Can haptic maps contribute to spatial knowledge of blind sailors ?

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Abstract

In this preliminary study, we compared the capability of a blind sailor to access geographical information needed to navigate via an haptic device and via a tactile map. We assessed this spatial knowledge in an egocentered, an allocentered and a combined frame of reference. The subject first explored haptic or tactile maps before answering a series of questions in order to locate 6 salient objects within each map. Then, we used the triangulation technique to obtain easily scoreable physical representations of these cognitive locations. Basically, our results showed no difference between haptic and tactile condition even if slight differences were observed between the frames of reference. We suggest that the subject took great advantage of the haptic map because its sequential and dynamic features implied to focus on learning and memorizing the movement patterns rather than directly touching the global layout with reduced movements as it is the case when using a tactile map.

1. Introduction

In the present paper we define spatial knowledge as the capability to locate objects in the environment. When a human subject tries to determine his own position with respect to salient points, his entire body is also considered as an object of the environment. In particular, during navigation, ie a displacement of the entire body, the subject has both to gain knowledge of the position of his starting and final points and to update his current position.

Spatial knowledge is based on two kinds of information. The egocentered frame of reference refers to the individual point of view in a route perspective whereas the allocentered one implies an bird's eye view or maplike perspective [10].

All these pieces of information contribute to the constitution of cognitive maps, mental spatial representations, supposed to reproduce the spatial characteristics of the physical world. However since no isomorphism may exist between cognitive maps and the actual environment, it is often convenient for a human subject to use geographic maps. They provide the subject with global and allocentered information.

From a functional point of view, neither the actual displacement in the environment, nor the geographic maps used in isolation can lead to the building of a situated cognitive map that may improve spatial efficiency during navigation. Indeed, sensori-motor and symbolic information have to be merged in coherent action and mental spaces to identify common landmarks in the physical world and in the geographic map. Since vision is predominantly involved in this process, identifying the common landmarks remains a major difficulty for blind people during navigation.

In a triangle completion task during which subjects were accompanied along the two first legs of a triangle and then asked to walk back alone to their starting point, Loomis et al. [11] showed that blindfolded sighted, adventitiously and congenitally blind subjects obtained similar results. This result is in line with the conclusion of Rieser et al. [13] who previously found no differences between the same categories of subjects when they had to point manually toward their starting point after following a locomotor path. More recently, Gentaz and Gaunet [3] show that the inference process of a spatial location of a point is predominantly based on the manual movements. Nevertheless the absence of difference may be explained by the fact that the previous tasks do not require distant information. Indeed, the "difference theory" shows that blind people do not suffer of a lack of spatial reasoning but rather of difficulties in perceiving distant information [2]. Geographic maps can potentially minimize this problem by providing blind people with distant information that becomes available within their manipulatory space. Espinosa et al. [1] argue that the combination of direct experience and tactile maps constitutes a useful procedure which should be used by the blind people and Jacobson [6] verified the importance of tactile maps for helping blind and visually im-

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paired people to form impressions of their surrounding space. Moreover, Rossano [14] emphasizes the importance of alignment in blind subjects' use of tactile maps. Usually maps are watched or touched with placing the north in front of the subject. However, during actual displacements in their environment the individuals never stay facing the north. This may lead to errors.
In this respect, virtual reality constitute valuable tools to provide blind people with a naturalistic and intuitive interface dedicated to the development of spatial knowledge. In particular, they can take advantage of haptic maps when getting the cartographic information via a computer controlled, motorized device held in the hand. Such a device produces force feed-backs when the user touches a virtual object. In some circumstances haptics can substitute for other sensory modalities like vision [12].
For example, Jansson [8] attempted to enable blind people to touch virtual geographical environments with an haptic mouse and with a Phantom Omni device, but the benefits of these new devices do not show real improvement. Later Jacobson [7] et *al.* use a force-feedback mouse and auditory labels or directions to give a mixed modal interface that allows more comprehensive feedback [4].
Here, in our preliminary study, and before the computer simulation of the displacement in its actual and virtual environments, we compare the capability of a blind sailor to access geographical information he needed to navigate via an haptic device and via a tactile map. We assessed this spatial knowledge in an *egocentered*, an *allocentered* and a *combined* frame of reference.

2. Method

2.1 Task and procedure

This preliminary experiment implied a congenitally blind thirty six years old male. During a first phase referred to as the *exploration phase*, the subject explored either a tactile or a haptic map. Then he answered 3 batteries of 18 questions during the *question phase*.

2.1.1. Exploration phase

Whereas the subject explored the tactile map using his two hands, he explored the haptic map with the Phantom device held in one hand only. These two maps of 30 cm by 40 cm contained a little part of land, a large part of sea and six salient objects.

On the tactile map, the sea was represented in plastic and the land was in sand mixed with paint. The salient objects were 6 stickers in different geometric shapes (e.g. "triangle", "rectangle", "circle") .
The haptic map came 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 was at the top and the south is at the bottom. The rendering of the sea was soft and a sound of waves was played when the subject touched it. The rendering of the earth was rough and three centimeters higher than the surface of the sea. A sound of land birds was played when there was a contact with the land. Between the land and the sea, the coastline, as a vertical cliff, could be felt and followed with the sounds of sea birds. The salient objects were materialized by a spring effect when the haptic cursor entered in contact with them. Then a vocal synthesis announced the name of the objects (e.g. "rock", "penguin" or "buoy"). The exploration phase stops when the subject is confident to know the objects layout.

2.1.2. Question Phase

Among the 3 types of questions the two first one imply responses given either in an *egocentered* or an *allocentered* frames of reference. Nevertheless, in the third battery, questions required an answer combining the two frames of reference. This condition is referred as the *combined* one. In each case, each direction estimate of a salient object was given from three other objects.

In the *egocentered* frame of reference, the subject performed a pointing task from his own point of view to answer the following kind of question :
"From the penguin, could you point to the rocks ?" Here, we gathered the direction estimates (e.g. 32° on the left) thanks to a particular protractor.

In the *allocentered* frame of reference, the subject was asked to assess the directions with vocal answers. Here the subject was supposed to verbally respond in degrees from 0 to 359 (e.g. 270° for the west) to the following kind of question : "From the the penguin, where is the rock located ?"

In the *combined* frame of reference, our goal was to access to the situated cognitive map of the subject. In this case, the subject had to answer the following kind of question with the protractor :
"You are positioned at the penguin and facing at the rock, where is the buoy ?"
For example, the subject told us the point "penguin" was 45 cardinal degrees from the point "rock" in allocentric questions. Then he imagined he was at the "penguin" facing the "rock" and estimated the "buoy" at 36 degrees on the right with the specific protractor. Consequently,

we ruled off a 91 cardinal degrees oriented line from the "penguin" to the "buoy". Thus, we merged egocentric and allocentric responses.

2.2. Data reduction

In the present study, we used triangulation technique to obtain easily scoreable physical representations of cognitive maps. This method was originally adapted by Hardwick et al. [5] from the more familiar triangulation method used in navigation to determine the position of a ship. Typically, respondents estimated the distance and direction to a location from three or more places. The resulting vectors could be drawn and where the lines cross, a triangle of error could be outlined whose mean center was taken as the cognitive location of a place [9].
We measured i) the average euclidean distance between the actual objects displayed on the haptic or tactile maps and the cognitive location of their counterpart in the mental space and ii) the average area of the error triangles. We compared the different maps used during the exploration phase (*haptic* vs *tactile*) and the frames of reference (*egocentered*, *allocentered* or *combined*) within which the subject answered the questions by means of a repeated measurement analysis of variance (ANOVA).

3. Results

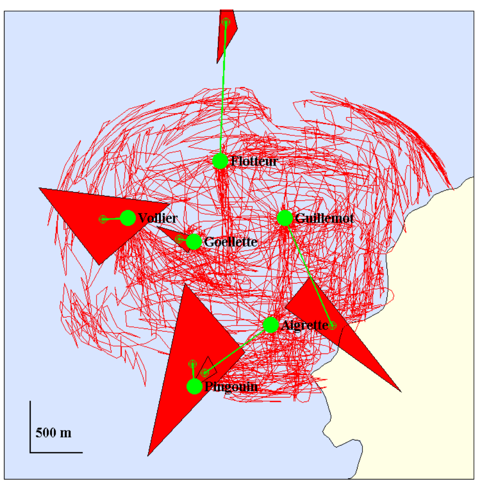

Figure 1: Error triangles built with projective convergence technique after haptic exploration and egocentered questions. The actual locations of the salient objects are displayed with large circles whereas their cognitive counterparts are depicted with small circles. The curved line is the trajectory of the haptic cursor during the exploration phase.

On a qualitative point of view (Figure 1), the haptic exploration of the virtual space shows that the subject clearly distinguished the sea and the land since his cursor never went beyond the coast line. Moreover, his exploration pattern was "gridline" (ie he uniformly explored the entire maritime space). Still qualitatively, even if error triangles areas greatly differed from each other, they were spread toward the periphery. As such, the global shape of the set of cognitive locations seems to be an enlarged reproduction of the shape of the actual objects. Nevertheless, some triangle superimpositions occurred.

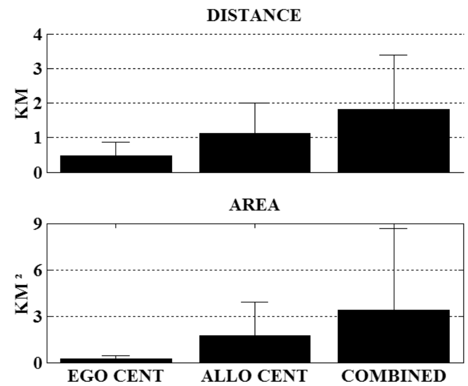

Figure 2: Means and standard deviations of the cognitive distances (KM) and the areas (KM^2) of the error triangles as a function of the frames of reference.

From quantitative point of view, the comparison of the sensory modalities showed that the cognitive distance was 1.02 ± 0.59 km when the subject explored the haptic map and 1.26 ± 1.57 km when he explored the tactile map with no significant difference ($F(1,5)=.39$; $p>.05$). In line with this result, no difference was found for the areas ($F(1,5)=.32$; $p>.05$) with 1.43 ± 2.10 km^2 for the haptic map and 2.13 ± 4.47 km^2 for the tactile one. The comparison of the reference frames is displayed on figure 2. It showed increasing values for both distance and area as a function of the reference frame. Nevertheless, whereas differences existed concerning the distance ($F(2,10)=4.52$; $p<.05$), we found no difference concerning the area ($F(2,10)=2.96$; $p>.05$). A post hoc comparison of the average distances showed that the allo centered condition do not differ ($p>.05$) from neither the ego centered nor the ego oriented one but that these two latest conditions differed form each other ($p<.05$).

4. Discussion

In the present paper, we compared the capability of blind sailor to build a situated cognitive map learned by means of either a tactile or a haptic map.
Our main results showed that similar performances could be obtained after a tactile or a haptic exploration. Even if the subject spent twice as long to explore the

haptic map than the tactile one (17 min vs. 6 min), two series of considerations may explain the reasons why he could take advantage in using the haptic map.
If we focus on the subject prior experience, we raise that subject had always explored tactile maps and could be considered as an expert. Conversely, before participating in our experiment, he never had the opportunity to use an haptic device. Despite the fact that he was a beginner in using such device, he reached a performance level equivalent to the level he obtained after years of tactile maps training. Consequently, if the subject becomes familiar with this device, we assume that he would increase his haptic perception and reduce the distance between the actual and cognitive locations.
Furthermore, we reach a limit of the technology. On the tactile map, the subject used his ten fingers during the exploration and got almost immediately a global but static perception of the layout. On the haptic map, he used the device as a single finger. Obviously, he could not manipulate ten Phantom together. Thus, with a unique device, he got a sequential and dynamic perception. This makes us suggest that during the additional time he needed, the subject memorized the pattern of movement necessary to go from an object to another.

This result reinforces the idea of the major role played by movement in the interaction between perception and action provided that the haptic interface would be natural and intuitive. Nevertheless, they also remind that further investigation is still required to disentangle the subtle influences of the frames of reference in the capability of blind sailors to build situated cognitive maps from haptic maps exploration. Finally, the subject produced more error when he answered the questions relative to the combined frame of reference. SeaTouch could be a useful software devoted to the specific training of blind subjects immersed in virtual environments that combine frames of reference.

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