Journal of Maps, 2010, 289-301

The assessment of non visual maritime cognitive maps of a blind sailor: a case study.

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Abstract

Nowadays, thanks to the accessibility of GPS, sighted people widely use electronic charts to navigate through different kinds of environments. In the maritime domain, it has considerably improved the precision of course control. In this domain, blind sailors can not make a compass bearing, however they are able to interact with multimodal electronic charts. Indeed, we conceived SeaTouch, a haptic (tactile-kinesthetic) and auditory virtual environment that allows users to perform virtual maritime navigation without vision. In this study we attempt to assess if heading or northing "haptic" views during virtual navigation training influences non-visual spatial knowledge. After simulating a navigation session in each condition, a blind sailor truly navigated on the sea and estimated seamark bearings. We used the triangulation technique to compare the efficiency of northing and heading virtual training. The results are congruent with current knowledge about spatial frames of reference and suggest that getting lost in heading mode forces the blind sailor to coordinate his current "view" with a more global and stable representation.

(Received 13th July 2009; Revised 18th February 2010; Accepted 5th March 2010)

ISSN 1744-5647
doi:10.4113/jom.2010.1087

1. Introduction

In 1982, on board "Dark Star", Henry Decker sailed alone for two thousand nautical miles from the Hawaii Islands to San Francisco. Nothing appeared noteworthy except that this sailor is completely blind. Using a tactile map and a vocal compass, he only received assistance to land at the destination marina. Since this accomplishment, the number of blind sailors, and the technology to support their sailing, has increased. Conventionally a blind sailor navigates by the wind to keep the course of the sailboat in a straight direction. However, managing geographical information, such as planning journeys and updating spatial location remains complex without seeing. In this context, our research aims at providing blind sailors with electronic charts to set up, learn and control their maritime voyages. In order to set up haptic (tactile-kinesthetic) and auditory maritime navigation software, we based our work on the strategies of sighted sailors, the knowledge of the spatial cognition domain, the specificity of blindness relative to maps and the potential of virtual reality to tackle non visual spatial problems. Maritime navigators widely use maps to set up their voyages and control their courses. During coastal navigation, they triangulate their current position from the bearings of three land or sea marks (Figure 1) by the use of a magnetic protractor.

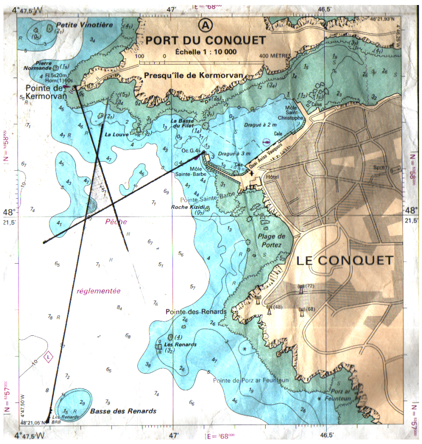

Figure 1. Maritime triangulation.

Recently, more and more maritime navigators also employ electronic charts. Vector maps, such as S-57 format from the International Hydrographic Office (IHO), allow managing different geographical information layers (Figure 2), in an interoperable format.

In addition, these electronic charts can be connected to a GPS (Global Positioning System). Thus the position and orientation of the ship are updated in real time. Most of the maritime software available (e.g. Maxsea) offers the user the ability to choose between at least two kinds of displays. Commonly, the top of the map is aligned with north (northing or allocentric view). However, in some cases, navigators choose to align the top of the map with the heading of the ship (heading or egocentric view) (Figure 3).

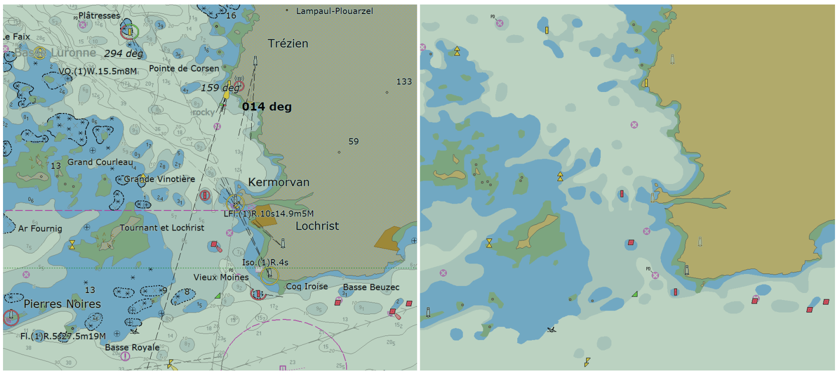

Figure 2. S-57 format maritime electronical charts in the SeeMyDEnc viewer. On the left, many layers (lights, soundings, names,) appear. On the right only a few layers (land, depth, and beacons) are displayed.

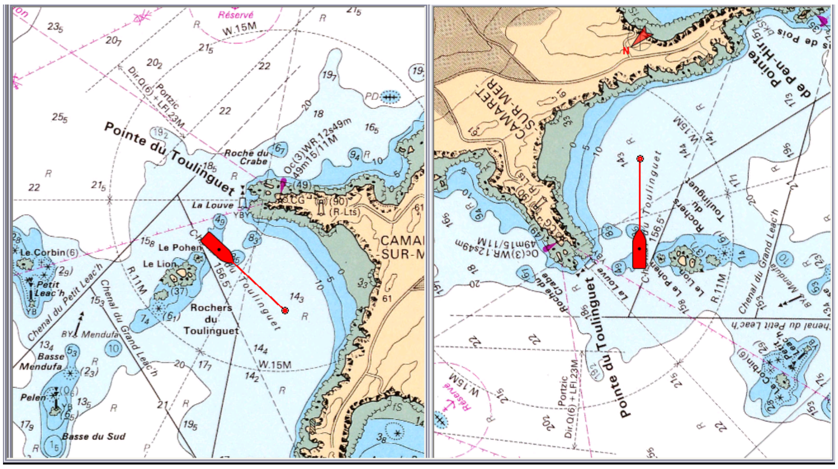

Figure 3. Mapmedia maritime raster format in the Maxsea viewer. On the left picture, the map is displayed in the northing view. On the right picture, the map is displayed in the heading view.

Wickens (2000) studied the influence of egocentric or allocentric display and found that a 'best type' did not exist, but rather was relative to the task. For example, he showed that an allocentric view lead to better results in a strategic task while an egocentric one provided better results in a wayfinding task. This result is in line with a recent finding of Porathe (2008) who showed that the 3D egocentric view was the most effective in a wayfinding task.

The cognitive processes involved in continually updating spatial information from the environment (or its representations) in either egocentric or allocentric views involve fundamentally different processes. In the egocentric frame of reference, locations are represented with respect to the particular perspective of a perceiver, whereas an allocentric reference frame locates points within a framework external to the holder of the representation and independent of his or her position and orientation (Klatzky, 1998). Coordinating information gained in egocentric and allocentric spatial frames of reference remains a key mechanism for the efficiency of the displacement (Thinus-Blanc and Gaunet, 1997).

Thus, many studies have focused on spatial reference frame relative questions. Some researchers have shown that egocentric spatial cognitive maps are automatically updated during displacement (Farrell and Robertson, 1998). Others have demonstrated that global spatial mental representations (allocentric) are mostly involved when subjects are disoriented (Wang and Spelke, 2002). Different researchers have emphasized the influence of the initial learning orientation on the memorisation of a layout (Mou et al., 2004). Some studies have shown that the identification of a salient axis in the configuration lead to encoding of the environment in an allocentric frame of reference (Mou et al., 2009). All of these results indicate that many parameters have to be taken into account to better understand how we encode spatial cognitive maps relative to the frame of reference. During most of these experiments subjects had to learn a configuration with vision and then estimate directions being blindfolded. Some studies also focused on the spatial capacities without vision. Blindness does not indicate a lack of comprehension of spatial concepts, but it leads people to encounter difficulties in perceiving and updating information about their surroundings and to estimate their own position during navigation (Fletcher, 1980). Spatial performances of blind people using tactile maps have been widely studied (Ungar, 2000), using a variety of techniques to connect and analyze non visual mental maps (Kitchin and Jacobson, 1997). Some results revealed a predominant influence of the pattern of movements during exploration (Tellevik, 1992; Ungar et al., 1995; Gaunet et al., 1997). More precisely, allocentric patterns of exploration, e.g. when subjects encode the environment layout independently of themselves, lead to the creation of more accurate cognitive maps (Gaunet and Thinus-Blanc, 1996). More recently, Lahav and Mioduser (2008) have found congruent results in a study in which blind people explored a multi sensory virtual environment. Using a force feedback joystick (Microsoft SideWinder), subjects used an allocentric strategy to explore the 54-square-metres room containing seven objects. In this respect, it appears that virtual reality can provide blind people with an immersive virtual navigation experience by means of haptic and auditory interfaces devoted to the improvement of spatial knowledge. Some studies have used virtual reality to provide blind people with electronic charts of “political boundaries” (Jansson and Billberger, 1999), the urban environment, i.e. “Audiotraffic” (Magnusson and Rassmus-Gröhn, 2004), or a university campus site, i.e. “Haptic Soundscape” (Jacobson, 2004; Lawrence et al., 2009). To our knowledge, no study has provided blind people with an open sea virtual environment.

In order to help blind sailors coordinate egocentric and allocentric spatial reference frames, we conceived and tested SeaTouch. This haptic and auditory software allows users to set up and simulate their itineraries within a virtually reproduced environment before actually sailing in the real version of this environment.

2. SeaTouch Design

SeaTouch software and hardware aims to provide for blind people's cartographic needs, in a maritime environment using haptic sensations, vocal announcements and realistic sounds (Figure 4). SeaTouch allows blind sailors to prepare their maritime itineraries. The digital maritime charts used in the development of SeaTouch conform to the S57 International Hydrographic Office (IHO) exchange format, ensuring opportunities for interoperoperability. The digital charts contain many relevant geographic objects; Handinav software was developed to transform the S57 data into XML structured files. Thus, objects of particular salience can be chosen to be displayed or not: sea areas, coastlines, land areas, beacons, buoys and landmarks are used in our research. When the simulation is on, the speed and direction of the boat result from the interaction of the direction and speed of the wind with the orientation of the boat. The user chooses the boat's heading during the entire simulation by using the right and left arrows of the computer keyboard. When the boat hits the coast, the simulation stops; this is indicated to the user *via* an auditory "crash".

Figure 4. A visualization of the SeaTouch virtual maritime environment. The participant's hand is interacting with the stylus of the Phantom haptic mouse. The land area, coastline, and maritime features are displayed.

The representational workspace is in the vertical plane, 40 centimetres wide, 30 centimetres high and 12 centimetres deep. Using a Phantom Omni haptic force-feedback device (from Sensable), *via* a haptic cursor, calibrated to the representational workspace blind participants explore the scene. They touch different objects on the maritime maps as 2D-extruded haptic features. The salient features are the sea surface, coastline, land area, navigational beacons, buoys and landmarks. The sea surface and land area are formed by two flat surfaces separated by two centimetres. Between the land and sea areas, the coastline forms a perpendicular wall, analogous to a cliff face that allows users to follow it with the Phantom. The display of coastline uses the "contact haptic force feedback" which is similar to a virtual wall. By contrast, for beacons, buoys and landmarks, we apply a "constraint haptic force feedback" to a spring of one centimeter diameter. This spring is an active force feedback field that maintains the cursor inside of the object with a 0.88 Newton force, analogous to a "gravity well". In order to move outside of the spring, participants have to apply a stronger force. The position of the boat is displayed by the same haptic spring effect. The boat can be located from anywhere in the workspace by pressing the first button of the Phantom stylus, then the haptic cursor is relocated to the current position of the boat. In the sonification module, as soon as the stylus is in contact with virtual geographic objects, audible naturalistic sounds are played. When in contact with the sea, a looping water sound is played. When the haptic stylus touches the coastline, a virtual cliff face, the sounds of seabirds are played, and when land areas are in contact with the stylus the sounds of land birds are played. In addition, using "Acapela" vocal synthesis, a text-to-speech software, auditory information can be automatically spoken by SeaTouch.

SeaTouch software allows virtual interaction with two modes of haptic perspective, both from an orthographic map view, or "bird's eye" perspective. The northing view provides a conventional presentation format of the scene, where the map remains invariant in a fixed frame of reference, aligned north up. The subject faces the north and it moves over the map. Thus exploration unfolds in an allocentric frame of reference (Figure 5). By contrast, the heading view takes place in an egocentric frame of reference. Although the participant remains in an orthographic map view, the participants' view of the map is continually re-orientated to always face the heading of the ship aligned to the top of the scene. This means that the ship does not rotate in the workspace, but the map rotates to maintain the heading of the ship to the top of the scene (Figure 6).

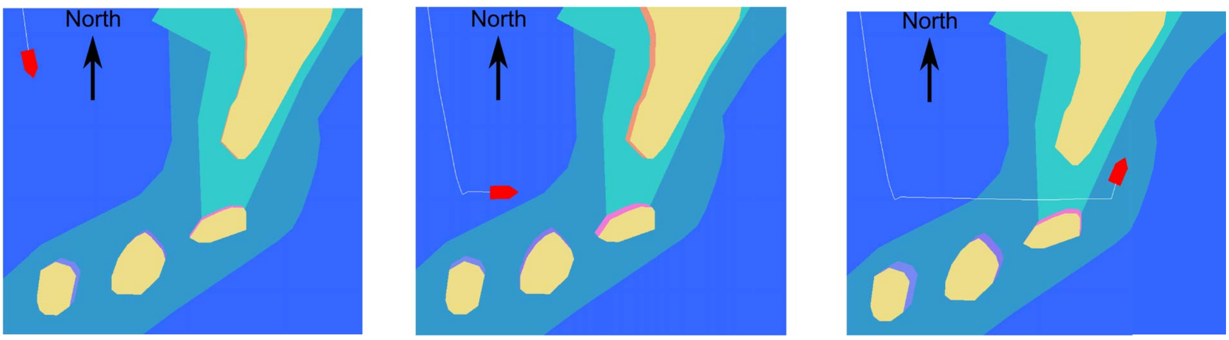

Figure 5. The northing/allocentric mode of SeaTouch: while changing boat directions, the boat moves on the map but the orientation of the map stays stable.

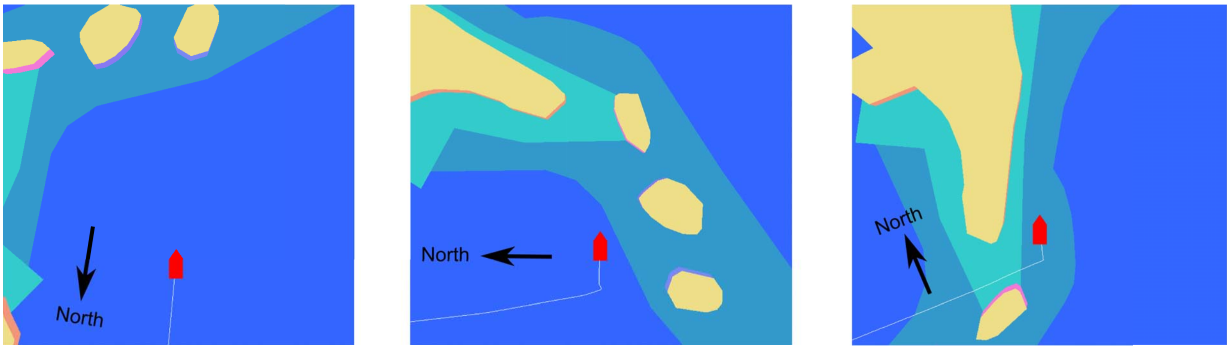

Figure 6. The heading/egocentric mode of SeaTouch: while changing boat directions, its position and orientation in the workspace remain stable but the map orientation moves to ensure a "boat up" view.

3. Method

3.1 The Subject

In this case study, we focused on the conditions which favoured the transfer of spatial knowledge from a virtual to a real environment. In this respect, a 29 year old blind sailor, having lost vision when he was 12, was recruited from a blind sailing association in Brest (France). He performed a virtual navigation in heading mode and in northing mode. He has been sailing once a month for the last six years prior to the experiment. This participant was familiar with maritime maps and used his own personal computer with text-to-speech software on a daily basis.

3.2 Procedure

In this experiment we aimed to assess the efficiency of the non-visual cognitive map built after training in heading and northing virtual navigations. These two navigation modes unfolded on a similar course except that the layout of the beacons was rotated to avoid effects due to different layouts on the one hand and a learning effect on the other hand. In each condition, this learning task was divided into two sub-learning phases (Figure 7). During the first sub-learning phase, the subject explored the virtual map and set an itinerary composed of five segments. It consisted of collecting headings and distances for each part of the course using the haptic device and vocal commands. "Origin" and "measure" vocal commands allowed the subject to collect the bearing and the distance between two haptic cursor's positions. During the second sub-learning phase, the subject navigated in the virtual environment to perform the course. After each learning task (i.e. heading or northing), he performed the evaluation task during which he was taken on board a sailboat. He was asked to estimate three beacons' directions during each of the five segments of the voyage (evaluation task Figure 7). Data were collected using a magnetic protractor. More precisely, the blind sailor performed finger-pointings, with the bearing recorder (noted by bringing the magnetic protractor in line with the direction of the arm of the subject). In this case study, the participant performed virtual training in heading condition before completing real navigation. This was followed by the same participant performing virtual training in northing condition before completing real navigation.

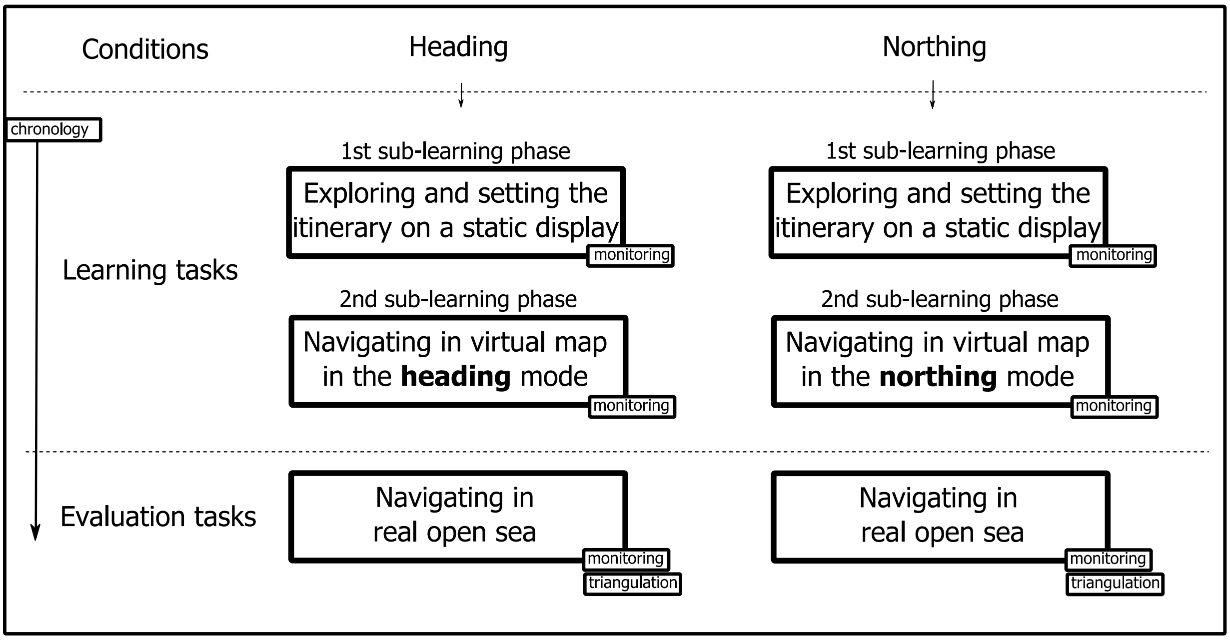

Figure 7. Experimental procedure.

3.3 Data Treatment

Using the triangulation technique on each of the five segments, each of the three estimations of direction from the ship to a beacon were extended past the beacon to cross the two others, indicating the true ship position. The connected intersections of these three lines create a triangle of 'error'. Five error triangles were created for the heading condition and five others for the northing condition. In line with the projective convergence technique (Hardwick et al., 1976), the triangle area represents the consistency of the estimations. Furthermore, the centres of these triangles are called cognitive locations. They represent the places where the subject thought he was during actual navigation. So the distance between the actual and the cognitive positions of the ship informs about the accuracy of the mental representation.

4. Results

During virtual navigations, we recorded the haptic patterns of exploration. Although the subject navigated for approximately the same duration in both modes, he covered 625 km in the heading mode and 274 km in the northing mode (Figure 8).

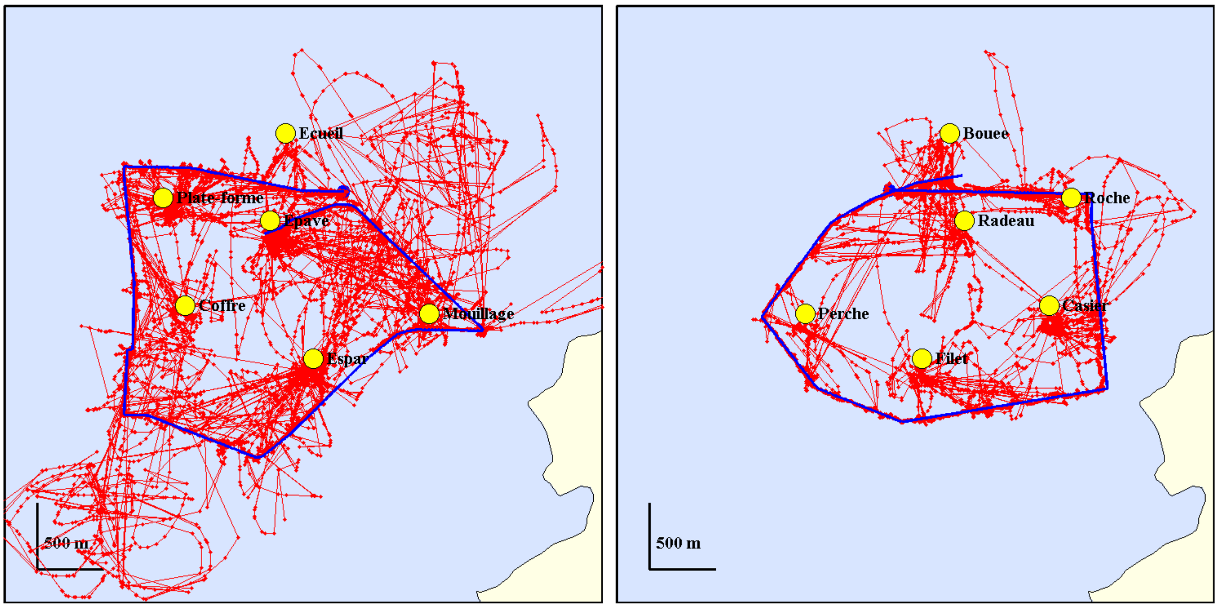

Figure 8. The haptic exploration strategies. On the left, the subject virtually navigated in heading mode whereas, on the right, he virtually navigated in northing mode. Large yellow circles correspond to the six virtual beacons. Blue thick lines are the virtual courses of the ship and thin red lines represent the trajectories of the haptic cursor.

The blind sailor therefore explored more actively the layout of the course in heading mode. Moreover when we focused on the specific south-west part of the exploration, we observed a tendency to form a circle around the left and right forward spaces. Apparently, the blind sailor did not find the next beacon. Actually, he stated that he lost the "Espar" beacon which meant that he *a priori* got lost (Figure 9). This was confirmed when he found back the beacon and exclaimed "OK, I am in bit of trouble...". Conversely such a so-called disorientation episode did not occur in northing mode (Figure 8 on the right).

Statistically, the non-parametric Wilcoxon paired test showed no significant difference ($p>0.05$) between the areas of the error triangles after training in heading and northing modes. However, the cognitive locations were more precise ($p<.05$) after navigating in heading than northing modes (Figure 10). This result is reinforced by the order of the experimental conditions. Indeed, if there was a learning effect, the blind sailor would grow better between heading and northing mode and decrease the amount of error in the northing mode. Conversely, the participant obtained more accurate cognitive locations after training in heading mode.

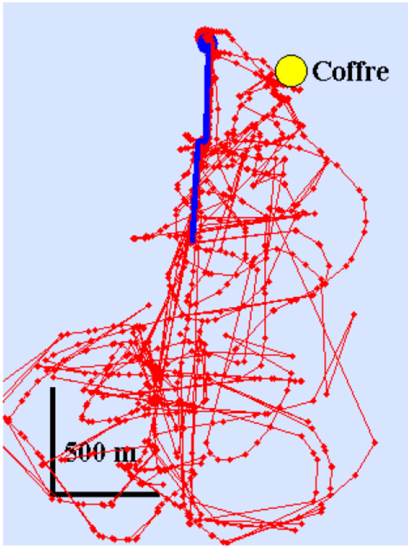

Figure 9. This pattern of exploration in circles shows the trajectory of the haptic cursor while the blind sailor was looking for the next beacon in the wrong direction.

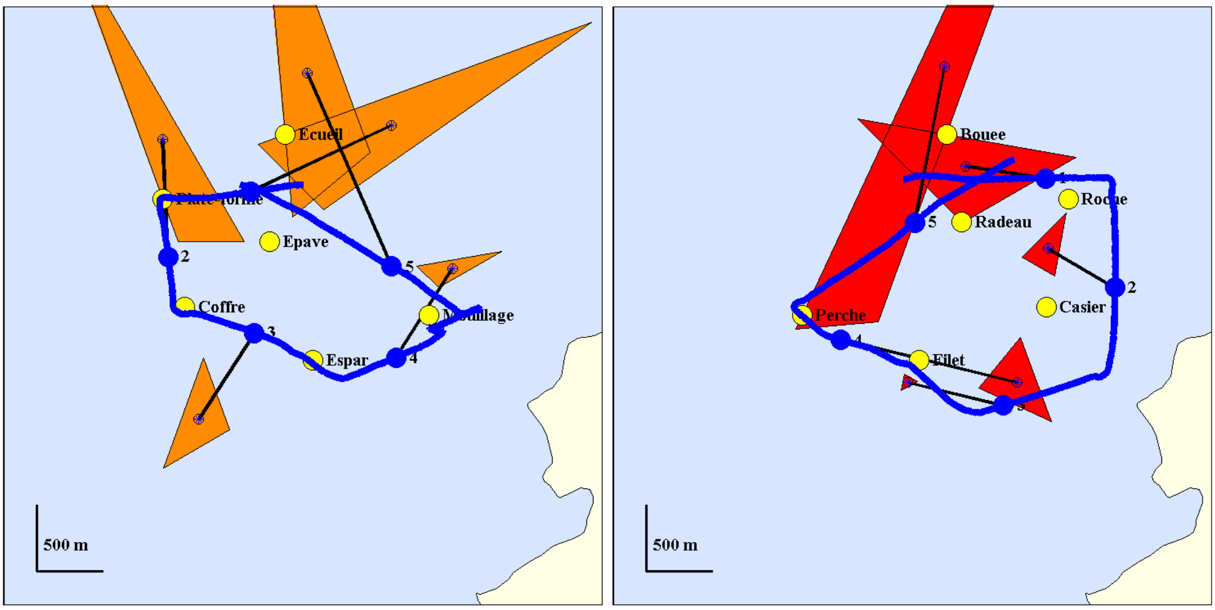

Figure 10. Results of the triangulation in the real environment. The left picture represents the results after heading mode training. The right picture represents the results after the northing mode training. Large yellow circles correspond to the six beacons. Triangles represent the area of the error triangles coming from the estimated directions. Small black circles are the position of cognitive locations and black lines depicts the distances between the actual and cognitive locations.

5. Conclusion

The analysis of the exploratory movements performed with the haptic stylus during the first phase of the study revealed that, when getting lost (parts of trajectories in wrong locations and far from the beacons) in the virtual environment in heading mode, the subject improved the precision of the cognitive locations in the real environment. This suggests that being lost in a virtual environment and thus, the necessity to identify his own current position, triggers the coordination of both types of spatial reference frames. Thus, the contribution of the heading (egocentric) mode appears to potentially help this blind sailor to build a more precise cognitive map. This result leads us to propose to blind sailors the possibility of switching between heading and northing mode during virtual navigation. This could help them to anticipate the difficulty of navigation in the real environment from multiple perspectives (i.e. in heading mode), and at the same time provide them with a mean to find their way back thanks to a more stable representation of the spatial environment (i.e. the northing mode). Conversely, conventional static tactile paper maps are unable to provide users with views of multiple perspectives and therefore participants do not get lost. Tactile maps cannot help with training users to handle both egocentric and allocentric spatial representations. Indeed, Wang and Spelke (2002) show that a disorientation episode requires the user to refer to the geometric properties of an allocentric representation in order to rebuild a consistent spatial representation. Thus, the results of this case study suggest that a virtual environment could contribute to provide blind sailors with new tools to improve their spatial knowledge acquisition. In addition, from a methodological perspective, this study reveals a new procedure to clarify the relationship between exploratory movements and the features of non-visual spatial cognitive maps as it linked motor components of action during the learning phase to the precision of spatial knowledge.

Software

The haptic map came from SeaTouch, a JAVA application developed in our laboratory for navigation training of blind sailors. This software uses the classic Open-Haptics Academic Edition Toolkit (http://www.sensable.com/products-openhaptics-toolkit.htm) and the Haptik library 1.0 (http://www.sirslab.dii.unisi.it/haptiklibrary/download.htm) to interface with the Phantom Omni (http://www.sensable.com/haptic-phantom-omni.htm) device. The contacts with geographical objects are rendered from a JAVA 3D representation of the map and environment.

Acknowledgements

We would like to acknowledge Arnaud who agreed to perform our experiment. We would also like to thank Dr Jean-Yves Guinard for his advice.

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