Supporting situation awareness on the move - the role of technology for spatial orientation in the field

Björn J.E. Johansson
Swedish Defence Research Agency
bjorn.j.e.johansson@foi.se

Charlotte Hellgren
Swedish Defence Research Agency
charlotte.hellgren@foi.se

Per-Anders Oskarsson
Swedish Defence Research Agency
per-anders.oskarsson@foi.se

Jonathan Svensson
Swedish Defence Research Agency
jonathan.svensson@foi.se

ABSTRACT

The study presented in this paper has investigated how technology can support spatial awareness when moving in wooded terrain. By "spatial awareness", we refer to the ability to point in the approximate direction of several objects while navigating in unknown terrain. The ability to localize objects in the terrain has importance for emergency operations, for example firefighting and search and rescue operations. A field experiment was conducted with two conditions, one with technical support and one without. The results show that technical support in terms of GPS, digital maps and electronic compass can dramatically improve the ability to accurately indicate directions to objects. Further, findings concerning use of tests on spatial orientation to predict the ability to indicate directions to objects in the terrain when having no technical support are presented.

Keywords

Situation awareness, spatial awareness, perspective taking test, Santa Barbara sense of direction test, GPS, electronic compass, positioning.

INTRODUCTION

When moving through unfamiliar terrain, there are in many cases not only a need to find a way from A to B, but also to keep track of other artifacts, vehicles, buildings or people in relation to the own position. For example, a fire-fighter engaged in fighting a forest fire needs to keep track of fellow fire-fighters, locate victims, keep track of where the fire is spreading, the location of water trucks etc. In more complicated situations, for example involving chemical outlets or objects that potentially can explode, such as gas tubes, this can be a life-and-death matter. Today, many rescue services utilize GPS- and compass based technologies[1] to support navigation and situation awareness. In some cases, navigational equipment as the ones mentioned above are only used for navigating from A to B, but more advanced products may also provide situational information, such as position of own units/personnel, resources or threats (Betts et al. 2005; Glanzer, 2012). At the same time, there are few studies of the actual benefits of using such technologies in terms of increased situation awareness. *In this study, we have investigated the benefits of having access to a digital map with GPS positioning and electronic compass when having to localize several distant objects while traversing in wooded terrain*. We have also compared three different spatial tests that we saw as potential predictors of performance for situation awareness/spatial awareness in terms of the ability to accurately remember and point in the direction of distant objects in the terrain, namely the Santa Barbara Sense of Direction Scale (self-rating, Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), the Paper Folding Test (spatial visualization; Ekstrom, French, & Harman, 1976) and the Perspective Taking Test (spatial orientation; Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001).

---

[1] See for example http://www.enr.gov.nt.ca/_live/pages/wpPages/Fire_Crews.aspx or

http://www.rmtracking.com/blog/2010/10/27/firefighters-use-gps-to-their-advantage/ (both viewed on 2013-02-05)

Theoretical background

The basic human ability to keep track of objects and directions in the physical world is crucial for a large number of activities. For emergency situations, such as firefighting and search and rescue operations this ability can be crucial for successful performance. Basic headings like forward, back, up, down, left and right are used hundreds of times each day as a reference in spoken language. The task is fairly simplistic as long as there is a visible reference to rely on. But we all know how complicated things may get as soon as we refer to objects that are located beyond our perceptual range. Most of us have on some occasion gotten lost when trying to find the way to a place we have not been to before. Many times, we find it hard to point in the direction even to familiar places when asked by a stranger in the street. The spatial ability to keep track of objects while moving does in several respects bear a strong resemblance to the concept "Situation awareness". Developed as a way to describe how fighter pilots keep track of their own position in relation to other aircrafts and potential threats, situation awareness has grown to be used as a concept in a wide variety of domains (Endsley, 1988; Endsley, 1997; Waag & Bell, 1997). Situation awareness has been defined as "the perception of the elements in the environment within a volume of time and space, the composition of their meaning and the projection of their status in the near future" (Endsley, 1988). This is similar to the definition of "spatial awareness" as described by Klippel, Hirtle, and Davies (2010) which says that spatial awareness is a part of survey knowledge and can be defined as the ability to plan new routes, shortcuts and detours. As can be seen, the definition of situation awareness does not apply entirely in the case of keeping track of the direction to distant objects while moving, as there is no direct perception of the objects. This paper addresses an issue that, from a theoretical point of view, seems to concern both situational and spatial awareness. A member of a search and rescue team with the task of identifying the position of a team-mate, a victim or an object in the environment must perform at least two tasks:

1. The person must be able to keep track of his/her own position in the environment and the direction towards he/she is traversing.
2. The person must establish and remember a "spatial map" of how the objects relate to himself/herself and be able rotate that "map" to compensate for own changes in position.

Point 1, concerning navigation, has been investigated extensively (see for example Hegarty et al., 2002). Point 2, how people create and maintain reference to other objects are often referred to as "spatial orientation". The concept of spatial orientation, or spatial maps was described already by Tolman (1948), whom after reviewing a series of rat-and-maze experiments concluded that the animals formed maps of the mazes they navigated through, including a sense-of-direction to their intended targets (Tolman, 1948). Since then, several research groups have been working on different methods for assessing and/or judging spatial ability. Sense of direction is "an awareness of location or orientation" (p.590; Kozlowski & Bryant, 1977). Using self-assessment of sense of direction and other spatial tests to predict different spatial-/mapping- and wayfinding performance has been done before (Hegarty et al., 2002; Heth, Cornell, & Flood, 2002; Ishikawa & Kiyomoto, 2008; Kozlowski & Bryant, 1977; Liben, Myers, & Christensen, 2010; Prestopnik & Roskos-Ewoldsens, 2000). Liben et al. (2010) used three different kinds of test (spatial perception, spatial visualization and mental rotation) and a modified version of the self-assessment test of sense of direction (SBSOD; Hegarty et al., 2002) to predict performance on three mapping tasks (self-location, self-orientation and building-direction). The mapping task of building-direction, was similar to the task in this study. Liben et. al.s' (2010) study showed that people with a high level of self-location accuracy had a better pointing accuracy than the persons with low self-location accuracy. There was both a correlation between the spatial tests and between the mapping tasks. The Paper Folding Test (Spatial visualization; Ekstrom et al., 1976) predicted performance in self-location and building-direction. The self-assessment of sense of direction (SBSOD; Hegarty et al., 2002) further explained both models regardless if the modified or full version was used.

Spatial updating is the ability to update the positions of objects when moving through an environment (Waller, Montello, Richardson, & Hegarty, 2002; Wang et al., 2006). The ability is dependent on if the spatial representation (i.e. a map) is allocentric (north-up) or egocentric (track-up) (Wang et al., 2006), their study supports the egocentric updating hypothesis, i.e. that humans update the location of objects relative to their own movements. This indicates that an aid for pointing in directions of objects should be presented in an egocentric way. On the other hand Waller et al. (2002) propose that the preference of the spatial memory's orientation can be updated when moving in an environment. In our study the subjects viewed both the paper map and the GPS-map in an egocentric view.

When using a technical aid for navigation or spatial updating there is always a reason for concern about overdependence on the technical aid. The equipment could be malfunctioning due to power failure, wrong settings or lost/low contact with satellites. Other negative effects when using a mobile navigation system has been reported concerning mental map building (Krüger, Aslan, & Zimmer, 2004), a lower ability to point to the origin of the route just traversed (Ishikawa, Fujiwara, Imai, & Okabe, 2008) or a lower ability to point to objects out of visual range (Willis, Hölscher, Wilbertz, & Li, 2009) and could be due to the fact that the technical aid demands attention of the user or that the GPS-map is presented in a different (egocentric) perspective from a paper map (often allocentric).

There is a difference between whether the spatial knowledge is acquired from map or from experience (Thorndyke & Hayes-Roth, 1982). Their study confirmed that survey knowledge is acquired via a map and procedural knowledge from navigation experience. If you learn from a map under moderate exposure the performance to determine relative locations on a map and the straight-line distance (start to goal) becomes better than when having experience. But, if you have experience, the performance gets better in terms of orientation (pointing to the destination) and estimation of route distance. If the person is very well acquainted with the environment the superiority of map learning vanishes since survey knowledge develops through experience. (Thorndyke & Hayes-Roth, 1982)

We can thus conclude that some research suggest that there are self-estimates and spatial tests that could predict performance in the kind of spatial awareness tasks that we have described above. Also, technical aids such as GPS-receivers should be beneficial, but poses some problems in respect of the ability to create "mental maps" over an area. The latter point is not directly investigated in this paper, but effects on performance have been investigated. The aim of the study was to investigate how spatial awareness of personnel working in complex environments, such as first responders, can be supported by having access to a digital map with GPS positioning and electronic compass. The research questions can be summarized as follows:

- How precisely can people remember and accurately indicate the direction (by pointing) to five different objects beyond visible range while traversing in wooded terrain?
- To what degree are people supported by state of the art technology such as digital maps, GPS and electronic compass when indicating the direction to five different objects while traversing in wooded terrain?
- Are there adverse effects, for example time needed to complete a task like indicating directions to objects beyond visible range, when using technologies such as digital maps, GPS and electronic compass?
- What type of test (self-rating, spatial visualization or spatial orientation) is the best predictor of success in terms of how accurate people can indicate the direction to five different objects beyond visible range while traversing in wooded terrain?

METHODS

The experimental task was to navigate a route with three stations, and the main task was at each station indicate direction to five objects. The task of indicating directions was performed with two conditions, with and without help of a GPS presenting the positions of the objects.

Participants

16 persons between the ages 19-42 (mean age 25.4) years participated in this study. Eight were women and eight were men. They were recruited by posters on the local campus and were given an honorarium of approximately €40 for participation.

Materials/Equipment

A paper map in A4-size was used to give the participants a first overview (Figure 1). The scale was 1:10458; 1 centimeter on the map was approximately 100 meters in the forest.

A GPS-receiver with an electronic compass and a digital map (from now on referred to as "GPS") was used for navigation. It was a Garmin GPSmap 62stc with the map database "Friluftskartan PRO v2" (Figure 2).

A Pocket Laser Range Finder (PLRF 15C from Vextronix AG) was used for indication of direction when the pointing task was performed. It was mounted on a tripod (Manfrotto 190B) (Figure 3). The accuracy of the PLRF device is ±4°.

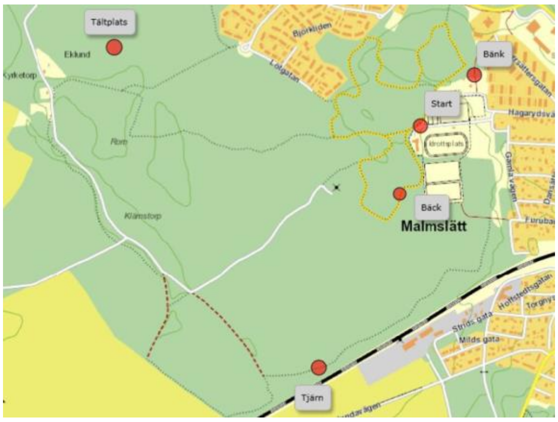

Figure 1: One of the four paper maps, the red circles indicating the current location and four other places to remember.

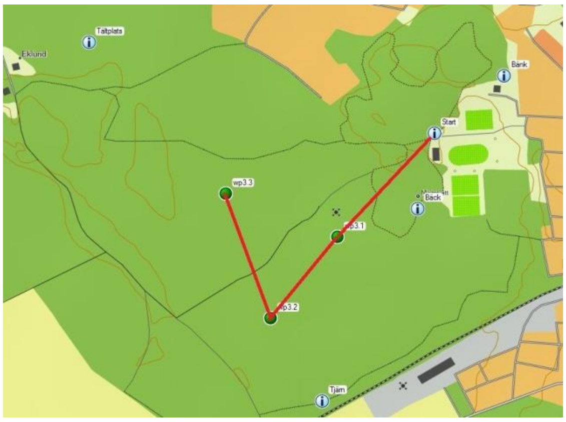

Figure 2: An example of the digital map. The red line is the guided "as the crow flies" route. The same objects to point to as in Figure 1 are marked as blue circle.

Measures

Performance measures were precision of the pointing task (mean deviation in degrees for all object at each station), and performance time of the pointing task.

The participants answered a background questionnaire concerning gender, age, experience of navigation, military service etc. and a final questionnaire concerning their mental workload (of navigating, remembering object location, and estimating direction) and physical demands. The mental workload and physical demands was rated on a 7-point rating scale (1 = Low – 7 = High).

Spatial performance was assessed by three scales. *SBSOD* was used for self-assessment of sense of direction. The other two were the *Paper Folding test* and the *Perspective Taking test*. The first is a test of spatial visualization that consists of 20 tasks. Each task shows a sequence of pictures of how a piece of paper is folded several times and in the last picture a hole is punched through the folded paper. The participant's task was to pick the correct alternative from five pictures that show the paper folded out with the holes in different positions. Performance was counted as a percentage of how many tasks they solved. The second is a test of spatial orientation, the ability to take on different perspectives and judge directions. The test consists of 12 tasks, and for each task the participant is presented with the same picture with seven objects. The subject's task is to imagine standing at one of the objects, looking at another object, and then estimate the angle to a third object. The result is a mean error in degrees for all tasks; if a task was unsolved a penalty of 45 degrees was issued.

Design and procedure

The experiment was performed with a within groups design with two conditions. The conditions were:

1. Without a GPS-receiver when direction to objects were indicated.
2. With support of a GPS-receiver when direction to objects were indicated.

Before the experiment, the participants answered a background questionnaire and they were also tested with the three spatial tests (SBSOD, the Paper Folding Test and the Perspective Taking Test). Then, they were taken to the starting location, where they were shown a paper map of the area in which the experiment took place. The map also showed their current location and the four other objects which the participants were instructed to remember as exactly as they could (see Figure 1 above). The participants' task was to navigate a route, including the starting position and three stations. At the starting position and at each of the three stations they should indicate the direction to the five objects (the start position and the four objects, i.e. at the start position they only indicated four objects). Before the experiment they were told that the main task was to as accurately and fast as possible indicate the direction to the five objects, and not the navigation task.

During the whole experiment they used the GPS-receiver with electronic compass while navigating between the stations and they were allowed to look at the GPS as often as they wanted, but they were instructed to stop walking while looking at it. This was done to prevent the participants to trip over objects like roots or stones. The paper map and the digital map in the GPS showed the same paths in the forest (Figure 1 & Figure 2), but when looking at the paper map they were not shown the route they were about to take. In the condition when the

GPS was used for indication of direction, the locations of the objects were marked with blue circles, with the letter I inside, on the GPS display. The sample points (stations) were shown as green dots on the GPS display (Figure 2). In the condition when the GPS was solely used for navigation all they could see was the route and the sample points (stations) as green dots. The guided route was always shown as a crow flies route (Figure 2), but the subjects were recommended to walk on the paths in the forest. At each station, they performed the task of indicating direction to five different objects as accurately as possible, with or without the help of the GPS. They indicated the direction by pointing the PLRF in that direction (Figure 3). All direction estimations were clocked.

The design was counter balanced, meaning that half of the participants started with the condition where they used the GPS for indication of direction and half of the participants started without the aid of the GPS for indication of direction. In the condition when the participants did not use the GPS they gave the GPS to the experimental leader and had to use their mental map when they indicated direction to the objects. Half of the participants in each condition started the route in one direction (to the north) and the other half in the other direction (to the south). The route had six stations and two starting points, and when the participants had performed the indication task at the third station the condition was changed. The third station was then used as a new starting position and they were shown a new paper map with five new objects. This means that each route had four sample points. The average distance between each station was approximately 400 meters. When the indication task at the last station was done, the participant received a final questionnaire containing questions about performance, difficulties and workload.

Figure 3: A participant directing the PLRF in the direction indicated by the GPS.

RESULTS

As stated above, there were four questions to be answered by this study: How good the pointing accuracy (direction indication) would be with and without technical support, if the technical support would enhance their pointing accuracy, if there was any downside of using the technical support, and if the spatial tests done before the experiment would correlate with the pointing accuracy. These questions will be answered below.

Deviation of indication of direction to objects, performance time, and ratings of mental and physical demands were analyzed with analysis of variance (ANOVA). Design for each ANOVA is given separately below in connection with the presentation of results. In case of violation of sphericity, the Greenhouse-Geisser corrected *p*-values are given. Post Hoc testing was performed with Sidak confidence interval correction. Correlation analyses were used with Pearson's correlation coefficient.

Spatial tests as predictors of performance

The average score on the perspective taking test was 31.6° with a standard deviation of 18.4°. The average score on the paper folding test was 0.6 with a standard deviation of 0.2. The self-rating scale SBSOD had a mean value of 4.3 with a standard deviation of 1.1. There was a significant correlation between the perspective taking and paper folding tests ($r = -0.54$; $p = .031$). Low scores on the perspective taking test and high results on the paper folding test meant good performance, which means that the negative correlation indicates a positive relation between the two tests. There were no correlations between the two tests and SBSOD.

There was a significant correlation between the precision of indication of directions and the result on the perspective taking test ($r = 0.64$; $p = .008$) when having no support of GPS (condition 1). This means there is a strong positive connection between performing well on the test and in the field. There was a strong tendency of correlation between performance on the paper folding test and the precision of indication of directions (*r* = -0.49; *p* = .052) when having no support of GPS (condition 1). The negative correlation indicates a positive connection between performing well on the test and out in the field. There was no correlation found between how they rated their own sense of direction (SBSOD) and their precision of indication of directions.

Since there was a high correlation between the perspective taking test and accuracy on the indication of direction task, in the analysis of variance below, the participants were divided in two groups according to the results on this test (high and low spatial performing). Eight participants with results ranging between 8.1–26.6 degrees (mean 16.8° ±7.4) were assigned to the high spatial performance group, and eight participants with results ranging between 29.7-71.8 degrees (46.5° ±12.9) were assigned to the low spatial performance group.

Precision of indication of direction

Precision of indication of direction, measured as mean deviation from correct position, was analyzed with a 3-way ANOVA mixed design, 2 GPS-conditions (with and without GPS) × 4 (sample points) × 2 spatial test (low and high spatial performance on perspective taking test). GPS-conditions and sample points were within groups variables and spatial test was a between groups variable.

The ANOVA showed a significant main effect of GPS-condition, $F(1, 14) = 44.3$, $p < .001$; a significant main effect of sample points, $F(3, 42) = 9.2$, $p < .001$; a strong tendency of main effect of spatial test, $F(1, 14) = 4.6$, $p < .051$; a significant interaction effect between GPS-condition and sample points, $F(3, 42) = 7.6$, $p < .001$; a significant interaction effect between spatial test and GPS-condition, $F(1, 14) = 5.7$, $p < .031$; and a tendency of interaction effect between spatial test, GPS-condition and sample points, $F(3, 42) = 2.6$, $p < .068$. There was no significant interaction effect between spatial performance and sample points.

Sidak post-hoc test regarding the interaction effects between the GPS-condition and station showed the following (which also explains the main effects of the GPS-condition and sample points): the precision of indication of direction with GPS was significantly better (lower deviation) than the precision without GPS at all sample points (*ps* < .001). The precision of indication without GPS was significantly better at the start compared to all three stations ($p < 0.05$) (Figure 4).

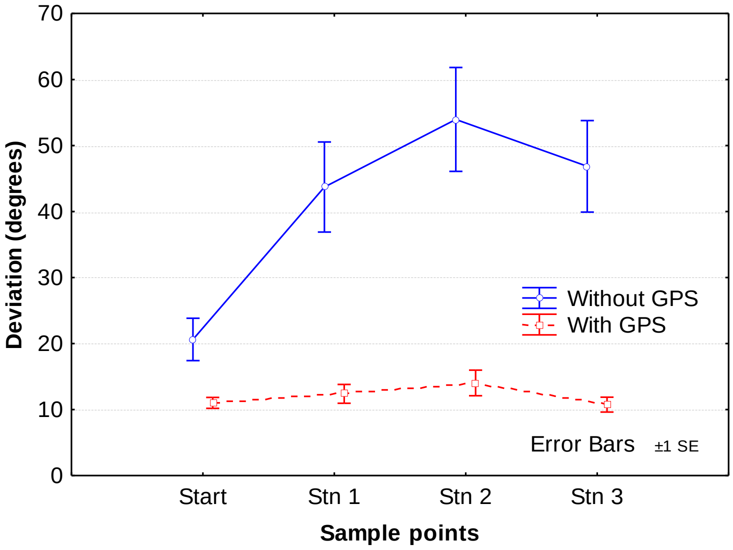

Figure 4: Precision of indication of direction, measured as deviation in degrees from correct direction. Mean values and standard errors for each GPS-condition at each sample point. A high score indicates low precision.

Sidak post hoc test concerning the interaction effect between spatial test and GPS condition shows that the participants with high perspective taking test scores had significantly better precision of indication of direction compared to those with lower spatial performance when no GPS was used (*p* = .037) (Figure 5).

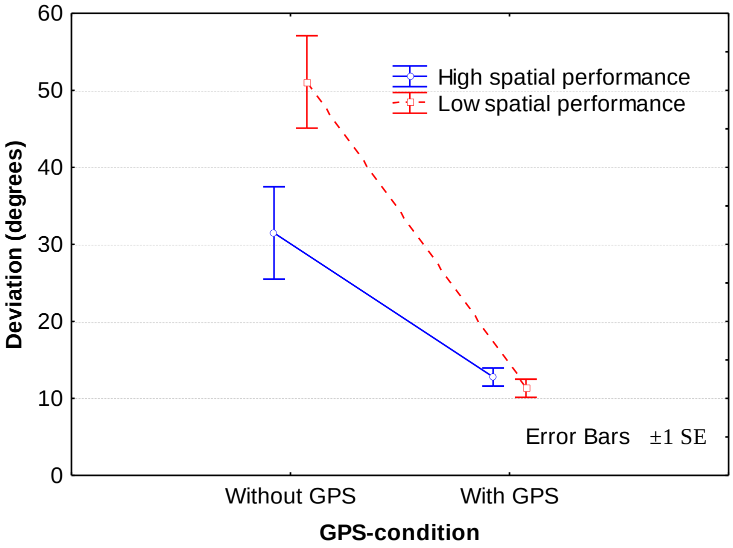

Figure 5: Pointing precision, measured as deviation in degrees from correct direction. Mean values and standard errors for participants with high and low spatial performance for each GPS-condition. A high score indicates low precision.

Performance time for indication of direction

Performance time for indication of direction was analyzed with an ANOVA with two repeated measures (with and without GPS). The ANOVA showed a significant difference between the two GPS-conditions, $F(1, 15) = 44.8$; $p < .001$. This was due to a significantly longer performance time with GPS 13.1 ±0.8 min compared to without GPS 6.9 ±0.5 min.

Mental workload and physical demands

The ratings of mental workload and physical demands were analyzed with a 2-way ANOVA, 2 GPS conditions (with and without GPS) × 4 types of demand (mental workload of navigation task, mental workload of remembering objects location, mental workload of estimating direction, physical demands).

The ANOVA showed a significant main effect of GPS-condition $F(1, 15) = 14.2$, $p = .002$; a significant main effect of type of demand, $F(3, 45) = 16.5$, $p < .001$ and a significant interaction effect between GPS-condition and type of demand, $F(3, 45) = 8.7$, $p < .001$.

Sidak post-hoc tests showed that the mental workload of remembering object location ($p = .019$) and estimating direction ($p < .001$) were rated significantly higher when no GPS was used compared to when it was used during the pointing task. When no GPS was used, mental workload was rated significantly higher for both remembering object locations and estimating direction compared to both mental workload of navigating to the stations (*p*s < .01) and physical demands (*p*s < .001). When the GPS was used only the physical demands were rated significantly lower than the mental workload of remembering object location ($p = .038$) (Figure 6).

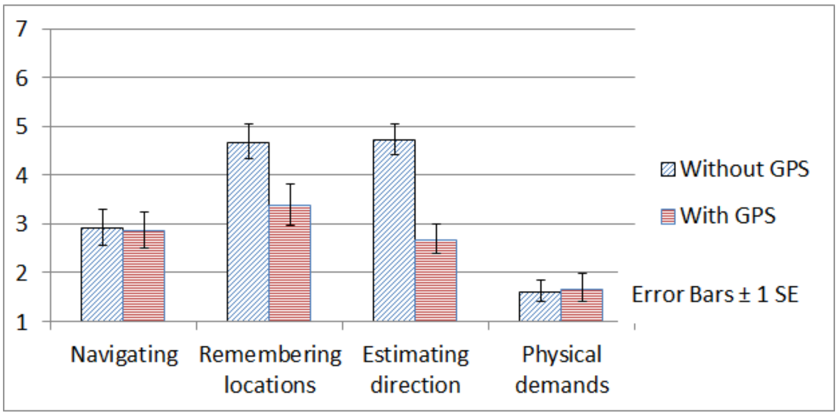

Figure 6: Ratings of mental workload of navigating to stations, remembering object locations, and estimating directions; and finally physical demands (1 = Low – 7 = High). Mean values and standard errors for each type of demand for each GPS condition.

DISCUSSION

The performance in terms of accuracy when indicating direction to the different objects increased significantly when the GPS was used compared to when it was not. Without the GPS, performance deteriorated with distance from the starting location. Performance without the GPS was acceptable just after reading the paper map (at the start position), but decreased dramatically already at the first station. Also, the mental workload was rated lower when having the technical aid concerning remembering the location of the objects while traversing and indicating the direction to the places. This was possibly due to the fact that the participants in the study did not have to spend resources on remembering where the objects they were to indicate direction to were located as this was possible to see in the GPS. The downside of using a technical aid like GPS is that it increased the time needed for indicating direction to the various objects. This was most likely an effect of the time needed to look at the map on the GPS and mentally make the transformation from the map to reality. When having the directions in mind the only thing the participant had to do was to turn the PLRF in the right direction. But when having the GPS as support the direction on the map needed to be transformed to reality and the PLRF aimed in that direction. The participants were mostly very thorough, which might explain both the accuracy and the prolonged time of indicating the directions. This might not be possible to do in a real situation during an emergency. However, for maintaining situational awareness during a search and rescue mission a general spatial awareness might be sufficient. Since the participants were so thorough when using the GPS a possible approach for lowering the time needed is to settle for a lower degree in terms of accuracy. It is however difficult to tell what “good enough” would be? Good enough will probably always be a highly context depending matter. Another interesting issue is to investigate the actual relationship between time needed for transformation of information to reality, accuracy and time. It is plausible that accuracy would deteriorate if the participants in the study would have less time to perform the pointing task. Another time adding factor is the PLRF, it would not be used in a real situation but was used here to get a correct direction. It would be interesting to see if there are more or less efficient tactics for making the transformation from map to reality as this seem to be a crucial part in terms of how much time that is needed to correctly indicate direction towards an object.

The perspective taking test was a good predictor of performance when having no technical aid in terms of GPS. This is an important finding as it possibly could be used both as a tool for assessing the spatial ability of personnel, and as a tool for identifying persons that would have the largest benefit of being equipped with a GPS or similar technologies. Remember that the usage of GPS allowed the low achievers on the perspective taking test to perform just as good as the high achievers. The paper folding test did also correlate with the performance of the indication task, but not as strongly as the perspective taking test. This suggests that the paper folding test also can be used for assessing ability, but that it is a less suitable candidate than the perspective taking test. The surprise in the test battery was the low correlation between the self-ratings of sense-of-direction (SBSOD) and performance. The SBSOD-scale has successfully been used in many previous studies (see “Theoretical background” above), but in this study the participants’ self-rated sense of direction could not predict their performance. One possible explanation of this is that the environment was unknown and the information gained through a map (Heth et al., 2002). Despite this, the assignment was similar to the original study by Hegarty et al. (2002) and should have yielded a significant result if the scale actually had provided a measure of spatial ability concerning the ability to indicate direction to objects in the environment.

Using technologies like GPS to improve spatial awareness is increasingly common in many disciplines, among them first responders. Naturally, there are many limitations in how such a tool can be used in the field. This study was conducted in near ideal conditions (no threats, unlimited time) and found a strong effect of using GPS to increase spatial awareness. It is not self-evident that the results would transfer to a real-world situation like a forest fire. In such situations, the performance in terms of spatial awareness is most likely even worse than in this study due to stress, fatigue, lack of information and poor capacity to transfer geographical information in visual form. The lack of accuracy that was found when the participants received no technical support indicates that there is a great need for introducing a tool with capabilities like in the experiment. In order to be useful for a first responder like a fire fighter, the tool needs to be small and light-weight, but yet easily readable. It also must have a highly reliable positioning system and compass, which preferably should work both indoors and outdoors (Glanzer, 2012).

CONCLUSION

To keep a reasonable stable and adequate level of spatial awareness in terms of being able to indicate direction to several objects while traversing, a technical aid like a GPS is clearly needed. Having a technical aid during indication of direction also decreased mental workload considerably. Although the accuracy improved significantly when using GPS-support it also demanded significantly more time to perform the task of pointing. The relationship between speed and accuracy when using GPS-support for spatial awareness needs to be further investigated. Spatial awareness in terms of being able to correctly indicate direction to several objects without the aid of a GPS while traversing was found to have a strong correlation with performance on the perspective taking test (Hegarty & Waller, 2004; Kozevnikov & Hegarty, 2001). Since the low achievers on the perspective taking test performed worse than the high achievers without the GPS, but equally well as the high achievers when they were allowed to use the GPS, this result indicates an additional value of providing those with lower spatial ability with a GPS. Furthermore, this relation between the perspective taking test and performance on the indication task, confirms the possibility of using the perspective taking test as a tool for assessing spatial ability of personnel.

REFERENCES

1. Betts, B. J., Mah, R.W., Papasin, R., Del Mundo, R., McIntosh, D.M., & Jorgensen, C. (2005). *Improving Situational Awareness for First Responders via Mobile Computing*. NASA/TM-2005-213470.
2. Ekstrom, R. B., French, J. W., & Harman, H. H. (1976). *Kit of factorreferenced cognitive tests*. Princeton, NJ: Educational Testing Service.
3. Endsley, M.R. (1988). Situation Awareness Global Assessment Technique (SAGAT), *Proceedings of the National Aerospace and Electronics Conference* (NAECON), 789-795. New York: IEEE.
4. Endsley, M.R. (1997). Level of automation: Integrating humans and automated systems. *In Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, 200-204. Santa Monica, CA: Human Factors and Ergonomics Society.
5. Glanzer, G. (2012). Personal and First-Responder Positioning: State of the Art and Future Trends. In Proceedings of *Ubiquitous Positioning, Indoor Navigation, and Location Based Service* (UPINLBS), October 2-4, Helsinki, Finland: IEEE.
6. Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, 32, 175-191.
7. Hegarty, M., Richardson, A.E., Montello, D. Lovelace, K., & Subbiah, I. (2002) Development of a self-report measure of environmental spatial ability. *Intelligence*, 30, 425-447.
8. Heth, C.D., Cornell, E.H., & Flood, T.L. (2002). Self-ratings of direction and route reversal performance. *Applied cognitive psychology*, 16, 309-324.
9. Ishikawa, T., Fujiwara, H., Imai, O., & Okabe, A. (2008). Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology, 28*(1), 74-82.
10. Ishikawa, T. & Kiyomoto, M. (2008). Turn to the left or to the west: verbal navigational directions in relative and absolute frames of reference. InT.J. Cova et al. (Eds.), *GIScience 2008*, LNCS 5266, 119-132.
11. Klippel, A., Hirtle, S., & Davies, C. (2010). You-Are-Here Maps: Creating Spatial Awareness through Map-like Representations, *Spatial Cognition & Computation: An Interdisciplinary Journal*, 10(2-3), 83-93.
12. Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object-manipulation and perspective-

taking spatial abilities. *Memory & Cognition*, 29, 745-756.

13. Kozlowski, L.T. & Bryant, K.J. (1977). Sense of Direction, Spatial Orientation, and Cognitive Maps. *Journal of Experimental Psychology: Human Perception and Performance*, 4, 590-598.
14. Krüger, A., Aslan, I., & Zimmer, H. (2004). The effects of mobile pedestrian navigation systems on the concurrent acquisition of route and survey knowledge. In S. Brewster and M. Dunlop (Eds.), *Mobile HCI 2004*, LNCS 3160, 446-450.
15. Liben, L.S., Myers, L.J., & Christensen, A.E. (2010). Identifying Locations and Directions on Field and Representational Mapping Tasks: Predictors of Success. *Spatial Cognition & Computation: An Interdisciplinary Journal*, 10(2-3), 105-134.
16. Prestopnik, J.L. & Roskos-Ewoldsen, B. (2000). The relations among wayfinding strategy use, sense of direction, sex, familiarity, and wayfinding ability. *Journal of Environmental Psychology*, 20, 177-191.
17. Tolman, C.E. (1948). Cognitive maps in rats and man. *Psychol. Rev*. 55, 189–208.
18. Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, 14(4), 560-589.
19. Waag, W. L., & Bell, H. H. (1997). Situation assessment and decision making in skilled fighter pilots. In C. E. Zsambok & G. Klein (Eds.), *Naturalistic decision making* (pp. 247-254). Mahwah, New Jersey: Lawrence Erlbaum Associates.
20. Waller, D., Montello, D.R., Richardson, A.E. & Hegarty, M. (2002). Orientation Specificity and Spatial Updating of Memories for Layouts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28(6), 1051-1063.
21. Wang, R.F., Crowell, J.A., Simons, D.J., Irwin, D.E., Kramer, A.F., Ambinder, M.S., Thomas, L.E., Gosney, J.L., Levinthal, B.R. & Hsieh, B.B. (2006). Spatial updating relies on an egocentric representation of space: Effects of the number of objects. *Psychonomic Bulletin & Review*, 13(2), 284-286.
22. Willis, K.S., Hölscher, C., Wilbertz, G. & Li, C. (2009). A comparision of spatial knowledge acquisition with maps and mobile maps. *Computers, Environment and Urban Systems*, 33, 100-110.