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Do not get lost in translation: The role of egocentric heading in spatial orientation

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HIGHLIGHTS

- Our data showed that a small scale map facilitated spatial retrieval.
- This suggested the primary role of egocentric heading information for orientation.
- Our data are consistent with the role of retrosplenial cortex in spatial translation.

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ABSTRACT

Much is known about how different spatial reference frames continually interact to support spatial navigation, but less explored is whether it is more crucial to process object-to-object information or egocentric heading information for effective orientation in a cluttered environment. To address this question, we evaluated the possible influence on spatial performance of an interactive aerial view of different scale (small vs. large) comprising an arrow indicating participants' egocentric heading. Results revealed that the presence of a small interactive aerial view including a visualized larger arrow facilitated the retrieval of stored spatial layout. These data are consistent with recent studies revealing the role of retrosplenial cortex in translating between different spatial reference frames, and may contribute to elucidate the continuous synchronization between the inter-object direction information in the environment with respect to egocentric current heading.

1. Introduction

The ability to navigate in our surrounding environment is a vital behavior, necessary to track a route from one place to another [1]: in this manner, individuals are able to remember an important spatial location (i.e., "How can I remember where I left my car?"), other locations (i.e., "My car was near the red car"), as well as its relation to themselves (i.e., "The red car was at my left when I entered in the supermarket!"). First, it implies the capacity to represent the relations between the objects in space (i.e., *allocentric reference frame*), and between these objects and ourselves (i.e., *egocentric reference frame*) [2]. The allocentric reference frame is constituted by object-to-object relationships, and spatial information is represented with respect to external elements for an extended period of time, specifically in the hippocampal area [3–5]. Conversely, the egocentric reference frame, which is constituted by self-to-object relationships, maintains and updates spatial information in relation to the current individual's position and heading with respect to the surrounding environment, especially in the posterior parietal area [6–10]. Much is known about how these different spatial reference frames continually interact to support spatial navigation [11–13], but it is still less explored how it is possible to anchor our current egocentric heading in the environment for an effective orientation.

According to recent neuroscientific evidence, a crucial role was assigned to the retrosplenial cortex (RSC), which is responsible for the continuous transformation between the spatial reference frames [14,15]. Already Aguirre and D'Esposito [16] have introduced "heading disorientation" in their taxonomy of topographical disorientation, specifying that after a damage in RSC, patients may present a difficulty in updating direction of orientation with

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respect to the external relevant stimuli. In this direction, Takahashi et al. [17] reported three patients with right retrosplenial lesion who were able to identify familiar objects, but showed a great impairment in remembering directional orientation between two locations. Indeed, for an effective orienteering, when we memorize the relationships between objects in space, we also encode the inter-object direction in respect to our current egocentric heading, resulting in an "ego-oriented bearing" from one object to the other [18] . Marchette et al. [19] clarified the role of RSC in establishing one's position and heading relative to external elements of our space. Using fMRI, they found that RSC is responsible for anchoring spatial reference frames to local environmental features, that may be generalized across local environments with similar geometrical structure. These findings showed that the retrieval of information is constrained by a specific reference to the observer's body (i.e., the egocentric current heading): it means that there is an alignment principle for anchoring the local environmental features with the previous stored one. Serino and Riva [20] found that participants were more precise in retrieving the position of an object when immersed in an egocentric experience with an interactive aerial view of the experienced virtual environment, since it provides information about their heading in the space. These preliminary findings are in value in supporting the role of the so-called mental frame syncing in the spatial processing [21,22], namely a cognitive process that permits an effective retrieval by the synchronization of the two types of allocentric representations [23], the viewpoint-independent representation (i.e., including object-to-object information) and the allocentric viewpoint- dependent representation (i.e., including information about egocentric current heading). Some evidence has shown that two regions within the hippocampus are specifically involved in the processing of allocentric information [24,25]. One is region CA3, which receives inputs from the entorhinal cortex and encodes an allocentric representation of the spatial scene toward which the individual orients. This is what Behrendt calls the allocentric viewpoint-dependent representation [23]. The second region consists of the neurons in CA1, which receives inputs from CA3 via Schaffer's collaterals and encodes allocentric representations involving only abstract, object-to-object information. This is what Behrendt calls allocentric viewpoint-independent representation [23].

On these premises, the main objective of the current study is to understand whether it is more crucial the role of object- to-object information or egocentric heading information for an effective spatial orientation. To achieve this aim, we evaluated the possible influence on performance of interactive aerial views of different scale (small vs. large) comprising arrows indicating participants' egocentric heading.

Spatial layouts were encoded and retrieved in a Virtual Reality (VR) immersive setup, and specifically in a computer- assisted virtual environment (CAVE). VR has already been confirmed to be a suitable medium to study complex spatial processing, since it gives the possibility to manipulate the perspective when investigating individuals' ability to reorient in space [26,27]. Moreover, in a CAVE, visual images are back-projected onto the screen of a small room surrounding the users, whose movements are tracked by sensors and the projections are adjusted continually to retain the users' viewpoints. Thanks to these features, it is possible to investigate how the interactive aerial view, and its arrow, rotates according to the direction of the participants' current egocentric heading direction.

2. Material and methods

Thirty participants [15 females and 15 males, mean age: 29.03 (8.90)] from the Institute of Movement Sciences Etienne-Jules Marey (Marseilles, France) took part in the study. All of the participants signed an informed consent form prior to participation. First, stereoscopic acuity was assessed to exclude participants with severe vision disorders. Then, the interpupillary distance (i.e., the distance between the pupils) was measured for each participant to calibrate the projection and to avoid possible feelings of discomfort (for example, nausea or headache) due to a conflict between visual and vestibular signals that may occur when navigating in an immersive virtual environment. After initial training in VR technology and the navigation interface (i.e., a simple navigation task in a large environment), the experimental procedure was initiated, consisting of an encoding phase, which was followed by the retrieval phase in three different conditions. The participants were placed in the centre of the CAVE, consisting of four projection screens: frontal, ground and lateral projections. Each frontal and lateral screen had a projection surface of 3 meters wide by 4 meters high. The three vertical walls were back-projected and the ground received direct projection with a 1400 × 1050 resolution and a 60 Hz frame rate. Stereoscopic projection was obtained by two digital light processing projectors attached to each projection surface. A motion capture system (ArtTrack), based on a set of eight cameras, allowed tracking the position and orientation of the observer's head in the environment and constantly updated the stereoscopic projected images according to the subject's point of view. The participants also had a Flystick (ArtTrack), a wireless interaction device that allowed them to explore and to interact with the environment by using a joystick on the top.

A virtual city (125 m by 150) was developed as the test environment. It was built around a central square with a tower in the middle, which represents the starting point of the navigation. In the encoding phase, starting from the center, each participant was instructed to find and memorize the position of an hidden plant with no time limit. The first group of participants searched for the hidden object while navigating in the virtual city without any interactive aerial view of the city (i.e., "encoding without an interactive aerial view"). A second group of participants could see a small scale aerial view of the virtual city that was always available in the field of view (i.e., "encoding with a small scale interactive aerial view"). Finally, a third group of participants could see a large scale interactive aerial view of the virtual city, always available in the field of view (i.e., "encoding with a large scale interactive aerial view"). Both "maps" (and their arrows) had the same size, but different scales: the first one had a visible radius of 25 m (i.e., small scale), and consequently, a visualized larger arrow indicating the current egocentric heading of participants. The second map, instead, had a visible radius of 50 m (i.e., large scale), and consequently a visualized smaller arrow. See Fig. 1 for an overview of the virtual city with the three experimental manipulations used for encoding and retrieval.

In the retrieval phase, all participants were asked to retrieve the position of the hidden plant in three different conditions (i.e., "retrieval without the interactive aerial view", "retrieval with a small scale interactive aerial view" and "retrieval with a large scale interactive aerial view"), entered in the virtual city from another starting point. To indicate the position of the object in the virtual city environment, this technique forced the participants to refer to their allocentric viewpoint-independent representation and sync it with the allocentric viewpoint-dependent representation [28]. Specifically, it forced participants to place their current egocentric heading to indicate the objects' bearings in the surrounding environments. When this new "ego-oriented bearing" [18] is the same as the one memorized, an effective retrieval can be achieved. The order of the conditions was randomized for each participant with no time limit. In the condition "retrieval without the interactive aerial view" participants entered the virtual city from the North, and attempted to retrieve the position of the plant they