Encoding and updating spatial information presented in narratives

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Four experiments investigated whether directional spatial relations encoded by reading narratives are updated following described protagonist rotations. Participants memorized locations of objects described in short stories that placed them, as the protagonist, in remote settings. After reading a description that the protagonist rotated to the left or the right of the initial orientation, participants made judgements about object relations in the described environment (Experiment 1). Before making these judgements, participants were instructed to physically rotate to match (Experiment 2) or mismatch (Experiment 4) the protagonist's described rotation and in Experiments 3 and 4 to also visualize the changed relations following rotation. Participants' performance suggested that they relied on the initial representation they constructed during encoding rather than on the updated protagonist-to-object relations. Participants' physical movement to match the described rotation and additional visualization instructions did not facilitate updating through a sensorimotor process. In these respects, updating spatial relations in situation models constructed from narratives differs from updating in perceptually experienced environments.

Keywords: Narratives; Spatial language; Embodiment; Spatial updating.

Through language we can construct vivid mental representations about familiar, unfamiliar, and even fictitious settings and events. For example, when reading a story in a book we not only process its text incrementally but also represent in memory the state of affairs described in the text.

The situational representations constructed during language processing are generally thought to retain the semantic content or gist of sentences and are known as "mental models" (Johnson-Laird, 1983) or "situation models" (Kintsch, 1998). These models are multidimensional,

representing a number of aspects of the situation described, including spatial, temporal, causal, motivational, protagonist-related, and object-related information (Gernsbacher, 1990; Johnson-Laird, 1983; Rinck & Denis, 2004; Zwaan & Radvansky, 1998).

In some processing frameworks for situation models (e.g., Zwaan, 2004; Zwaan, Langston, & Graesser, 1995; Zwaan & Radvansky, 1998), people are thought to monitor these dimensions during comprehension, such that shifts in these dimensions incur a processing cost, reflected by increased reading times (e.g., Zwaan, Magliano, & Graesser, 1995) and associated changes in the patterns of activation of neural regions (Speer, Zacks, Reynolds, & Hedden, 2005). Supporting the proposal that monitoring these situational dimensions helps organize information in a coherent spatiotemporal framework (Zwaan & Radvansky, 1998) is evidence that people monitor the location of the protagonist in time and space. Readers spontaneously adopt the perspective of the explicit or implied protagonist when constructing situation models from narratives (Black, Turner, & Bower, 1979; Rall & Harris, 2000; Ziegler, Mitchell, & Currie, 2005) and monitor the protagonist's movement in space (Glenberg, Meyer, & Lindem, 1987).

In this work, we examine factors that may affect whether readers can monitor and update the location of the protagonist in space, in a situation model constructed through a narrative. Specifically, we examine whether instructions to physically move in a way that is congruent with the protagonist's described movement and to visualize the described environment facilitate how readers update protagonist-to-object relations in the situation model. Our enterprise is motivated by two lines of research: (a) research investigating the perceptuomotor basis of language processing, and (b) research investigating *spatial updating*—the mechanism that allows people to keep track of the changing self-to-object relations (Loomis, Da Silva, Fujita, & Fukusima, 1992; Rieser, Guth, & Hill, 1986; Wang & Spelke, 2000). We consider this research below and then outline the rationale of our studies in more detail.

The perceptuomotor basis of language processing

Some frameworks of language processing take the stance that situation models have an embodied basis, in light of evidence that perceptual experiences can be recruited during language processing (see Fischer & Zwaan, 2008, for a review of the role of the motor system in comprehension). In Zwaan's (2004) *immersed experiencer framework*, during comprehension, readers construct an experiential simulation of the described situation. This is compatible with accounts of embodied cognition that consider the representations (or neural activations) recruited during perception and motor action to be stored and partially reenacted later, "off-line" (Barsalou, 1999; Simmons, Pecher, Hamann, Zeelenberg, & Barsalou, 2003). For instance, visual representations of object orientation and shape seem to be activated during word and sentence comprehension: People are faster to make judgements about whether pairs of words (e.g., cup–saucer) are semantically related when the configuration of the words on the computer screen matches their canonical relative position in the world (i.e., cup above saucer) than when it is mismatched (Zwaan & Yaxley, 2003). Spatial congruity effects extend to the sentence level as well: After reading sentences implying different shapes or configurations of the referent (e.g., "He pounded the nail into the wall" vs. "into the floor"), people are faster to respond to pictures that match the implied configuration (i.e., a horizontal vs. a vertical nail; Stanfield & Zwaan, 2001; Zwaan, Stanfield, & Yaxley, 2002).

To the extent that readers monitor the protagonist's location in space and time (Zwaan & Radvansky, 1998) and that representations of spatial information in situation models have an embodied basis (Zwaan, 2004), physical motion congruent with the protagonist's described motion may help readers update spatial information in the situation model. Processing action sentences is indeed influenced by the congruity between described and actual movement: Participants were faster to judge sentences when the implied motion of the sentence was congruent with the

direction of their manual response (Glenberg & Kaschak, 2002). Comprehending a sentence that implied action in one direction (e.g., "close the drawer", implying action away from the body) interfered with real action in the other direction to respond (e.g., manual movement toward the body). These and related findings suggest that sentence comprehension involves the simulation of action (see Borregine & Kaschak, 2006; Kaschak & Borregine, 2008; Zwaan & Taylor, 2006, for insights into the time course of these simulations during sentence processing).

Effects of motor congruency on comprehension have been documented in electrophysiological measures as well. In an event-related potential (ERP) study (Aravena et al., 2010), when participants responded to an action sentence with an incompatible manual action (e.g., responding to a sentence with the verb "applauded", implying action with an open palm, by pressing a button with a closed fist) they exhibited an N400-like component, typically associated with difficulties in semantic integration. In line with the earlier behavioural findings, the incompatibility of the implied action with motor processes interfered with the semantic processing of the sentence. Moreover, compatible sentence–action pairings facilitated motor potentials associated with the precision and quickness of movement, suggesting that motor processes and action-language comprehension influence each other mutually and bidirectionally. In another study, action verbs presented subliminally during movement preparation affected encephalogram (EEG) recordings of the "readiness potential" (RP), an electrophysiological correlate of motor preparation, as well as the subsequent reaching movement (Boulenger et al., 2008). Altogether, these findings from cognitive neuroscience implicate cortical structures for planning and executing motor actions to processing action-related language.

Although these behavioural and electrophysiological studies demonstrate action–sentence compatibility effects for situation models for word pairings or single sentences, they do highlight the interaction between physical movement and the processing of described actions. In frameworks of situation models with an embodied basis, like the immersed experiencer framework (Zwaan, 2004), the simulation of perceptuomotor experiences is not limited to processing at the word level or clause level, but extends to the discourse level as well. Indeed, when people process route descriptions they mentally simulate the perceptual and motor aspects of the described situation (e.g., Brunyé & Taylor, 2008). Moreover, these simulations are modulated by concurrent sensorimotor information. For example, participants read route texts faster when hearing the sound of fast (vs. slow) footsteps; this was not the case when reading survey texts, which did not imply physical movement of the assumed observer (Brunyé, Mahoney, & Taylor, 2010). Thus, processing language recruits embodied representations pertinent to the described situation.

Spatial updating

Research on the factors affecting spatial updating can inform our predictions about updating in situation models. Specifically, they can illuminate how updating within mental representations of environments constructed from narratives is similar to or different from updating within representations constructed from other sources. Indeed, one of the factors affecting spatial updating is whether the environment about which people are reasoning is immediate and perceptually available versus remote.

When people move in perceptual environments they automatically update spatial information on the basis of proprioceptive cues, vestibular information, and copies of efferent commands that are available during movement (Klatzky, Loomis, Beall, Chance, & Golledge, 1998). Physical movement can lead to the automatic updating not only of perceived objects but also of objects that have been described as being in the immediate environment (Klatzky, Lippa, Loomis, & Golledge, 2003), suggesting that spatial representations derived from different inputs may be functionally equivalent (see Loomis, Klatzky, Avraamides, Lippa, & Golledge, 2007, and Loomis, Klatzky, Giudice, in press, for a detailed discussion of functional

equivalence). Thus, when reasoning about an immediate environment, people seem to be able to update automatically self-to-object relations, regardless of whether the environment has been perceptually experienced or encoded linguistically.

However, people do not seem to update automatically their orientation relative to locations in remote environments; in remote environments, updating appears to be more effortful and deliberate (Wang, 2004; Wang & Brockmole, 2003). In Wang and colleagues' paradigm, participants first encoded in memory the locations of five objects placed around them in the lab and also imagined the locations of five objects from a remote environment—for example, an imagined familiar environment (their kitchen, in Wang, 2004) or the remote environment in which they were situated (the campus, in Wang & Brockmole, 2003). Upon rotating to adopt a perspective that differed from their initial learning perspective, participants pointed to each object in the lab and each location in the remote environment. When participants rotated relative to objects in their immediate environment, pointing towards lab objects was faster and more accurate than towards locations in the remote environment. However, when they rotated relative to locations in the remote environment, there was no advantage for pointing to locations in the remote environment—participants pointed equally well both to immediate and remote locations. Thus, people seem to update automatically only locations in their immediate environment, though they can deliberately update locations in remote environments just as efficiently when they are explicitly instructed to.

Another factor affecting spatial updating is whether people's change in orientation involves real or imagined movement (Presson & Montello, 1994; Rieser, 1989). Even though updating in remote environments may not be automatic (Wang, 2004; Wang & Brockmole, 2003), when physically moving while reasoning about remote environments, people can successfully update their orientation relative to remote locations. Information available during physical movement may thus be necessary for spatial updating, as suggested by findings that people update locations

effortlessly when they move but require deliberate processing to compute new self-to-object relations when they imagine moving (e.g., Presson & Montello, 1994; Rieser, 1989; Rieser, Garing, & Young, 1994). For example, in the study by Rieser et al. (1994), young children and their parents were asked to imagine being in the classroom, while being in fact at home, and to point to a number of objects, first from the child's seat and then from the teacher's seat and orientation. Participants in one condition were asked to imagine walking towards the teacher's seat and rotating to adopt the teacher's facing perspective, whereas, in another condition, to physically walk the path they were imagining. When they had walked the path they had imagined, both adults and children were similarly fast and accurate at pointing from the teacher's seat. In contrast, when they had only imagined the path, adults were significantly more accurate than children. In this condition, 5-year-olds were faster than 9-year-olds and adults, but their responses revealed they were making judgements from their own seat ("no shift" responses), suggesting that they did not understand the task. But even adults who pointed accurately when they had only imagined the path were significantly slower than when they had physically walked the path.

Physical movement can therefore be represented relative to imagined, remote environments that are called to working memory in similar ways to the way it is represented relative to the immediate environment. One possible mechanism underlying the updating of remote objects is that people establish links between their body and remote objects, anchoring objects into a sensorimotor framework (De Vega & Rodrigo, 2001). Recruiting a sensorimotor framework when moving, even with respect to a remote environment, is also broadly in line with the embodied cognition view that sensorimotor mechanisms are recruited even when cognition is decoupled from the immediate environment (e.g., Simmons et al., 2003; see Wilson, 2002, for a discussion).

To summarize, people can update automatically their orientation relative to objects in their immediate environment that they have perceived or that

have been described to them, and they can update their orientation relative to objects in imagined, remote environments upon explicit instruction (though this updating seems to be more deliberate and less automatic) and upon physical (but not imagined) movement.

These findings can be largely accounted for by a framework positing distinct transient sensorimotor and enduring allocentric spatial representations that can interface (Avraamides & Kelly, 2008). In line with earlier proposals (Mou, McNamara, Valiquette, & Rump, 2004; Sholl, 2001; Waller & Hodgson, 2006), Avraamides and Kelly (2008) argued that upon experiencing a spatial layout, people construct these two representations simultaneously: The transient sensorimotor representation codes self-to-object relations, whereas the enduring allocentric representation maintains object-to-object relations and is stored in memory from a preferred direction, as suggested by McNamara (2003). According to this framework, one's position in the layout can serve as an interface between the two representations: It is the origin of the sensorimotor representation, and it is represented as a location in the allocentric representation. When reasoning about the immediate environment, pointing to immediate objects from memory is more efficient for imagined perspectives aligned with one's facing direction, because at any given moment their sensorimotor representation is oriented to one's facing direction. In contrast, when reasoning about a remote environment, one's sensorimotor representation is irrelevant to the task since it maintains the immediate surroundings, so one uses the allocentric representation instead. This distinction can account for why sensorimotor alignment effects (i.e., better performance when reasoning from imagined perspectives that are aligned with one's actual facing orientation) are observed in immediate environments but not in remote ones. However, although by default sensorimotor and allocentric representations are dissociated when reasoning about remote environments, the two representations can interface through manipulations that encourage one to anchor the locations of remote objects to the sensorimotor representation (e.g., physically rotating

to face objects in the remote environment, performing a physical movement that simulates movement in the remote environment, or visualizing the remote objects). Under such conditions, sensorimotor alignment effects are tenable when reasoning about remote environments (Kelly, Avraamides, & Loomis, 2007; May, 2007).

Can people update spatial relations in narratives?

With respect to remote, imagined environments that have never been perceptually experienced but have instead been described, it is currently unclear whether readers' sensorimotor spatial representation at a given moment can be linked to the enduring representation of the described environment and thus facilitate updating protagonist-to-object relations within that environment. On one hand, if language can give rise to embodied spatial representations that are functionally equivalent to those derived from other modalities, based on previous evidence with perceptual scenes (e.g., Kelly et al., 2007; May, 2007), one should expect the automatic updating of remote locations that are encoded through language. On the other hand, a description of a remote environment may rely on a different type of embodiment that is detached from immediate perceptual experiences or actions. The text may activate high-order motor representations but not specific motor programs that could influence updating (De Vega, 2008). Also, narratives typically include information about several situational dimensions, which can be demanding on working memory resources to incorporate and maintain in a situation model (e.g., De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2011; Pazzaglia, De Beni, & Meneghetti, 2007). Therefore, people may monitor situational dimensions—including the protagonist's location in space—as needed; upon constructing a spatial model from the narrative, they would thus update spatial relations only when necessary.

A study by Avraamides (2003) has examined directly spatial updating for locations described as

part of narratives. Participants read stories describing themselves within various settings (e.g., a museum, a hotel lobby, etc.) and were asked to remember the locations of six objects located at the extensions of the body axes (i.e., above, below, front, back, left, and right). In one condition, participants sat on a swivel chair and were asked to physically rotate to various canonical orientations (i.e., 90° to the left, 90° to the right, and 180° of the learning perspective) to match a described protagonist's rotation in the memorized environment and locate target-objects from that orientation. Performance for the learning perspective (i.e., 0°) was faster than that for any of the testing perspectives, which was interpreted as participants not updating the object locations during the physical movement. However, this interpretation may not have been warranted. To determine whether updating took place, Avraamides (2003) used performance from the learning perspective as the baseline for comparing performance for other perspectives. This is problematic in light of what is now known about the privileged status of the learning perspective in memory—namely, that in the absence of any environmental cues, the learning perspective determines a preferred direction from which spatial memories are stored (e.g., McNamara, 2003; Mou, McNamara, et al., 2004). Thus, the performance difference between the learning and the testing perspectives reported by Avraamides (2003) may have indicated a preferred status for the learning perspective as opposed to an updating failure.

We carried out a series of experiments to investigate this possibility and to reexamine whether the orientation of one's body may influence the retrieval of spatial information in situation models. Across Experiments 1 and 2, we examined whether real movement accompanying a described change in the protagonist's perspective facilitates updating the protagonist's relations to objects in the situation model. Updating in imagined, described environments may be similar to updating in imagined, remote environments, in terms of being facilitated by physical movement (Rieser et al., 1994). Such a facilitative effect would be broadly compatible with proposals that situation models have an embodied basis (e.g., Zwaan, 2004) and with findings suggesting an interaction between physical motion and sentence processing (e.g., Glenberg & Kaschak, 2002). On the other hand, a facilitative effect may be absent if spatial relations in the described environment are not relevant or are hard to compute. This is consistent with findings that readers may not encode or monitor spatial information that is not central to the task (Radvansky & Copeland, 2000; Zwaan & van Oostendorp, 1993), instead computing protagonist-to-object relations only when necessary. In Experiments 3 and 4, we examined whether explicit instructions to visualize the described environment, following the protagonist's described movement and the participants' accompanying physical movement, can facilitate updating protagonist-to-object relations. A facilitative effect would be compatible with findings that instructions to encode spatial relations within stories are generally effective, even if they increase processing load (Zwaan & van Oostendorp, 1993). It would also be compatible with findings that updating in remote (though experienced) environments is successful upon explicit instruction (Wang, 2004; Wang & Brockmole, 2003).

In the four experiments, participants read narratives that placed them within a fictitious environment at a particular orientation surrounded by various objects (Avraamides, 2003; Franklin & Tversky, 1990). Following learning, participants (as the protagonists) were described as rotating to a new perspective in the scene that was 90° to the left or right of the learning perspective. Subsequently, they were asked to respond to a series of statements of the form "Imagine facing *x*, point to *y*". Thus, trials involved adopting imagined perspectives that were aligned or counteraligned to the learning perspective and aligned or counteraligned to the testing perspective. Performance from the opposite-testing perspective was used as a baseline to determine the presence of separate effects attributed to the initial encoding and the subsequent updating of locations (see also, Kelly et al., 2007). If participants maintained a memory representation that remained fixed to the initial learning orientation even after the

described change of perspective, performance should be better for the learning than the opposite-testing perspective. If participants updated their initial representation (by either overwriting the original or by creating an additional representation), then performance for the testing perspective should be better than performance for the opposite-testing perspective.

General method

Overview

In order to examine whether readers can monitor changes in orientation in a described environment and update spatial relations within it, participants in Experiment 1 maintained a physical orientation that was at all times aligned with their learning orientation and only imagined rotating to the novel perspective following learning. To investigate the effects of physical movement on updating described locations, participants in Experiments 2 and 3 were asked to physically rotate in a way congruent with the protagonist's described rotation. Furthermore, in Experiment 4 we included a condition in which participants rotated to the opposite direction from the protagonist so that their physical orientation was incongruent to that of the protagonist; this enables us to establish whether such sensorimotor incongruence interferes with updating. To determine whether visualization instructions would facilitate (or hinder) spatial updating beyond physical rotation on its own, participants in Experiments 3 and 4, following the physical rotation, were asked to visualize where each object was relative to the protagonist's updated orientation in the described environment.

Design

All experiments employed a within-subjects design with perspective alignment as the independent variable. Perspective alignment depended on whether the imagined perspective adopted in a given testing trial was aligned with the orientation from which locations were encoded (learning perspective), the protagonist's orientation following the described rotation (testing perspective), which was imagined in Experiment 1 and physically adopted

in Experiments 2 and 3 (and in one condition of Experiment 4), or with either of the two remaining canonical orientations—that is, the orientations opposite to the learning and testing perspectives. In Experiment 4, we manipulated within participants the direction of the physical rotation to create conditions in which the participants' physical orientation during testing was congruent with the learning orientation, congruent with the updated orientation of the protagonist, or incongruent with both.

Materials

Four target stories and one practice story were constructed, each segmented into eight sections that were displayed separately during a given block. In Experiments 1, 2, and 3, the narratives in the experimental blocks were each about a protagonist's visit to a construction site, a hotel lobby, an opera house, and a museum, and the narrative for the practice block was about a visit to a courtroom. In Experiment 4, only three narratives were used, one for each of the three experimental conditions of alignment of the participant's and the protagonist's physical orientation: The construction site narrative was dropped. Although no information was provided about the size of the remote environments, the typical size of the type of places that were described is larger than that of the laboratory in which the experiment took place (a 4×4-m square room). All narratives were in Greek and were described in the second person, as if the participant were the protagonist. Text presented during the learning phase included descriptions of the protagonist observing objects or locations and at one point rotating in the remote environment, with interstitial instructions for participants to form a mental image of the scene.

The structure of the narrative text was as follows: (a) A 3–4-sentence introduction provided the rationale for the protagonist's presence in the described location (e.g., "You are meeting a friend for dinner at Hotel Palace"), along with additional, filler information to make the story more engaging (e.g., "The hotel is brand new and you have never been here before. But you have heard from many people that it is the most luxurious hotel in

town."). (b) The introduction was followed by a description of the geometry of the environment. In all stories, the protagonist was described as standing at the centre of a square room, facing a specific direction. (c) Protagonists were then described to turn their head around to the four canonical egocentric directions to observe four objects or locations (e.g., in the case of the hotel lobby, the swimming pool could be seen in the front, the reception to the left, the elevators to the right, and the lobby entrance at the back of the protagonist). The order in which locations were introduced in the text was counterbalanced across narratives. These objects/locations, hereafter referred to as *orienting stimuli*, served in the testing phase as facing cues for adopting imagined perspectives. These orienting locations were supplemented by visual details to allow participants to construct a vivid mental image of the environment (e.g., "the painting depicts a scene from the ancient Greek mythology with the 12 gods from mount Olympus. You stare at the painting for a while thinking that its colours do not match well with those of the courtroom"). (d) Next, some text explicitly instructed participants to form a mental image that included the four orienting locations. (e) Following this instruction, four additional objects or locations were described as being at the corners of the square room (e.g., in the hotel narrative, a bar, a fountain, a gift shop, and a tavern were described as being at the corners of the lobby), which protagonists were described to examine by turning their heads around the room. These objects/locations, hereafter referred to as *target stimuli*, served as pointing targets in the testing phase. Their locations in the environment were described using both egocentric (e.g., "in the front right corner of the lobby") and allocentric (e.g., "between the entrance and the elevators") terms and were accompanied by visual details to aid the construction of a vivid representation. (f) Next, some text instructed participants to form a mental image of the environment that included both the orienting and the target locations. (g) Subsequently, in Experiment 1, a reorientation instruction was displayed, describing the protagonist to rotate 90° to the left or right. In

Experiments 2 and 3, an additional sentence was presented instructing participants to physically rotate towards the same direction. In Experiment 4, depending on congruency condition, the reorientation instruction asked participants to rotate towards the same or opposite direction to the protagonist, or else to remain in the learning orientation. (h) A sentence then instructed participants to report to the experimenter which object was now in front of the protagonist (i.e., the protagonist's updated orientation). This aimed at verifying that participants had updated their imagined facing direction in the described scene. In Experiment 3, in addition to reporting the object in front of them, participants were also asked to visualize all objects of the described environment from the protagonist's new orientation. (i) Finally, two filler sentences concluded the narrative, and participants proceeded to the testing phase.

Set-up
The experimental set-up used across experiments is shown in Figure 1. A computer running the E-Prime 2 software generated trials and was connected to three identical 19-inch LCD monitors using a VGA (video graphics array) splitter. Thus, the displays generated by the computer were mirrored on three monitors that were positioned to the front of and the sides of the participants' initial facing direction. Directly in front of them at their initial facing direction, participants had a keyboard and a joystick (Logitech Attack 3), which were used to carry out the experiment.

Participants sat in a swivel chair at a comfortable distance from the monitors. In Experiment 1, participants were not allowed to turn during the testing phase, whereas in Experiments 2, 3, and 4, they were instructed to turn 90° to the left or right, lifting the joystick and moving it along with them.

Procedure
Each experiment consisted of one practice block and four (in Experiments 1, 2, and 3) or three (in Experiment 4) blocks of experimental trials, each of which included a learning phase and a testing phase. In each learning phase, participants read a
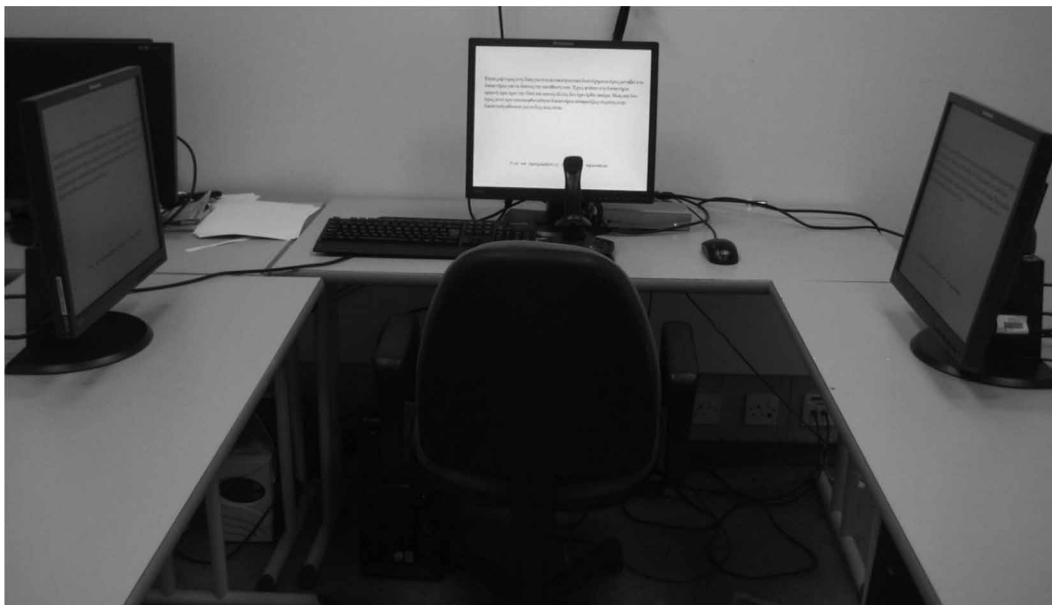
Figure 1. *The experimental set-up used in Experiments 2, 3, and 4. During the learning phase, participants were oriented in the direction shown by the chair. Prior to testing, they rotated 90° to the left or right of the learning orientation and completed the testing trials on one of the side monitors.*

different narrative describing in the second person a protagonist at a remote environment. Each story was presented a few sentences at a time as described in the Materials section. Participants had unlimited time to read the text on the screen, and, prior to the reorientation instruction, they could move freely back and forth between the screens of text (i.e., they could reread descriptions of the locations and objects in the environment). An example of the arrangement of objects during the narrative is shown in Figure 2.

For each narrative, participants first read an introduction of the protagonist with a rationale for being at the remote environment, followed by a description of the geometry of the environment (a square room) and the protagonists' facing direction while at the centre of the room. Then participants read about the protagonist turning around to observe the four orienting stimuli at the protagonist's canonical egocentric directions, and they were then given an explicit instruction to form a mental image including the four orienting locations. Next, participants read descriptions of the four target stimuli, at the four corners of the
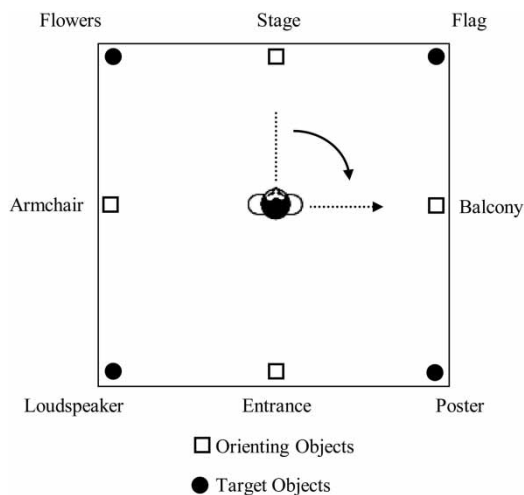

Figure 2. *Arrangements of objects in the opera house narrative. Dotted line indicates the learning orientation. Dotted arrow represents an updated orientation, when the protagonist is described to rotate 90° to the right.*

remote environment, and were again given an explicit instruction to form a mental image of the environment with the orienting and target

locations. Up until this point, participants could use keyboard buttons to go back to previous screens of text in order to read again any of the descriptions. Next, participants read that protagonists rotated 90° to the left or right of their initial facing direction in the remote environment.

In Experiment 1, participants were asked to imagine themselves as protagonists rotating towards the described direction. In Experiments 2 and 3, they were also instructed to carry out the equivalent rotation in the laboratory. In Experiment 4, they either stayed in their initial orientation and imagined rotating with the protagonist or rotated to the same or opposite direction to the protagonist. In Experiments 2, 3, and 4, participants were asked to take the joystick in their hands before rotating and move it with them to their new orientation. In all four experiments, participants were then asked to report to the experimenter the protagonist's updated orientation (i.e., which object was in front of the protagonist following rotation). This was done to ensure that participants monitored the protagonist's change of orientation. If participants failed to report the correct object, they were asked to go back to reread the narrative. In Experiments 3 and 4, following the rotation, participants were also instructed to visualize where each object was relative to the protagonist's updated orientation in the described environment.

After reading the final two filler sentences of the narrative, aimed at diverting the focus of attention away from the facing object, participants proceeded to the testing phase. The testing phase, at participants' new orientation, involved a series of trials in which participants were asked to point to target stimuli from imagined perspectives established by orienting stimuli. Thus, each trial started by presenting on the computer screen a sentence of the form "Imagine facing x", where x was one of the four orienting stimuli. Participants pressed a button on the joystick to indicate that they have adopted the imagined perspective. The time participants took to do so, their *orientation latency*, was recorded. Then, a statement of the form "point to y" was shown, where y was one of the four target stimuli. Participants were instructed

to point with the joystick to the target location from the imagined perspective and press the trigger to log their response. The time participants took to do so, their *pointing latency*, was also recorded. The accuracy of pointing (correct vs. incorrect) was also recorded and analysed.

Each experimental block involved two repetitions of the 16 possible combinations of orienting and target locations (randomized for each participant), resulting in a total of 128 trials per participant for all four narratives. The practice block contained 16 trials only. In Experiments 1, 2, and 3, the direction (left or right) of the protagonist's described physical rotation was random for the practice block and randomized across experimental blocks for each participant. In Experiment 4, the protagonist rotated to the left in all stories for half of the participants and to the right for the other half.

Data analysis

Accuracy, orientation latency, and response latency were analysed with repeated measures analyses of variance (ANOVAs) employing Greenhouse–Geisser corrections for violations of sphericity when necessary.

Planned contrasts were subsequently used to examine whether encoding and sensorimotor alignment effects were present. An encoding alignment effect refers to a performance advantage of the learning perspective—the perspective from which locations in the narrative were described—suggesting that people maintained the layout in memory from a preferred direction aligned with the learning perspective (Kelly et al., 2007; McNamara, 2003). A sensorimotor alignment effect refers to an advantage of the testing perspective (Kelly et al., 2007; Mou, McNamara, et al., 2004)—the perspective following the reorientation description (and physical rotation in Experiments 2, 3, and 4). As in previous studies (e.g., Kelly et al., 2007), the orientation opposite to the testing orientation was used as a baseline to which performance from the learning and the testing orientations was evaluated. Specifically, an encoding alignment effect in accuracy was computed by subtracting for each participant the

accuracy for trials aligned with the opposite-testing perspective from that for those aligned with the learning perspective. Similarly, a sensorimotor alignment effect was computed by subtracting the accuracy for the opposite-testing perspective from accuracy for the testing perspective. For orientation and pointing latency measures, the subtraction of these terms was reversed when computing the encoding and sensorimotor alignment effects.

EXPERIMENT 1

Some studies suggest that when people reason about environments that have been encoded through reading narratives, they are sensitive to the protagonist spatial location and monitor described spatial shifts (e.g., Glenberg et al., 1987). However, they may update the protagonist's spatial location only when necessary, given the cognitive demands of incorporating and maintaining situational dimensions in a mental model (De Beni et al., 2005; Pazzaglia et al., 2007). Indeed, there is evidence that when people reason about environments that have been encoded from direct perception, they do not automatically update spatial relations with imagined movement (e.g., Presson & Montello, 1994; Rieser et al., 1994). Thus, the primary goal of Experiment 1 was to establish that protagonist-to-object directional relations encoded in narratives are not updated automatically following imagined rotation. In this respect, Experiment 1 serves as a control condition for the subsequent experiments in which the protagonist's described rotations are accompanied by participants' physical movement.

A secondary goal of Experiment 1, given a confluence of previous evidence, was to verify that people maintain spatial relations in memory from the initially described orientation. Such evidence comes from studies on spatial frameworks (e.g., Franklin & Tversky, 1990), where participants read descriptions of the locations of six objects occupying the extensions of the protagonist's three egocentric axes (i.e., above, below, front, back, left, right). Following encoding, the protagonist is described to adopt the four canonical

orientations (i.e., 0°, 90°, 270°, and 180°), and participants are asked to locate, from each of these orientations, all memorized objects by choosing the appropriate verbal label (e.g., front, left). Participants generally are fastest to locate objects on the above–below axis, slower to objects on the front–back axis (though faster for front than back), and slowest for objects on the left–right axis. Importantly, this pattern of accessibility is present in all four orientations adopted by the protagonist, suggesting that participants update spatial information as the protagonist reorients in the scene. Also relevant to the current study is that participants are faster to locate objects from the initial orientation of the protagonist than the subsequent orientations that the protagonist is described to adopt. This suggests that people maintain spatial information from language in an orientation-dependent representation whose orientation is determined by the initial described orientation.

Additionally, the initially described or experienced orientation has an advantage when reasoning about environments presented through both route and survey perspectives. In a study by Shelton and McNamara (2004), participants learned four-leg paths either by viewing movies of simulated motion within a virtual environment or by reading text descriptions about the movement (Experiment 1); these movies and descriptions, in separate conditions, involved either a route (i.e., ground-level perspective and changing heading at turns) or a survey perspective (i.e., aerial perspective and a fixed northbound heading). Participants' memories were tested using scene recognition: Participants indicated whether survey and route perspective images taken from various angles were from the memorized environments. When learning survey texts and movies, participants were faster to recognize survey scenes (but not route scenes) from the displayed or described orientation than any other orientations. Similarly, when learning from route text, participants were faster to recognize route scenes (but not survey scenes) from the initial orientation described in the text description. However, when learning from route movies, they were faster to recognize route scenes from the orientation that matched their heading at each leg

of the route. A follow-up experiment (Experiment 3) using both scene recognition and judgements of relative directions (JRDs; "Imagine being at x facing y, point to z") for paths learned from route movies showed that the advantage of the heading of each leg was limited to scene recognition. For JRDs, there was instead an advantage of the initial orientation, as participants pointed faster from orientations aligned with the initial orientation of the path. Related findings from Wilson, Tlauka, and Wildbur (1999; see also Wildbur & Wilson, 2008) also show that, upon encoding from language a three-leg path, participants are faster and more accurate to point between points in the path from orientations that are aligned with their facing orientation (and their first leg of the path) than from those that are counteraligned. Overall, these findings suggest that the initial orientation adopted in a viewed or described environment has a preferred status in memory, possibly indicating that it is used to maintain an orientation-dependent allocentric memory (see also McNamara, 2003).

With these goals in mind—of establishing whether participants update spatial relations following the protagonist's imagined movement and whether they use the protagonist's initial orientation as a preferred direction in memory—we had participants in this experiment maintain their initial facing orientation and asked them to imagine rotating 90° to the left or right as described in the text. In contrast to previous studies (e.g., Avraamides, 2003; Franklin & Tversky, 1990), spatial updating is not assessed by comparing performance between the learning and updated orientations of the protagonist, which is problematic given evidence for the preferred status of the initial orientation. Instead, it is examined by comparing performance between trials that entail adopting the updated protagonist orientation and the perspective that was exactly in the opposite direction (see Kelly et al., 2007).

Method

Twenty students (6 male and 14 female) participated in the experiment in exchange for either course credit or monetary compensation (€10). All participants signed informed consent forms prior to the experiment and were debriefed afterwards. In this experiment, participants remained at all times aligned with their learning orientation and were not allowed to rotate in their swivel chair.

Results

Data from one participant were discarded from all analyses due to low accuracy (<20%). There was no evidence of speed–accuracy trade-offs: Accuracy was negatively correlated with both response latency and orientation latency, $r(18) = -.54$, $p < .05$, and $r(18) = -.52$, $p < .05$, respectively. Orientation and response latency were correlated positively although the correlation was not significant, $r(18) = .35$, $p = .15$.

Participants' accuracy depended on whether the imagined perspective adopted in each testing trial was aligned with the orientation participants had during learning; the main effect of perspective alignment was significant, $F(3, 54) = 4.67$, $p < .01$, $\eta^2 = .21$. As shown in Table 1, participants were the most accurate when imagined perspectives at testing were aligned with the learning orientation. Planned contrasts showed a significant encoding alignment effect, $t(18) = 3.04$, $p < .01$: Accuracy was reliably higher for trials aligned with the learning perspective than for those aligned with the perspective opposite to testing. Although the average accuracy was somewhat higher for trials aligned with the testing perspective (81%) than those aligned with the perspective opposite to testing (78%), this difference was not reliable; the sensorimotor alignment effect was not significant, $t(18) = 1.30$, ns. The magnitude of the encoding and sensorimotor effects for accuracy is depicted in Figure 3.

Participants' orientation latency also depended on whether the imagined perspective adopted during testing trials was aligned with that of learning; again, there was a significant main effect for perspective alignment, $F(3, 54) = 3.02$, $p < .05$, $\eta^2 = .14$. Participants were faster to adopt an imagined perspective when it coincided with the learning orientation than any of the other three

Table 1. *Mean accuracy, orientation latency, and response latency as a function of perspective in Experiments 1, 2, and 3*

	Imagined perspective			
Experiment	Learning	Testing	Opposite testing	Opposite learning
Experiment 1				
Accuracy (%)	89.24 (17.84)	81.03 (20.82)	78.12 (25.25)	82.99 (22.07)
Orientation latency (ms)	2,895 (1,057)	3,617 (1,509)	3,582 (1,666)	3,568 (1,734)
Response latency (ms)	3,538 (1,418)	4,624 (2,013)	4,489 (1,974)	5,142 (2,489)
Experiment 2				
Accuracy (%)	88.19 (13.98)	81.60 (18.42)	77.40 (19.46)	81.17 (21.18)
Orientation latency (ms)	3,006 (778)	3,341 (956)	3,500 (1,156)	3,474 (1,374)
Response latency (ms)	3,398 (1,154)	4,544 (1,734)	4,443 (1,659)	4,512 (1,927)
Experiment 3				
Accuracy (%)	84.71 (19.96)	70.98 (24.60)	68.86 (22.72)	69.64 (23.48)
Orientation latency (ms)	3,201 (995)	3,889 (1,319)	3,805 (1,243)	3,688 (1,251)
Response latency (ms)	4,219 (1,199)	5,712 (1,979)	5,607 (1,909)	5,695 (2,172)

Note: Values in parentheses are Standard Deviations.
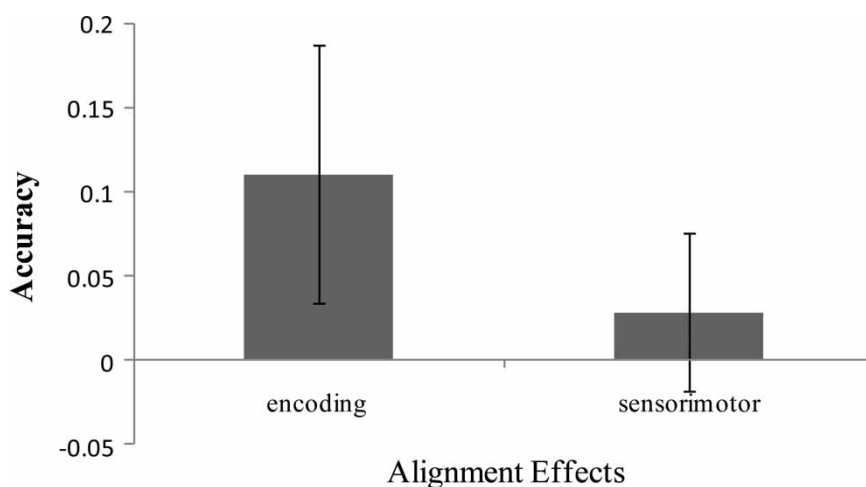
Figure 3. *Encoding alignment and sensorimotor alignment effects for accuracy in Experiment 1. The sphericity assumption was violated in this analysis ($\varepsilon = .64$), therefore separate confidence intervals were computed for each contrast. Error bars represent 95% confidence intervals.*

perspectives (see Table 1). As with accuracy, planned contrasts revealed a significant encoding alignment effect, $t(18) = 2.39$, $p < .05$, but no sensorimotor alignment effect, $t(18) = -.13$, *ns* (Figure 4a).

Results for response latency converged with those for accuracy and orientation time. How fast participants responded from an imagined perspective depended on whether it was aligned with that of learning; the main effect of perspective alignment was significant, $F(3, 54) = 10.72$, $p < .001$, $\eta^2 = .37$. As shown in Table 1, participants were fastest to respond from perspectives aligned with their learning orientation than from the other three orientations. As shown in Figure 4b, there was a significant encoding alignment effect, $t(18) = 3.54$, $p < .01$, but no sensorimotor alignment effect, $t(18) = -0.48$, *ns*.
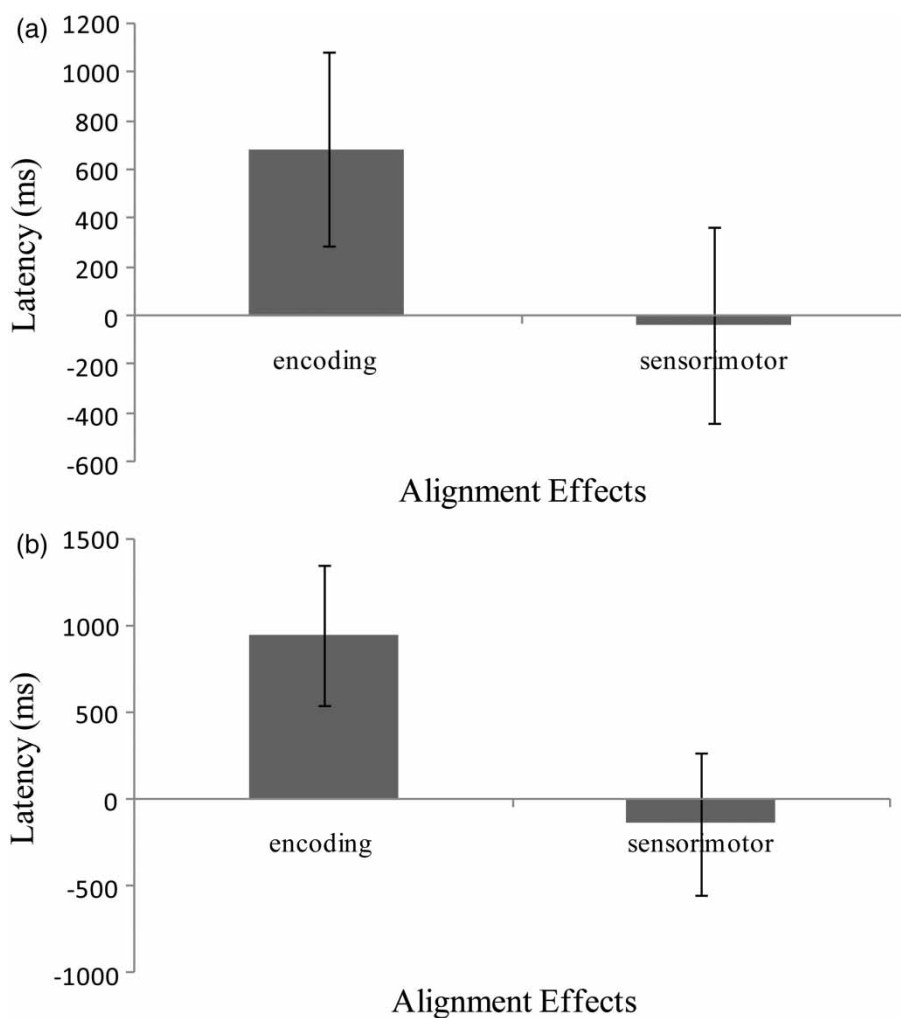
Figure 4. *Encoding alignment and sensorimotor alignment effects for latency in Experiment 1. Error bars represent 95% confidence intervals based on a pooled estimate of variability (Masson & Loftus, 2003). Panel a depicts orientation latency, and Panel b depicts response latency.*

Discussion

Results from Experiment 1 suggest that participants represented the locations described in the narrative relative to the orientation they had occupied while reading the narrative and did not update protagonist-to-object directional relations during the imagined rotation. These findings suggest that, just like perceptual environments (e.g., Mou, McNamara, et al., 2004), scenes experienced through narratives are maintained in orientation-dependent representations that are not updated with imagined

movement. The advantage of reasoning from perspectives aligned with the protagonist's initial orientation is in line with Shelton and McNamara (2004), Wilson et al. (1999), and Franklin and Tversky (1990). If reading the sentence about the protagonist rotating involves simulation of the perceptuomotor experience of rotating within the described environment, as suggested by frameworks of situation models with an embodied basis (Zwaan, 2004), such mental simulation may not be sufficient to update at once all spatial relations within the model.

It is, however, possible that updating spatial relations within the situation model could be facilitated by readers physically emulating the protagonist's described movement. Physical movement leads to the automatic updating of immediate environments encoded from vision (e.g., Presson & Montello, 1994; Rieser, 1989), audition (Klatzky et al., 2003), haptics (Giudice, Betty, & Loomis, 2011), and verbal descriptions (e.g., Klatzky et al., 2003). However, physical movement relative to remote environments does not typically lead to the automatic updating of spatial relations (Avraamides & Kelly, 2010; De Vega & Rodrigo, 2001), although deliberate updating is possible upon explicit instruction (Wang, 2004; Wang & Brockmole, 2003). For instance, when people were asked to rotate relative to an object from their kitchen (Wang, 2004) or a location in their campus (Wang & Brockmole, 2003), they were able to update locations in that remote environment. Similarly, in the study by Rieser et al. (1994), walking towards the teacher's desk and rotating at it allowed updating of the locations of classroom objects. Given these findings about remote but perceptually experienced environments, physical movement relative to objects in remote, described environments may allow linking of remote locations to a sensorimotor framework and therefore enable updating of spatial relations within the situation model.

Experiment 2 may also allow us to rule out an alternative explanation for the findings of Experiment 1. In Experiment 1, participants imagined rotating to the updated perspective but then JRDs entailed carrying out further imagined transformations. It is thus possible that the frequent reorientations required by JRDs had masked the effects of updating. As previous research with perceptual environments indicates that it is very difficult to ignore a physical rotation (Farrel & Robertson, 1998), such masking is unlikely to occur in Experiment 2.

EXPERIMENT 2

In Experiment 2, we investigated whether physical movement would enable participants to update protagonist-to-object relations in remote environments that are encoded from narratives. If physical movement helps participants to link objects in a sensorimotor framework, we would expect to observe faster and/or more accurate performance when responding from the testing perspective than its opposite perspective, whether in addition or in place of facilitation of the encoding perspective. Facilitation of the testing perspective would be compatible with the facilitative effect of physical motion in updating remote environments (e.g., Rieser et al., 1994), with findings of an interaction between physical motion and sentence processing (Glenberg & Kaschak, 2002), and with situation models having an embodied basis (e.g., Zwaan, 2004).

Method

Twenty-seven students (9 male and 18 female) participated in the experiment in exchange for either course credit or monetary compensation (€10). All participants signed informed consent forms prior to the experiment and were debriefed afterwards. The set-up and procedure were identical to those of Experiment 1 with one notable exception. When a story protagonist was described to rotate 90° to the left or right, a reorientation instruction was simultaneously presented, asking participants to carry out the equivalent rotation in the laboratory to face one of the monitors positioned on either side. Testing trials were thus presented on one of the side screens depending on the direction of rotation.

Results

There was no evidence of speed–accuracy trade-offs: Accuracy was negatively correlated with response latency, $r(26) = -.62$, $p < .001$, but it was not significantly correlated with orientation latency, $r(26) = -30$, $p = .13$. Orientation and response latency were correlated positively, $r(26) = .42$, $p < .05$.

Participants' accuracy depended on whether the imagined perspective adopted in each testing trial was aligned with the orientation participants had

during learning; there was a significant main effect for perspective alignment, $F(3, 78) = 6.91$, $p < .001$, $\eta^2 = .21$. As shown in Table 1, the average accuracy was higher for trials aligned with the learning perspective and lower for those aligned with the perspective opposite to testing, as confirmed by a significant encoding alignment effect, $t(26) = 4.64$, $p < .001$. Average accuracy was also higher for trials aligned with the testing perspective than for those aligned with the perspective opposite to testing, as confirmed by a significant sensorimotor alignment effect, $t(26) = 2.17$, $p < .05$. However, a pairwise t test revealed that the encoding alignment effect was significantly greater than the sensorimotor alignment effect, $t(26) = 2.36$, $p < .05$. The magnitude of the encoding and sensorimotor effects is shown in Figure 5.

Participants' orientation latency also depended on whether the imagined perspective adopted during testing trials was aligned with that of learning; again, there was a significant main effect for perspective alignment, $F(3, 78) = 3.60$, $p < .05$, $\eta^2 = .12$. As shown in Table 1, orientation latency was shorter for trials aligned with the learning perspective than for the other three perspectives. There was a significant encoding alignment effect, $t(26) = 3.33$, $p < .01$ (Figure 6a) but,

unlike participants' accuracy, no sensorimotor alignment effect was found, $t(26) = 1.43$, $p = .16$.

A similar pattern emerged for participants' response latency: There was a significant main effect for perspective alignment, $F(3, 78) = 12.26$, $p < .001$, $\eta^2 = .32$, a significant encoding alignment effect, $t(26) = 5.2$, $p < .001$, but no significant sensorimotor alignment effect, $t(26) = -0.51$, ns (Figure 6b). As shown in Table 1, response latency was shorter for trials aligned with the learning perspective than for all other conditions.

Discussion

The results of this experiment suggest that, even when participants rotated physically as if they were the protagonist, their reasoning about spatial relations persisted to show facilitation primarily for their initial, learning perspective. The encoding alignment effect in both accuracy and the two latency measures suggests that, when reading descriptions of locations, participants constructed a spatial representation with a preferred direction determined by the learning perspective and referred to this representation at testing.

That a sensorimotor alignment effect of smaller magnitude was found only for accuracy may reflect constraints on updating described environments:
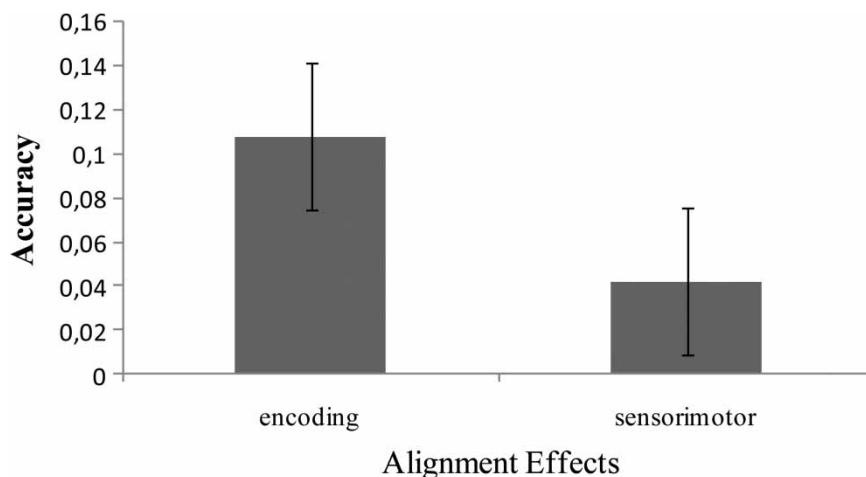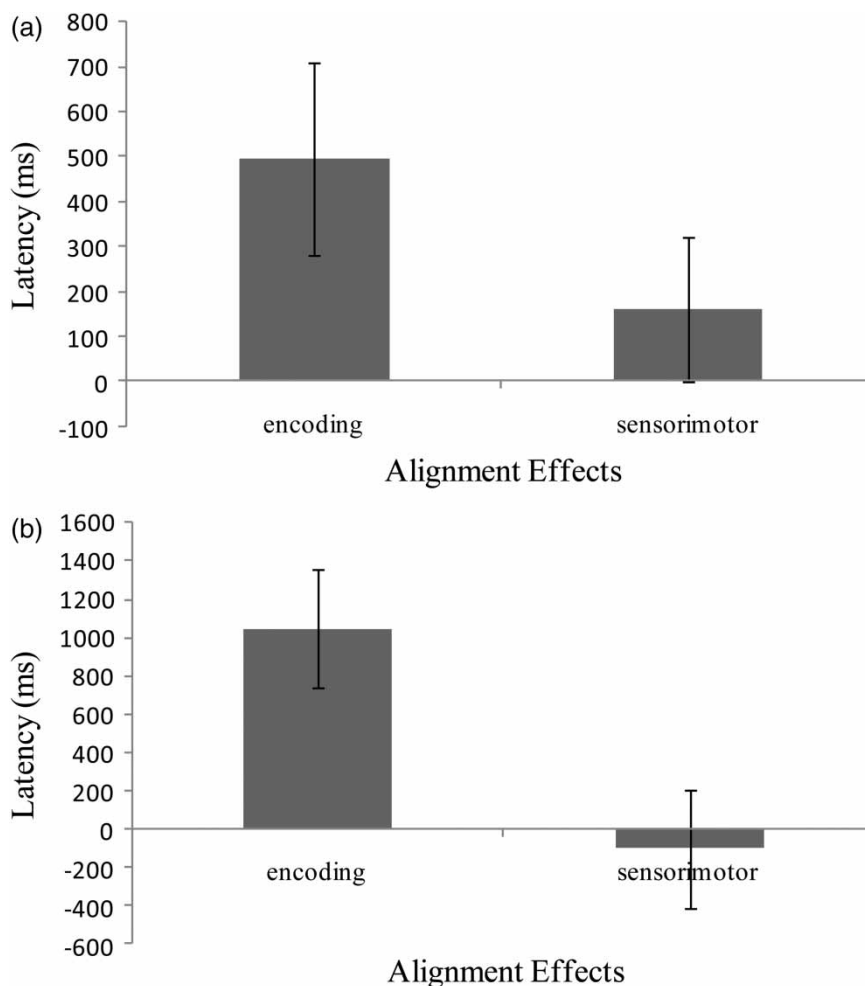

Figure 5. *Encoding alignment and sensorimotor alignment effects for accuracy in Experiment 2. Error bars represent 95% confidence intervals based on a pooled estimate of variability.*

Figure 6. *Encoding alignment and sensorimotor alignment effects for latency in Experiment 2. Error bars represent 95% confidence intervals. Panel a depicts orientation latency, and Panel b shows response latency. Note that as the sphericity assumption was violated in orientation latency (ε = .68), separate confidence intervals were computed for each condition. For response latency, the 95% confidence intervals are based on a pooled estimate of variability.*

Although participants could make more accurate judgements from the protagonist's new perspective within the described environment (relative to the opposite perspective), making these judgements was still effortful as suggested by the absence of a sensorimotor effect in the latency data. This pattern may suggest that, when physically rotated to the new perspective, participants updated only the location of the object that was in front of them but did not update, either automatically or deliberately, the locations of all other memorized objects. In other words, readers may monitor the orientation of the protagonist while ignoring the changes in the remaining protagonist-to-objects relations in the situation model. This is in line with findings that readers may not encode or monitor spatial information that is not central to the task (Radvansky & Copeland, 2000; Zwaan & van Oostendorp, 1993), instead computing protagonist-to-object relations as needed.

Monitoring only the object that was directly in front of the protagonist after rotating may have

been encouraged by instructions: Upon rotating, participants were asked to report to the experimenter the object they were facing and received feedback. Although the goal of this instruction was to verify that participants updated their imagined facing orientation along with the physical rotation and to enhance the link between the remote locations and one's body, it might have conferred an unfair advantage for the testing perspective relative to opposite testing perspective, resulting to a reliable sensorimotor effect for accuracy. This same instruction may also have led to an accuracy advantage for the testing perspective, albeit nonsignificant, of similar magnitude in Experiment 1. As Table 1 shows, even when participants only imagined rotating, they were more accurate responding from the testing than from the opposite-testing perspective. Compatible with the above possibility are the findings from a study by Mou, Zhang, and McNamara (2004), where participants read narratives and then physically reoriented to different perspectives. Following reorientation, one of the objects was further described. Responses towards that described object were subsequently more efficient than those made towards the other objects.

To explore further the possibility that the sensorimotor effect in accuracy here was affected by instructions, in Experiment 3 we instructed participants to deliberately update all locations after the protagonist's described and their own physical rotation, by explicitly asking them before testing to imagine where each object in the described environment would be.

EXPERIMENT 3

In Experiment 3, we examined whether explicit instructions to visualize the described environment, following the protagonist's described movement and the participants' accompanying physical movement, can facilitate updating protagonist-to-object relations. In this experiment, after physically rotating, participants were instructed not just to report the object they were facing but also to visualize all orienting and target objects. In essence, this

instruction encouraged participants to update offline where each object was relative to the new perspective of the protagonist. If participants used an updated representation during the testing phase, then performance should be faster and/or more accurate for the testing than for the opposite-testing perspective. Alternatively, if the sensorimotor alignment effect disappeared, this would suggest that they ignored the updated representation and referred to the original representation constructed prior to rotation. It would also suggest that the accuracy effect reported in Experiment 2 was due to instructions prior to testing encouraging participants to update only the object aligned with their testing perspective.

Method

Twenty-eight students (5 male and 23 female) participated in the experiment in exchange for either course credit or monetary compensation (€10). All participants signed informed consent forms prior to the experiment and were debriefed afterwards.

The set-up and procedure were identical to those of Experiment 2 with one notable exception. When participants rotated 90° to adopt a new testing perspective, they were asked to report verbally which object they were facing and to imagine where every other object of the described environment was, relative to the protagonist's new facing direction.

Results

There was no evidence of speed–accuracy trade-offs. Accuracy was negatively correlated with response latency, $r(27) = -.44$, $p < .05$, which, in turn, was positively correlated with orientation latency, $r(27) = .47$, $p < .05$. No correlation was present between accuracy and orientation latency, $r(27) = .01$, $p = .97$.

As in the previous experiments, participants' accuracy was the highest for trials involving judgements from a perspective aligned with the learning orientation (Table 1). Indeed, the difference in accuracy among the alignment perspectives was

reliable, $F(3, 81) = 14.24$, $p < .001$, $\eta^2 = .35$. The average accuracy was higher for trials aligned with the learning perspective than for those aligned with the perspective opposite testing, leading to a significant encoding alignment effect, $t(27) = 4.91$, $p < .001$. The average accuracy was numerically higher for trials aligned with the testing perspective (71%) than for those aligned with the perspective opposite to testing (69%); however, the sensorimotor alignment effect was not significant, $t(27) = 1.23$, ns. The magnitude of the encoding and sensorimotor effects is shown in Figure 7.

Participants' orientation latency also differed reliably across the different imagined perspectives; again, there was a significant main effect for perspective alignment, $F(3, 81) = 6.97$, $p < .001$, $\eta^2 = .21$. Participants were faster to adopt an imagined perspective when it coincided with the learning orientation than any of the other three perspectives (Table 1). As with accuracy, there was a significant encoding alignment effect, $t(27) = 3.45$, $p < .01$, but no sensorimotor alignment effect, $t(27) = -0.51$, ns, whose magnitudes are represented in Figure 8a.

The pattern of findings for accuracy and orientation latency extended to response latency as well. Participants were faster responding from perspectives aligned with the learning orientation than from any of the other perspectives (Table 1). Response latencies across conditions of perspective alignment differed reliably, $F(3, 81) = 16.24$, $p < .001$, $\eta^2 = .38$. And as with accuracy and orientation latency, there was a significant encoding alignment effect, $t(27) = 5.16$, $p < .001$, but no sensorimotor alignment effect, $t(27) = -0.69$, ns (Figure 8b).

Discussion

When participants were explicitly instructed to update all objects of the described environment after rotating to a new perspective, there was no sensorimotor effect for any of the dependent measures. The sensorimotor alignment effect found for accuracy in Experiment 2 was not found here. This could be because instructions in Experiment 2 encouraged participants to monitor the protagonist's relation to the object in front of them upon rotation, whereas instructions in Experiment 3 asked them to consider relations to all locations in the described environment. Nonetheless, although these instructions seem to have removed the accuracy advantage for the testing perspective, visualizing all protagonist-to-object relations before testing did not have a
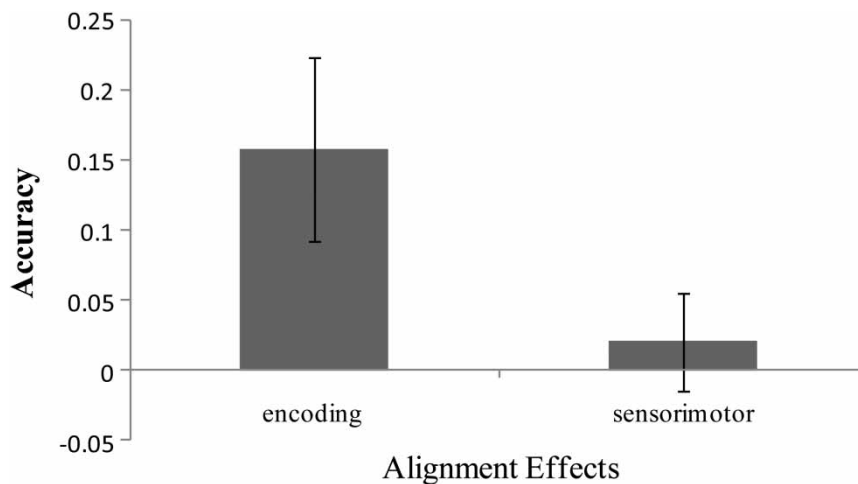

Figure 7. Encoding alignment and sensorimotor alignment effects for accuracy in Experiment 3. The sphericity assumption was violated in this analysis ($\varepsilon = .64$), therefore separate confidence intervals were computed for each condition.
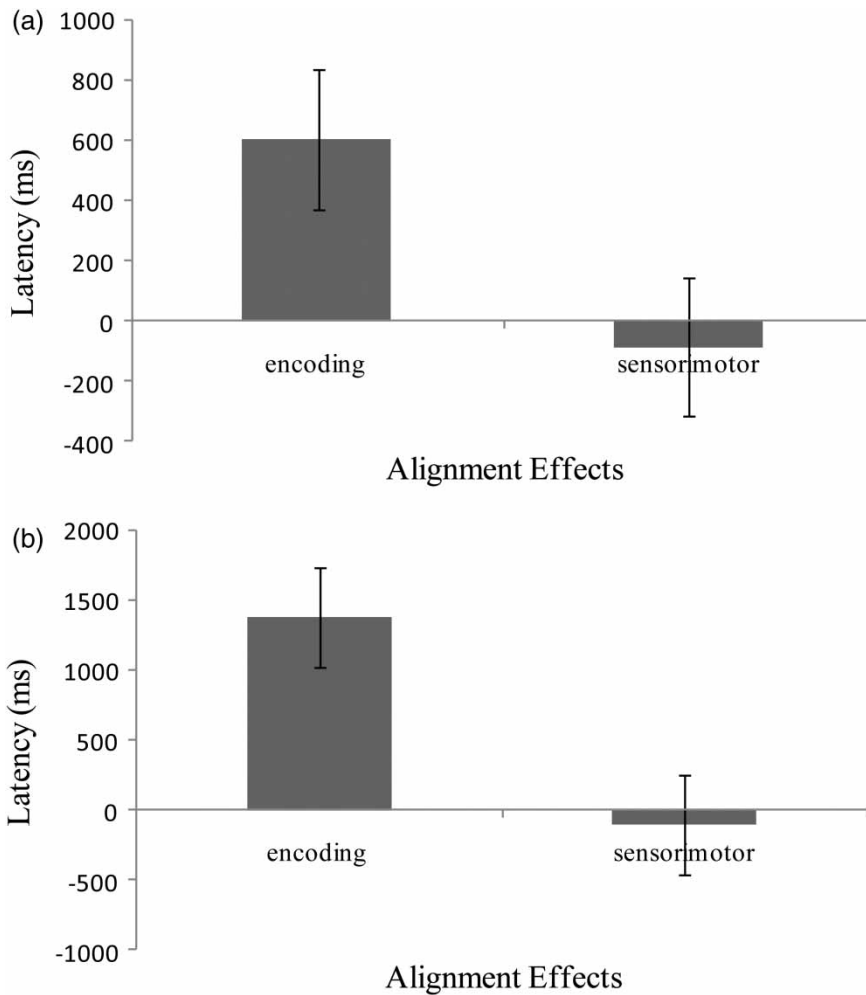
Figure 8. *Encoding alignment and sensorimotor alignment effects for latency in Experiment 3. Error bars represent 95% confidence intervals based on a pooled estimate of variability. Panel a depicts orientation latency, and Panel b depicts response latency.*

persisting effect on test trials. Instead, as suggested by the encoding alignment effects for both accuracy and latency, participants at testing seem to have referred to the spatial representation they initially constructed, whose preferred direction was aligned with the perspective originally described in the narrative.

Together, these first three experiments show that there is no sensorimotor facilitation when one physically rotates in alignment with the protagonist's updated orientation. Despite this lack of sensorimotor facilitation, sensorimotor influences may still contribute to spatial reasoning in the form of sensorimotor interference, when one's physical orientation is misaligned with the protagonist's updated orientation. Although Experiment 1 showed no evidence for such interference when participants remained aligned with the learning orientation, the learning orientation has a special status for memory organization as evidenced in previous studies (e.g., Shelton & McNamara, 2004). Thus, in Experiment 4, we examined whether any sensorimotor facilitation or interference contributes to performance at testing by creating conditions in

which participants physically rotated to a perspective that was aligned with the protagonist's updated orientation, aligned with the initial learning orientation, or misaligned to both.

EXPERIMENT 4

In Experiment 4, we manipulated directly the congruency between participants' physical orientation at test with the initial and updated orientations of the protagonist. If the physical orientation of one's body at the time of testing exerts sensorimotor influences on performance, it should result in a sensorimotor alignment effect when aligned with the protagonist's updated orientation (congruent condition) and a reversed sensorimotor alignment effect (i.e., better performance for the opposite testing perspectives than for the testing perspective) when aligned with the opposite orientation (incongruent condition).

Method

Twenty-eight students (6 male and 22 female) participated in the experiment in exchange for either course credit or monetary compensation (€10). All participants signed informed consent forms prior to the experiment and were debriefed afterwards.

The set-up and procedure were identical to those of Experiment 2 except that participants read only three narratives (plus one for practice). Participants first read the sentence that reoriented the protagonist to the left or right, then reported the object that the protagonist was facing and visualized the remaining objects, and then were asked to physically rotate themselves to the left or right. For one of the narratives, participants were instructed to physically rotate to the same direction as that described for the protagonist's reorientation. Thus, during testing their physical orientation was congruent with the updated orientation of the protagonist (*congruent with updated* condition). In another narrative, participants rotated to the opposite direction of that of the protagonist, so that their physical orientation at test was incongruent with

the updated orientation of the protagonist (*incongruent* condition). Finally, in a third narrative, participants were instructed to remain in the same physical orientation as they had during learning despite the protagonist's reorientation (*congruent with learning* condition). Therefore, in this condition, participants' physical orientation was congruent with the protagonist's initial orientation. The assignment of narratives to congruency conditions was counterbalanced across participants. Narratives were presented in a different random order for each participant. For half of the participants, the protagonist was described to rotate to the left in all three narratives and for the other half to the right.

Data were first analysed with a repeated measures ANOVA with terms for the congruency between participant's and protagonist's orientations (congruent with learning, congruent with updated, incongruent) and imagined perspective (learning, testing, opposite learning, opposite testing). Encoding and sensorimotor alignment effects were computed as in the previous experiments and were assessed with planned contrasts carried out separately for each congruency condition.

Results

No evidence of speed–accuracy trade-offs was found. Accuracy correlated negatively with response latency, $r(27) = -.36$, $p = .058$, which correlated positively with orientation latency, $r(27) = .75$, $p < .001$. No correlation was present between accuracy and orientation latency, $r(27) = -.12$, $p = .56$.

Response accuracy depended on the imagined perspective that participants adopted in each trial, $F(3, 81) = 4.86$, $p < .01$, $\eta^2 = .15$. As shown in Table 2, participants were overall more accurate when responding from an imagined perspective that was aligned with the learning orientation (i.e., the initial protagonist orientation) than from any of the other three perspectives, ps $< .05$. In contrast, the congruency between participants' physical orientation at test and the protagonist's orientation did not influence performance.

Table 2. *Mean accuracy, orientation latency, and response latency as a function of congruency and perspective in Experiment 4*

|	Imagined perspective			
Congruency	Learning	Testing	Opposite testing	Opposite learning
Congruent with learning				
Accuracy (%)	90.63 (17.55)	81.25 (25.57)	82.25 (28.07)	83.93 (21.75)
Orientation latency (ms)	2,818 (1,109)	3,115 (1,318)	3,108 (1,198)	3,128 (1,235)
Response latency (ms)	3,430 (1,506)	4,358 (1,962)	4,634 (2,747)	4,354 (2,070)
Congruent with updated				
Accuracy (%)	91.52 (14.85)	84.37 (19.43)	81.70 (21.65)	81.70 (22.94)
Orientation latency (ms)	2,921 (884)	3,236 (1,269)	3,323 (1,159)	3,119 (1,176)
Response latency (ms)	3,728 (2,097)	5,150 (2,424)	4,884 (1,634)	5,295 (2,430)
Incongruent				
Accuracy (%)	87.95 (17.84)	83.04 (20.19)	81.25 (25.57)	80.80 (25.79)
Orientation latency (ms)	2,852 (1,038)	3,089 (1,005)	3,237 (1,124)	3,410 (1,124)
Response latency (ms)	3,288 (1,012)	4,464 (1,748)	4,631 (1,559)	4,513 (1,701)

Note: Values in parentheses are Standard Deviations.

Neither the main effect of congruency nor the interaction between congruency and imagined perspective was significant, $F(2, 54) = 0.08$, *ns*, and $F(6, 162) = 0.48$, *ns*, respectively. Despite the absence of an effect of congruency, we assessed the presence of encoding and sensorimotor alignment effects in each congruency condition. Planned contrasts revealed significant encoding alignment effects in all three conditions: $t(27) = 2.20$, $p < .05$ for the congruent with learning, $t(27) = 2.41$, $p < .05$ for the congruent with updated, and $t(27) = 2.20$, $p < .05$ for the incongruent condition. However, none of the three conditions yielded a significant sensorimotor alignment effect: $t(27) = 0.35$, *ns*, for the learning congruent, $t(27) = 0.71$, *ns*, for the updated congruent, and $t(27) = 0.56$, *ns*, for the incongruent condition. Figure 9 presents the magnitude of the alignment effects as a function of congruency.

Participants' orientation latency was also influenced by imagined perspective, $F(3, 81) = 4.78$, $p < .01$, $\eta^2 = .15$. Overall, participants were faster to adopt the learning perspective than either of the perspectives opposite to learning and testing, *p*s < .05. Although they were also numerically faster to orient to the learning than the testing perspective (Table 2), pairwise comparisons showed that this difference was not reliable, $p = .13$. Neither the

effect of congruency nor the interaction between congruency and imagined perspective was significant, $F(2, 54) = 0.26$, *ns*, and $F(6, 162) = 0.67$, *ns*, respectively. Planned contrasts revealed a significant encoding alignment effect for the updated congruent condition, $t(27) = 2.18$, $p < .05$. For the congruent learning and the incongruent conditions, the encoding alignment effect was marginally significant, $t(27) = 2.04$, $p = .051$, and $t(27) = 2.03$, $p = .052$. No sensorimotor alignment effect was found in any of the congruency conditions: $t(27) = 0.38$, *ns*, for the congruent with learning, $t(27) = 0.51$, *ns*, for the congruent with updated, and $t(27) = 0.85$, *ns*, for the incongruent condition (Figure 10a).

As with accuracy and orientation latency, performance assessed by response latency also depended on imagined perspective, $F(3, 81) = 16.49$, $p < .001$, $\eta^2 = .38$. As seen in Table 2, participants responded faster from the learning perspective than from the remaining perspectives, *p*s < .001. In contrast to the other measures, congruency did exert a significant main effect on response latencies, $F(2, 54) = 3.82$, $p < .05$, $\eta^2 = .12$. Participants responded more slowly when their orientation during testing was congruent with the protagonist's updated orientation (4,764 ms) than when it was the same as learning (4,194 ms) and when it was incongruent with the
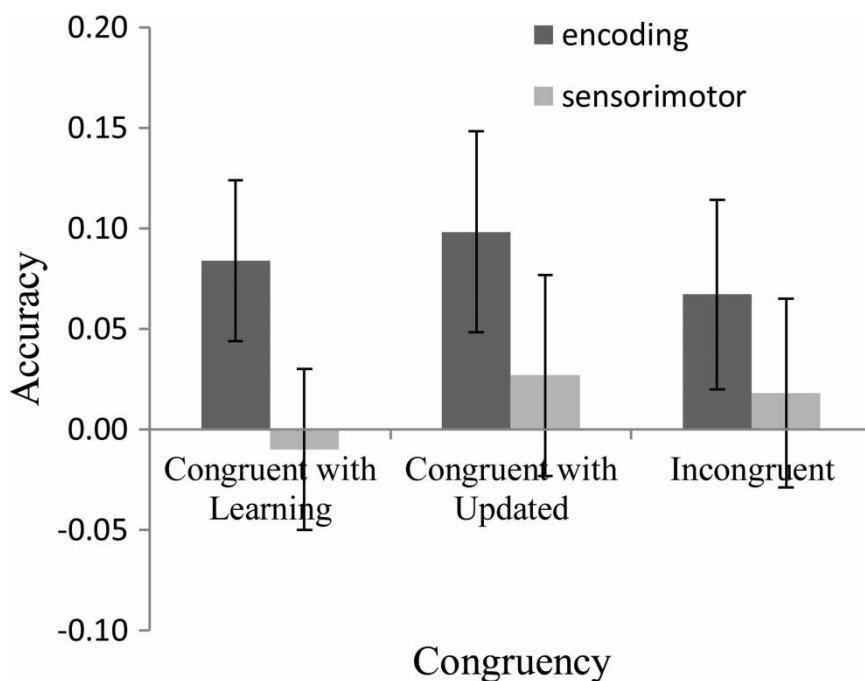
Figure 9. *Encoding alignment and sensorimotor alignment effects for accuracy in Experiment 4. The sphericity assumption for congruency was violated in this analysis (ε = .70). Therefore, separate confidence intervals were computed in each congruency condition.*

protagonist's updated orientation (4,224 ms). Pairwise comparisons confirmed that indeed participants were reliably slower to respond when their testing orientation was congruent with the updated orientation than when it was congruent with the learning orientation, $p < .05$. However, the difference between responding from orientations that were congruent versus incongruent with the protagonist's updated orientation was not significant, $p = .15$. Despite the overall difference in response latencies across congruency conditions, the interaction between congruency and imagined perspective was not significant, $F(6, 162) = 0.59$, *ns*. Planned contrasts verified that the patterns obtained for accuracy and orientation latency regarding the presence of alignment effects held for response latency as well. As shown in Figure 10b, significant encoding alignment effects were present in all congruency conditions: $t(27) = 2.48$, $p < .05$ for the congruent with learning, $t(27) = 3.63$, $p < .01$ for the congruent with updated, and $t(27) = 6.12$, $p < .001$ for

the incongruent condition. None of the three conditions yielded a significant sensorimotor alignment effect: $t(27) = 0.46$, *ns*, for the congruent with learning, $t(27) = 0.79$, *ns*, for the congruent with updated, and $t(27) = 0.51$, *ns*, for the incongruent condition.

Discussion

Experiment 4 replicated the absence of sensorimotor facilitation reported in Experiment 3, when participants physically rotated to the same direction as the story protagonist. It also extended the findings from the first three experiments by showing that physically rotating to the opposite direction from the protagonist did not exert any sensorimotor interference.

The only effect of the participants' testing orientation on performance was a main effect of congruency on response latency. However, this congruency effect was not consistent with interference: Participants responded relatively faster when they were physically counteraligned with the
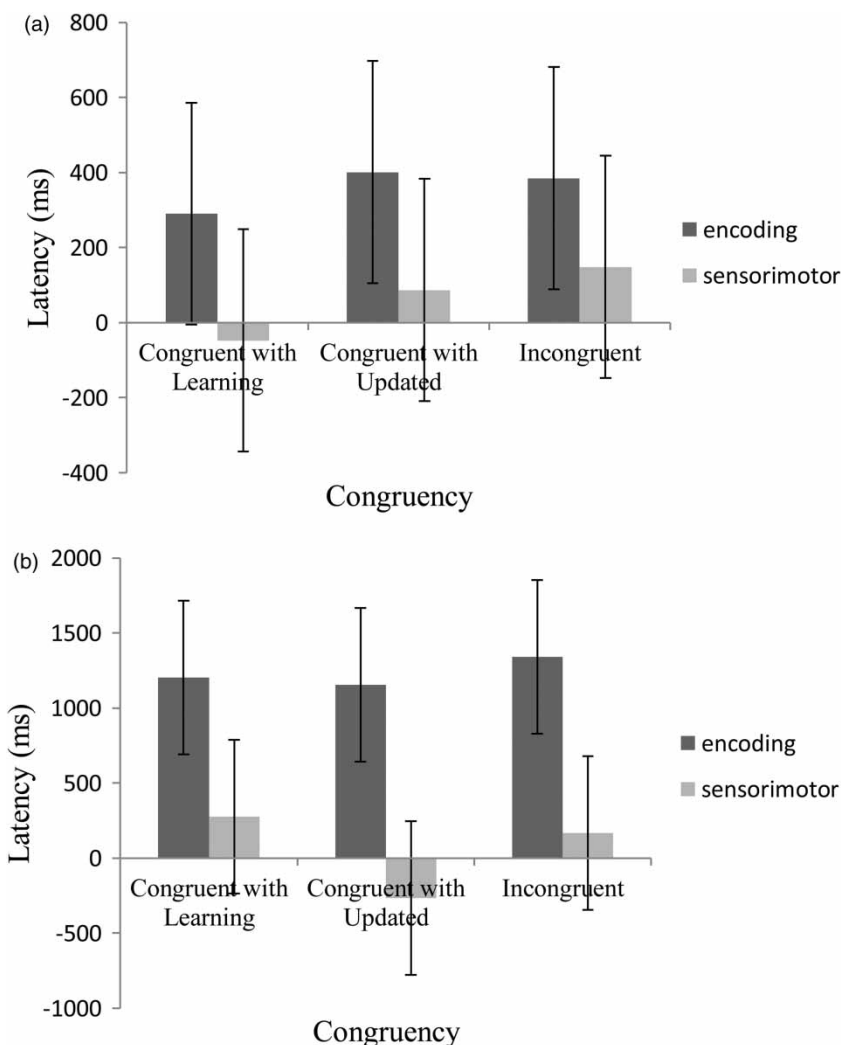

Figure 10. *Encoding alignment and sensorimotor alignment effects for latency in Experiment 4. Error bars represent 95% confidence intervals based on a pooled estimate of variability. Panel a depicts orientation latency, and Panel b depicts response latency.*

protagonist's updated orientation than when they were physically aligned with it. Thus, physically adopting an orientation conflicting with the protagonist's orientation did not lead to a decrement in performance. That they responded somewhat faster than when aligned with the protagonist's orientation may be because this unnatural incongruent condition (i.e., when rotating in one direction in the actual environment while being instructed to imagine rotating in the opposite

direction in the described environment) encouraged participants to rehearse memorized locations further after their physical rotation. Critically, regardless of any overall differences in responding across congruency conditions, performance from the protagonist's updated orientation did not differ from that for the counteraligned orientation: No sensorimotor alignment effects were observed in Experiment 4 in any of the congruency conditions, for any measure of performance.

SUMMARY AND CONCLUDING DISCUSSION

A clear pattern of results was obtained across the four experiments. Readers of narratives encoded spatial information in situation models and adhered to their initial representations despite the subsequent movement of the protagonist and their own imagined (Experiment 1) or physical movement (Experiments 2, 3, and 4). The encoding alignment effects across the four experiments suggest that, as with perceptually experienced environments (e.g., Kelly et al., 2007; Mou, McNamara, et al., 2004), in the absence of environmental cues, egocentric experience at encoding determines the organization of spatial memory.

Although participants were able to monitor the described change of perspective, as suggested by accurately naming the object in front of the protagonist upon the protagonist's rotation, there was no indication that they updated protagonist-to-object relations, even when these new relations were brought to the foreground of working memory through visualization instructions (Experiments 3 and 4). Although in Experiment 2, in addition to the encoding alignment effect, participants were more accurate in making judgements from the protagonist's updated perspective (relative to the opposite perspective), this sensorimotor effect may not reflect that physical motion facilitated updating of protagonist-to-object relations. Instead, in Experiment 2, the participants' physical motion and the instruction to report the object they faced may have jointly conferred the accuracy advantage for the testing perspective by encouraging participants to monitor the protagonist's orientation. When instructions in Experiment 3 encouraged participants to monitor the protagonist's relation to all objects, this accuracy advantage of the testing perspective disappeared. This lack of sensorimotor facilitation when physically rotating in alignment with the protagonist was corroborated in Experiment 4, which also extended the findings of the first three experiments by demonstrating that physically rotating in misalignment to the protagonist's updated orientation in the memorized environment did not cause sensorimotor interference.

Altogether, our results suggest that updating spatial relations in described environments differs from updating in environments that have been derived from direct perception. First, whereas spatial relations among objects that have been encoded through perceptual experience are updated with movement, they are not when they have been encoded through narratives. Previous work has shown that physical (but not imagined) movement relative to a remote, perceptually experienced environment enables people to update self-to-object relations (Rieser et al., 1994), but we did not find reliable evidence of such a sensorimotor effect when people moved relative to an imagined, described environment. Secondly, whereas spatial relations about perceptually experienced environments can be deliberately updated through instruction, they do not seem to be here. Previous work has shown that, upon instruction, people can successfully update remote, perceptually experienced environments (Kelly et al., 2007; May, 2007; Wang, 2004; Wang & Brockmole, 2003) and even remote environments encoded through a combination of vision and language (Avraamides & Kelly, 2010); however, our instructions to deliberately visualize, with unlimited time, each described object from the protagonist's new orientation did not lead to successful updating. Instead, participants preferred to use their initial representation of the situation model when carrying out the pointing trials, even if that involved consuming effort to compute the new spatial relations.

One possible explanation for the absence of sensorimotor influence following the physical rotation is that swivelling to a new orientation is not as strong a manipulation as walking to a new standpoint and orientation (e.g., Kelly et al., 2007; Rieser et al., 1994). However, this explanation seems unlikely; although swivelling with a chair does not provide the same proprioceptive information as physical movement, it does produce vestibular signals and changes in the visual field of participants that allow them to adopt the change of perspective. An alternative explanation that may account for the discrepancy between the present findings and those of Rieser et al. (1994) is that physical movement exerts sensorimotor

influence when linked to imagined movement in remote environments, only when these environments involve minimal memory maintenance costs. Whereas in our experiments participants most likely devoted considerable working memory resources in constructing and maintaining a situation model in memory (De Beni et al., 2005; Meneghetti et al., 2011; Pazzaglia et al., 2007), in the study of Rieser et al., they reasoned about a highly familiar environment.

Indeed, the lack of reliable sensorimotor effects in our studies could be because, given the cognitive demands of constructing and maintaining a situation model, readers do not encode or monitor information that is not central to the task, instead opting to compute spatial relations within a situation model as needed (see also Radvansky & Copeland, 2000; Zwaan & van Oostendorp, 1993). When experiencing through vision spatial information, which is three-dimensional and nonlinear, spatial information is continuously and near-simultaneously integrated into an ongoing mental representation. By comparison, incorporating information from spatial descriptions into a situation model requires considerable effort. When spatial information is experienced through language, which is sequential and linear, it requires effort to be decoded into a spatial mental representation (see Levelt, 1989, on the *linearization problem*). Indeed, participants take more time to learn the locations of objects when these are provided through simple linguistic statements than through vision (Klatzky, Lippa, Loomis, & Golledge, 2002).

Since linguistically presented spatial information is hard to represent, it may be disregarded if it is not critical to the causal chain of events in stories. Under normal reading instructions (not emphasizing the environment in the story), readers are not very much focused on constructing precise spatial representations: They process spatial information relatively fast and are relatively poor at verifying spatial inferences (Zwaan & van Oostendorp, 1993). Instead, during story comprehension, readers primarily focus on and track causal information (Bloom, Fletcher, van den Broek, Reitz, & Shapiro, 1990), which may be more instrumental to story coherence than spatial information. In our studies, at the end of the room's description,

participants may have considered the protagonist's rotation to be inconsequential, seeing that the stories did not provide a motivational context for the protagonist to change orientation (other than they may have been, perhaps, exploring the environment). Thus, in the absence of a strong motivation for the protagonist's change of orientation in the story, readers may have disregarded it even when it was accompanied by their own movement. This account is compatible with the general function of situation models. Situation models immerse readers and listeners into distal or fictitious settings but are not involved in the moment-to-moment activity that requires an accurate representation of egocentric relations (e.g., avoiding an obstacle during navigation). Such tasks rely more on information gathered from direct perception. Thus, a performance advantage for the protagonist's updated orientation may be tenable if participants are provided with strong motivation in the narrative for the protagonist's reorientation or if they spend more time at the new orientation (for instance, by encoding further details of the environment from that orientation).

In conclusion, when people consult situation models they have constructed from narratives in order to make judgements about spatial relations within them, they seem to be accessing enduring allocentric representations. These representations have a preferred direction that, in the absence of conflicting, described environmental cues, defaults to the initially described orientation of the protagonist's (and here the readers') vantage point. That readers' physical rotation did not reliably affect the updating of spatial relations within the situation model is compatible with Avraamides and Kelly's (2008) dissociation between allocentric and sensorimotor spatial memory representations. The lack of reliable sensorimotor influences on updating here may be seen as in conflict with processing frameworks for situation models that posit that people engage in experiential simulation while reading (e.g., Zwaan, 2004). But our findings may instead provide a more nuanced understanding of sensorimotor influences on situation models and their limitations. During the online comprehension of

sentences with spatial information, while people are constructing a situation model, they may be more likely to recruit sensorimotor representations of self-to-object relations than when they subsequently call the resulting situation model to memory to make judgements about spatial relations "outside the narrative" (i.e., at testing, when they have finished reading the descriptions). During these judgements in our task, mental simulation may still be involved; however, it does not seem to be anchored to people's sensorimotor representation of spatial relations in that moment, at least if changes in their orientation (accompanying the protagonist's) are not strongly motivated by the storyline. Kaschak and Borregine (2008) made a related point—that task demands can affect the extent to which sensorimotor (in their case, motor congruence) effects can be found after the online processing of a sentence. Altogether, sensorimotor influences may affect the updating of situation models more strongly if they are deployed while the situation model is being constructed (versus later) or if they are tied to contingent movements of the protagonist that are of causal importance in the storyline (increasing the likelihood that a representation of the described movement is maintained active). Nonetheless, updating situation models encoded through narratives appears to be fundamentally different than updating environments that have been perceptually experienced.

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