt and C. Nieuwenhuis, Ed. (Delft, the Netherlands, May 13- 17, 2007) ISCRAM 2007.

[19] Streefkerk, J.W., van Esch-Bussemakers, M.P., Neerincx, M.A., and Looije, R. 2008. Evaluating context-aware mobile interfaces for professionals. In handbook of research on user interface design and evaluation for mobile technology. Lumsden, J. Ed. In press.

[20] Viita, D. Werner, S. 2006. Alignment effects on simple turn decisions in track-up and north-up maps. In proceedings of the Human factors and ergonomics society 50th Annual meeting. (San Francisco, CA, USA, Oct. 16- 20). HFES 2006. HFES, Santa Monica, CA, 1519- 1522.

[21] Wickens, C.D., Liang, C-C., Prevet, T., Olmos, O. 1996. Electronic maps for terminal area navigation: effects of frame of reference and dimensionality. The international journal of aviation psychology, Lawrence Erlbaum Associates, 6, 3 (July 1996), 241-271.