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# Walking during the encoding of described environments enhances a heading-independent spatial representation

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ABSTRACT

Previous studies demonstrated that physical movement enhanced spatial updating in described environments. However, those movements were executed only after the encoding of the environment, minimally affecting the development of the spatial representation. Thus, we investigated whether and how participants could benefit from the execution of physical movement during the encoding of described environments, in terms of enhanced spatial updating. Using the judgement of relative directions task, we compared the effects of walking both during and after the description of the environment, and walking only after the description on spatial updating. Spatial updating was evaluated in terms of accuracy and response times in different headings. We found that the distribution of response times across Headings seemed not to be related to the physical movement executed, whereas the distribution of accuracy scores seemed to significantly change with the action executed. Indeed, when no movement occurred during the encoding of the environment, a preference for the learning heading was found, which did not emerge when walking during encoding occurred. Therefore, the results seem to suggest that physical movement during encoding supports the development of a heading-independent representation of described environments, reducing the anchoring for a preferred heading in favor of a global representation.

## 1. Introduction

The ability to maintain spatial relations between the self and the surrounding objects and the possibility to constantly monitor the changing relations during movement are essential to guarantee adequate daily navigation. Indeed, these abilities prevent people from getting lost, allow them to re-orient and ease the identification of the right way or reference landmarks. In spatial cognition literature, spatial updating exactly refers to the ability to keep track of the changing self-to-object relations when moving (Rieser, 1989; Wang & Spelke, 2000).

According to the model by Mou, McNamara, Valiquette, and Rump (2004), spatial updating seems to be supported by the architecture of spatial representation, which involves two different representational systems: an enduring allocentric and a transient sensorimotor system.

The enduring allocentric system maintains the enduring object-to-object relations and remains stable during movement. Indeed, the spatial information retained in memory is contained in an allocentric framework, where it is not possible to perform online information updating. This system accounts for the preference of reasoning from a specific heading direction, which usually is the learning heading — that is, the initial heading direction from which the environment is encoded.

The empirical evidence actually suggests that a specific allocentric reference frame is selected from the environmental cues to store the information accordingly. In the absence of relevant landmarks, people adopt the heading direction from which they have encoded the environment as the reference frame (hereafter, learning heading), determining the preference for the learning heading (Wilson, Wilson, Griffiths, & Fox, 2007). In spatial cognition literature, the ease of reasoning from the learning heading direction compared to other heading directions is named encoding alignment effect (Kelly, Avraamides, & Loomis, 2007).

The sensorimotor egocentric system stores self-to-object information and updates online changing egocentric relations when the observer is moving inside the environment, without a considerable effort. According to the model of Mou et al. (2004), spatial updating occurs only in immediate environments, since self-to-object relations are maintained and updated only in the sensorimotor system. When spatial updating occurs, the sensorimotor alignment effect – that is, the ease of reasoning from a heading that is aligned with the observer's actual facing direction – emerges (Kelly et al., 2007).

The sensorimotor alignment effect has been commonly associated to the occurrence of spatial updating, since its positive value indicates that

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the observer updates the spatial relations as a function of her/his actual heading direction (Kelly et al., 2007). On the other hand, it is well established that the encoding alignment effect is related with the anchoring to the learning heading, since its positive value indicates that the observer relies on the heading direction from which s/he first encoded the environment (Kelly et al., 2007; Shelton & McNamara, 1997). Even though the notion of alignment effects is widely used in spatial cognition, the assumption of their independence or dependency is still controversial. Indeed, results from a recent study (Santoro, Murgia, Sors, & Agostini, 2017) seem to indicate a relation between the two alignment effects, but they are not strong enough to disconfirm previous evidence which rather suggest the independence of the effects (Avraamides & Kelly, 2010; Kelly et al., 2007).

In the immediate environments – real environments perceptually accessible in a given moment – the updating of egocentric relations occurs online and without cognitive effort because the observer completely relies on the sensorimotor system. However, it has been demonstrated that people are able to update egocentric relations also in remote environments, namely previously-experienced real environments which are not perceptually accessible in a given moment. In this case, several studies agreed in claiming that spatial updating occurs with the aid of physical movement, while imagined movement seems to be unable to foster spatial updating (e.g., Avraamides, Galati, & Papadopoulou, 2013; Rieser, Garing, & Young, 1994). In spatial updating literature, while immediate and remote environments have been widely studied, described environments have received less attention by researchers.

The occurrence of spatial updating in described environments, namely environments linguistically described and not previously experienced, has been investigated only in a few studies (e.g., Avraamides, 2003; Avraamides, Galati, Pazzaglia, et al., 2013; Rieser et al., 1994). Only some of them suggested that people were able to update egocentric relations within narratives, and physical movement seemed to be a crucial factor (Hatzipanayioti, Galati, & Avraamides, 2014; Santoro et al., 2017). The idea that spatial updating can also occur in described environments is supported by evidence suggesting that verbal descriptions are functionally equivalent to perceptual experience concerning the cognitive spatial representation produced (Loomis, Klatzky, Avraamides, Lippa, & Golledge, 2007; Lyon & Gunzelmann, 2011). Furthermore, embodied cognition suggests that while reading a story the reader could be so engaged to totally impersonate the protagonist. Indeed several studies confirmed the ease of performing actions consistent with the protagonist's and the difficulty of performing actions in opposition to the protagonist (Zwaan, 2004; Zwaan & Radvansky, 1998). Moreover, it has been demonstrated that the reader simulates perceptual and motor elements described in the story (Brunyé, Mahoney, & Taylor, 2010). Thus, if the reader imagines to be the protagonist, then s/he will act in the sensorimotor system, determining the occurrence of spatial updating within described environments.

Among the studies that investigated spatial updating in described environments, only a few focused specifically on the effect of walking (Hatzipanayioti et al., 2014; Santoro et al., 2017), compared to other physical movements, such as rotation (e.g. Avraamides, Galati, Pazzaglia, et al., 2013). In a recent study (Santoro et al., 2017), blindfolded participants were provided with a narrative describing an environment with eight objects inside and asked to mentally imagine the environment described. Then the protagonist of the narrative was described as turning 90° to the right or to the left; according to the assigned condition, participants were asked to remain still and imagine the rotation, to physically rotate or to physically rotate and walk a few steps. The results suggest that physical movement, and in particular walking, fosters spatial updating within described environments, as demonstrated by a higher sensorimotor effect. This evidence has been explained as a consequence of the different patterns of information obtained by rotation and by walking. Moreover, it has been suggested that the multisensory pattern of vestibular, proprioceptive and efferent motor information (hereafter, idiothetic information) obtained by walking can reduce the "supremacy" of the learning heading compared to the other headings.

It is noteworthy that the movements, either imagined or physically performed, involved in the previously described studies occurred only after the encoding of the environment, since movements were executed only during the protagonist's reorientation. Thus, when participants performed the movements, they had already encoded the environment with the described objects and then the information derived from movements could minimally affect the spatial representation. Indeed, in the light of the encoding alignment effect, the heading direction – which remained the same during the description of the environment – could somehow "guide" the encoding of information and, consequently, influence the corresponding spatial representation. In such a situation, it is possible that the additional information provided by movements could only enrich an already-structured spatial representation, and not fully contribute to its construction.

Based on previous evidence in literature, we wondered whether physical movement performed simultaneously with the encoding of the environment would affect spatial updating even more. Indeed, it is possible that the idiothetic information deriving from movements could significantly contribute to the construction of the spatial representation of the environment, by unbinding the reader from the learning heading. A recent study by Hatzipanayioti, Galati, and Avraamides (2014, Experiment 3) partially answered our question. The authors examined whether extensive physical movements enhanced spatial updating during the encoding of described environments, determining the occurrence of the sensorimotor alignment effect. The authors asked participants to reproduce the protagonist's movements by walking into the room as they read the narrative, and found both an encoding and a sensorimotor alignment effect. Unfortunately, they did not totally disentangle the question, since they did not systematically manipulate the effect of walking during the encoding of the environment.

Overall, our literature review highlighted that physical movements can promote spatial updating, and in particular this has been demonstrated when movements are performed after the encoding of described environments. To the best of our knowledge, only Hatzipanayioti et al. (2014) investigated the role of physical movements during encoding, but no study compared the effects of physical movements versus no movements during encoding. To better clarify this aspect, we investigated whether allowing participants to walk simultaneously with the protagonist's movements both during environment encoding and reorientation would affect spatial updating differently, compared to participants only walking during the protagonist's reorientation. We expected a higher sensorimotor effect for the participants who also walked during the description of the environment (encoding + reorientation) compared to those participants who only walked after the description (reorientation), as a consequence of enhanced spatial updating.

Thus, the present study aimed to investigate whether and how participants could benefit from the execution of physical movement during the encoding of described environments, in terms of enhanced spatial updating.

## 2. Method

### 2.1. Participants

Sixty university students (15 M; 45 F) participated in this experiment in exchange for academic credits. Their age varied from 18 to 30 years (M = 19.8; SD = 1.6). All participants signed the informed consent before starting the experiment. The participants were naive regarding the purpose of the experiment.

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