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Facilitated pointing to remembered objects in front: Evidence for egocentric retrieval or spatial priming?

Jonathan W. Kelly and **Timothy P. McNamara**
Vanderbilt University

Abstract

Recent spatial memory theories propose that long-term spatial memories are retrieved egocentrically. One source of evidence comes from imagined perspective-taking, where participants learn an object layout and later imagine standing at one object, facing a second (orienting) object, and point to a third (target) object from the imagined perspective. Pointing is fastest for target objects in the anterior, compared to posterior, half of imaginal space. This "front-facilitation" is consistent with asymmetric sensory and biomechanical body properties (favoring the anterior half of body space), supporting claims of egocentric retrieval. However, front-facilitation might actually result from spatial priming: proximity differences might cause orienting objects to prime target objects in the anterior, compared to posterior, half of imagined space. Using a modified perspective-taking task, which unconfounded front-facilitation and spatial priming, two experiments identified separate influences of front-facilitation and spatial priming when imagining perspectives within the surrounding environment or a remote environment.

Spatial behaviors such as finding one's car in a parking lot depend on long-term spatial memories, and the organizational properties of those memories have received considerable research attention. The preponderance of evidence indicates that spatial memories are orientation dependent, organized around a small number of reference directions centered on the environment (Kelly & McNamara, 2008b; Mou & McNamara, 2002; Shelton & McNamara, 2001). Several recent spatial memory theories (Avraamides & Kelly, 2008; Sholl, 2001) propose that environment-centered long-term spatial memories are retrieved in an egocentric form conducive to body-based actions (this is conceptually similar to the spatial framework model; Franklin & Tversky, 1990). The current research project evaluates some of the evidence supporting this proposal.

Perspective-taking performance is commonly used as an index of organizational properties of spatial memory. In a typical experiment, participants learn a layout of objects like that depicted in Figure 1. Participants later imagine standing in a specific location (in this case, the center of the layout, indicated by the "+"), facing one (orienting) object, and point to another (target) object from that perspective. Perspective-taking results have been interpreted as evidence that long-term, environment-centered spatial memories are retrieved egocentrically (Sholl, 2001). Of particular relevance is the finding that pointing is faster and more accurate when the target object is in the anterior, compared to posterior, half of space from the imagined perspective. For example, a participant who imagines facing the bear in Figure 1 would be faster and more accurate when pointing to the wolf (in the anterior half of space) than when pointing to the frog (in the posterior half). As noted by Sholl (2001), this asymmetric retrieval of spatial memory—herein referred to as "front-facilitation" —is consistent with other asymmetric

Address correspondence: Jonathan W. Kelly, Department of Psychology, Vanderbilt University, 111 21st Ave South, Nashville, TN 37203, Email: E-mail: jonathan.kelly@vanderbilt.edu.

properties of the human body: the visual system detects information in front of the head, and the arms and legs are biomechanically suited to act on locations in front of the body. Thus, front-facilitation has been considered as evidence for egocentric retrieval of spatial memory. Front-facilitation occurs when the participant is physically located within the to-be-imagined environment (Sholl, 1987; referred to herein as "situated retrieval"), and also when the participant is not physically located within the to-be-imagined environment (Hintzman, O'Dell & Arndt, 1981;Shelton & McNamara, 1997;Sholl, 1987,1999;Werner & Schmidt, 1999; referred to herein as "remote retrieval").

However, aspects of the perspective-taking task itself might be responsible for front-facilitation. Rather than demonstrating egocentric retrieval, front-facilitation might be due to spatial priming from the orienting object. Specifically, object recognition is faster when preceded by presentation of nearby, compared to distant, objects (McNamara, 1986). Because perspective-taking experiments typically present the orienting object in front of the body from the imagined perspective ("Imagine *facing* the bear"), the orienting object might prime other objects in front of the imagined perspective (objects near the orienting object) more than objects behind the imagined perspective (objects far from the orienting object). Furthermore, stimulus-response compatibility, whereby spatial properties of stimuli can prime responses with similar spatial characteristics (Proctor & Vu, 2006), might also contribute to this spatial priming effect. In the current experiments, we do not distinguish between priming due to shared spatial properties between orienting and target objects and shared spatial properties between orienting objects and pointing responses.

Experiments by Hintzman et al. (1981) lend credence to the idea that front-facilitation is at least partially due to spatial priming. In one experiment, participants imagined different perspectives by imagining the orienting object to their side, compared to the traditional method of imagining facing the orienting object. If front-facilitation is due entirely to spatial priming, then presenting the orienting object to the left should result in facilitated pointing to the left, compared to right, and equivalent retrieval of objects in front and back. In fact, responses were 33% faster[1] when the target object was on the same side, compared to the opposite side, as the orienting object, indicating spatial priming by the orienting object. Furthermore, responses were 10% faster for target objects in front of, compared to behind, the imagined perspective, indicating front-facilitation even when controlling for spatial priming. However, the necessary statistics to evaluate front-facilitation were not presented, and the authors' conclusions were based only on the larger spatial priming effect, downplaying the comparatively smaller front-facilitation.

In these experiments, employing a paradigm similar to Hinztman et al. (1981), blindfolded participants imagined perspectives within a learned layout. Orienting objects were presented to the sides of the imagined perspectives ("Imagine the lion is to your left. Point to the wolf."), allowing for separate evaluation of front-facilitation and spatial priming. Facilitated pointing to target objects in front of the imagined perspective, compared to behind, will indicate front-facilitation, a key piece of evidence in support of egocentric spatial memory retrieval. Facilitated pointing to target objects on the same, compared to opposite, side as the orienting object will indicate spatial priming. These effects are not mutually exclusive.

Experiment 1 sought to determine whether front-facilitation—which has been interpreted as evidence for egocentric retrieval of long-term spatial memories—occurs during situated

[1]This value was estimated from Hintzman et al. (1981; Figure 18). For consistency with the present experiments, this calculation only considered front-left, front-right, back-left and back-right responses. Spatial priming was calculated by comparing latencies for target objects on the same vs. opposite side as the orienting object. Front-facilitation was calculated by comparing latencies for target objects in front vs. back.

retrieval. Objects within the surrounding environment are particularly relevant to egocentric, body-based actions. Therefore, it is reasonable to think that such egocentric actions—such as reaching for a cup of coffee or walking through a doorway—depend on egocentric spatial representations, and so front-facilitation should be most likely to occur during situated retrieval. In contrast, objects in remote environments are less relevant to body-based actions, and egocentric representation of their locations is unnecessary. Experiment 2 explored whether front-facilitation occurs under such remote retrieval conditions.

Experiment 1

In Experiment 1, participants studied a layout from a fixed position and orientation (in Figure 1, standing at the +, facing the bear), but were allowed to turn their heads during learning. After learning, they donned a blindfold, rotated 90° to their left or right (for this example, assume they turned to the right and so were actually facing the horse), and made pointing judgments from imagined perspectives within the surrounding environment. The ease with which different perspectives within the surrounding environment can be imagined depends on their alignment with 1) reference directions in long-term memory and 2) body orientation during retrieval (Kelly, Avraamides & Loomis, 2007;Kelly & McNamara, 2008a;Mou, McNamara, Valiquette & Rump, 2004). Because either factor might influence front-facilitation, participants imagined three perspectives: the learning perspective (aligned with the learning view but misaligned with the body; “Imagine the lion is to your left”), the body-aligned perspective (aligned with the body but misaligned with the learning view; “Imagine the bear is to your left”), and the misaligned perspective (misaligned with the learning view and the body; “Imagine the frog is to your left”). The body-aligned perspective seemed prima facie most likely to result in front-facilitation, since body-based actions are necessarily executed from a body-aligned perspective.

A control experiment verified that any front-facilitation found in these experiments was not due to the pointing device itself. Participants pointed in directions indicated by arrows presented on a monitor. For consistency with Experiments 1 and 2, only front-left, front-right, back-left and back-right responses were analyzed. Forward and backward pointing were equally fast and accurate, indicated by pointing latency [front: $M=804$ ms, $SE=46$; back: $M=805$ ms, $SE=35$; $t(10)=.021$, $p=.983$] and absolute error [front: $M=7.62°$, $SE=1.25$; back: $M=7.08°$, $SE=.92$; $t(10)=.752$, $p=.469$].

Methods

Participants—Sixteen adults (8 men) from the Nashville community participated for monetary compensation. Average age was 23.6 years.

Stimuli and Design—The layout comprised eight objects spaced every 45° around a 3 m diameter circle, centered within a 5×7 m room (Figure 1). Participants stood in the center of the layout. They faced the bear (0°) during learning and then, prior to testing, turned 90° to their left or right to face the lion (90°) or the horse (270°). Test trials comprised the names of two objects: an orienting object and a target object. Participants imagined as if the orienting object were to their side (e.g., “Imagine the horse is to your right.”) and then located the target object from that perspective. Target objects of interest were those to the front-left, front-right, back-left and back-right of the imagined perspective[2].

[2]Rump and McNamara (2007) reported facilitated pointing in directions parallel to salient room axes. Here this effect was circumvented by using target objects requiring oblique pointing responses. Other target object locations were also included, but served only as filler trials to prevent stereotyped responses.

The primary independent variables were imagined perspective, cue proximity, and egocentric direction. Imagined perspective could be the learning perspective (0°), the body-aligned perspective (90° when facing 90° or 270° when facing 270°), or the misaligned perspective (90° when facing 270° or 270° when facing 90°). Cue proximity could be near (e.g., when the orienting object was on the left and the target object was front-left or back-left from the imagined perspective) or far (e.g., when the orienting object was on the left and the target object was front-right or back-right). Egocentric direction could be front (when the target object was front-left or front-right from the imagined perspective) or back (when the target object was back-left or back-right).

Trials were split into four blocks of 48 trials. Each block contained factorial combinations of imagined perspective, cue proximity and egocentric direction, repeated three times, plus twelve filler trials (to prevent stereotyped responses) with target objects directly in front, back, and to the sides. Each block was pseudo-randomized, such that the same imagined perspective never occurred twice in a row. Two blocks presented the orienting object on the left, and two presented the orienting object on the right (order was counterbalanced). Dependent measures were pointing latency and absolute angular error. Data were recorded on a laptop using Vizard software (WorldViz, Santa Barbara, CA).

Procedures—After providing informed consent, participants were blindfolded and led into the experiment room. The blindfold was removed once they were positioned in the center of the layout, facing 0°. Participants were instructed not to move their feet during learning, and to rotate their heads to view the objects. After studying for 60 sec, participants closed their eyes and pointed to all objects in a random order. This study-test sequence continued until participants accurately pointed to all objects twice (judged visually by the experimenter).

After learning, participants sat in a swivel chair in the center of the layout and donned a blindfold and headphones, which delivered auditory trial instructions. A wireless joystick (Logitech Freedom 2.4) affixed to a small board was placed on their laps. Prior to testing, participants turned 90° to their left or right. Order of physical facing direction was counterbalanced across blocks. Each trial described the to-be-imagined perspective by presenting the orienting object to the side. Responses were recorded when the joystick was deflected 30° from vertical. After each trial block, participants returned to face 0° and reviewed the layout.

Results and Discussion

Pointing latency was more responsive to the independent variables than was angular error, although the two variables were positively correlated (r=.50) and showed no evidence of a speed-accuracy tradeoff. For brevity, we focus on latency.

Pointing latency (Figure 2) was analyzed in a repeated-measures ANOVA with terms for imagined perspective (learning, body-aligned, or misaligned), cue proximity (target object near or far from the orienting object), and egocentric direction (front or back). A main effect of imagined perspective [$F(2,30)=21.34$, $p<.001$, $\eta_p^2=.59$] indicated faster pointing from the body-aligned perspective [M=2.70 s, SE=.38] than the learning perspective [M=3.79 s, SE=.53; $F(1,15)=14.30$, $p=.002$, $\eta_p^2=.49$], which was faster than the misaligned perspective [M=4.96 s, SE=.73; $F(1,15)=27.22$, $p<.001$, $\eta_p^2=.65$]. A main effect of cue proximity [$F(1,15)=15.09$, $p=.001$, $\eta_p^2=.50$] indicated that spatial priming occurred (faster pointing to target objects on the same side as the orienting object, M=3.35 s, SE=.43, compared to the opposite side, M=4.28 s, SE=.63). A main effect of egocentric direction [$F(1,15)=11.90$, $p=.004$, $\eta_p^2=.44$] indicated front-facilitation (faster pointing to target objects in front, M=3.42, SE=.44, compared to behind, M=4.21, SE=.62). Imagined perspective interacted with cue proximity [$F(2,30)=7.51$, $p=.002$, $\eta_p^2=.33$]: spatial priming was greater when imagining the misaligned perspective (1.96 s) than the learning [.50 s; $F(1,15)=8.16$, $p=.012$, $\eta_p^2=.35$] or body-aligned [.31 s; $F(1,15)=7.89$, $p=.013$, $\eta_p^2=.35$] perspectives. No other effects were significant.

Front facilitation occurred from all three imagined perspectives, even when controlling for spatial priming effects. Consistent with asymmetrical sensory and biomechanical properties of the human body, front-facilitation supports the notion that spatial memories are retrieved egocentrically during situated retrieval, an important component of recent spatial memory theories (Avraamides & Kelly, 2008; Sholl, 2001).

Spatial priming also influenced spatial memory retrieval, as pointing was faster for target objects near the orienting object, compared to far. This was particularly true when participants imagined the misaligned perspective, for which overall latencies were greatest. Even when spatial priming is expressed as a percentage (calculated as percent latency reduction when pointing to near compared to far objects), priming was larger for the misaligned perspective (33.0%) than the learning (12.4%) or body-aligned (10.9%) perspectives.

Similar to previous work (Kelly et al., 2007; Kelly & McNamara, 2008a; Mou et al., 2004), pointing was faster when imagining the learning perspective or the body-aligned perspective, compared to the misaligned perspective. Facilitated pointing from the learning perspective is thought to result from organizational properties of long-term spatial memory. According to Shelton and McNamara (2001), reference directions are selected based on cues in the learning environment, and those reference directions serve to organize the long-term representation. Participants faced a single orientation during learning (although they were free to rotate their heads to inspect the layout), and this facing direction coincided with the long axis of the room. One or both of these factors might have contributed to the facilitated responses when imagining the learning perspective. Facilitated pointing from the body-aligned perspective compared to the misaligned perspective is thought to be due to an egocentric sensorimotor representation of the environment. The sensorimotor representation is updated during self-motion, and is thought to underlie actions such as obstacle avoidance. Additionally, the sensorimotor representation interferes with the ability to imagine perspectives misaligned with the body (May, 2004), and must be suppressed in order to imagine the environment in new egocentric coordinates.

The front-facilitation found in Experiment 1 supports the claim that spatial memories of the surrounding environment are retrieved egocentrically (Sholl, 2001). However, spatial memories of remote environments might be retrieved quite differently than those of the surrounding environment, since memories of remote environments are less relevant for body-based actions. Experiment 2 tested for front-facilitation during remote retrieval of spatial memories.

Experiment 2

Whereas Experiment 1 indicated that spatial memories of the surrounding environment are retrieved egocentrically, Experiment 2 explored whether spatial memories of remote environments are also retrieved egocentrically. After learning, participants were led to a remote location for retrieval.

Methods

Participants—Sixteen adults (8 men) from the Nashville community participated for monetary compensation. Average age was 24.2 years.

Stimuli, Design, and Procedures—Learning was identical to Experiment 1. After learning, participants were led to another room on a different floor of the building, where they were seated and donned the blindfold and headphones. The same imagined perspectives from Experiment 1 were used in Experiment 2, but because participants no longer physically occupied the learning environment (and so body-alignment was irrelevant), the imagined perspectives are now referred to in environment-centered terms: 0° (the learning perspective), 90° and 270°. As in Experiment 1, testing occurred over four blocks of 48 trials. Each block comprised factorial combinations of imagined perspective (0°, 90° or 270°), cue proximity (near or far) and egocentric direction (front or back), repeated three times, plus twelve filler trials.

Results and Discussion

Latency was more responsive to the independent variables than was angular error, and there was no evidence of speed-accuracy tradeoff (latency and error were positively correlated, r=.23). For brevity, we focus on latency.

Pointing latency (Figure 3) was analyzed in a repeated-measures ANOVA with terms for imagined perspective (0°, 90° or 270°), cue proximity (near or far), and egocentric direction (front or back). A main effect of imagined perspective [$F(2,30)=16.80$, $p<.001$, $\eta_p^2=.53$] indicated faster responses when imagining the 0° perspective (M=2.87 s, SE=.44) than the 90° or 270° perspectives [90°: M=4.55 s, SE=.61, $F(1,15)=20.72$, $p<.001$, $\eta_p^2=.58$; 270°: M=4.19 s, SE=.52, $F(1,15)=15.37$, $p=.001$, $\eta_p^2=.51$]. A main effect of cue proximity [$F(1,15)=6.52$, $p=.022$, $\eta_p^2=.30$] indicated faster responses to target objects on the same side as the orienting object (M=3.55 s, SE=.45), compared to the opposite side (M=4.19 s, SE=.57). A main effect of egocentric direction [$F(1,15)=19.59$, $p<.001$, $\eta_p^2=.57$] indicated faster responses to target objects in front of the imagined perspective (M=3.45 s, SE=.43), compared to behind (M=4.29 s, SE=.58). Imagined perspective interacted with cue proximity [$F(2,30)=4.99$, $p=.013$, $\eta_p^2=.25$], where the benefit of pointing to objects near the orienting object was larger when imagining the 90° (.89 s) and 270° (.94 s) perspectives, compared to the 0° perspective (.09 s). No other effects were significant.

Responses from all three imagined perspectives were faster when pointing to objects in front of, compared to behind, the imagined perspective. This front-facilitation supports theories claiming that spatial memories of remote environments are retrieved egocentrically (Avraamides & Kelly, 2008; Sholl, 2001). This is somewhat surprising, since remembered locations within a remote environment cannot be egocentrically acted upon without first traveling to that environment. Front-facilitation during remote retrieval might indicate that retrieval processes during situated and remote retrieval share common neural structures (Sholl, 2001), a possibility pursued in more detail in the General Discussion.

Spatial priming occurred when imagining the 90° and 270° perspectives, but it is unclear why it was reduced when imagining the learning perspective. This finding is inconsistent with Experiment 1, where spatial priming occurred for the learning perspective. Similar to Experiment 1, the relative ease with which participants imagined the 0° perspective indicates that their spatial memories were organized around a reference direction coincident with the learning direction and primary room axis.

The delay between learning and testing was slightly longer under the remote testing conditions of Experiment 2 than the situated testing conditions of Experiment 1, due to the additional time (1–2 min) required to walk to the remote testing location. It is unclear what effect this delay might have had on performance, but overall latencies were similar in Experiments 1 (3.81 s) and 2 (3.87 s).

General Discussion

Several recent spatial memory theories posit that long-term spatial memories are retrieved egocentrically during situated and remote retrieval (Avraamides & Kelly, 2008; Sholl, 2001). One source of evidence for egocentric retrieval is that pointing to objects from imagined perspectives within a remembered environment is facilitated for objects in front of, compared to behind, the imagined perspective (Shelton & McNamara, 1997; Sholl, 1987, 1999; Werner & Schmidt, 1999). However, experiments by Hintzman et al. (1981) suggest that front-facilitation might be due to spatial priming. By presenting orienting objects to the sides of imagined perspectives, thereby unconfounding front-facilitation and spatial priming, Hintzman et al. found evidence for spatial priming and concluded that spatial priming fully accounted for the response profile. However, this conclusion does not completely correspond with their results, which show a 10% latency reduction when pointing to the front.

The current experiments directly assessed front-facilitation while controlling for spatial priming. Front-facilitation occurred during situated (Experiment 1) and remote (Experiment 2) testing, supporting the proposal that spatial memories are retrieved egocentrically. According to Sholl (2001), spatial memories of surrounding or remote environments are retrieved within an egocentric self-reference system. During situated retrieval, the self-reference system operates as a sensorimotor self-reference system, which has a preferred orientation consistent with one’s body orientation. During remote retrieval, the self-reference system operates as a representational self-reference system. Sholl considers long-term spatial memories to be orientation-independent, and so any perspective should be equally accessible through the representational self-reference system. However, results from the current experiments and others (Mou & McNamara, 2002; Shelton & McNamara, 2001) indicate that spatial memories are orientation-dependent.

Egocentric spatial memory retrieval provides an isomorphic mapping between representation and response, allowing for facilitated execution of memory-guided actions. Front-facilitation found here is consistent with the body’s sensory and biomechanical asymmetries. This makes sense during situated retrieval, when egocentric actions can be directed toward surrounding objects. But why did front-facilitation also occur during remote retrieval, when the retrieved objects could not be acted on egocentrically from the remote environment? According to Sholl (2001), the sensorimotor and representational self-reference systems (active during situated and remote retrieval, respectively) share overlapping neural architecture. As a result, the representational system is imbued with the same egocentric properties as the sensorimotor system. One potential benefit of this shared architecture is that egocentric retrieval of a remote space could be useful for planning future actions within that space. Furthermore, this shared architecture might underlie the findings of May (2007), where imagined perspective changes (e.g., imagining a 135° rotation) resulted in similar performance costs under situated and remote test conditions.

In sum, these experiments indicate that long-term, orientation-dependent spatial memories are retrieved egocentrically, during both situated and remote retrieval. This egocentric retrieval reflects the fundamental role of spatial memories in supporting the body-based actions necessary for navigation.

Acknowledgments

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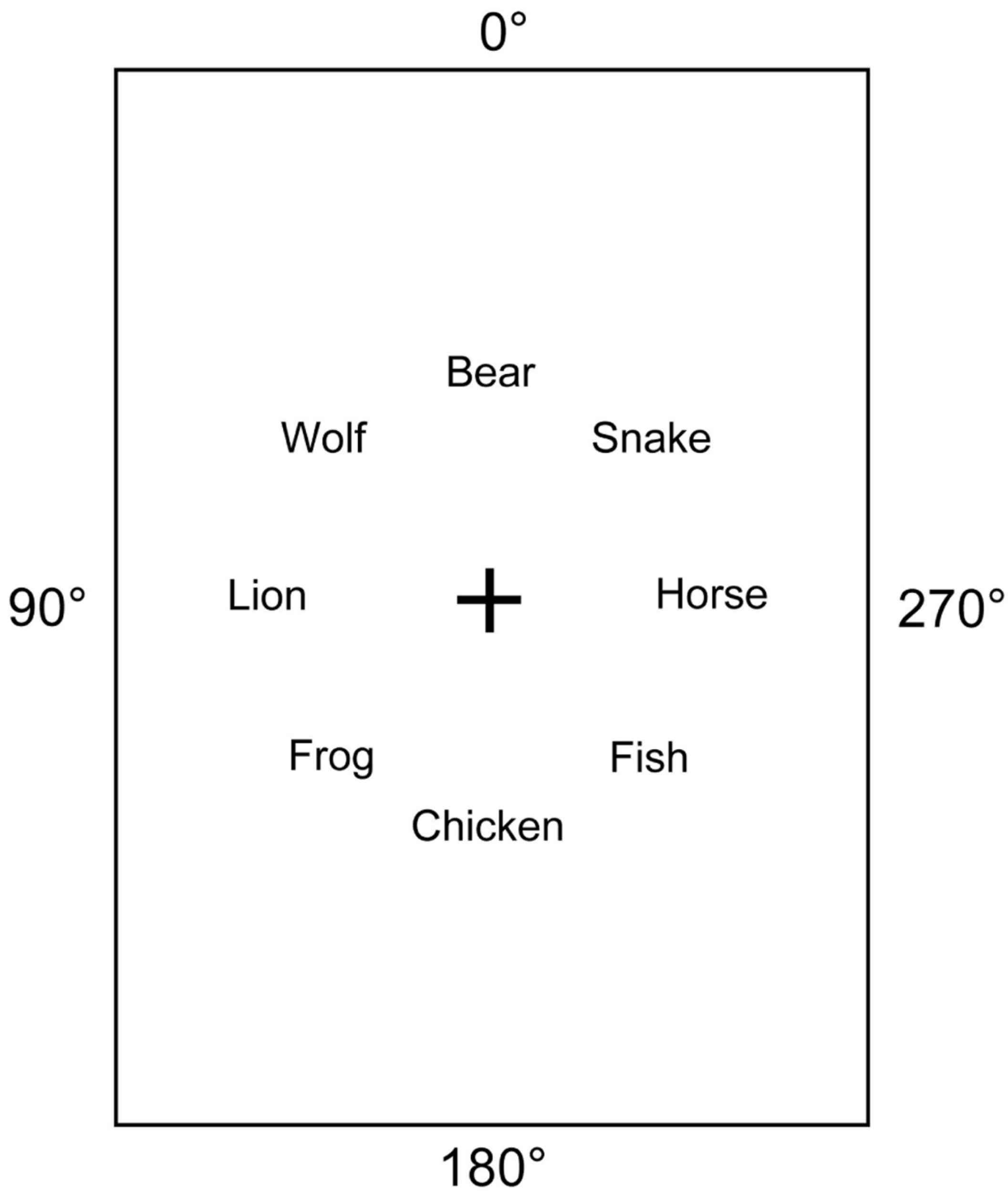

Figure 1.
Plan view of the objects and surrounding room used in Experiments 1 and 2. The learning location is represented by the +.

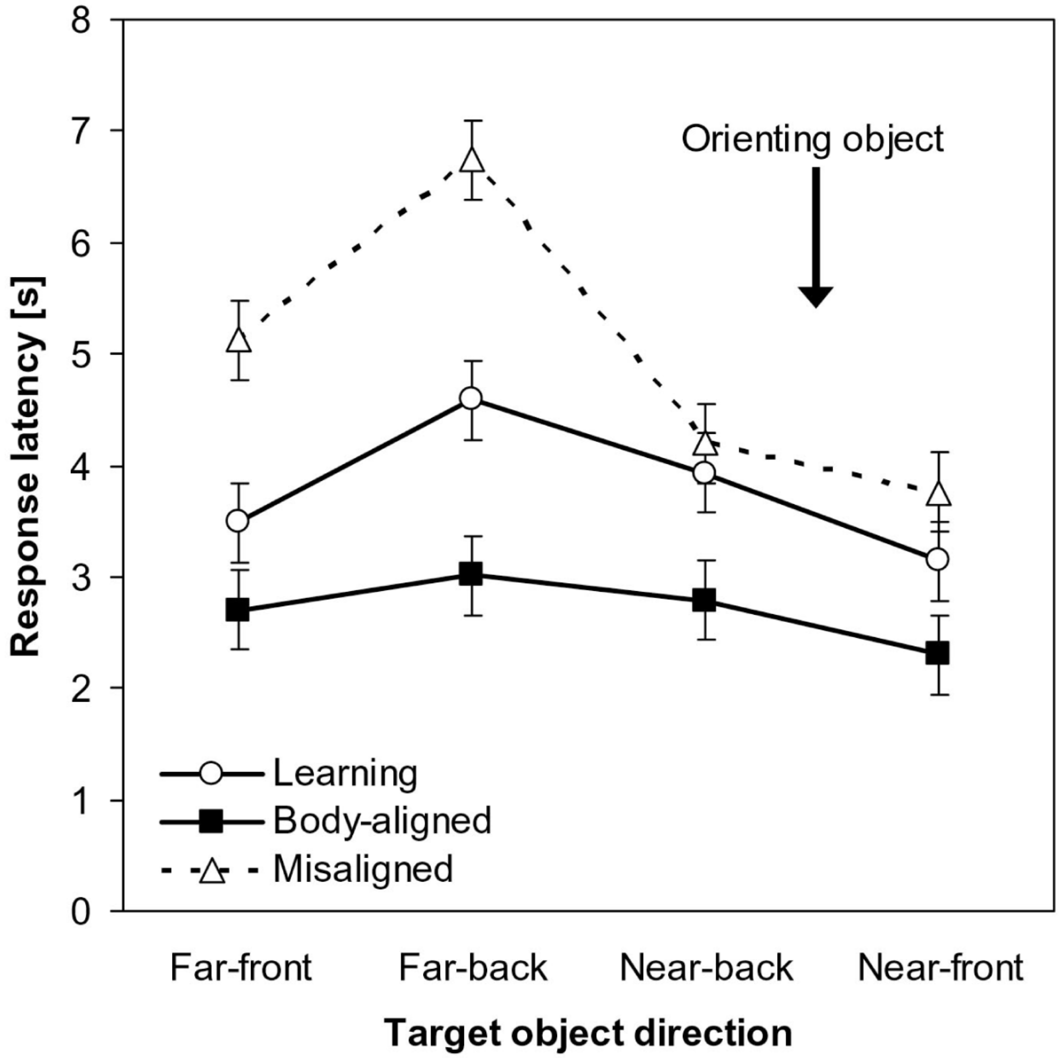

Figure 2.

Pointing latencies in Experiment 1 as a function of target object direction, plotted separately for the three imagined perspectives. The target object could be on the same side of the imagined perspective as the orienting object (near; e.g., when orienting and target objects were both to the left) or on the opposite side (far; e.g., when the orienting object was on the left and the target object was on the right). Additionally, the target object could either be in the anterior half of space from the imagined perspective (front) or the posterior half (far). The arrow indicates the orienting object's location. Error bars are standard errors estimated from the ANOVA.

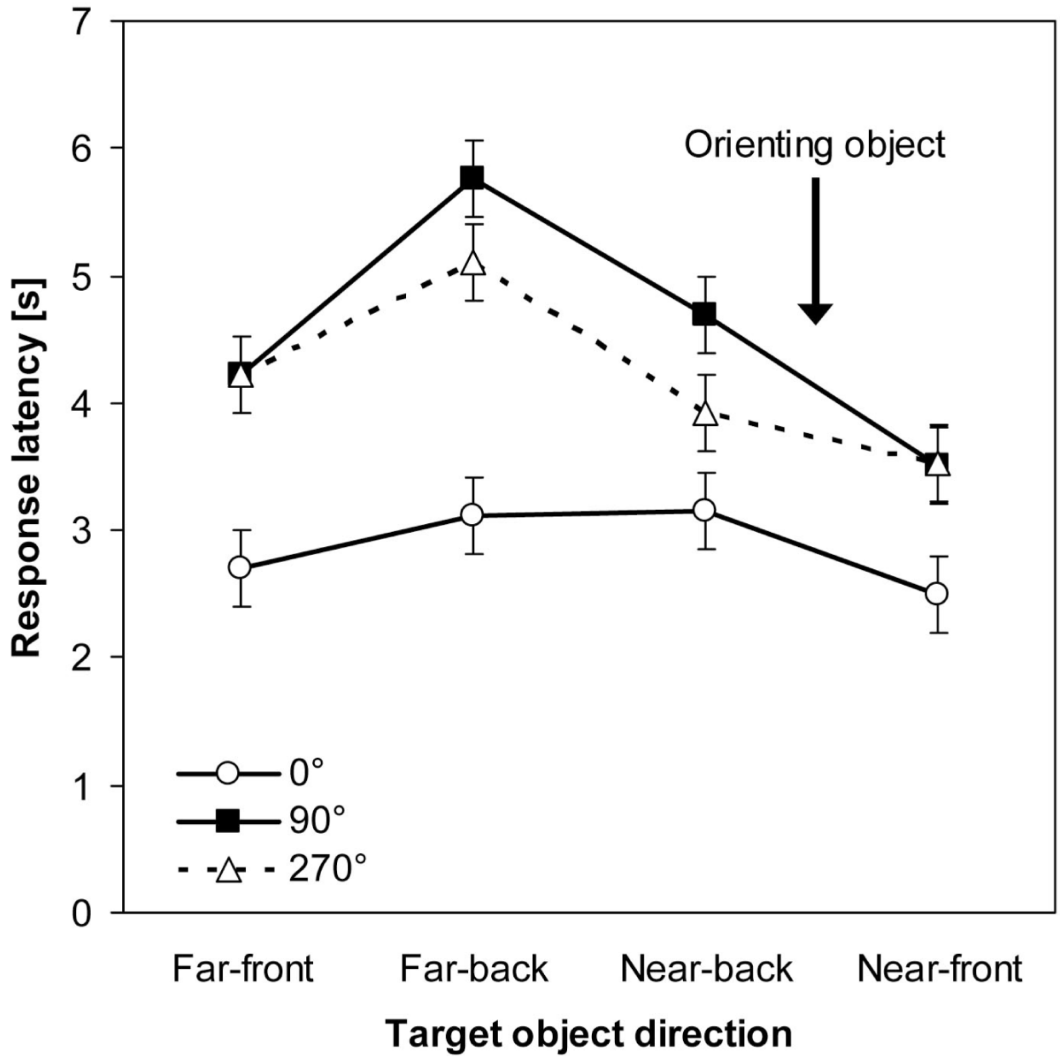

Figure 3.
Pointing latencies in Experiment 2 as a function of the target object direction, plotted separately for the three imagined perspectives. The target object could be on the same side of the imagined perspective as the orienting object (near; e.g., when orienting and target objects were both to the left) or on the opposite side (far; e.g., when the orienting object was on the left and the target object was on the right). Additionally, the target object could either be in the anterior half of space from the imagined perspective (front) or the posterior half (far). The arrow indicates the orienting object's location. Error bars are standard errors estimated from the ANOVA.