Reducing workload by navigational support in dynamic situations

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ABSTRACT

By presenting continuously updated heading and distance information on a small head-mounted display (HMD), as a supplement to a GPS-receiver, we examined if workload could be reduced and performance increased, when navigating in a demanding situation. The purpose was to present limited but sufficient information to facilitate navigation. The technique was tested on ground troops, but could also be used by rescue services and police in situations that require navigation in unknown environments. The main findings were that the workload was reduced in one aspect (during navigation) but increased in another (looking for foot placement). There were no clear differences in performance, except that participants stopped fewer times to look at the GPS-receiver if they had updated heading and distance information. This suggests that a supplement display with minimal information could be useful when navigating with a GPS-receiver in an unknown environment.

Keywords

Navigation, GPS-receiver, head-mounted display (HMD), minimal information, workload, attention, dynamic environments.

INTRODUCTION

Navigation is a basic skill for all people (Young, Stanton, Walker, Jenkins, & Smart, 2008). It is however a demanding task which is often done in combination with another task, e.g. driving, which requires constant attention to the surroundings. Navigation in a stressful and dangerous situation (forest fire, natural disaster or combat area) is especially challenging and it is therefore desirable to be able to keep track of the current location, both for knowing where to go and where to return to. In situations such as a forest fire or a combat area, the person navigating is usually occupied with other attention demanding tasks such as searching the surroundings for threats, operating complicated equipment, etc. Often they also have both hands occupied, either by carrying or operating equipment. To use a map and compass in those circumstances are both time-consuming and demands cognitive resources. This could force the person in the field to focus too much on navigation solely. For these scenarios a system that can keep track of the current location and facilitate navigation is desirable. A GPS-based system can be used for this purpose, but the introduction of a navigational support such as a GPS-receiver can both be for the better and for the worse (Young et al., 2008) in terms of workload, behavior, and performance. Despite the fact that a GPS-receiver is used the workload can still be too high and the question is how to present the information and what kind of information that is needed. *The aim of the study was to see if workload could be reduced and performance be enhanced in a demanding situation, by using a small head-mounted display (HMD), presenting continuously updated heading and distance information, as a supplement to a GPS-receiver.* A secondary aim was to assess the user's opinions and investigate if the HMD had any negative effects on the navigational patterns and overall behavior. The HMD was mounted on a pair of glasses and the idea was to present as little but sufficient information as possible to facilitate navigation.

Navigation

Navigation is composed of two components; locomotion (physical movement towards a place) and wayfinding (Freundschuh, 2001; Montello, 2005). Locomotion is the ability to coordinate information from the sensory and motor systems, and to identify obstacles and barriers when moving (Montello & Sas, 2006).Wayfinding is dependent on our working-memory, planning, and decision-making (Montello & Sas, 2006). An important aspect of wayfinding is to be oriented, that is to be aware of the own location in relation to the destination (Montello, 2005).

Thorndyke and Hayes-Roth (1982) proposed two ways of acquiring knowledge for finding one's way: by reading maps or by frequently navigating in the environment. In their study two groups (map learners and navigators familiar with the environment) estimated distance, orientation and localization of objects in a building. Map learners had an advantage to navigators concerned global relationships, as they had a bird's eye view of the environment, but on the other hand the map learners had a disadvantage when they had to mentally rotate the map when estimating orientation (Ibid.).

During navigation in dangerous situations there are a few things that need to be considered: the navigator often has more than one task, the workload probably is high, and that the navigational tool might have an unwanted effect on the standard procedure.

Multiple tasks

When in a demanding and stressful situation the navigator usually needs to focus on the surroundings and the task at hand rather than on the navigational support tool. More important tasks such as overlooking the terrain to know where to step, looking for potential threats or just finding the way in a smoke-laden area. These reasons in combination with finding ones way might lead to an increased workload.

Workload

Hollnagel and Woods (2005) explain workload as the users' own experience of the mental effort to perform a task. The workload increases with the quantity, the complexity and the novelty of the task/-s (Wickens & Hollands, 1999). The effect of the workload is not dependent on if it is high or low, but rather of how the person adapts to the situation (Wickens & Hollands, 1999). A low workload could mean that the person shifts focus from the task and lose more attention than if having a high workload but being fully concentrated on the task (Hollnagel & Woods, 2005).

To navigate in well-known areas can become an automatic behavior whereas navigation in an unknown environment demands a lot of cognitive attention (Montello & Sas, 2006). Since navigation in a dynamic situation seldom allows full concentration or takes place in a well-known environment, the workload of the navigator may increase.

Consequences of a Navigational Support Tool

There are both positive and negative aspects when introducing new technical navigational support tools. A navigational support tool can lessen the workload by managing some of the wayfinding tasks, such as update the orientation, planning, and decision–making (if a route is predefined). This enables the user to focus more on locomotion (scan the surroundings to look for threats, identifying surface support and obstacles) and adapt the route appropriately. To use a navigational aid is not always preferable when there is a time aspect. In Young et als. (2008) study it was only faster to use a GPS-receiver for long missions since the startup and planning time were longer than when using a map and compass. But the upside was that using a GPS-receiver gave a more accurate wayfinding with fewer errors compared to using a map and compass. If time efficiency or lower workload is the most important aspect, is something that needs to be considered before choosing a navigational support tool.

Navigation with a map that is read with north-up demands mental rotation in order to be able to orientate (Thorndyke & Hayes-Roth, 1982). A digital map on the other hand can preferentially be presented in an egocentric perspective (with the track-up instead of north-up), which reduce the need of mental rotation (Montello & Sas, 2006; Wickens & Hollands, 1999).

Head-mounted Display (HMD)

A HMD can be used as a supplement to a GPS-receiver, a compass or another kind of monitor or display. There are contrasting studies as whether this technique is enhancing performance or not. Previous studies with military personnel (Kumagai & Massel, 2005) showed that a HMD provided a higher accuracy of bearing estimation compared to only using a compass, but the study lacked a concurrent task that demanded the user's attention. Krupenia and Sanderson (2006) performed a laboratory study of *inattentional blindness* (missing an unexpected event when focusing on something else) when using a standard monitor (computer screen) and when using both the standard monitor and a HMD, during three levels of attention; focused, divided and "just watch". The event detection was somewhat poorer for all conditions when using the HMD. On the other hand, Liu, Jenkins, Sanderson, Watson, Russell, Leane, & Kruys (2009) did a study, with anesthesiologists using a HMD, with opposite results. Two experiments were performed and in the first experiment (*inattentional blindness*) there were no differences either in how fast or how many unexpected events that were detected between using a HMD or a standard monitor. In the second experiment (constrained context) some events were detected faster when using the HMD. Overall the user's subjective opinions were that they were faster at detecting events when using a HMD (Liu et al., 2009). So using a HMD in a dynamic environment can sometimes facilitate the task, at least at the subjective level.

When in a stressful situation the ability to absorb and process information is limited. In a situation like a forest fire or a combat area the focus needs to be on the situation and not on interpreting navigational information. Kumagai and Massel (2005) found that explicit directional information was preferred to implicit directional information, and that egocentric displays lead to significantly fewer head-miss directions than exocentric displays. Furthermore, the navigational information needs to be sufficient but not more than that, because too much information can distract more than it actually helps (Montello & Sas, 2006).

DESIGN

This study had two conditions, one where the participants navigated while only using a GPS-receiver and a second where they were also equipped with a HMD showing heading and distance to upcoming waypoints. A counter-balanced within-group design was used. Each participant was tested individually; they performed and evaluated both conditions.

The experiment was conducted in wooded terrain 10 kilometers south west of Tjällmo, Östergötland, Sweden. The area for the experiment was approximately 2.5 x 2 kilometers with a mixed terrain of pine forest and peat soil. Two separate routes with the same goal-position were used (see figure 1) the routes could be traversed in either direction. The distance as the crow flies was 635 meters for Route 1 and 598 meters for Route 2. Twenty paper figures were placed along the two routes; their position can be seen in figure 1. Looking for the paper figures (threats) was a secondary task so that all focus would not be on navigation.

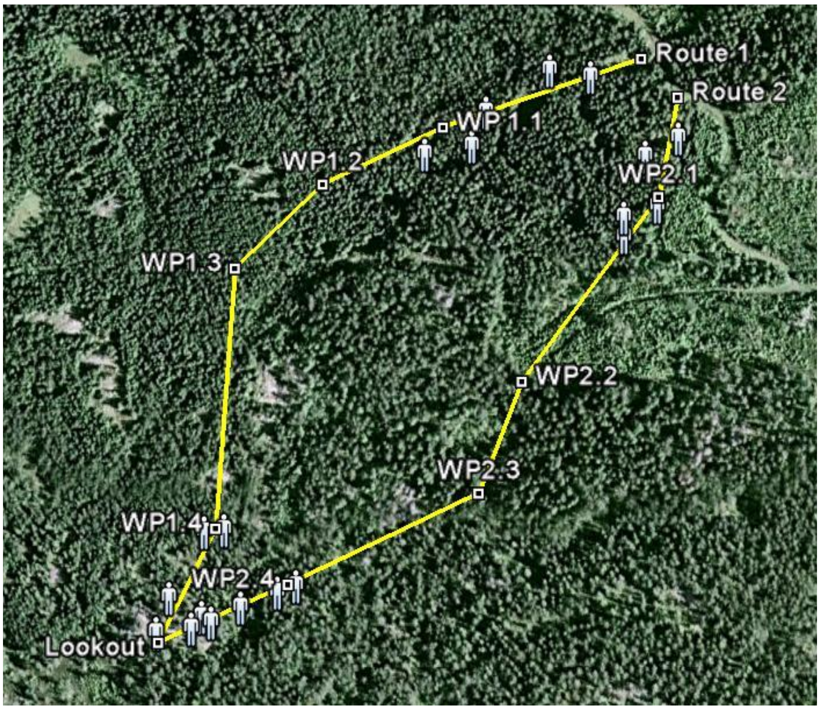

Figure 1: The two routes being used in the experiment. Both routes could be entered from a nearby road. The figures on the map indicate the position of the paper figures.

Participants

14 military personnel volunteered to participate in the study. The age of the participants varied from 22-50 years with the mean age of 26.7 years. All participants were male and had no prior experience of the area where the experiment was conducted. They had different experience of navigation with a GPS-receiver with a digital map, their self-assessed experience was on average 4.57 (±1.28) on a 7-point semantic scale ranging from 1= very low to 7=very high.

Equipment

The participants wore their own military equipment (field uniform, combat west and helmet) as well as the test system. The test system consisted of a GPS-receiver, a computer and a HMD (See figure 2, left), they were also equipped with a dummy weapon. The GPS-receiver had two functions: to enable the use of a digital map and to provide the HMD with distance and heading information to the next waypoint. Both the GPS-receiver and the HMD were connected to the computer, which was worn in a harness as a back-pack (see figure 2, right) the total weight of the system was 5.05 kilograms. A program on the computer provided the HMD with the positional data received from the GPS-receiver.

Figure 2: A schematic picture of the test system (left) and a participant wearing the whole test system containing a computer, a GPS-receiver, and a HMD (right).

GPS-receiver

A *Garmin GPSMAP 60CSx* was used in both conditions. With batteries it weighs 213 grams, the size was 155×61×33 millimeters and the size of the display 38×56 millimeters (160×240 pixels). The position was updated every second, the compass had a precision of ±5° and a GPR precision of <10 meters 95% of the time. The GPS-receiver had an electronic compass which was used to calculate the heading when participants were standing still. "*Friluftskartan PRO*" a detailed map was used and presented in an "egocentric" perspective (the map oriented so that the heading of the user was "up" on the map). The participants could see their current location, upcoming waypoints and the route between the waypoints. Additional information on the display was an arrow pointing in the direction of the waypoint, the distance to the waypoint and an arrow pointing north.

HMD

The HMD was a monochrome video viewer manufactured by MicroOptical Corporation. It had a monochrome LCD display capable of presenting a 320x240 pixels resolution. The display was mounted on a pair of glasses (See figure 3, left). The display received positional data originating from the GPS-receiver. The information in the display was minimal, in order not to distract the user (Montello & Sas, 2006). It displayed a small image with a headings' arrow and the distance in the lower right corner (See figure 3), when arriving within a ten meters radius of the waypoint the arrow turned into a circle indicating "waypoint reached". If the user needed additional information the GPS-receiver could be used.

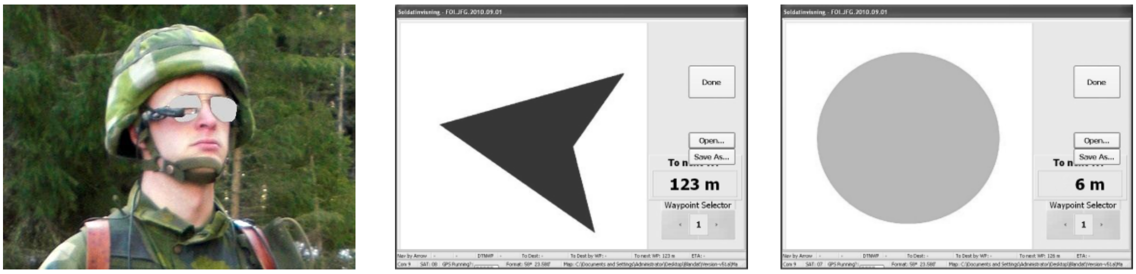

Figure 3: A participant wearing the HMD (left). The heading indicator and distance to waypoint (middle) and the symbol when arriving at a 10 meters radius of the waypoint (right).

Measures

The performance measures were collected by observations and computer logging. Subjective measures were collected by four self-assessment questionnaires. The performance measures were the time spent navigating, time standing still, how many times and for how long the participants looked at the GPS-receiver, and their navigational behavior (concerning heights, glades and peat soils). The secondary task measures were the number of and distance to identified figures. The questionnaires were answered by free-text answers or self-ratings on a 7-point semantic scale. The questionnaires concerned abilities, trust in the navigational support tools, and evaluation of the navigational support tools. The participant's answers have been translated from Swedish by the authors.

Procedure

First of all the participants answered a questionnaire about their background and their navigational abilities. They were then instructed in how to use the test system before undertaking the task of navigating. In condition A; the participants were to navigate by only using a GPS-receiver and in condition B; they were equipped with both the GPS-receiver and the HMD. Every participant was randomly assigned to start on one of the routes in either of the two conditions. After completing each condition they answered a questionnaire about the navigational support tool and how it felt to navigate. After the completion of both conditions they answered an evaluation-questionnaire.

There were a few limitations for the participants. Before commencing, they were informed that certain areas in the forest were prohibited grounds, such as roads and clear-felled areas. Another thing was that they had to halt when they looked at the GPS-receiver.

The participants aim was to navigate the routes (with four waypoints) with either one or two navigational support tools, while looking for threats. To miss unexpected events would be devastating in a safety-critical situation; and one of the reasons the participants were to look for threats in the environment. Upon detection of a threat the participant notified the experimenter. Their mission was to get to the destination "look-out" (see figure 1) in a way they found comfortable yet tactical. The route presented in the navigational tools was the recommended route, but the participants could deviate from the route as they saw fit as long as they passed every waypoint. They could decide if they wanted to walk over or around heights and glades, and they could use the navigational support tools as often or as little as they wanted. The point of that was to see if their navigational behavior changed depending of the navigational support tools.

RESULTS

Performance

The different performance measures were time travelled and standing still, usage (occasions and time) of the GPS-receiver and identified threats (number and distance).

All participants were able to navigate both of the routes without getting lost, and there were no significant differences in the time travelled and time standing still between the two conditions. What could be observed was the great variation between participants but not for the two conditions.

Nevertheless, there was a significant difference for the usage of the GPS-receiver. The participants used the GPS-receiver less times when also having the HMD (ANOVA-test $F(1,13)=20.96$; $p<.05$). The average use of the GPS-receiver was 21.21 (±4.68) times and when also having the HMD 11.93 (±7.18) times. There was a tendency that the participants used the GPS-receiver for a longer time when not having the HMD (ANOVA-test $F(1,13)=4.32$; $p=.058$). The average time for using the GPS-receiver was 251.36 (±282.54) seconds and when equipped with the HMD 109.29 (±80.18) seconds.

For the secondary task of looking for threats in the environment there were no significant differences for either number of identified threats or distance to the threats. The average number of identified threats (out of ten) was 6.64 (±2.65) when using the GPS-receiver and 8.07 (±2.16) when also using the HMD. The average distance to the identified threats were 18.67 (±4.46) meters in the GPS-receiver condition and 19.02 (±4.16) meters in the GPS-receiver and HMD condition.

Workload

The participant's workload was assessed by the evaluation questionnaire that was completed after the experiment. The participants rated their workload of: navigating, keeping the information from the navigational support tool in mind, looking for threats, and looking at the ground for foot placement (mean ratings see table 1), the rating scale was ranging from one (low) to seven (high). Four one-way repeated-measures ANOVAs were used to compare the workload between the two conditions. There was a statistical difference of workload during navigation $F(1,13)= 6.05$, $p<.05$ and when looking for foot placement $F(1,13)=12.69$, $p<.05$. When using both the GPS-receiver and the HMD the workload was rated lower for navigation but higher when looking for foot placement compared to when only using the GPS-receiver.

Table 1. The participants self-rated workload during the two conditions. Scale: 1=low; 7= high.

	GPS-receiver only	Std. Dev.	GPS-receiver and HMD	Std. Dev.
Navigation	3.93	±1.21	2.71	±1.49
Information	2.93	±1.00	2.43	±1.60
Looking for threats	3.07	±1.73	3.92	±1.39
Looking for foot placement	1.86	±1.17	3.43	±1.22

As well as rating their workload the participant could write and explain why and how they experienced the workload. A few of the opinions of why using both navigational support tools gave lower workload was:

> *"The combination of displays eliminated the need to fetch the GPS-receiver, kneel and let go of the weapon" (Participant 3)*

> *"The GPS-receiver provided more information and the external display only showed the most important information. The GPS-receiver used for reference points and the HMD showed orientation without the need to stop" (Participant 9)*

> *"You need to remember the information from the GPS-receiver but the external display is always present with updated information" (Participant 11).*

A few opinions from the participants of why or how the external display increased the workload:

> *"It was easier to focus on where I was stepping without the external display" (Participant 4)*

> *"Heavy workload when using the external display depended almost exclusively on the novelty" (Participant 8)*

> *"I sometimes looked at the external display instead of the surroundings" (Participant 14).*

Behavior

When the HMD was used it always showed updated heading and distance, and with the GPS-receiver the participants could always decide how often and how long they wanted to look at it.

Figure 4 is an example of a person navigating in a tactical, but not always efficient, manner. On Route 1, although the GPS-receiver was consulted, the participant took the long (west) way around the hill between WP1.2 and WP1.3 instead of taking the closer east way around the hill. The way from WP1.4 to the final destination deviates from the guided route but the participant was not jeopardizing being detected. On Route 2 the HMD was used and the participant seldom used the GPS-receiver. This was noticeable when the participant crossed the first peat soil between the lookout and WP2.4 (see figure 4, right) without considerations, because it was the guided route and the map had not been consulted. When approaching the second peat soil, just after WP2.3, the participant started to go over it but after consulting the GPS-receiver navigated around it (see figure 4, right).

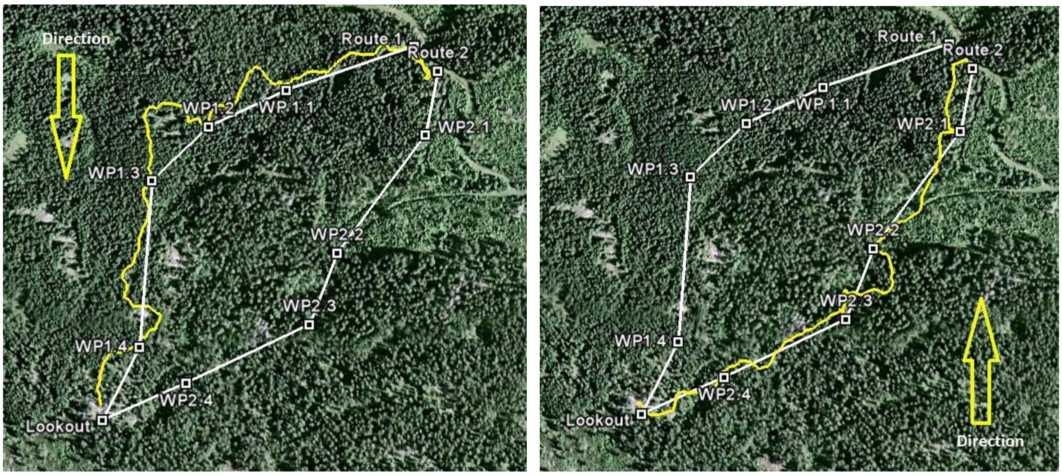

Figure 4: The two routes of one of the participants. Route 1 was navigated by using the GPS-receiver (left) and Route 2 was navigating mostly by using the information from the HMD (right).

There were two participants that breached the limitation of walking on roads and therefore jeopardized their own safety (an example can be seen in figure 5, right). The tactical manner for a soldier would be to walk around glades and hills, and approach the waypoint from the right angles, despite this there were a few participants that walked over hills and glades instead of walking around them. As many as half of the participants approached the final destination from an opposite direction (see figure 5, left), which not only could have jeopardized their own safety but the whole operation. All these breaches were independent of the navigational tool and merely an individual difference.

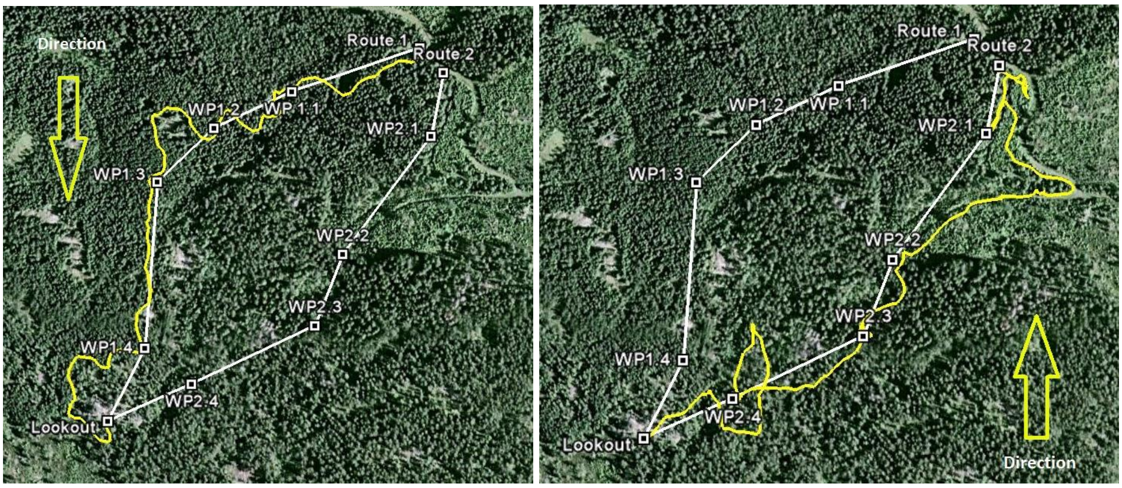

Figure 5: The two routes of one of the participants. Route 1 was navigated by using both the GPS-receiver and the HMD. Route 2 was navigated by the use of the GPS-receiver.

During navigation with both the GPS-receiver and the HMD some participants depended too much on the information in the HMD and did not consult the map in the GPS-receiver when facing an obstacle. An example of this can be seen in figure 5 (left), after reaching WP1.2 there was a big hill and without consulting the map the participant took the west way around the hill, instead of the shorter east way. This participant navigated only by the information from the HMD and since he was reluctant to cross heights he circled around the hill of the *lookout*, and jeopardized being discovered (figure 5, left). The same participant had troubles interpreting the information from the GPS-receiver and had to turn back to WP2.4 to “clear it” (figure 5, right). After WP2.2 the participant followed a path in the forest that lead out to a road and instead of turning back the participant breached the restriction and continued to walk on the road and could not reach WP2.1 until finding a suitable crossing over a creek.

DISCUSSION

The results presented above are derived from an experiment with a military scenario. However, the results should be valid for any profession where people move in dangerous areas that are unknown to them. Firefighters, like soldiers, mostly occupy both hands by either carrying or operating equipment needed to solve their primary task rather than navigating. Traditional GPS-receivers that need to be handled in order to update one’s heading is thus in many cases troublesome. We therefore believe that the experiment has some validity also in domains outside the military. The additional display with heading and distance information did not have a great impact on the participant’s performance compared to using only the GPS-receiver. The significant difference was that the need of using the GPS-receiver decreased when having updated information in front of the eye at all times. However the most important result was that the additional display did not have a negative effect on the participant’s performance. They did not traverse for a longer time or missed more threats in the environment due to the additional display.

The combination of a GPS-receiver and a HMD had both positive and negative effects. The use of the HMD lowered the workload during navigation; the reason for this is probably the simplicity of the presented information and less need to stop, look and interpret the digital map. All the information the participants saw in the display was the direction and the distance to the next waypoint, something that was sufficient according to several participants. The GPS-receiver could be used when facing an obstacle or, as many participants did, used to orient themselves when a waypoint was reached. The additional display was unfortunately also a factor that increased the workload in specific situations. As it was always present in front of the eye some of the participants felt it “demanded” constant attention and it was therefore perceived as being in the way when looking for threats and searching the surroundings to know where to put one’s feet. A solution to this might be to enable the user to prompt when the heading and distance information is wanted. The display would be present in front of the eye at all times, but it would probably not be as distracting if it was turned off. Another solution is that the display could be removed from the line of sight when not needed. Nevertheless, in contrast to Krupenia and Sanderson’s (2006) study, the HMD did not have an actual effect on the ability to detect the threats. Neither did it cause more falls, but the participants still experienced it as more demanding.

A problem that was irrespective of navigational aid was that the participant sometimes relied too much on the aid and followed the guided route blindly without reflecting if it was a dangerous or inappropriate passage. A handful of the participants only used the HMD and never consulted the GPS-receiver, which put them in situations that could have been avoided if the GPS-receiver would have been used. Both these behaviors were disturbing, but are probably something that will improve if the users get properly educated and accustomed to using the tools. As many as ten out of the fourteen participants expressed that the interface of the additional display was plain and easy to understand. Another thing the participants pointed out was that the technology used (the HMD) was completely new to them and just the novelty of it was one of the biggest reasons for both their performance and dependence of the display. With more practice and a smoother response of the heading indicator most participants felt that the display would help them navigate and lower their workload.

To use a small display, with heading and distance information that always is present before the eye and in no need of handling could be a good supplement to a GPS-receiver for all kinds of people working in dynamic situations. To be able to understand the information given and to facilitate navigation are two of the most important things and these two abilities seems to be enabled by using the display to present heading and distance. The display is not restricted to navigational information; it can also be used to present text, for example to communicate new orders or to spread new information, although this feature has not been tested in this study. Stressful situations are in themselves demanding and as little effort as possible needed for navigation is for the better, because it allows the navigator to focus on more important things.

CONCLUSION

After the study we can conclude that navigation with a GPS-receiver is effortful and that the supplement of a HMD with minimal information (heading and distance) could in some aspects lower the workload but not increase performance. However, performance was not worse when equipped with the HMD compared to when only using the GPS-receiver. The participants felt that the task of navigating was easier when equipped with the HMD but the display itself was in the way when scanning the ground for foot placement. The guidance in the HMD did not invoke strange moving patterns or erratic behaviors compared to when only equipped with the GPS-receiver. All in all, we feel that more practice with the navigational tools and further studies with several professional groups are needed to fully estimate the support that minimal information would do during navigation in a stressful environment.

ACKNOWLEDGMENTS

The authors thank: Maj. Arne Lamberth (Swedish Armed Forces), Ulf Hörberg, (Swedish Defence Research Agency), Jan Gustavsson (Swedish Defence Research Agency), Peter Andersson (Swedish Defence Research Agency), and the officer cadets that voluntarily participated in this study for their time, ideas and good spirits.

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