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ORIGINAL ARTICLE

Egocentric updating of remote locations

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Abstract The study examined whether people update remote spatial locations in unfamiliar environments during physical movement. Participants learned a layout of objects from one perspective and carried out perspective-taking trials after physically rotating to a new perspective in either the same room as learning or in an adjacent room. Prior to rotation in the adjacent room participants were instructed to visualize the objects as being around them. Responses to perspective-taking trials involved either pointing or verbal labeling. In both testing environments, participants pointed more efficiently from imagined perspectives aligned with either the initial learning perspective or their current facing orientation than from a novel imagined perspective; this indicates that they had updated the encoded spatial relations during the physical rotation and treated remote objects as immediate. Differences in performance among perspectives were less pronounced for verbal labeling in both environments, suggesting that this response mode is more flexibly used from imagined perspectives.

Egocentric updating of remote locations

Research in spatial cognition has provided ample evidence that, during movement, people effortlessly update the changing egocentric spatial relations (i.e., self-to-object directions and distances) of objects in their immediate surroundings (Klatzky, Loomis, Beall, Chance, & Golledge, 1998). Updating seems to rely on idiothetic information such as proprioceptive feedback, vestibular signals, and copies of efferent commands, given evidence that it takes place during physical but not imagined movement. For example, in the seminal study of Rieser (1989), participants located memorized objects equally well from the orientation they studied them and from novel perspectives they adopted by means of physical rotation. However, when they imagined rotating to the novel perspectives, pointing errors and response latencies increased compared to the learning orientation. Physical movement may be a prerequisite for on-line spatial updating[1] because people can then rely on the internalized covariation of idiothetic information and optic flow to monitor on-line the locations of objects, even non-visible ones, during movement (Rieser, 1989).

Although the on-line updating of egocentric relations is important for the control of moment-by-moment action (e.g., negotiating turns, avoiding obstacles), tasks such as navigating our environment can also require processing locations that lie beyond our immediate surroundings. For example, planning a movement toward a non-visible destination requires considering the spatial relation between its location and ourselves to determine the initial heading of our movement. Also, once the movement has commenced we must, at least occasionally, update the location of the destination relative to our current position and orientation, in order to monitor the course of our movement.

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[1] We use the term on-line updating to refer to updating that takes place effortlessly during movement as opposed to the deliberate computation of updated spatial relations that may take place following the movement.

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Previous research has established that people can compute, with considerable accuracy, the locations of remote targets that range from objects in a room they have just walked out of (Rider & Rieser, 1988) to distal landmarks in their city (Frankenstein, Mohler, Bülthoff, & Meilinger, 2012). Although people can on demand relate remote locations to their position in order to compute egocentric relations, evidence suggests that they do not maintain and update these relations on-line as they move (Wang & Brockmole, 2003a, b). Presumably, this is because distal locations are represented within an enduring representation that is detached from one's body as opposed to a transient sensorimotor representation that maintains the most recently updated egocentric relations (Avraamides & Kelly, 2008; Waller & Hodgson, 2006). Support for this comes from a study by Waller and Hodgson (2006) who had participants imagine standing in the middle of their bedroom and point to various objects with eyes open, eyes closed, and after being disoriented by rotating in place for 1 min. Relative to pointing with eyes closed, disorientation did not impair performance suggesting that locations were maintained in a representation that was detached from participants' actual position and orientation. In a different experiment in which participants pointed to objects placed around them in the lab, disorientation resulted in increased error compared to pointing with eyes closed (Waller & Hodgson, 2006). Thus, people maintain immediate spatial relations in a transient egocentric representation that is susceptible to disruption from disorienting movement and remote locations in a more enduring representation that is immune to disorientation.

In another study, Wang (2004) had participants memorize from a particular orientation the locations of a number of objects placed around them in the lab but also imagine the locations of several objects from their own kitchen. Participants were then instructed to physically rotate to different orientations and point to objects from the lab or their kitchen. When they turned relative to objects in the lab, they pointed faster and more accurately to lab objects than kitchen objects, which suggests that they updated their orientation relative to the immediate but not the remote environment. But, when they rotated relative to kitchen objects they pointed equally well toward objects from the two environments. Similarly, Wang and Brockmole (2003b) had participants point to immediate laboratory objects and distal campus landmarks after rotating relative to the contents of either environment. When they rotated relative to campus landmarks participants pointed equally fast and accurately to laboratory objects and campus landmarks. However, when they turned relative to laboratory objects they pointed faster and more accurately to laboratory objects than to campus landmarks. The findings from both studies suggest that, with physical movement, people update automatically only objects from their immediate surroundings. However, they also indicate that linking physical movement to objects in a remote environment can result in the on-line updating of remote locations.

Further evidence in support of the hypothesis that linking one's physical movement to a remote environment can lead to on-line updating of remote locations comes from a study by Rieser, Garing, and Young (1994). Rieser et al. visited young children and their parents at their homes and asked them to visualize the children's classroom from the child's seat and to point to a number of objects first from the child's seat and then from the teacher's seat. In one condition, participants imagined walking from the child's seat to the teacher's seat and imagined rotating to adopt the teacher's typical facing orientation. In another condition, they physically walked the path they imagined. When physically moving to adopt the teacher's seat, both parents and children pointed as well from the teacher's seat as they did from the child's seat. But, when they imagined moving, performance dropped. Children pointed less accurately and slower from the teacher's seat than their own seat. Adults pointed with equal accuracy from the two positions but took longer to do so from the teacher's than from the child's seat. These findings parallel those from studies on the updating of immediate locations (e.g., Rieser, Guth, & Hill, 1986), suggesting that instructions to visualize a remote environment and to imagine the physical movement as occurring in that environment result in treating distal objects as immediate and updating them during movement.

The present study aims at testing this hypothesis further by comparing directly updating performance for immediate and non-immediate locations in sessions with physical and imagined rotations. In general, actions in immediate environments (e.g., maintaining orientations in one's surroundings) benefit from keeping spatial relations up-to-date, whereas those in remote environments (e.g., monitoring movement course to a non-visible destination) can be carried out even if spatial relations are intermittently updated. However, as indicated from the studies reviewed above (Rieser et al., 1994; Wang, 2004), it is likely that spatial relations in a remote environment can be automatically updated when, by means of visualization, remote locations are linked to one's sensorimotor framework.

In contrast to previous studies (Rieser et al., 1994; Wang, 2004; Wang & Brockmole, 2003a, b) that examined updating using remote but familiar environments, here we investigate updating in unfamiliar situations. In many cases, familiar environments are maintained in memory from multiple orientations, which makes it difficult to differentiate experimentally whether spatial judgments involve retrieving precomputed relations from memory or truly updating these relations on-line. Moreover, familiar environments may be held in more vivid or rich representations (e.g., neuroimaging studies show stronger activations in brain areas involved in spatial orientation when viewing familiar than unfamiliar scenes; Epstein, Higgins, Jablonski, & Feiler, 2007), and thus be more readily updated with physical movement. In contrast, encoding new spatial relations poses a load on working memory (Baldwin & Reagan, 2009; Garden, Cornoldi, & Logie, 2002; Meilinger, Knauff, & Bülthoff, 2008; Meneghetti, De Beni, Gyselinck, & Pazzaglia, 2011), which may influence updating. That is, if updating spatial relations for unfamiliar environments is indeed more cognitively costly, people may deliberately update them only when necessary (e.g., when they need to evaluate the course of navigation toward a remote destination). Indeed, there is evidence that updating can be under volitional control (Waller, Montello, Richardson, & Hegarty, 2002).

The study adopts a paradigm used by Kelly, Avraamides, & Loomis (2007). In that study, participants memorized the locations of eight objects placed around them in a virtual room. Participants began studying the objects from a fixed orientation (henceforth, the learning perspective) but they were allowed to freely turn to view all objects from any orientation as long as they turned back to the learning perspective at the end. Subsequently, objects were removed and participants physically rotated to a new orientation (henceforth, the *updated perspective*) that was 90° to the left or right of the learning perspective. While occupying the updated perspective they carried out a series of perspective-taking trials in which they imagined facing one of the memorized objects and pointed to another. Participants were faster and more accurate to point from an imagined perspective that was aligned with either the learning or the updated perspective, compared to a baseline novel perspective that was directly opposite to the updated perspective (henceforth, the novel perspective). This finding suggested that participants had constructed an orientation-depended representation at encoding (McNamara, 2003), but had also updated object locations when they physically turned to the updated perspective (Mou, McNamara, Valiquette, & Rump, 2004). In a different condition in the same experiment, participants walked to an adjacent room following learning and carried out trials from a perspective that was globally aligned with the testing (updated) perspective of the first experiment. Although the learning perspective did have a performance advantage in this experiment, pointing was equally fast and accurate from the updated and the novel perspectives, suggesting that participants did not update the remote objects locations while moving to the new location and orientation in the adjacent room. However, in a follow-up experiment, Kelly et al. (2007) instructed participants to visualize the remote objects as being around them after they had occupied the updated perspective in the adjacent room and found that performance was, as in the first experiment, better for both the learning and the updated perspectives compared to the novel perspective. Kelly et al. argued that visualization instructions promoted the re-encoding of the remote locations in a sensorimotor representation that maintained egocentric locations relative to the updated orientation of the body (see also Avraamides & Kelly, 2008).

Since visualization instructions in Kelly et al. (2007) were provided after participants had rotated to the updated perspective, it is not possible to deduce from the results whether movement leads to the updating of the remote locations. It seems rather likely that participants in that study retrieved the encoded spatial relations from memory and updated them deliberately to take into account their new position. In contrast to Kelly et al. (2007), in the present study visualization instructions were provided before participants rotated to the updated perspective. If visualization instructions encourage participants to treat remote locations as immediate (Avraamides & Kelly, 2008; Kelly, Avraamides, & Loomis, 2007; Rieser et al., 1994), participants should retrieve the spatial relations from memory while at the learning perspective and then update them automatically when rotating from the learning to the updated perspective in both immediate and remote testing conditions. In that case, we expect participants to point faster and/or more accurately from an imagined perspective that is aligned with the updated than the novel perspective. Since the task entails responding to object locations from imagined perspectives, participants have no reason to update spatial relations deliberately when rotating to the updated perspective. Therefore, if an advantage for the updated perspective is found it would constitute evidence for automatic updating.

An advantage of the paradigm of the present study is that it does not use the learning perspective as the baseline for assessing updating. Previous studies have assessed updating by comparing performance between the updated and the learning perspectives (Presson & Montello, 1994; Rieser, 1989; Wang & Simons, 1999), a practice that now seems problematic given recent evidence that egocentric experience often determines the orientation from which spatial memories are stored (see McNamara, 2003, for a review). The paradigm used here assesses updating by comparing performance between the updated and novel perspectives, which deviate equally from the likely privileged learning perspective. It also allows examining whether participants indeed maintain orientation-dependent spatial memories from a privileged learning perspective by comparing performance from the learning and the novel perspectives.

A further novelty of the study is that, in addition to pointing, it includes conditions in which participants respond by verbal labeling. Manual responses, such as pointing, are strongly anchored to one's body and typically lead to a greater sensorimotor effect (i.e., greater performance difference between body-aligned and misaligned responding) than verbal labeling. Although choosing the appropriate egocentric verbal label (e.g., "on my right") is by definition body-dependent, executing the response is not a spatially directed task and may thus not be subject to facilitation or interference from the orientation of the body (see Avraamides & Kelly for a review). Indeed, previous studies comparing directly pointing and verbal responding in perceptual (e.g., Avraamides, Ioannidou, & Kyranidou, 2007) and memorial tasks (Avraamides, Loomis, Klatzky, & Golledge, 2004; De Vega & Rodrigo, 2001; Kelly & McNamara, 2008; Rodrigo, De Vega, & Padrón, 2012; Wang, 2004; Wraga, 2003) provide evidence that verbal responses are executed more flexibly from misaligned imagined perspectives. If sensorimotor representations are activated through visualization, pointing may be more susceptible to sensorimotor interference than labeling even when responding to remote objects. To our knowledge, this is the first study to compare the pointing and verbal labeling of objects of a remote environment that has been encoded through vision.

Finally, prior to the main experimental session, participants completed a session of trials in which they adopted the novel perspective not by imagined rotation, but with physical rotation in the immediate environment. This physical rotation session served as practice for the main experiment.[2] At the same time, it allowed us to verify that performance for different perspectives is similar when they are adopted through physical movement. Thus, inferior performance from the novel than the physical perspective in the main experimental session would be safely attributed to the absence of automatic updating with imagined rotations. Another aim of the physical rotation session is to compare pointing and verbal labeling under conditions of successful updating. Although previous studies documented that verbal responses are used more flexibly from misaligned perspectives than pointing, perhaps they are less ideal when used from successfully updated perspectives: compared to pointing from a new perspective aligned with one's body, verbal labeling may incur a cost on performance since it requires assigning labels to the appropriate regions of space.

[2] Spatial updating studies generally include practice block trials that involve physical rotation. Although it could be argued that completing the physical rotation session might have influenced the pattern of results for the imagined rotation session, the most likely influence would be improved performance for the novel perspective, which would work against our efforts to document a difference between performance for the updated and the novel perspectives.

Method

Participants

Thirty-four (10 male) undergraduate and graduate students at the University of Cyprus participated either voluntarily or in exchange of course credit. Participants were randomly assigned to pointing and verbal labeling conditions, while balancing across the two conditions their gender and whether they were volunteers (vs. participating for credit).

Stimuli and design

Learning was conducted in a 5.15 × 4 m room containing typical laboratory items (e.g., desks, computers, screens). Three layouts were created, each containing seven different test objects placed around the participant at 45° increments, forming an imaginary circle with 1.5 m radius. The layout used for the physical rotation session included no object at 225° whereas those used for the imagined rotation session had no object at either 45° (Fig. 1) or 225°. In the main experimental session, all participants were tested both in the learning room (immediate environment) and in an adjacent room (remote environment). A different set of objects was memorized for each testing environment. The order of the testing environments and the assignment of layouts to testing environments were counterbalanced across participants. All participants, regardless of response modality condition (pointing and verbal labeling), were outfitted with a joystick affixed on a plastic board suspended in front of their waist with shoulder straps, and a headset delivering pre-recorded sound files during testing trials. Participants in both response conditions pressed a button on the joystick to progress through testing trials. Those in the pointing condition indicated the location of a target object by deflecting the shaft of the joystick in the direction of the object. In the verbal labeling condition, participants spoke into the headset's microphone, selecting one of eight possible verbal labels: front, back, right, left, front right, front left, back right, and back left (see also Avraamides et al., 2007; Kelly & McNamara, 2008). Verbal responses were recorded by the computer and analyzed offline for accuracy.

Procedure

Participants first carried out the physical rotation session and subsequently the imagined rotation session.

Physical rotation session

After a short familiarization phase with the response medium and the task, participants were placed in the central location, facing 0°, and surrounded by the seven layout

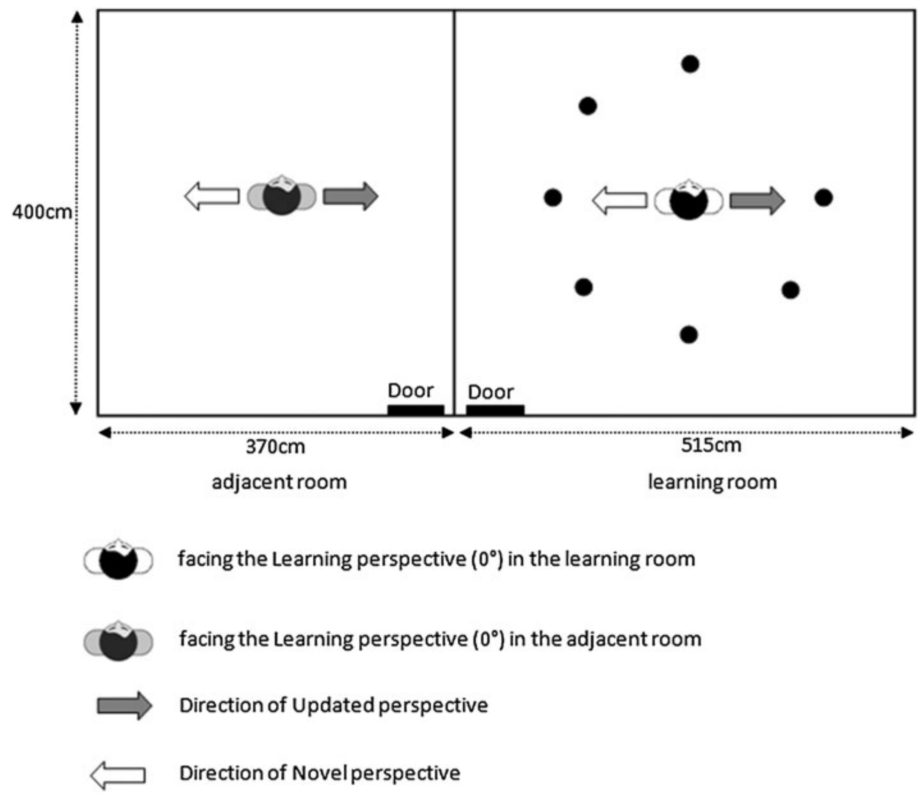


Fig. 1 Schematic depiction of the learning and testing environments, an example arrangement of objects, and the direction of the updated and novel perspectives when rotating 90° to the right

objects. They were asked to study the objects until they were confident that they had memorized their locations. They were allowed to turn in place to inspect the objects but not to leave their standpoint. Following learning, the objects were removed and participants were asked to rotate 90° to their right or left. After a short interval in which instructions for testing were repeated, they carried out a series of trials in which they first physically adopted a perspective by facing an object, and then from that perspective located another object in the layout. In each trial, upon first hearing a sound clip specifying the orienting object (e.g., "Face the bottle"), participants physically rotated to face that object and then pressed a button on the joystick. Next, upon hearing a second clip indicating the target (e.g., "Find the necklace"), participants pressed the button as soon as they knew their response. The time it took them to do so—their decision latency—and the accuracy of their response were our primary measures of interest. Immediately after the button press, participants executed their response (i.e., pointing to or labeling the location of the target object). Additionally, the time participants took to adopt the perspective (orientation latency) and to execute their response (response latency) was recorded. For pointing trials, the response was completed when participants deflected the joystick 30° from the vertical. For verbal trials, a voice key, connected to the headset, terminated the response at the onset of speaking.

Imagined rotation session

Each participant was tested twice, once in the learning room (immediate environment) and once after moving to an adjacent room (remote environment). For testing in the immediate environment, the design and procedure were identical to that of the physical rotation session except that, after rotating 90° to adopt the updated perspective, participants remained oriented to the updated perspective at all times and adopted perspectives during test trials through imagery. For testing in the remote environment, participants were blindfolded and guided to the adjacent room, adopted a perspective that was aligned with the learning perspective, removed the blindfold, and then turned 90° to adopt the updated perspective. Before rotating, they were instructed to visualize the memorized objects as if they were standing in the learning standpoint and orientation. As with the immediate environment, they remained oriented to this perspective during testing. To equate the time that elapsed between learning and testing in the two conditions, participants tested in the immediate environment were also blindfolded after learning, led outside half-way toward the adjacent room and returned to the learning room, guided back to their learning perspective, instructed to visualize the objects around them, and then asked to rotate 90° to adopt the updated perspective.

Table 1 Mean accuracy and decision latency as a function of perspective for the physical rotation session

	Perspective						
	0°	45°	90°	135°	180°	270°	315°
Accuracy (%)							
Pointing	69.58 (18.69)	68.00 (15.10)	67.29 (14.26)	66.88 (21.17)	68.75 (17.46)	68.75 (20.33)	62.50 (16.93)
Verbal	90.33 (11.48)	77.33 (25.20)	87.78 (13.31)	70.22 (24.05)	95.11 (8.44)	90.67 (11.07)	84.78 (17.92)
Decision time (ms)							
Pointing	1,898.18 (1,028.90)	2,120.50 (1,852.95)	1,913.52 (808.30)	2,277.82 (1,393.55)	2,183.82 (952.13)	2,083.48 (968.35)	2,230.57 (1,573.19)
Verbal	1,813.96 (1,021.35)	4,947.97 (4,732.99)	2,223.53 (1,232.73)	4,436.46 (3,945.70)	2,201.84 (1,301.59)	2,571.146 (1,621.28)	3,625.95 (3,143.34)

Values in parentheses indicate standard deviations

Analyses

Data were first analyzed using separate omnibus ANOVAs for the two sessions with response modality (pointing, verbal labeling), perspective (learning, updated, novel), and, in the imagined rotation session, testing environment (immediate, remote) as factors. For both sessions, we used planned contrasts to examine, separately for pointing and verbal labeling, a priori hypotheses concerning differences of interest among perspectives. The updated versus novel contrast allowed us to examine whether participants updated spatial relations when they physically rotated to a new perspective, whereas the learning versus novel contrast allowed us to examine whether participants had formed orientation-dependent memories. For pointing, actual joystick responses were quantized in 45° increments (by rounding up raw responses to the nearest multiple of 45°) to provide comparable accuracy data to the verbal labeling condition. Descriptive statistics of accuracy and decision latency for perspectives beyond those of primary interest are provided in Tables 1 and 2.

Results

Physical rotation session

Accuracy data from two participants in the verbal labeling condition were lost due to equipment malfunction and data from one participant in the pointing condition were discarded from the analyses due to low accuracy (<10 %).

The perspective participants physically adopted did not affect accuracy and did not interact with the mode of responding (Fig. 2). Overall, participants located objects more accurately when responding verbally (89.4 %) than through pointing (68.5 %), $F(1,29) = 28.13$, $p < .001$, $\eta^2 = .49$.

The perspective participants physically adopted did, however, significantly affect their decision latencies, $F(2,62) = 5.28$, $p < .01$, $\eta^2 = .15$. They were faster to decide how to respond from the learning perspective ($M = 1{,}856$ ms), slower from the updated perspective ($M = 2{,}068$ ms), and slowest from the novel perspective ($M = 2{,}327$ ms),[3,4] but only the difference between

[3] In line with previous studies (e.g., Kelly & McNamara, 2008), we report latencies based on all data. Analyses based on correct responses only yielded the same findings.

[4] Further testing carried out in our lab confirmed that angles at diagonals often function as attractors of responses. An alternative account is that the large pointing errors stem from the exocentric nature of pointing, i.e., reproducing the directional relation between the pointer and the target (Philbeck, Sargent, Arthur, & Dopkins, 2008).

Table 2 Mean accuracy and decision latency as a function of perspective for the imagined rotation session

	Perspective							
	0°	45°	90°	135°	180°	225°	270°	315°
Accuracy (%)								
Immediate pointing	64.71 (23.48)	62.96 (20.03)	63.73 (24,63)	65.42 (17.27)	65.69 (23.91)	47.84 (25.33)	50.20 (23.29)	52.94 (27.79)
Immediate verbal	91.18 (24.38)	81.48 (32.75)	91.18 (24.38)	89.17 (12.69)	86.27 (23.74)	72.35 (29.17)	82.16 (27.31)	82.35 (26.00)
Remote pointing	69.61 (20.61)	72.50 (19.58)	70.59 (22.46)	62.96 (28.60)	59.80 (22.87)	50.00 (28.36)	66.47 (29.94)	52.94 (19.75)
Remote verbal	87.25 (26.70)	78.33 (18.08)	88.24 (26.20)	81.48 (32.75)	82.35 (25.33)	63.14 (37.48)	82.35 (29.15)	74.31 (30.63)
Decision time (ms)								
Immediate pointing	3,037.81 (2,294.27)	2,833.06 (1,102.27)	2,023.53 (1,189.57)	5,139.33 (2,627.32)	2,883.82 (1,566.89)	4,148.12 (2,624.98)	3,800.09 (1,841.26)	4,263.15 (2,684.82)
Immediate verbal	1,390.31 (773.76)	2,257.13 (1,554.53)	1,576.88 (818.44)	3,276.12 (1,466.27)	2,166.25 (1,453.97)	2,898.73 (2,042.94)	2,156.66 (1,460.51)	3,188.17 (2,834.04)
Remote pointing	2,813.93 (1,383.26)	3,978.78 (1,542.16)	2,208.87 (984.46)	2,828.69 (1,343.60)	3,324.11 (2,163.21)	3,952.23 (1,586.57)	3,858.95 (1,809.09)	3,770.19 (1,548.95)
Remote verbal	1,712.73 (1,670.15)	2,540.44 (1,378.42)	1,875.75 (1,723.47)	3,890.97 (3,500.59)	1,863.14 (843.64)	4,112.03 (4,477.82)	2,120.01 (1,757.94)	3,560.74 (3,573.21)

Values in parentheses indicate standard deviations

the learning and novel perspectives was reliable. This appeared to be due to verbal labeling: when labeling, decision latencies from the novel perspective were longer than from the learning perspective, $F(1,16) = 10.84$, $p < .01$, $\eta^2 = .40$, and from the updated perspective (see Fig. 3), though not reliably so, $p = .15$. When responding through pointing, decision latencies from the novel perspective did not differ reliably from those of the updated or learning perspectives. Nonetheless, the mode of response did not significantly affect decision latencies overall, nor did it interact with the perspective participants adopted. However, inspection of the means for all perspectives (Table 1) indicates that verbal labeling was particularly slow, compared to pointing, when carried out from oblique perspectives (i.e., 45°, 135°, and 315°).

For orientation latency, only the main effect for perspective was significant, $F(2,62) = 4.65, p < .05, \eta^2 = .13$. Participants were fastest to orient to the updated perspective ($M = 2{,}439$ ms), slower to orient to the learning perspective ($M = 2{,}716$ ms), and slowest to orient to the novel perspective ($M = 2{,}918$ ms). However, only the difference between orienting to the updated versus novel perspectives was reliable, $p < .05$. For response latency, only the main effect of response modality was significant, $F(1,31) = 88.68$, $p < .001$, $\eta^2 = .74$: participants were slower for labeling ($M = 1{,}935$ ms) than for pointing ($M = 822$ ms).

Imagined rotation session

There was a significant interaction between testing environment and response modality, $F(1, 32) = 4.96$, $p < .05$, $\eta^2 = .13$: participants pointed more accurately in the remote than in the immediate environment ($p < .05$), but labeled locations with comparable accuracy in both environments, $p = .55$. As in the physical rotation session, participants were overall more accurate to respond verbally ($M = 87.1$ %) than through pointing ($M = 64.2$ %), $F(1, 32) = 9.83$, $p < .01$, $\eta^2 = .25$ (see Fig. 4), but their accuracy in this session did depend on the perspective they imagined adopting, $F(2,64) = 5.47$, $p < .01$, $\eta^2 = .17$. Participants were more accurate to respond from the learning and updated perspectives than the novel perspective (p's $< .05$), but no more accurate from the learning than the updated perspective, $p = 1$.

When participants pointed to locations in their immediate environment, they were more accurate from the learning and updated perspectives than the novel perspective, $F(1,16) = 5.03$, $p < .05$, $\eta^2 = .24$ and $F(1,16) = 8.74$, $p < .01$, $\eta^2 = .35$, respectively (Fig. 4). When tested in the remote environment, they pointed with comparable accuracy across perspectives. The same pattern held for verbal labeling: when tested in the immediate environment, participants were more accurate from the learning and

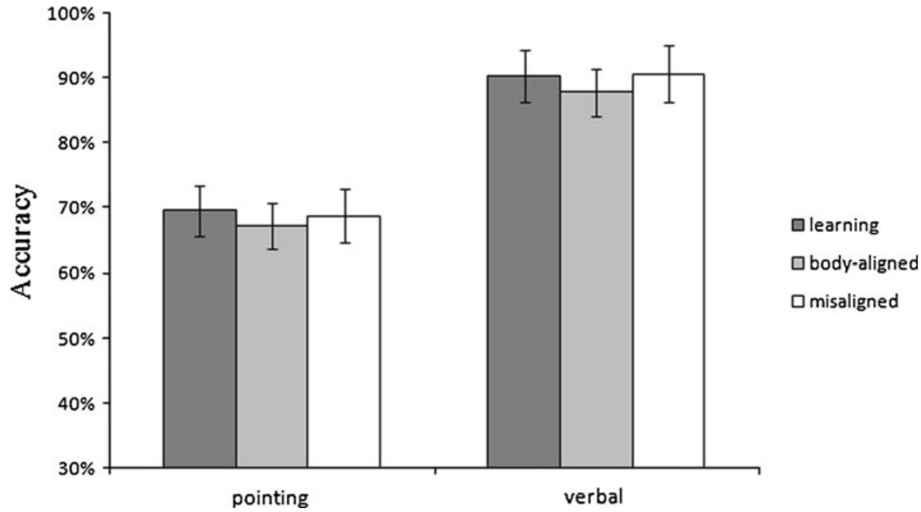


Fig. 2 Accuracy for pointing versus verbal labelling as a function of perspective from the physical rotation session. *Error bars* represent standard errors

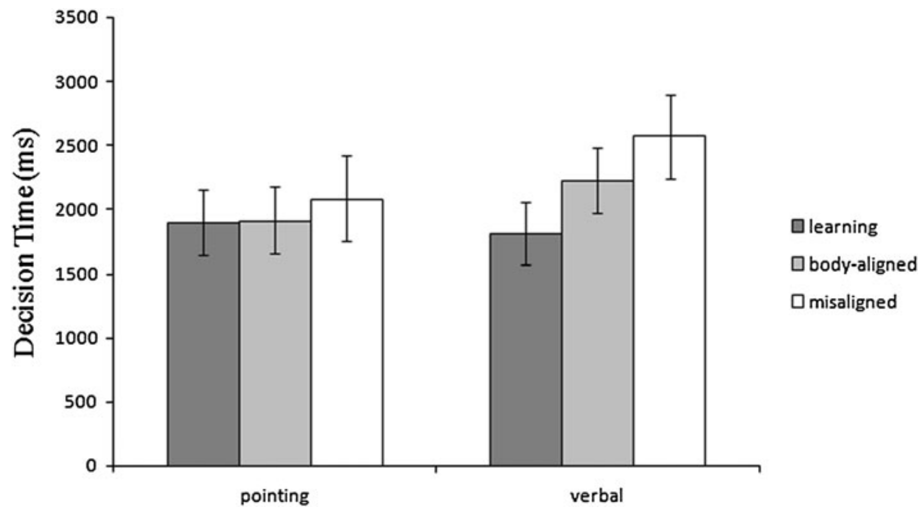


Fig. 3 Decision latency for pointing versus verbal labelling as a function of perspective from the physical rotation session. *Error bars* represent standard errors

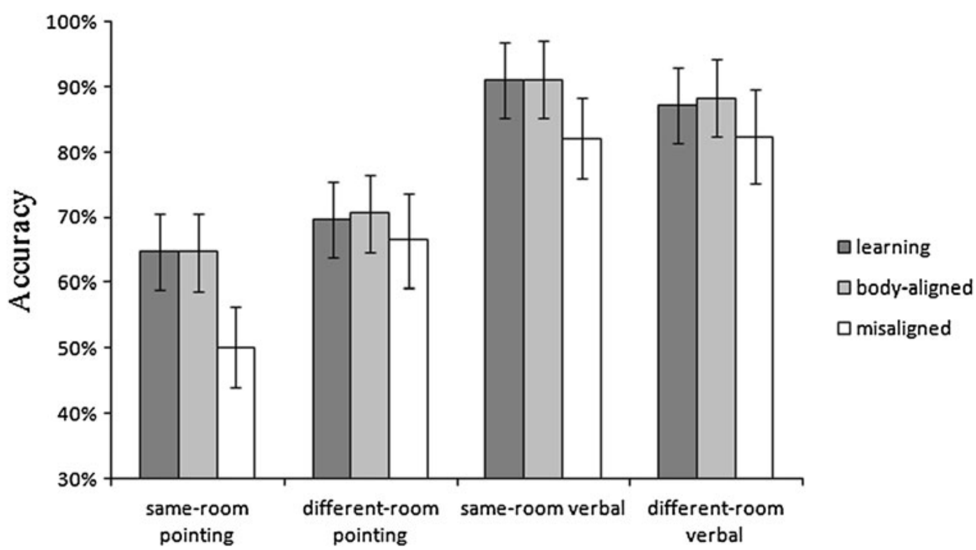
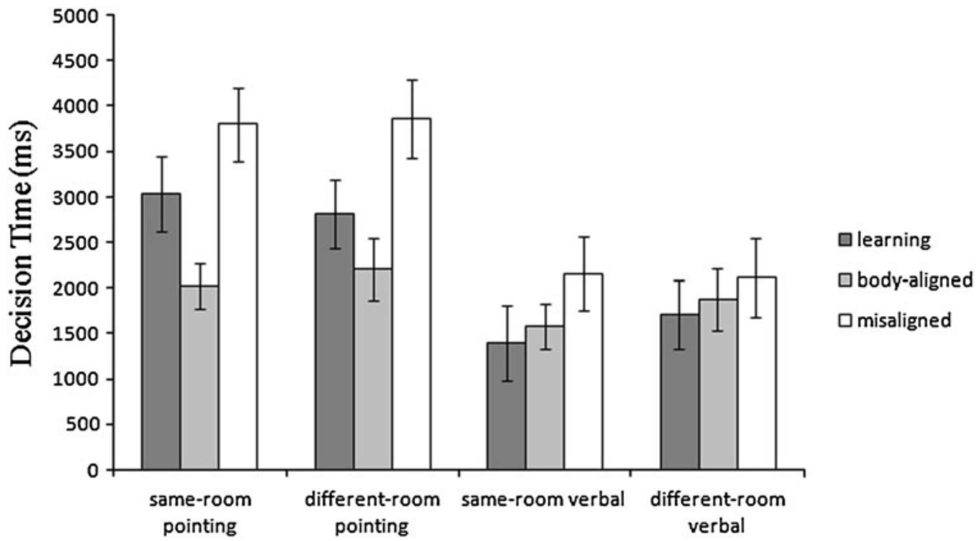


Fig. 4 Accuracy for pointing versus verbal labelling as a function of perspective and testing location from the imagined rotation session. *Error bars* represent standard errors

updated perspectives than the novel perspective, $F(1,16) = 4.84$, $p < .05$, $\eta^2 = .23$ for both contrasts. When tested in the remote environment, their labeling accuracy was comparable across the three perspectives.

When tested in the immediate environment participants were faster to decide where to point from the updated than the novel perspective, $F(1,16) = 29.10, p < .001, \eta^2 = .11$ (Fig. 5). Although they were also faster to point from the

Fig. 5 Decision latency for pointing versus verbal labeling as a function of perspective and testing location, from the imagined rotation session. *Error bars* represent standard errors



learning than the novel perspective, this difference was not reliable, $p = .11$. When tested in the remote environment, participants were faster to point from the learning and the updated perspectives than the novel perspective, $F(1,16) = 14.69$, $p < .001$, $\eta^2 = .48$ and $F(1,16) = 18.51$, $p < .001$, $\eta^2 = .54$. When responding verbally in the immediate environment, participants were significantly faster to respond from the learning than the novel perspective, $F(1,16) = 11.04$, $p < .01$, $\eta^2 = .41$ (Fig. 5). They were also faster from the updated than the novel perspective, but only marginally so, $F(1,16) = 3.98$, $p = .06$, $\eta^2 = .20$. When they responded verbally in the remote environment, they were faster to respond from the learning than the novel perspective, $F(1,16) = 9.77$, $p < .01$, $\eta^2 = .40$. However, there was no difference between the updated and novel perspectives, $p = .55$. The difference between updated and novel perspectives was greater for pointing than verbal labeling, as shown by independent-samples *t* tests, in both immediate and remote environments, $t(32) = 2.73$, $p < .05$ and $t(32) = 2.54$, $p < .05$, respectively.

Decision latencies were also significantly affected by response modality, $F(1,32) = 7.24$, $p < .05$, $\eta^2 = .19$, and by the imagined perspective, $F(2,64) = 18.54$, $p < .001$, $\eta^2 = .37$ (Fig. 4). In fact, the effect of the imagined perspective depended on the response modality, as revealed by their interaction, $F(2,64) = 7.17$, $p < .01$, $\eta^2 = .18$. Specifically, for both modalities there was a disadvantage for the novel perspective, though it patterned somewhat differently across modalities: pair-wise comparisons showed that, for pointing, participants were fastest for updated trials, slower for learning trials, and the slowest for novel trials, p's $< .01$. For verbal labeling, participants were faster for learning than novel trials ($p < .01$); however, updated trials were not reliably faster than novel trials ($p = .16$) and were comparably fast to learning trials ($p = .50$).

For orientation latency, only the main effect of imagined perspective was significant, $F(2,64) = 11.73$, $p < .001$, $\eta^2 = .27$. Pair-wise comparisons showed that participants were fastest to orient to the updated perspective ($M = 1{,}115$ ms), slower to orient to the learning perspective ($M = 1{,}438$ ms), and slowest to orient to the novel perspective ($M = 1{,}621$ ms), p's $< .001$. For response latencies, only the main effect of response modality was significant, $F(1,32) = 74.87$, $p < .001$, $\eta^2 = .70$: participants were slower for verbal labeling ($M = 1{,}719$ ms) than for pointing ($M = 816$ ms).

Discussion

Our findings suggest that when reasoning about spatial relations in immediate environments, physical motion facilitates the updating of spatial relations. First, in the physical rotation session, where participants physically rotated to adopt new perspectives, they computed pointing responses comparably fast and accurately from every perspective they adopted through physical movement. This suggests that they updated relations from their learned egocentric perspective, replicating closely findings that people point with equal accuracy and speed from the learning perspective and any other perspective they adopt by physically rotating (Rieser, 1989). That participants here were not reliably faster to compute pointing responses from their learning perspective suggests that, even if they had formed an orientation-dependent representation at encoding (McNamara, 2003), they were able to update it when physically rotating to a new perspective.

Additionally, results from the imagined rotation session further indicate that, in the immediate environment, participants updated locations when they physically rotated to the updated perspective at the beginning of that session. Performance from the updated perspective was superior to the novel perspective to which they imagined rotating. This held for responding both through pointing and verbal labeling, although the difference between the updated and novel perspectives was greater for pointing than verbal labeling. This finding is in line with those from previous studies indicating that, when responding from perspectives that are misaligned with one's body orientation, verbal labeling might be used more flexibly than pointing, possibly because of being less susceptible to sensorimotor interference (Avraamides et al., 2004; Kelly & McNamara 2008; Wraga, 2003).

The sensorimotor advantage of the updated perspective persisted, at least in some respects, when people reasoned about spatial relations in a remote environment. In terms of decision latencies, the strong sensorimotor effect observed when pointing in the immediate environment was not mitigated by remote testing: participants were faster to respond from the updated than the novel perspective in both environments. In terms of accuracy, the sensorimotor advantage was reduced in the remote environment; this was because accuracy improved relative to the immediate environment, particularly from the novel perspective. That is, although in remote testing participants were more accurate to point from the novel perspective than in immediate testing, they were still slower to compute pointing responses relative to the updated perspective. That people were more accurate from the novel perspective in the remote than the immediate environment may indicate that they can overcome sensorimotor interference more easily when not physically immersed in the memorized layout. Moreover, the fact that they were slower to point from the novel than the updated perspective is line with Rieser et al.'s (1994) conclusion that, with physical movement, remote objects can be updated and be treated as immediate. Thus, people *can* update remote locations that they have brought into working memory through visualization instructions.

Although participants in the remote environment updated the encoded relations, as suggested by the documented sensorimotor effects, they still kept a distinct representation from the learning perspective, in line with current theories of spatial memory (Mou et al., 2004; Waller & Hodgson, 2006). Performance in the remote environment was better from the learning than the novel perspective. At the same time, this representation from their learning perspective seems to not have been as readily accessible as the updated representation they created following the physical rotation: participants pointed faster (though equally accurately) from the updated than the learning perspective in both environments.

These findings can be accounted for by models of spatial memory claiming that, upon experiencing a spatial layout, people simultaneously construct an enduring spatial representation that is maintained in long-term memory and a transient representation that is updated during physical movement (Easton & Sholl, 1995; Mou et al., 2004; Waller & Hodgson, 2006; see also Avraamides & Kelly, 2008). The advantage we report of the learning perspective over the novel perspective suggests that participants constructed an enduring spatial representation and maintained it in memory from a preferred direction determined by egocentric experience. At the same time, they also constructed a transient representation that they updated upon rotating, as evidenced by the advantage we report of the updated over the novel perspective. Visualization instructions in the remote environment could have contributed to treating the remote objects as immediate, by reinstantiating this transient representation (Kelly et al., 2007). Extending the results of Kelly et al. (2007), the present study shows that participants not only reinstated such a representation but also updated automatically the egocentric relations it contained. As shown in Exp. 2, when participants rotated to the updated perspective in the remote environment, they updated egocentric relations as if objects were immediate.

Our findings afford further nuances on updating, by suggesting that these distinct representations are maintained and accessed differently when having to respond through verbal labeling than through pointing. In contrast to pointing, when having to locate objects verbally, participants maintained and accessed with comparable ease their initial representation of spatial relations (or the mapping of verbal labels to regions of space they had established during learning) and the representation of new relations they computed upon physically rotating to the updated perspective. Participants were equally fast and accurate to label locations from the learning and updated perspectives, in both immediate and remote testing. Remote testing led to a modest reduction of the sensorimotor effect for labeling, but this was due to reduced accuracy from the updated perspective rather than increased accuracy from the novel perspective. And for decision latencies, the sensorimotor effect observed in the immediate environment was removed at the remote environment, but again this was due to a decrement in performance from the updated perspective rather than an improvement from the novel one.

Thus, when reasoning from imagined perspectives, language may offer a more flexible response medium, seeing that pointing responses are relatively more difficult to produce (Avraamides et al., 2007; De Vega & Rodrigo, 2001; Kelly & McNamara, 2008). Pointing from imagined perspectives may be difficult due to updating failures during imagined movement (Presson & Montello, 1994; Rieser, 1989); verbal labeling can thus be used more flexibly than pointing when failing to update spatial relations from an imagined perspective. In line with this possibility, De Vega and Rodrigo (2001) claimed that with verbal responding people operate in a representational—as opposed to sensorimotor—framework. The distinction between sensorimotor and representational frameworks made by De Vega & Rodrigo (2001) is indeed pertinent here: when relying on a sensorimotor framework to point, people can respond with ease only from imagined perspectives aligned with their body orientation because of influence from sensorimotor information; in contrast, when relying on a representational framework to compute verbal responses, people can more easily override conflicting information from their body orientation.

A related explanation for the more flexible labeling performance from imagined perspectives in remote testing is that pointing and labeling are subject to different degrees of sensorimotor interference. The increased accuracy for pointing from the novel perspective in remote testing is consistent with proposals that spatial decontextualization relaxes sensorimotor codes that, in an immediate environment, are automatically activated and interfere with localizing targets from imagined perspectives (May, 2007). When responding verbally in remote testing, there wasn't any such evidence of a reduction of sensorimotor interference, insofar as the reduced sensorimotor effect for accuracy and decision latency was not due to improved performance from the imagined novel perspective.

Since removing sensorimotor interference by testing in a remote environment did not improve verbal labeling from imagined novel perspectives, an alternative explanation may account for the overall relative advantage of the updated perspective. When rotating to a new orientation, people need to reassign spatial labels to particular regions of space. Once this is achieved (e.g., upon being encouraged by visualization instructions), performance from this new perspective, aligned with their body orientation, can be superior to that from other imagined perspectives that require spatial terms to be recomputed. Responding from perspectives other than the learning perspective incurred a cost on labeling performance, presumably because participants had to reassign spatial terms on each trial. Support for this possibility—of having to reassign verbal labels upon rotating—also comes from differences in pointing and labeling performance in the physical rotation session, where participants repeatedly rotated to each adopted perspective. In the absence of sensorimotor influences in this condition, pointing performance was more flexible—it was unaffected across perspectives, at least for the time needed to compute a response. In contrast, verbal labeling performance was affected by the perspective participants physically adopted: participants were slower to compute verbal responses from the updated and the novel perspectives than the learning perspective. Since this could not be due to any sensorimotor influences, it likely reflects costs associated with re-mapping verbal labels to the appropriate regions of space after each rotation. This is in line with evidence that it is more difficult to interpret verbal labels (e.g., front, back, left, right) when one's egocentric reference frame changes, and to make labeling judgments (left vs. right) from imagined perspectives (e.g., Avraamides & Sofroniou, 2006; De Vega & Rodrigo, 2001).

To summarize, people are able to update spatial relations in both immediate and remote environments, but the demands of the mode of responding shapes their performance. In an immediate environment, locating objects from repeatedly changing perspectives is more computationally demanding for labeling because people have to reassign terms anew, whereas pointing can be deployed without sensorimotor interference. But when rotating only once to adopt a new perspective in the immediate environment, people do experience sensorimotor interference when pointing to locate objects from imagined perspectives, whereas labeling remains effective, possibly due to relying on a representational rather than sensorimotor framework. In a remote environment, visualization instructions can help people reinstate an earlier sensorimotor representation, such that they can successfully update spatial relations upon moving to adopt a new perspective. At the same time, people also maintain a distinct representation created at encoding, aligned with their learning perspective. When locating objects through pointing in a remote environment, people seem to access their sensorimotor representation with more ease than their initial representation, continuing to experience sensorimotor interference (though it is somewhat tempered relative to the immediate environment). When locating objects through labeling in a remote environment, people do not experience such sensorimotor interference; instead they access both their initial and sensorimotor representations with equal ease and accuracy. Thus, pointing and labeling lend themselves as better modes of responding under different circumstances.

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