Can virtual reality provide digital maps to blind sailors? A case of study

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Abstract:

It has been shown that blind people mainly encode space relative to their body. But mastering space consists in coordinating body and environmental reference. Tactile maps are powerful tools to help them to encode spatial information. However only digital charts can be updated during voyage and they very often only rely on the visual modality. Virtual reality can present information using auditory and haptic interfaces. Previous work showed that virtual navigation facilitates acquiring spatial knowledge. This study aims at measuring if a blind sailor can learn a maritime environment with a virtual map as well as with a tactile map. The results tend to confirm this, and suggest pursuing investigations with non visual virtual navigation.

Keywords:
Blind, sailing, virtual reality, navigation, spatial frame of reference.

1. Introduction

1.1. Spatial frames of reference

We know that "the main characteristic of spatial representations is that they involve the use of reference (p.11)" (Millar, 1994). In the *egocentered frame of reference*, locations are represented with respect to the particular perspective of a subject. It is the *first person* reference.

On the contrary, in the *allocentered frame of reference*, information is independent of the position and the orientation of the subject. It is the *map* reference.

Mastering navigation requires coordinating these two spatial frames of reference. Matching *first person* point of view and *map* representation leads to the building and use of cognitive maps (Thinus-Blanc, 1996), considered as a sort of cartographic mental field (Tolman, 1948).

1.2. Blindness reference frames

The lack of sight tends to lead to body centered spatial frames of reference (egocentric) because of the sequentially properties of manual exploration and pedestrian wayfinding do not provide blind people with global and simultaneous information like vision does (Hatwell, 2000) .

How do blind people build efficient spatial representations?

During the previous century different theories tried to answer this question and many controversies appeared about the role of previous visual experience (See Ungar 2000 for a review). Eventually, it seems that "lack of vision slows down ontogenic spatial development […] but does not prohibit it" (Kitchin and Jacobson 1997). So, we emphasize that certain weak spatial performances of blind people do not come from a lack of spatial reasoning. They rather are the consequences of difficulties to access and actualize spatial information (Klatzky, 2003).

How could we help blind people to build updated spatial cognitive map?

1.3. Cognitive travel aids

Trying to answer this question, we discover a sort of paradox: nowadays, among the numerous digital maps connected to G.P.S., almost all of the cognitive travel aids rely on the visual modality. For example, the TomTom© system enables to present information in an egocentered spatial frame of reference (*Heading*) or allocentered one (*Northing*).

Even if blind people are the most concerned with navigation difficulties (Golledge, 1993), only a few non visual geographical information systems (GIS) are adapted to them. Recently, a system made up of two video-cameras in glasses and a matrice of taxels (tactile pixels) provides blind people a tactile surface directly presenting the near space information (Pissaloux et al. 2005). Even if this tool is based on egocentric information, experimentations have shown that the possibility to touch simultaneously multiple objects helps blindfolded subjects to perceive relations between objects-to-objects too (Schinazi, 2005).

To go further, virtual reality suggests using haptic and auditory interface to provide blind people with GIS that could permit to prepare itineraries and control them.

1.4. Virtual navigation

In the last fifteen years, the virtual reality community has widely investigated the question of the construction of spatial representations using virtual navigation.

Different researchers study the influence of the user's points of view on the acquisition of spatial knowledge (Tlauka and Wilson, 1996; Darken and Banker, 1998; Christou and Bülthoff, 2000). They globally conclude that transfers between virtual and real environments are more efficient when virtual navigation involves multiple orientations. These results are in accordance with others which show the negative effect of misalignment of the map and the body during virtual navigation (May et al. 1995). However, other studies find that an additional bird's eye view (allocentric) and active decision are required to enhance spatial knowledge during virtual navigation (Witmer et al., 2002; Farrell et al. 2003).

Eventually, Peruch and Gaunet (1998) suggest that virtual reality could use other modalities than vision.

1.5. Haptic and auditory environment

Few works take into account the potential of virtual reality to help blind people to acquire spatial knowledge. Using a force feedback device (phantom haptic device) and surrounding sounds, Magnusson and Rasmus-Gröhn (2004) show that blind people can learn a route in a haptic and auditory virtual environment and reproduce it in the real world. In this experiment, subjects navigate in an egocentered frame of reference and use the phantom device as a white cane.

Later, Lahav and Mioduser (2008) ask blind subjects to learn the configuration of a classroom in a real or in a virtual environment. Performances are assessed by pointing directions from objects to others. Results reveal that the virtual exploration is more efficient than the real one. The authors suggest that one possible explanation for their findings may have been that the use of the haptic interface provides the subjects with exploring the environment quicker and also reconstructing a spatial cognitive map more globally.

Even if these results are encouraging, to our knowledge, no study has compared the efficiency of virtual environments and tactile maps to build non visual spatial representation. Our point is to validate haptic and auditory virtual map before investigating non visual virtual navigation.

1.6. The case of the blind sailors

Rowell and Ungar (2003) show that blind people do not regularly use tactile maps because they are rare and incomplete. One important underlying reason for this is the length of production of such a map. Digital maps and virtual reality could potentially give an answer.

In Brest (France), some blind sailors consult weekly maritime charts. Their case is specifically interesting because they are in the efficient habit of using maps in natural environment. So they form a convenient control group to assess the potentiality of a new kind of map.

In this study, we compare the precision of the spatial cognitive maps elaborated by a blind sailor after exploring tactile or virtual maps. The latest are provided by *SeaTouch*, an haptic and auditory software for blind sailors navigation.

2. Experimentation

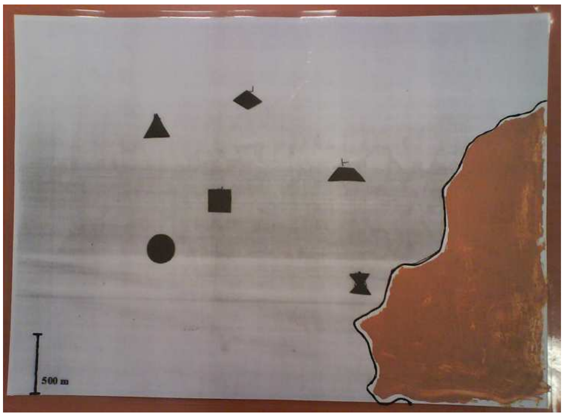
2.1. Subject

The twenty-nine-year-old subject involved in this experiment lost vision at eighteen. His level of education is the baccalaureate. This blind sailor is familiar with maritime maps more than computers.

2.2. Material

The tactile and *SeaTouch* maps of 30 cm by 40 cm contain a little part of land, a large part of sea and 6 salient objects.

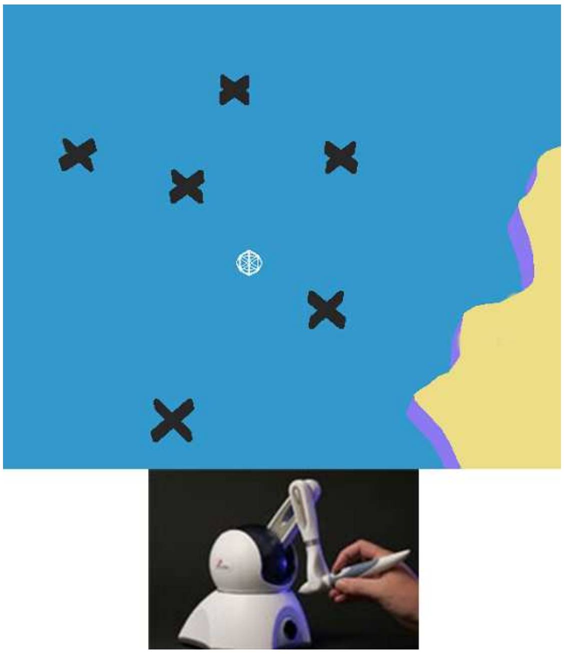
On the tactile map, the sea is represented in plastic and the land is in sand mixed with paint. The salient objects are 6 stickers in different geometric shapes (e.g. *triangle*, *rectangle*, *circle,…*). So, different textures can be perceived by touching (See picture 1).



Picture 1: Tactile map.
Revoir format

The haptic map come from *SeaTouch*, a JAVA application developed in our laboratory for navigation training of blind sailors. This software uses the classic *OpenHaptics Academic Edition Toolkit* and the *Haptik library 1.0 final* to interface with the *Phantom Omni* device. The contacts with geographical objects are rendered from a *JAVA3D* representation of the map and environment. Like a computer screen, this map stands in the vertical plane and implies that the north is at the top and the south is at the bottom of the workspace. The rendering of the sea is soft and sounds of waves are played when the subject touches it. The rendering of the earth is rough and three centimeters higher than the surface of the sea. A sound of land birds is played when there is a contact with the land. Between the land and the sea, the coastline, as a vertical cliff, can be felt and followed with the sounds of sea birds. The salient objects are materialized by a spring effect (attractor field) when the haptic cursor enters in contact with them.

Then a synthetic voice announces the names of each object (e.g. *rock*, *penguin* or *buoy*) (See Picture 2).



Picture 2: *SeaTouch* Map (at the top) and the Phantom haptic device (at the bottom). The crosses represent the salient objects vocally announced. T the clearer part depicts the coast.

2.3. Tasks

During the exploration phase, the subject has to learn the six salient objects layout. Whereas he explores the tactile map using his two hands, he explores the haptic map with the Phantom device held in one hand only. The exploration phase stops when the subject is confident about the objects layout.

At the end of the exploration phase, the subject performs pointing task from his own orientation with a tactile protractor. Without consulting the map, he answers 18 questions as follows: "From the *penguin*, could you point to the *rock*?" Here, the subject faces the north direction of the map. So in this aligned condition, ego- and allo- centered spatial frames of reference are aligned.

Our goal is to access to the situated cognitive map of the subject. In other words, we aim at assessing the non visual spatial representation of the subject when combining ego- and allo- centered frames of reference. Thus, we ask the subject to estimate directions by answering 18 questions as follows: "You are positioned at the *penguin* and facing at the *rock*, where is the *buoy*?" In this non aligned condition, the imagined orientation of the subject is not aligned with the orientation he had while exploring the map. Thus the subject is forced to deduce this new orientation from inter-objects relations. Then answering with the specific tactile protractor becomes possible. Consequently, the subject merges ego- and allo- centered spatial frames of reference. For example, the point *penguin* is 45 cardinal degrees from the point *rock* (allocentric). The subject imagines he is at the *penguin* facing the *rock* and estimates the *buoy* at 36 degrees on the right (egocentric). Consequently, we rule off a 81 cardinal degrees oriented line from the *penguin* to the *buoy*.

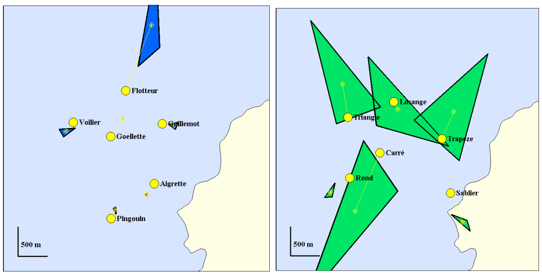
2.4. Data reduction

Firstly, we measure the angular errors of responses.

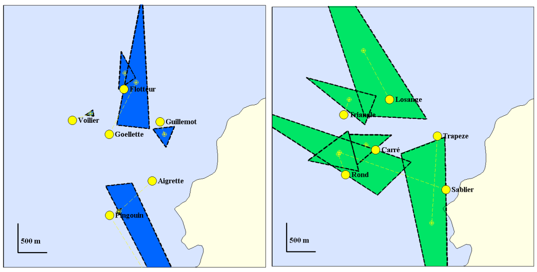
Secondly, we use projective convergence technique to obtain easily scoreable physical representations of cognitive maps. This method was originally adapted by Hardwick et al. (1976) from the more familiar triangulation method used in navigation to determine the position of a ship. Typically, the subject estimates directions to a location from three places. The resulting vectors can be drawn and where the lines cross, a triangle of error can be outlined (Kitchin and Jacobson, 1997). Here, the triangle areas allow us to assess spatial performances.

2.5. Results

Because the values do not respect the normal distribution, we use the non parametric test of Wilcoxon to compare the performances obtained after the exploration of *SeaTouch* and tactile maps.
Our first result is that the subject angular errors were significantly less important (p=0.017) after the *SeaTouch* map exploration than after tactile map exploration. This result is confirmed by the areas of error triangles (p=0.046) obtained by the projective convergence technique (see picture 3).



Picture 3: Error triangles after *SeaTouch* (left) and tactile (right) maps explorations in the aligned condition.



Picture 4: Error triangles after *SeaTouch* (left) and tactile maps (right) explorations in misaligned condition.

However, our second result shows that there is no significant difference between the angular errors (p=0.161) and the areas of error triangle (p=0.463) obtained after the exploration of the *SeaTouch* and tactile maps in misaligned condition (see picture 4).

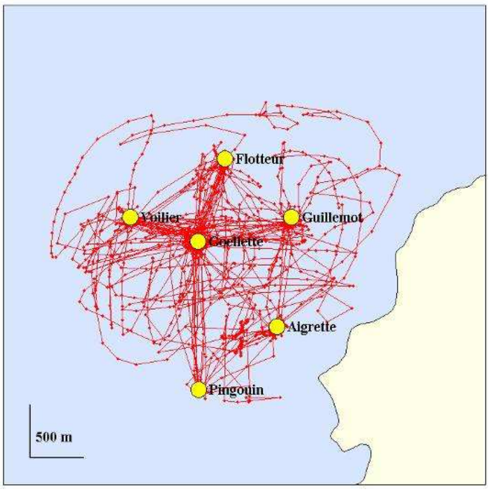
2.6. Discussion

Even if we only take into account the results of this solely subject, it is surprising to discover that the exploration of the *SeaTouch* map leads to better spatial representation than the exploration of the tactile map in aligned condition. This suggests that haptic and auditory maps could be efficient to encode a geographical layout when ego- and allo-centered spatial frames of reference are aligned. However this result is not found in misaligned condition. Does that mean that haptic maps do not favor the coordination of ego- and allo- centered spatial frames of reference when they are not aligned?

The main difference between tactile and virtual maps is that the first is explored with ten fingers whereas the second proposes the use of only one sort of "super finger". This implicates more manual movement on the *SeaTouch* map than on the tactile one in order to learn the layout. A previous study has shown that blindfolded subjects use a mode of coding based on exploratory movements to infer a spatial point in space (Gentaz and Gaunet, 2006). This argument is reinforced if we consider that virtual exploration time (8') is twice as long as tactile one (4'). Moreover, during the *SeaTouch* map exploration, the subject says several times that he had to verify where the salient objects are. Then he spends time to rediscover them and seems to refine his encoding. On the contrary, during the tactile map exploration, the subject explores the whole map with his two hands and said "OK". Consequently we suggest that the sequential characteristic of the *SeaTouch* map forces the subject to encode more precisely his movements. It is known that movements are mainly encoded in an egocentered spatial frame of reference (Millar, 1994). So this could explain the best performances obtained after the *SeaTouch* map exploration in aligned situation only.

Another difference comes from the verticality of the plane of *SeaTouch* maps. Hatwell et al. (2000) show that blind people take great advantage of the vertical reference. Here, the axis of the gravity and the north-south direction are confused. This could provide the subject with a common invariant between the gravity proprioceptive sensations and the north axis reference of the map. Moreover, the exploration trajectories show that many back-and-forth movements take place into the vertical plane (See picture 5).

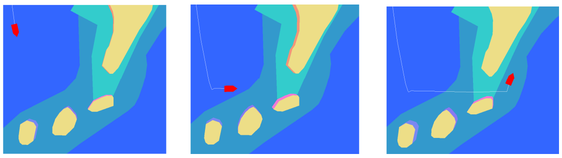
However, the results do not show any improvement of the ego- and allo-centered spatial frames of reference coordination after the *SeaTouch* map exploration. This would reveal that the subject remains as dependant of the initial encoding orientation after having explored vertical planed map as having explored an horizontal one (Mou et al., 2004). However, we have to perform this experiment with many more participants to be able to argue this conclusion.



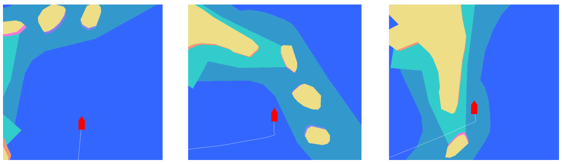
Picture 5: Red lines represent the exploration movements with the haptic interface device.

3. Perspectives

More than reproducing this experiment with other subjects, we envisage setting up another experiment where blind sailors could navigate in a virtual maritime environment. In order to learn more about the coordination of the ego- and allo-centered spatial frames of reference, we project to compare the influence of navigation in *Northing* (See picture 6) and *Heading* mode (See picture 7).



Picture 6 : The *Northing* mode of *SeaTouch*: while changing boat directions, the boat moves on the map but the orientation of the map stays stable.



Picture 7: The *Heading* mode of *SeaTouch*: while changing boat directions, its position and orientation in the workspace stay stable but the map moves.

By this respect, we would like to investigate the consequences of the multiplicity of virtual orientations on the capacity of blind sailors to match the map and their current orientations.

4. References

Christou, C. & Bülthoff, H. (2000) Perception, representation and recognition: A holistic view of recognition. Spatial Vision, Springer, 13, 265-275.

Darken, R. and Banker, W. (1998) Navigating in natural environments: A virtual environment training transfer study. VRAIS98: Virtual Reality Annual Symposium, 98, 12-19.

Farrell, M.; Arnold, P.; Pettifer, S.; Adams, J.; Graham, T. & Mac Manamon, M. (2003) Transfer of route learning from virtual to real environments. Journal of Experimental Psychology: Applied, 9, 219-227.

Gentaz, E. & Gaunet, F. (2006) L'inférence haptique d'une localisation spatiale chez les adultes et les enfants : étude de l'effet du trajet et du délai dans une tâche de complètement de triangle. L'année psychologique, 106, 167-190.

Golledge, R. Geography and the Disabled: A Survey with Special Reference to Vision Impaired and Blind Populations. Transactions of the Institute of British Geographers, JSTOR, 18, 63-85.

Hardwick, D.; McIntyre, C. & Pick Jr, H. (1976) The Content and Manipulation of Cognitive Maps in Children and Adults. Monographs of the Society for Research in Child Development, JSTOR, 41, 1-55.

Hatwell, Y.; Streri, A. and Gentaz, E. (2003) Touching for knowing: cognitive psychology of haptic manual perception. John Benjamins Pub.

Kitchin, R. and Jacobson R. (1997) Techniques to Collect and Analyze the Cognitive Map Knowledge of Persons with Visual Impairment or Blindness: Issues of Validity. Journal of Visual Impairment and Blindness, 91, 360-376.

Klatzky, R.; Lippa, Y.; Loomis, J. & Golledge, R. (2003) Encoding, learning, and spatial updating of multiple object locations specified by 3-D sound, spatial language, and vision. Experimental Brain Research, Springer, 149, 48-61.

Lahav, O. and Mioduser, D. (2008) Haptic-feedback support for cognitive mapping of unknow spaces by people who are blind. International Journal of Human-Computer Studies, 66, 23-35.

Magnuson, C. and Rassmus-Gröhn, K. (2003) Non-visual Zoom and Scrolling Operations in a Virtual Haptic Environment. EuroHaptics 2003.

Millar, S. (1994) Understanding and Representing Space: Theory and Evidence from Studies with Blind and Sighted Children. Oxford : University Press.

Mou, W., McNamara, T., Valiquette, C. and Rump, B. (2004) Allocentric and egocentric updating of spatial memories. Journal of Experimental Psychology: Learning, Memory, and Cognition, 30, 142-157.

Peruch, P. & Gaunet, F. (1998) Virtual environments as a promising tool for investigating human spatial cognition. Cahiers de psychologie cognitive, Association pour la diffusion des recherches en sciences cognitives, 17, 881-89

Pissaloux, E., Maingreaud, F, Velazquez, R. Hafez (2005) Space cognitive map as tool for navigation for visually impaired.

Rowell, J. & Ungar, S. (2003) The world of touch: an international survey of tactile maps. Part 1: production. British Journal of Visual Impairment, 21, 98-104.

Schinazi, V. (2005) Spatial representation and low vision: Two studies on the content, accuracy and utility of mental representations. *International Congress Series, Elsevier BV, 1282*, 1063-1067.

Thinus-Blanc, C. (1996) Animal Spatial Cognition: Behavioural and Brain Approach. World Scientific.

Tlauka, M.; Brolese, A.; Pomeroy, D. and Hobbs, W. (2005) Gender differences in spatial knowledge acquired through simulated exploration of a virtual shopping centre. Journal of Environmental Psychology, Elsevier, 25, 111-118.

Tolman, E. (2008) Cognitive map in rats and men Psychological Review, 55, 189-209.

Ungar, S., Kitchin, R. and Freundschuh, S. (2000) Cognitive mapping without visual experience In Kitchin and Freundschuh, Cognitive Mapping: Past, Present and Future, London: Routledge, 221-48

Witmer, B.; Sadowski, W. & Finkelstein, N.(2002) VE-based training strategies for acquiring survey knowledge. Presence: Teleoperators and Virtual Environments, MIT Press Cambridge, MA, USA, 11, 1-18