Spatial Updating in Narratives

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Abstract. Across two experiments we investigated spatial updating in environments encoded through narratives. In Experiment 1, in which participants were given visualization instructions to imagine the protagonist's movement, they formed an initial representation during learning but did not update it during subsequent described movement. In Experiment 2, in which participants were instructed to physically move in space towards the directions of the described objects prior to testing, there was evidence for spatial updating. Overall, findings indicate that physical movement can cause participants to link a spatial representation of a remote environment to a sensorimotor framework and update the locations of remote objects while they move.

Keywords: Spatial updating, narratives, sensorimotor interference, transient representations, reading comprehension.

1 Introduction

1.1 Egocentric Updating of Spatial Relations

Many of our daily tasks rely on the on-line processing of spatial information. For instance, navigating in an unfamiliar environment requires considering either continuously or at frequent temporal intervals where we are and how we are oriented relative to the locations of landmarks, the origin of travel, the goal destination etc. Previous studies have established that people are capable of keeping track of the changing spatial relations between their body and the main objects of the environment without much effort even when movement takes place without vision (Farell & Thomson, 1999; Rieser, 1989; Wang & Spelke, 2000). The mechanism that allows people to continuously monitor egocentric relations is commonly referred to in the literature as spatial (or egocentric) updating.

Studies investigating spatial updating typically require participants to memorize the location of one or more objects and then point to them from an initial standpoint, as well as from novel standpoints. Novel standpoints can be adopted either by physical or imagined movement, consisting of rotation, translation, or a combination of the two. Converging findings indicate faster and more accurate performance when pointing from the learning standpoint or from novel standpoints adopted through physical movement compared to standpoints adopted through imagined movement (e.g., Presson & Montello, 1994; Rieser, Guth, & Hill, 1986). A popular explanation

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for these findings is that the idiothetic cues (i.e., proprioceptive information and vestibular signals), which are present during physical locomotion, are necessary for effortless updating (Rieser, 1989). Another explanation is that imagined movement leads to sensorimotor interference from the automatically-activated physical codes that signify self-to-object relations; these codes must be suppressed in order to compute the location of an object from an imagined perspective (May, 2004).

1.2 Representational Systems of Spatial Memory and Updating

Successful spatial updating during movement without visual cues relies on people maintaining accurate spatial representations. Thus, several studies have focused on the organizational structure of the spatial representations that support updating. A few accounts have emerged. Mou, McNamara, Valiquette and Rump (2004) posited that maintaining and updating spatial information involves two memory systems: an egocentric system storing self-to-object relations that are updated when the observer moves, and an allocentric system that codes object-to-object relations that remain stable during movement.

Participants in the study of Mou et al. (2004) studied a layout of objects from one standpoint and then performed Judgments of Relative Direction (JRDs) after moving to a novel standpoint. The researchers manipulated independently: (1) the angle between the learning perspective and the imagined perspective adopted during a JRD (e.g., "Imagine standing at x, facing y, point to z" where x, y, and z are objects from the layout) task and (2) the angle between the participant's actual orientation and the imagined perspective adopted for the JRD task. Two independent alignment effects were observed. First, performance was superior when the imagined perspective matched the orientation of the learning perspective; this is now a well-established effect indicating that memories are maintained from a preferred direction (see McNamara, 2003, and Galati & Avraamides, 2013, for a discussion of how the preferred orientation is selected). Second, in line with typical findings from spatial updating studies, performance was better for imagined perspectives aligned with the participant's physical orientation at test (Kelly, Avraamides & Loomis, 2007). Based on these findings Mou et al. (2004) argued that in addition to storing object-to-object locations in an orientation-dependent representation, people code self-to-object relations in a representation that gets updated with movement.

Similarly, Waller and Hodgson (2006) argued for a transient memory system in which egocentric relations are kept with high precision but decay rapidly in the absence of perceptual support, and an enduring system in which information is maintained for prolonged intervals but in a coarser manner than the transient system.

More recently, Avraamides and Kelly (2008) proposed that spatial updating relies on an egocentric sensorimotor system that represents the self-to-object relations for the main objects in one's immediate environment. In this proposal, in line with May's (2004) explanation, the automatic activation of the sensorimotor system may cause interference to an allocentric system that people must use in order to compute a response from an imagined standpoint. Another consequence of this proposal is that interference is absent when reasoning about remote environments, since distal locations are not maintained within a sensorimotor framework.

These theories of spatial memory, which posit separate systems for egocentric and allocentric storage, imply that egocentric updating relies on the sensorimotor system and can thus only take place when reasoning about immediate spatial locations, insofar as self-to-object relations are maintained in sensorimotor, transient representations.

Empirical support for this prediction comes from a study by Kelly, Avraamides and Loomis (2007), who examined spatial reasoning in immediate and remote virtual environments. In one experiment, participants studied and committed to memory a layout of objects placed around them within a virtual room. Half of the participants remained in the same room for testing whereas the other half walked out of the virtual room and assumed a position in the center of an adjacent virtual room. In both testing conditions participants rotated 90^{o} to their left or right, adopting a physical orientation that was offset from the orientation they had during learning. While at this testing orientation, participants were asked to point to the memorized objects from various imagined perspectives by responding to perspective taking (JRD) trials of the form 'imagine facing x, point to z', with x and z being objects from the layout. For testing in both the same and the adjacent room, performance was better for imagined perspectives aligned with the participants' initial learning orientation than other orientations, in line with proposals that spatial memories are orientation dependent (e.g., Mou & McNamara, 2002). Additionally, when participants were tested in the same room, but not in the adjacent room, performance was also better for the imagined perspective aligned with the orientation participants occupied during testing. The selective influence of the participants' orientation at testing was taken to indicate that participants updated their orientation relative to the memorized objects when rotating from their initial perspective in the immediate environment, but not the remote environment. This is consistent with two-system accounts of memory that consider egocentric updating to operate on representations within a sensorimotor system–representations that are most readily available for spatial relations in immediate environments.

1.3 Spatial Updating in Remote Environments

Although studies suggest that effortless updating may be limited to reasoning about immediate locations, there is some evidence that it can occur under certain circumstances in remote environments as well (Kelly et al., 2007; Rieser, Garing & Young, 1994). Specifically, when people represent their physical movement relative to a remote environment, they can successfully update their orientation relative to remote locations.

For example, in one study, Rieser et al. (1994) asked young children and their parents, while at their homes, to imagine being in the classroom and to point to classroom objects from two perspectives: first from the children's seat and then from the teacher's seat in the classroom. In one condition, participants imagined walking from the children's seat to the teacher's seat. In another condition, they physically walked the path they were imagining. Parents and children who carried out physical movement towards the teacher's seat showed similar performance in terms of accuracy and response latency suggesting that they could update their position in the remote environment, whereas when they had only imagined the movement, parents were more accurate than children. Overall, these findings indicate that physical movement coupled with instructions to visualize a remote environment can enable effortless updating.

One possible explanation for how people update remote locations is that, by following the visualization instructions and performing compatible physical or imagined movements, they can link the remote environment to their sensorimotor framework and update the distal locations as if they were immediate. The proposal that visualization instructions can recruit the sensorimotor system, even with respect to a remote environment, is broadly compatible with the embodied cognition view that sensorimotor representations can be reenacted "offline", even when reasoning is decoupled from the immediate environment (e.g., Simmons, et. al, 2003; Wilson, 2002)

Further support for the proposal that visualization can facilitate spatial updating comes from an experiment conducted by Kelly et al. (2007; Experiment 3). Using the layout and the procedure of the experiment described earlier (with testing in the immediate or adjacent virtual room), in this experiment, participants in the different room condition received instructions to imagine the objects of the layout as being around them while standing in the center of the testing room. Following these visualization instructions, participants physically rotated 90° to the left or right and carried out a series of pointing trials from imagined perspectives. Compared to when rotation was not accompanied by visualization instructions, when physical rotation was coupled with visualization instructions, participants pointed faster and more accurately from the imagined perspective that was aligned with their orientation at testing than the perspective opposite to it. This, so called, *sensorimotor alignment effect* suggests that, despite rotating with respect to a remote environment, participants could still update egocentric relations.

Altogether, a confluence of findings suggests that spatial updating operates on spatial relations maintained in a transient system of spatial memory and thus occurs effortlessly in immediate environments. Although spatial relations about remote environments are not maintained in such a system and are thus not updated by default, providing visualization instructions that link the remote objects to a sensorimotor framework can cause updating with physical movement.

1.4 Functional Equivalence of Representations Derived from Perception and Language

In addition to vision, people encode spatial information in memory through other sensory modalities, such as touch and audition, and through symbolic modes of representation, such as language. One proposal is that the spatial representations derived from different modalities are functionally equivalent (Avraamides, Mello, & Greenauer, 2013; Bryant, 1997; Giudice, Betty, & Loomis, 2011; Loomis, Klatzky, Avraamides, Lippa & Golledge, 2007). This claim stems from the hypothesis that once the spatial representation is formed, it is no longer dependent on the modality from which it was encoded but is instead dependent on the properties of the representation (Loomis & Klatzky, 2007). A prediction that follows is that if spatial updating occurs in environments experienced perceptually, it should also take place in environments encoded through indirect inputs, such as language.

Avraamides, Loomis, Klatzky and Golledge (2004) examined the possibility of functional equivalence by having participants memorize objects that were either encoded visually or through verbal descriptions (e.g., “there is a ball at 3 o’clock, 6 feet away from you”). Then, participants had to reproduce from memory the relative direction of pairs of objects by rotating a rod. Results showed that participants’ accuracy was comparable whether the objects were encoded visually or verbally (Experiment 3), suggesting that the representations derived from the two modalities were functionally equivalent.

Other studies (e.g. Klatzky, Lippa, Loomis & Golledge, 2002) provide support for functional equivalence by demonstrating that despite the inherent differences between language and vision (e.g., serial vs. near-simultaneous encoding, slower encoding with language than vision), representations derived from the two modalities support in the same manner the execution of spatial tasks (for a review see Loomis et al, 2007, Avraamides et al., 2013, and Loomis, Klatzky & Giudice, 2013).

However, studies demonstrating that language supports representations that are functional equivalent with vision, have involved primarily short descriptions for the locations of objects. In addition, in many cases (e.g., Avraamides et al., 2004) these objects were described at locations within environments that were previously experienced visually. Thus, it is not yet clear whether object locations in environments that are in their entirety constructed through descriptions are represented and updated the same way as object locations that are encoded directly through visual perception. Here, we investigate spatial updating for locations encoded from narratives. Narratives typically describe fictitious environments that are remote to the reader; that is, they refer to environments that differ from those in which readers are physically present while reading the text.

1.5 Spatial Relations in Narratives

When reading narratives people construct mental representations of the state of affairs described in the text. These representations, retaining the semantic content or gist of sentences, are known as situation models (Kintsch, 1998) or mental models (Johnson-Laird, 1983). Several aspects of the situation can be included in these models, including spatial, temporal, causal, motivational, protagonist-related and object-related information, which readers monitor during comprehension (e.g., Zwaan, 2004; Zwaan, Langston, & Graesser, 1995). Relevant to our enterprise here, readers monitor the protagonist’s location and perspective in space and time in an effort to organize information in a coherent spatio-temporal framework (Zwaan & Radvansky, 1998). A potential mechanism implicated in this monitoring is that readers simulate perceptually what is being described in text by activating their own motor and perceptual experience. In support of this potential mechanism are findings showing that described actions interfere with real actions, such that the execution of a manual response interferes with the processing of an action described in the text (Glenberg & Kaschak, 2002).

If readers of narratives indeed activate motor-related processes when interpreting described movements, this sensorimotor simulation during reading may result in the same effortless updating of spatial relations as that effected by physical movement in immediate environments or visualization in remote environments. That is, with narratives, it is possible that even imagined movement within the described environment could lead to successful spatial updating. The experiment reported next examines this possibility with narratives that involve described protagonist rotations.

2 Imagined Movements in Narratives

2.1 Experiment 1

In order to examine whether readers automatically update the protagonist's orientation within a situation model, we investigated readers' spatial judgments when, prior to testing, the protagonist is described to rotate from an initial orientation to adopt a novel orientation. The paradigm used was adapted from the one used by Kelly et al. (2007), such that in the present experiment (1) the environment and the objects to be memorized were described rather than presented visually, and (2) participants did not carry out any physical movement but rather imagined the protagonist's movement and change in orientation prior to testing. If readers simulate the change in protagonists' orientation in space by activating motor processes in imagined movements then imagined movements should suffice for updating spatial relations in a narrative. In this case, and as long as readers have updated their situation model following the protagonists' described rotation, performance should be particularly good when responding from imagined perspectives aligned with the final orientation of the protagonist.

Participants were presented with narratives that described a protagonist in a fictitious environment (a hotel lobby, a court room, an opera house, and a construction site), each of the 4 environments presented as a different block. The stories in the narratives were loosely based on those used by Franklin and Tversky (1990). Each narrative comprised a series of short segments of text that included information about the geometry of the described environments and the placement of critical objects in them. Four objects were positioned at canonical orientations (front, back, right and left) and 4 additional objects at diagonal orientations in the corners of the environment. Participants were instructed to imagine being at the protagonist's position and to create a vivid mental image about the described environment. First, participants read an initial segment of text that described the protagonist entering a room through the door, walking to its center, and adopting an *initial orientation* facing towards a starting object; the door that was then behind the protagonist served as an additional object of the layout. Then, participants read a second segment of text in which the protagonist was described to rotate 90° either to the left or to the right to inspect another object. Participants read additional text that provided information about all remaining objects (one object at their back and four in the corners of the room) from this orientation (hereafter referred to as the *description orientation*). Finally, participants read a description of a sudden event (e.g., a loud noise or a telephone ringing) that caused the protagonist to turn 180° to face the opposite direction from the description orientation. After the protagonist was described to adopt this new orientation (referred to as the *updated orientation*), participants read instructions to create a mental image of the described environment from this orientation.

Following this learning phase and after memorizing the positions of all objects participants carried out a series of perspective taking trials, with the use of a joystick, in which they responded to auditory statements (delivered through headphones) of the form ‘imagine facing x, point to z’ with x and z being objects from the narrative. Objects at canonical orientations served as facing objects to establish imagined perspectives, whereas those in the corners served as the targets to which participants pointed. Participants remained oriented towards the same physical orientation (aligned with the initial orientation of the protagonist[1]) throughout learning and testing. As narratives used the pronoun “you” we assume that participants mapped the initial orientation of the narrative to this physical orientation

2.2 Results

Pointing error and latency were analyzed as a function of the imagined perspective participants had to adopt on a given trial. Since the results for accuracy and latency converged, we present only the analyses on latency data for the sake of brevity.

As shown in Figure 1, participants were faster to point to targets when the imagined perspective adopted was aligned with the protagonist’s initial orientation. Performance did not differ between imagined perspectives aligned with the description orientation and the updated orientation.

Thus, participants’ performance suggested that they organized their memory around the protagonist’s initial orientation in the narrative and did not update spatial relations when the protagonist rotated to new orientations. This finding is compatible with proposals that support that people maintain spatial layouts in orientation-dependent memories based on a variety of cues available at encoding (e.g., symmetry of the layout, structure of the general space, instructions, observation standpoint, etc.) and refrain from changing the preferred orientation of their memories unless additional cues provide a substantial benefit for re-interpreting the layout (Mou & McNamara, 2002).

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[1] As narratives used the pronoun “you” to describe the position of the protagonist in the environment, we assume that participants mapped the initial orientation of the narrative to this physical orientation.

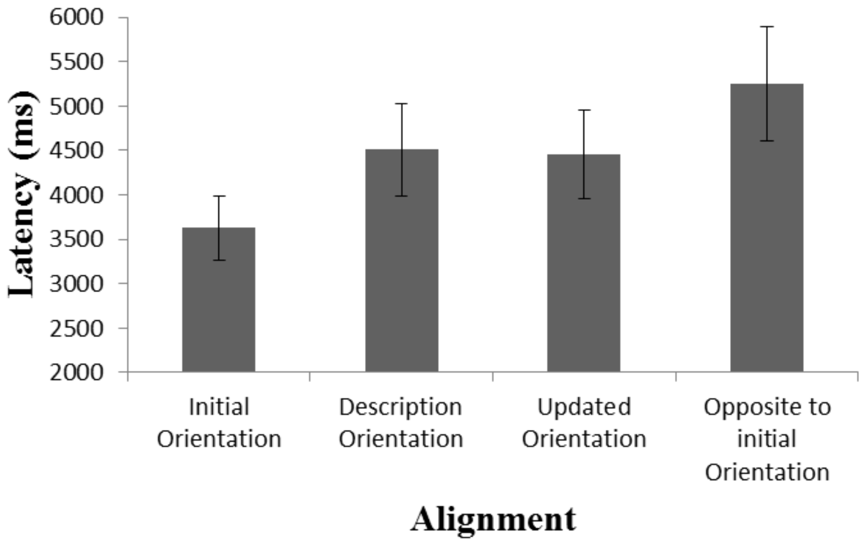

Fig. 1. Average latency as a function of imagined perspective. Error bars represent standard errors of the mean

Thus, in this context, instructions to vividly represent the environment and to imagine the protagonist's movement may have not been sufficient to reorganize the reader's initial representation of the described environment. This is compatible with claims that remote environments (including described ones) are not updated effortlessly with either physical or imagined movement (Avraamides & Kelly, 2008).

Overall, the findings of Experiment 1 indicate that, as with perceptual environments, imagined movement does not readily result in spatial updating.

3 Physical Rotation with Narratives

In the experiment described in previous section, simply imagining the protagonist's movement did not enable readers to successfully update their spatial representations. This is in line with previous findings that imagined movement in environments encoded perceptually is not sufficient for spatial updating (e.g., Rieser et al., 1994). These findings clarify that even if readers simulate the described movement, recruiting motor processes, this simulation does not lead to effortless and automatic spatial updating. The question that arises is whether updating in narratives *could* occur if the described movement is accompanied by the reader's physical movement.

A study from our laboratory (Avraamides, Galati, Pazzaglia, Meneghetti & Denis, 2013) investigated this possibility. In that study, participants read several narratives that described protagonists rotating in fictitious environments in order to inspect objects placed around them. When the protagonist was described to rotate to a different orientation, participants physically rotated to a direction that was either congruent or incongruent with the protagonist's rotation (Experiment 4). Despite this manipulation, performance in perspective-taking pointing judgments showed neither facilitation nor interference from the participant's physical orientation (whether congruent or incongruent). Instead, performance was best from the orientation in which object locations were encoded in memory, consistent with the findings presented in the previous section. The lack of influence of physical rotation suggests that people can easily suppress any sensorimotor information stemming from their physical movement when reasoning about an environment that is completely detached from their sensorimotor framework, such as an environment in a narrative world.

The results of Avraamides et al. (2013) indicate that even physical rotations, intended to link the participants' sensorimotor system to the protagonist's movement in the narrative environment, fail to result in successful spatial updating. These findings are at odds with those from studies with perceptual environments showing that physical movement coupled with visualization instructions may lead to the effortless updating of remote environments and, thus, a sensorimotor alignment effect. However, methodological differences across experiments could potentially account for the discrepancy between results. One difference is that participants in Avraamides et al. (2013) executed physical rotations by turning the swivel chair they sat on to a new orientation, whereas in the studies of Kelly et al. (2007) and Rieser et al. (1994) participants carried out extensive physical walking. It could be that the stronger idiothetic cues that are present in physical walking are necessary for updating. To examine this, we conducted another experiment in which participants (1) physically walked during the encoding of objects in a narrative, and (2) physically rotated, while standing, to adopt a new orientation just prior to testing.

4 Extensive Physical Movement in Narratives

4.1 Experiment 2

To further examine whether more involved movement *can*, in fact, give rise to a sensorimotor alignment effect and facilitate the updating of spatial representations acquired through narratives, we conducted an experiment that recruited extended physical walk. Previous studies have shown that visualization instructions and physical walk in space (Kelly et al., 2007; Rieser et al., 1994) can indeed result in spatial updating in remote environments–at least for remote environments encoded perceptually. The question is whether the same occurs for environments encoded through narratives.

In this experiment, participants were presented with a single narrative that provided a detailed description about the geometry of a store. The geometry involved 4 objects that were located at canonical orientations and 4 additional objects that were located at diagonal orientations. Participants had to memorize the position of all objects during the learning phase and then proceed to the testing phase, which involved carrying out pointing judgments with eyes open or closed. Manipulating visual access during testing aimed at investigating whether visual input influences the presence of sensorimotor interference by providing perceptual markers for the discrepancy between the actual and imagined facing direction. Participants initially stood with their backs next to one of the laboratory walls and were told that it represented the entrance of a clothing store, while the other walls of the laboratory mapped to those of the described environment. Then participants were given a printed version of the narrative to read and were instructed to move in the laboratory reproducing the movement of the protagonist in the description as they read it. The description had participants walk to the center of the room and adopt an initial facing orientation (0^{o}). Next, they walked to the far end of the room towards an object described as being directly in front of them. Then, participants followed the described movements in the narrative and moved within the room to “view” or “interact with” described objects that were present at both the four canonical (i.e., near the center of each wall) and diagonal (i.e., in the corners of the store) directions. At two occasions in the description, these movements took participants back to the center of the room. At all other instances, participants walked directly from one object to the other. After memorizing the locations of all objects, participants were instructed to return to the center and face the 0^{o} orientation and, from there, visualize the environment in the narrative. Just prior to testing participants were asked to physically rotate 90^{o} to their right. After adopting this testing orientation, they were seated and carried out perspective-taking trials just like in Experiment 1 (i.e., they responded to statements of the form ‘imagine facing x, point to z’), using a joystick that was placed in front of them. This final rotation was not linked explicitly to any described protagonist rotation.

4.2 Results

Following Kelly et al. (2007), we computed the presence of (1) an *encoding alignment effect* by subtracting the latency for responding from the initial learning orientation from the latency of responding from a baseline perspective that was opposite to the testing orientation, and (2) a *sensorimotor alignment* effect by subtracting the latency of pointing from an imagined perspective aligned with the testing orientation from the latency of responding from the baseline perspective. A significant encoding alignment effect would indicate that participants created an orientation-dependent memory at the time of encoding as claimed by McNamara and colleagues (e.g., Mou & McNamara, 2002). A significant sensorimotor alignment effect would show that participants updated the representation of the environment described in the narrative when they physically rotated to the testing perspective.

As shown in Figure 2, both alignment effects were present regardless of whether participants carried out testing with their eyes open or closed. Notably, both effects were greater when responding with eyes open. If visual access enhanced sensorimotor facilitation/interference by providing participants with a perceptual marker for their facing direction, this could explain the larger sensorimotor effect in the eyes open condition. However, this explanation cannot account for the larger encoding alignment effect. An alternative possibility is that the optic array introduced noise on the execution of mental transformations, making it harder for participants in the eyes open condition to adopt and maintain imagined perspectives other than the preferred orientation and their physical perspective at testing. Another possibility is that the available visual information made it difficult for these participants to feel as present in the remote environment as participants in the eyes closed condition.

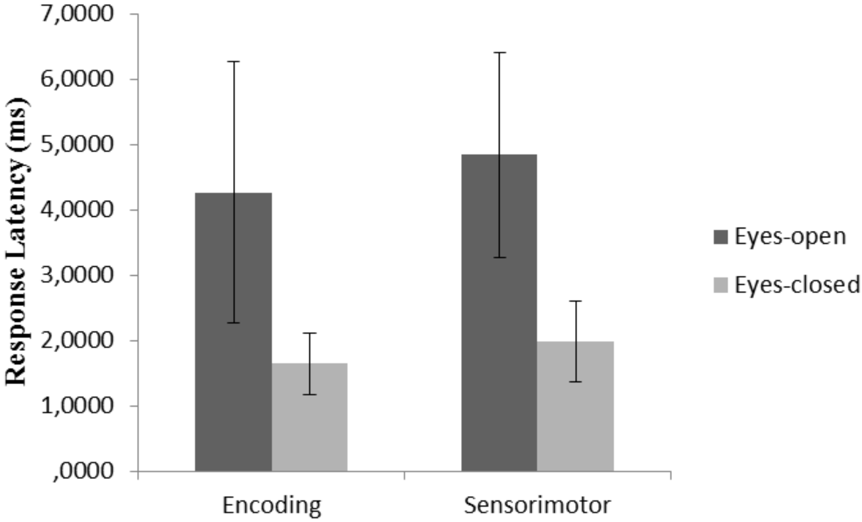

Fig. 2. Encoding alignment and sensorimotor alignment effects for response latency in Experiment 1. Error bars represent standard errors.

These results extend the findings of studies showing that extended physical movement (Rieser et al., 1994) and visualization (Kelly et al., 2007) can update spatial relations within remote environments encoded perceptually, by demonstrating that extended physical movement is effective for updating remote environments acquired through narratives as well. Whereas mere rotation or visualization on their own may be ineffective for updating spatial relations in described environments, more involved movement, like walking, can help participants link their sensorimotor framework to the remote environment (Avraamides & Kelly, 2008; May, 2004) and update it more successfully as they simulate the protagonist's changes in orientation.

5 Conclusion

The results from the two experiments reported here extend our understanding of how spatial updating takes place in remote environments and inform theories of spatial memory.

Specifically, Experiment 1 shows that despite evidence that text comprehension can have an embodied basis, with readers recruiting motor processes when reading about movement in narratives, such imagined movement does not necessarily result in the effortless updating of spatial relations. Findings from Experiment 2 indicate that updating of remote environments described in narratives can nevertheless take place, provided that the remote environment is linked efficiently to the reader's sensorimotor framework. Carrying out extensive movement towards imagined objects during learning seems to be sufficient in establishing this link. The findings from Experiment 2 contrast with those of Avraamides et al. (2013) who failed to observe any sensorimotor facilitation or interference stemming from physical rotation. Our conjecture is that the physical rotations performed while seating in a chair were not adequate to establish a strong link between the participants' sensorimotor framework and the remote described environment, possibly due to the lack of strong proprioceptive information.

Overall, the combined findings from Experiment 1 and Experiment 2 suggest that remote environments encoded from narratives are not unlike remote environments encoded from visual perception. In both cases, relations between remote objects can be updated with physical movement that creates strong links between the remote environment and people's sensorimotor framework. In this sense, our findings support the idea of functional equivalence for representations created from direct perceptual input and indirectly through language.

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