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Revisiting Perspective-Taking: Can People Maintain Imagined Perspectives?

Marios N. Avraamides, Marios Theodorou, Andri Agathokleous, and Andia Nicolaou

Abstract: Three experiments were conducted to examine whether people can adopt and maintain imagined perspectives in the absence of target information. The task used entailed providing information about an imagined perspective in advance of target information to examine whether this would facilitate perspective-taking performance and reduce or eliminate alignment effects that are commonly reported in the literature. The three experiments employed different types of spatial environments: an environment learned from navigating a computer screen (Experiment 1), and an immersive environment that was either remote (Experiment 2) or immediate (Experiment 3) at the time of retrieval. Across the three experiments, results showed that information about an imagined perspective can be utilized ahead of target information. Furthermore, they suggested that alignment effects can be reduced as a result of processing information about perspective ahead of target information, but only when reasoning about specific nonimmediate spatial relations (Experiments 1 and 2). Results are discussed in connection with previous findings on spatial updating and the organizational structure of spatial memory.

Keywords: perspective-taking, imagined perspectives, spatial memory, orientation, reference frames

1. INTRODUCTION

Many tasks of everyday life entail reasoning from imagined spatial perspectives. For example, when providing navigation instructions to a pedestrian in our city we typically imagine ourselves at various positions and orientations within the route to specify the relative location of a landmark or decide whether a turn should be to the left or right. Such tasks, which involve locating a landmark or an object from an imagined perspective, require
projecting an egocentric reference frame (i.e., a self-centered set of orthogonal axes) onto a position in space, orienting it accordingly, and then using it to compute the location of the target (Avraamides, Ioannidou, & Kyranidou, 2007). Intuitively, one could predict that processing information about one’s position and orientation ahead of target information, would allow adopting the imagined perspective in anticipation of target identity and thus speed-up target localization.

However, some findings suggest that people may not be able to adopt or maintain imagined perspectives in memory in the absence of target information (Hintzman, O’Dell, & Arndt, 1981; Wang, 2005). The goal of the present research is to examine whether, under certain circumstances, advance perspective information can facilitate imagined perspective-taking. We limit our endeavor to changes in spatial perspective within the sagittal plane, i.e., when one imagines adopting different facing orientations while remaining upright and in the same imagined location (cf. Rieser, 1989).

Perspective-taking is a popular task in spatial cognition research that is frequently used to investigate the organizational structure of spatial memory (e.g., Greenauer & Waller, 2010; Kelly & Avraamides, 2011; Mou, McNamara, Valiquette, & Rump, 2004). The typical paradigm involves observing a layout of objects and then carrying out a series of Judgments of Relative Direction (JRD) by responding from memory to statements of the form “Imagine being at x, facing y. Point to z,” with x, y, and z being objects from the layout. The pattern of pointing error (i.e., the angular deviation of the response from the correct bearing) and response latency is used to infer the way participants had encoded the layout in memory.

For example, McNamara and colleagues (e.g., McNamara, 2003; Mou et al., 2004) have observed that performance is typically better from one imagined perspective than the others. Based on their findings, they posited that people encode spatial locations using an allocentric reference frame (i.e., a reference frame that maintains object-to-object relations), which is stored in memory from a preferred direction. This preferred direction can be determined based on a variety of factors, including egocentric experience, instructions, the symmetry of the layout, the geometric structure of the enclosing space, and external cues (McNamara, 2003).

In a different line of research, perspective-taking has been used to examine how people are able to track the egocentric relations (i.e., self-to-object directions and distances) that change with movement in the environment. The mechanism that allows one to do so is known as spatial updating (Loomis, Klatzky, Golledge, & Philbeck, 1999). The typical paradigm in spatial updating studies involves encoding the location of one or more objects.

1Perspective-taking is a broad term that may involve nonspatial dimensions such as adopting the thoughts and feelings of others. Even within the spatial dimension, perspective-taking may involve various dichotomies and distinctions of perspectives, e.g., route vs. survey, egocentric vs. allocentric, etc.
and pointing to them before and after moving to a new position and/or orientation either physically or imaginarily. A typical finding is that pointing to memorized targets is more efficient following physical than imagined movement, which is interpreted as a failure to update spatial relations during imagined movement (Presson & Montello, 1994; Rieser, 1989). This suggests that spatial updating depends on information that is present only during physical movement, such as vestibular information, proprioceptive cues, and copies of efferent commands.

Although spatial memory studies afford insights by contrasting performance from different imagined perspectives, spatial updating studies examine differences between imagined and actual perspectives. Although performance differences among perspectives are well documented in both lines of research, the locus of the differences has not yet been established.

One hypothesis is that the advantage of the preferred direction in spatial memory studies and the actual perspective in spatial updating studies can be attributed to the starting points of a viewpoint alignment process. According to this hypothesis, the starting point for viewpoint alignment is the participants’ preferred direction in spatial memory studies (since participants are typically tested at a remote location, where their actual perspective is irrelevant) and their actual perspective in spatial updating studies (which is available, since participants remain in the layout). Therefore, in both paradigms, when participants adopt an imagined perspective, they rotate an imagined egocentric frame to the desired orientation, starting from either the direction they have stored in memory or their own actual perspective.

Based on this hypothesis, the increased latency for responding from other imagined perspectives reflects the time it takes to align a reference frame with the instructed orientation. In line with this account, a number of studies from the spatial memory literature (e.g., Mou, Liu, & McNamara, 2009; Mou, Zhao, & McNamara, 2007) adopted a two-step pointing procedure in which participants were first provided with the imagined standpoint and the facing target and, upon pressing a button, with the pointing target. These studies have analyzed latency for the second step only presumably to factor out the time needed to adopt the imagined perspective.

A different hypothesis is that the main difficulty of responding from an imagined perspective is not due to the imagined perspective being misaligned with one’s preferred or actual orientation, but with maintaining it for the extended period of time needed to compute a response. Maintaining an abstract reference frame on an imagined location and orientation may be cognitively demanding, especially if one has to overcome interference from knowing where objects are relative to one’s actual position and orientation (May, 1996, 2004). As May (1996, 2004) argues, sensorimotor codes are automatically activated during imagined perspective-taking, causing interference to the process of computing the response vector relative to the imagined perspective.

Furthermore, once this response has been computed, one still needs to transform it to body coordinates (i.e., realign it with their actual perspective)
in order to execute a body-dependent response such as pointing. A prediction stemming from May’s sensorimotor interference hypothesis is that people should be better able to maintain imagined perspectives when reasoning about a remote layout (as in the case of spatial memory studies) than about their immediate surroundings (as in the case of spatial updating studies). May (2007) examined this prediction in experiments that compared participants’ spatial memories when testing took place in the same environment as learning (immediate condition) or at a different one (remote condition).

In the first experiment, single-trial testing was employed (i.e., participants switched imagined perspectives on every trial of testing), yet in the second experiment, testing trials were blocked by perspective. Results revealed strong alignment effects (i.e., a performance difference between the 0° imagined perspective and the 45° or 135° perspectives) in Experiment 1 with both immediate and remote testing, although alignment effects tended to be weaker in the remote condition. Alignment effects were substantially weaker in Experiment 2, especially in the remote testing condition. Overall, latency was shorter in Experiment 2 than in Experiment 1, suggesting that the blocked design allowed participants to maintain an imagined perspective across the trials of the block.

The present study uses a different approach to examine whether adopting and maintaining imagined perspectives is possible with single-trial testing. The paradigm used involves presenting information about the imagined perspective in advance of target information, therefore providing participants the opportunity to adopt an imagined perspective in anticipation of the target. We examine the impact of early information about an imagined perspective on later target localization in terms of alignment effects—specifically, the latency difference between responding from perspectives that are misaligned vs. aligned with the preferred direction or actual perspective. If participants are able to adopt and maintain an imagined perspective, not only will overall latency decrease, but any alignment effects will be reduced or even completely eliminated.

Three previous studies have used this paradigm with mixed results regarding the effects of advance perspective information. In the first study, Hintzman, O’Dell, and Arndt (1981) showed participants an arrow surrounded by eight dots arranged in a circle at 45°-increments (Experiment 2). In each trial the arrow was presented at one of the eight possible orientations (i.e., it pointed to one of the dots), and one of the dots appeared larger to serve as the target. The time between the presentation of the arrow and the target dot, the stimulus-onset asynchrony (SOA), varied across blocks.

Participants were instructed to use a response board to point to the target from the orientation of the arrow. Participants’ overall response latency was equal for the two delay conditions (750 and 1500 ms SOA) but was, in both conditions, shorter than the simultaneous condition (0 ms SOA). Furthermore, with all three SOAs, response latency was shorter when the arrow pointed upright (0°) and increased as its angular deviation from 0° became greater,
with only a dip in latency at 180°. Notably, the increase of response latency as a function of angular deviation was somewhat steeper in the simultaneous condition (7.79 ms per degree) than in the 750 ms and the 1500 ms delay conditions (6.62 ms and 6.95 ms, respectively). Although these findings could constitute evidence that participants were able to adopt, and to some extent maintain the imagined perspective, methodological details in the experiment allow for alternative explanations.

Specifically, differences in SOA may have been confounded by the amount of information participants needed to process during the response interval. During the response interval of the two delay conditions participants had to process only information about the target, whereas in the simultaneous condition participants had to process both orientation and target information. Hintzman, O’Dell, and Arndt (1981) took the equal performance of the two delay conditions to support this alternative explanation. Furthermore, they attributed the slope difference between the simultaneous and delay conditions to differences in perceiving arrows of different orientations.

Like Hintzman, O’Dell, and Arndt (1981), Sohn and Carlson (2003) had participants carry out perspective-taking trials within a layout that remained visible on the screen at all times. The display depicted a top-down view of an oval table and five names at locations around it. In each trial participants were given a name and were asked to imagine sitting around the table at the position and orientation suggested by the name. From this imagined perspective they identified the position of a second name using the verbal labels near-left, far-left, near-right, and far-right. The arrangement of names around the table resulted in conditions of low, medium, and high misalignment relative to participants’ perspective (i.e., the upright direction).

Information about the imagined perspective was presented before the target (advance perspective condition) or information about the target was presented before the imagined perspective (advance target condition), with trials presented in blocks of SOAs of 0, 200, 400, 600, or 800 ms. Results indicated that participants were faster with advance perspective than with advance target condition. Furthermore, alignment effects (using the small misalignment as the baseline) were found in both advance perspective and advance target conditions. Importantly though, the alignment effects became smaller with increasing SOAs but only in the advance perspective condition; in the advance target condition, the alignment effects remained stable across SOAs. This pattern of results indicates that participants in the advance perspective condition were able to adopt the imagined perspective ahead of target information.

In a follow-up experiment, Sohn and Carlson (2003) only included SOAs of 0 and 500 ms but varied the type of responding (spatial vs arbitrary) in order to examine whether alignment effects can be accounted for by the presence of stimulus-response incompatibilities (see also Avraamides & Kelly, 2010 for a discussion on S-R compatibility in spatial cognition studies). In the arbitrary condition the verbal labels were mapped to arbitrary keys on the keyboard.
Results from this experiment showed again that participants were faster with advance perspective than with advance target trials. Also, advance target trials resulted in faster performance than trials with simultaneous presentation. Importantly, compared to spatial responses, arbitrary responses reduced the misalignment effect, suggesting that the effect can be partially attributed to response conflicts. The reduction of the alignment effect in this experiment did not, however, interact with the order in which information was presented. The alignment effect was not eliminated even when advance perspective information was combined with arbitrary responding.

Overall, the results of Sohn and Carlson (2003) suggest that alignment effects may represent both costs associated with a process of viewpoint alignment and interference from response conflicts. Thus, providing advance perspective information may enable people to adopt an imagined perspective in anticipation of the target but the presence of response conflicts may not allow eliminating the alignment effect completely. However, the alignment effect, albeit reduced, was not eliminated with arbitrary responding, which could mean that additional sources of the effect exist. Alternatively, it could be that the manipulations of the study did not provide the optimal conditions for either advance viewpoint alignment or relaxation of response conflicts.

Regarding viewpoint alignment, it is possible that, in the presence of conflicting perceptual information, participants adopted the imagined perspective but could not maintain it until the target was presented. But, if this was the case, they could easily readopt the perspective as soon as the target information became available. Regarding the relaxation of response conflicts, it might be the case that mapping keys to spatial labels might not constitute a completely conflict-free response, at least not without extensive practice. It is possible that at least some participants referred to the spatial label and then retrieved the instructed label-key mapping in order to respond.

In contrast to the two previous studies that used perceptual stimuli, Wang (2005) examined the effects of providing advance perspective information using a memory task. In a series of experiments, Wang had participants sit on a swivel chair in the middle of a room and rotate freely to encode the locations of five objects placed around them. Following learning, participants assumed a predetermined facing orientation and then carried out perspective-taking trials in which they imagined facing an object from the layout and pointed to another. As trials exhausted all possible combinations of objects as referents and targets, angular disparity (i.e., the angular difference between the actual and the imagined perspective) varied systematically from 0° to 180° at 60°-intervals.

In Experiment 1, information about the referent and the target objects appeared either simultaneously or with a 10-second SOA. Results indicated that in both conditions pointing error and latency increased with angular disparity, with a dip at 180°. Importantly, the two conditions did not differ from each other in either overall response latency or error. Also, latency and error as a function of angular disparity were equivalent for the two conditions.
In Experiment 2, participants were presented with the referent object first and then indicated verbally when they were ready for the target information. Even with this self-paced procedure, a substantial alignment effect was found, suggesting that participants were not able to maintain an imagined perspective in anticipation of target information. Furthermore, in both experiments advance perspective information provided no benefit at all for performance, despite that fact that the amount of information to be processed during the response interval was less. May’s (1996, 2004) sensorimotor interference hypothesis may account for Wang’s (2005) findings: advance perspective information is not helpful because participants are still faced with strong interference stemming from the automatic activation of sensorimotor codes. Therefore, although computing a response towards an object from an imagined perspective, participants must suppress the location of the target relative to their actual orientation in the environment. Compatible with this explanation are findings from other studies showing that reasoning about one’s immediate surroundings is strongly influenced by one’s orientation in the environment (e.g., Avraamides & Kelly, 2010; Kelly, Avraamides, & Loomis, 2007; Mou et al., 2004).

In summary, the studies of Hintzman, O’Dell, & Arndt (1981) and Sohn and Carlson (2003) provided results compatible with the idea that people may adopt and maintain imagined perspectives in the absence of target information. However, in both studies participants viewed the layouts on a screen and were not required to commit any information to memory as displays remained perceptually available. Therefore, it is unlikely that they have encoded egocentric relations to the objects that could give rise to sensorimotor effects. In contrast, in the study by Wang (2005), participants learned objects that surrounded them and remained within the layout during testing. It is very likely that in this case participants encoded egocentric relations (see Wang & Spelke, 2000 for evidence on egocentric encoding) that could potentially give rise to sensorimotor effects. Results from this study showed no effects for the advance presentation of perspective information.

Given the methodological differences and conflicting results of previous studies, the present study attempts to further investigate whether advance perspective information may speed up overall performance and reduce or eliminate alignment effects in situations where sensorimotor effects are either expected or not. We focus on reasoning about spatial layouts that are held in memory but we vary whether the layout is presented on a computer screen (Experiment 1), as an immersive environment that is no longer immediate at

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2 This explanation is also discussed by Wang (2005).
3 Although it is more likely that with depicted environments participants maintain a self-to-layout rather than self-to-objects relations, previous studies show that stimulus-response compatibilities are still present (Avraamides et al., 2007; Sohn & Carlson, 2003). Our conjecture is that SR incompatibilities with depicted environments are easier to ignore than when the observer is embedded to the layout.
2. EXPERIMENT 1

The goal of Experiment 1 was to examine whether an alignment effect is present when reasoning about remote spatial locations. Participants learned a layout of objects and then carried out perspective-taking trials in which the necessary information (i.e., the imagined perspective and the target) were provided in different orders so that advance-perspective, advance-target, and simultaneous conditions were formed. If information about perspective can be used in advance of target information to carry out viewpoint alignment, then the advance-perspective condition should lead to (1) faster overall performance and (2) reduced alignment effects.

2.1. Method

2.1.1. Participants. Participants were 32 students (21 women) enrolled in an introductory psychology course at the University of Cyprus. They participated in the experiment in exchange for course credit.

2.1.2. Stimuli. A photorealistic virtual environment (VE) was created using the Source 3D game engine (Valve Corporation) and was presented to participants on a desktop computer. The VE consisted of four red-brick walls forming an enclosed square space with no ceiling (Figure 1). One of the walls contained a row of windows, while the other three were identical and had no discernible features. The initial viewpoint was in the center of the room and oriented towards the wall with windows. Thus, the initial facing orientation was aligned with one of the orthogonal axes of the room. Previous studies have shown that when both egocentric experience and the geometry of the room are aligned, this axis frequently serves as a reference direction for encoding (Mou & McNamara, 2002). Furthermore, studies have also shown that the initial experienced perspective has a privileged status in memory, even if participants subsequently experience the layout from other perspectives (Avraamides & Kelly, 2005). Therefore, this initial orientation was likely to serve as the basis for encoding the layout consistently across participants. A spatial array was formed by placing virtual models of six objects (a lamp, a clock, a chair, a sign, a trashcan, and a telephone) at locations near the four walls. Objects were
placed at angles of $0^\circ$, $45^\circ$, $90^\circ$, $180^\circ$, $225^\circ$, and $270^\circ$ measured clockwise from the initial viewpoint. The layout is shown schematically in Figure 2. The testing phase was controlled by an E-Prime script and a joystick was used to execute pointing responses.

2.1.3. Design. The experiment followed a $3$ (order: advance-perspective, advance-target, simultaneous) $\times 6$ (imagined perspective: $0^\circ$, $45^\circ$, $90^\circ$, $180^\circ$, $225^\circ$, and $270^\circ$) within-subject design.

2.1.4. Procedure. Prior to the experiment participants carried out 4–5 pointing trials using campus and city landmarks to familiarize themselves with the joystick and with the task of pointing from imagined perspectives.

The experiment started with a learning phase during which participants studied the spatial layout by rotating the viewpoint around the center of the room using the mouse. Participants were given unlimited time to study the layout and encode locations in memory. Once they indicated that they had memorized the layout they were asked to adopt their initial orientation in the scene.

Following learning, participants moved to a different laboratory to complete the testing phase. Participants’ actual facing direction at the time of testing was offset by $90^\circ$ from their facing direction at the time of learning.
Trials involved adopting an imagined perspective in the memorized layout by imagining standing in the center of the VE facing an object from the layout and pointing to another object with the joystick. In the advance-perspective condition, participants were first presented with a statement of the form “imagine facing x,” where x was an object from the layout. They were instructed to adopt the imagined perspective and then press a button on the joystick to request the target. Following the button press, a statement of the form “point to y” was presented, where y was a different object from the layout.

Participants were asked to point to the target and press the trigger of the joystick to log their response. The order in which the information was given in the advance-target condition was reversed. Participants were first presented with the target information and were asked to press the joystick button once they had retrieved its location. The information about the imagined perspective was then presented. Finally, in the simultaneous condition perspective and target information were presented within a single display. The three conditions were blocked and each participant completed two blocks of trials in each condition. The order in which blocks were presented was counterbalanced across participants using a $3 \times 3$ Latin square, with the two blocks of each condition presented sequentially. Each block contained 30 trials (all possible pairs of objects) presented in a different randomized order for each participant.
2.2. Results

Accuracy and latency data were recorded. A response was considered accurate if participants pointed within ±22.5° from the correct angle. Latencies were measured by the time all information about the trial became available, that is, when target information was presented in the advance-perspective condition and when perspective information was presented in the advance-target condition. Only trials with correct responses were used in the latency analyses. Initial analyses evaluated the presence of speed-accuracy trade-offs by correlating accuracy and latency both between and within participants. For within-participant analyses we computed, separately for each participant, the correlation between the mean accuracy and latency of each combination of order and imagined heading. These initial analyses indicated that there was no speed-accuracy trade-off between accuracy and latency. The between-participant correlation of overall latency and accuracy scores was negative but did not differ significantly from zero, $r(31) = -.24$, $p = .19$. The average within-participant correlation was also negative ($M = -.20$) and differed significantly from zero, $t(31) = 4.68$, $p < .001$.

Data were analyzed first with an omnibus ANOVA and were then followed up with contrasts targeting the a priori hypothesis regarding alignment effects (i.e., reduced alignment effects with advance-perspective information). As many studies in spatial memory report a sawtooth pattern of findings with performance being particularly low from imagined perspectives that are at oblique angles from the learning perspective (e.g., Kelly & McNamara, 2010; Mou & McNamara, 2002), alignment effects were examined separately for perspectives at oblique angles (45° and 225°) and perspectives at orthogonal angles (90°, 180°, and 270°). For this and the subsequent experiments, statistical analyses on accuracy were carried out. The patterns observed mirrored those obtained for response latencies. Therefore, for the sake of brevity, we focus on analyses of response times.

A repeated-measures ANOVA with terms for order (advance-perspective, advance-target, simultaneous) and imagined perspective (0°, 45°, 90°, 180°, 225°, and 270°) was carried out and the Greenhouse-Geisser method was use to correct sphericity violations when needed. The analysis revealed a significant main effect for information order, $F(2, 62) = 59.90$, $p < .001$, $\eta^2 = .66$. Pairwise-comparisons showed that mean latency was shorter for the advance-perspective ($M = 4369$, $SD = 1239$), intermediate for the advance-target ($M = 5425$, $SD = 1759$), and the longest for the simultaneous condition ($M = 6840$, $SD = 1584$; $p$’s < .001). A main effect for the imagined perspective was also obtained, $F(5, 155) = 25.93$, $p < .001$, $\eta^2 = .46$, as well as a significant order x perspective interaction, $F(10, 310) = 2.73$, $p < .01$, $\eta^2 = .08$. Figure 3 presents the average latency as a function of order and imagined perspective.

To test whether alignment effects were present in the three order conditions, we carried out planned contrasts comparing perspectives at either
orthogonal or oblique angles with the initial learning perspective. For orthogonal angles the contrast weights used were \(-1, .33, .33, \) and \(.33\), respectively, for the \(0^\circ\) learning perspective and the orthogonal \(90^\circ, 180^\circ, \) and \(270^\circ\) perspectives. For perspectives at oblique angles the weights used were \(-1, .5,\) and \(.5\), respectively, for the \(0^\circ\) learning perspective and the oblique \(45^\circ\) and \(225^\circ\) perspectives. All contrasts differed significantly from zero corroborating the presence of significant alignment effects for both orthogonal and oblique imagined perspectives in all three order conditions, \(p<.001\).

To examine whether the magnitude of the alignment effects differed in each order condition we first computed alignment scores by subtracting the latency for the learning perspective from each of the other perspectives and then carried out contrast analyses across order conditions. For perspectives at oblique angles, none of the contrasts were significantly different from zero indicating that the extent of the alignment effect was equal across order conditions. However, for perspectives at orthogonal angles both contrasts involving the advance perspective condition were statistically significant; \(t(31) = 3.49, p < .001\) for advance perspective vs. advance target and \(t(31) = 2.21, p < .01\) for advance perspective vs. simultaneous. As seen in Figure 4 the alignment effects involving perspectives at orthogonal angles were smaller in the advance perspective condition than in the advance target and the simultaneous conditions. The latter conditions did not differ from each other, \(p = .73\).

2.3. Discussion

Results from Experiment 1 showed that providing information about perspective in advance of target information benefited overall performance. It also
Figure 4. Alignment effects as a function of the order of information and the imagined perspective type (orthogonal vs. diagonal angle), Experiment 1.

reduced the alignment effect, but only for imagined perspectives at angles that were orthogonal to the learning perspective. The alignment effect involving imagined perspectives at oblique angles was not affected by the order of information manipulation.

As the amount of information processed during the response interval was the same for the advance-perspective and the advance-target conditions, the overall difference in latency suggests that participants were able to take advantage of the perspective information in order to align their viewpoint with the imagined perspective. However, the presence of significant alignment effects in all conditions, and the absence of an interaction, also suggest that if participants adopted an imagined perspective in the advance-perspective condition, they could not maintain it in anticipation of the target. The reduced alignment effect for orthogonal angles in the advance-perspective condition may indicate that participants were sometimes able to maintain imagined perspectives that were aligned with the geometrical structure of the room or simply that they could re-adopt these perspectives quickly when target information became available.

It should be noted that studies of spatial memory reporting sawtooth patterns often claim that orthogonal perspectives are also represented in memory along with the preferred direction (e.g., Mou & McNamara, 2002). The present findings show that providing advance information about perspective may further enhance the sawtooth pattern. This suggests that the superior performance from orthogonal angles that is typically observed in spatial memory studies may have its locus to the process of viewpoint alignment.

Experiment 1 used a three-dimensional VE that was experienced in two dimensions on a computer screen. Although it is unlikely that participants developed sensorimotor codes with this type of learning, it might be the case
that as testing was also done on a computer (albeit in a different laboratory), that they experienced response conflicts. The long history of research on what is known as Stimulus-Response (SR) compatibility documents that responses to stimuli are facilitated when the location of the response is spatially congruent with the location of the target (e.g., both on the left) and impaired otherwise (Fitts & Deininger, 1954; Kornblum, Hasbroucq, & Osman, 1990).

As many models on SR compatibility claim, the presentation of a stimulus automatically activates the corresponding response based on well-established associations maintained in long-term memory (De Jong, Liang, & Lauber, 1994; Kornblum et al., 1990; Zorzi & Umiltà, 1997). As in the present case testing was carried out at a computer screen that was identical to that used for learning, it is possible that the presentation of the target primed its location (cf., Richardson & Spivey, 2000), which in turn activated a response towards that location.

To avoid the presence of potential SR compatibility effects, participants in Experiment 2 learned the layout in immersive VR and completed the testing while immersed in a different environment and at a different physical orientation. Previous studies have provided evidence that sensorimotor effects are relaxed with this type of remote testing (e.g., Kelly et al., 2007). Therefore, if participants are able to maintain imagined perspectives in the absence of target information, reductions of the alignment effects should be observed.

3. EXPERIMENT 2

Experiment 2 employed immersive VR equipment. Although encoding information through immersive VR differs in some respects from the way real environments are perceived (e.g., narrower field of view with VR), many studies using immersive VR for spatial updating (e.g., Chance, Gaunet, Beall, & Loomis, 1998; Ruddle & Lessels, 2006) and spatial memory tasks (e.g., Kelly & McNamara, 2008) have reported the same findings that are typically obtained with real environments. Importantly for the scope of the present experiment, Williams, Narasimham, Westerman, Rieser, and Bodenheimer (2007) have shown that equivalent sensorimotor alignment effects are found with real and virtual environments (see also Avraamides et al., 2011; Kelly et al., 2007).

In Experiment 2, participants studied a spatial layout while rotating in place in the center of an environment that was identical to that of Experiment 1. Following learning, participants moved to a different virtual environment and carried out pointing trials from imagined perspectives. Another difference from Experiment 1 is that information about perspective and target was provided auditorily.
3.1. Method

3.1.1. Participants. Participants were 15 students from an introductory psychology course at the University of Cyprus who participated in the experiment in exchange for course credit.

3.1.2. Stimuli and Design. A virtual environment, identical to that of Experiment 1, was created using 3-D modelling software. The six-object layout was the same as that of Experiment 1. In contrast to Experiment 1, participants experienced the layout by means of immersive VR. The virtual environment was viewed with an nVisor SX60 head-mounted display (HMD; NVIS, Reston, VA) with a 1280 × 1024 resolution, a 60° diagonal field of view, and a 60-Hz refresh rate. An InertiaCube3 (InterSense, Billerica, MA) tracker mounted on the HMD relayed orientation data to update graphics in real time. The VE for the testing phase portrayed a laboratory containing common objects such as chairs, desks, computers, etc. (Figure 5). Prerecorded audio clips with duration of 2 seconds provided information about the perspective and target in each trial through the HMD’s headphones. A Python script written in the Vizard software (Worldviz, CA) was used to present the VE and control the experiment. The design was identical to that of Experiment 1 with the exception that the simultaneous condition was dropped.

3.1.3. Procedure. Participants started the experiment standing in the center of the VE facing the windows but they were allowed to rotate freely in place in order to inspect the layout. As in Experiment 1, once they indicated that

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Figure 5. Screenshot of the virtual environment presented in the testing phase, Experiment 2 (color figure available online).
they had memorized all object locations, they were asked to turn back to their initial orientation. Following learning, participants were asked to close their eyes and were then rotated in place by the experimenter for about 30 seconds with the direction of rotation changing every few seconds. This was done to prevent participants from associating their orientations in the learning and the testing environment. At the end of the rotation participants were oriented at about 135° to the right of their initial facing orientation. When they opened their eyes they experienced a different virtual environment depicting a research laboratory (Figure 5).

Participants were first asked to point with their arm towards the door of the physical room in order to determine whether they kept track of their orientation during the 30s disorienting movement. As judged informally by the experiment, none of the participants were able to do so. Participants then completed four blocks of trials, two in each order condition. For each trial, statements providing information about the imagined perspective and the target were delivered though the headphones. A joystick was fixed on a tripod that was placed in front of the participants and was oriented along their facing orientation. In addition to response latency, in Experiment 2 we have also recorded orientation latency, i.e., the time between the presentation of the first piece of information (perspective in the advance perspective condition and target in the advance target condition) and participants’ key press to request the second piece of information.4

3.2. Results

Data from one participant were discarded from all analyses due to very low accuracy (<25%). The initial analyses suggested that no speed-accuracy trade-off was present. The between participants correlation of overall accuracy and latency was negative although it was not significant, \( r(13) = -0.32, p = 0.27 \). The average within-participant accuracy-latency correlation was negative (\( M = -0.45 \)) and differed significantly from zero, \( t(13) = -6.10, p < .001 \).

The ANOVA with terms for order (advance-perspective, advance-target) and imagined perspective (0°, 45°, 90°, 180°, 225°, and 270°) revealed significant main effects for order (\( F(1,13) = 28.4, p < .001, \eta^2 = .69 \)) and imagined perspective, \( F(5,65) = 13.39, p < .001, \eta^2 = .51 \). As seen in Figure 3, performance was overall faster in the advance-perspective (\( M = 4119, SD = 1093 \)) than in the advance-target condition (\( M = 5191, SD = 1182 \)). The interaction between order and imagined perspective was not

4Orientation latencies, in general, do not show consistent patterns and many studies have shown that they do not vary systematically with rotation angle (e.g., Creem, Downs, Wraga, Harrington, Proffitt, & Downs, 2001; Kehner, Guerin, Miller, Turk, & Hegarty, 2006).
significant, \( p = .56 \). Average latencies as a function of order and imagined perspective are presented in Figure 6.

As in the previous experiments, planned contrasts were used to determine the presence of alignment effects in the order conditions. In the advance-target condition both contrasts differed significantly from zero, suggesting the presence of alignment effects for imagined perspectives with both orthogonal, \( t(13) = -3.34, p < .01 \), and oblique, \( t(13) = -6.04, p < .001 \), angles. In contrast, in the advance-perspective condition only the contrast for oblique angles was significant, \( t(13) = -5.39, p < .001 \). The contrast for imagined perspectives at orthogonal angles was not significant, \( t(13) = -.75, p = .47 \). These results suggest that advance perspective information eliminated the alignment effect, albeit only for imagined perspectives that were orthogonal to the learning perspective. This was further corroborated by the contrast analyses comparing the extent of alignment effects between the two order conditions. The contrast analysis for orthogonal angles was significant, \( t(13) = 2.30, p = .05 \). The contrast for oblique angles was marginally significant (\( t(13) = 1.94, p = .07 \)) suggesting that the alignment effect was somewhat reduced in the advance perspective condition for oblique angles as well. Figure 7 depicts the alignment effects for the two order conditions.

For orientation latency, none of the effects was found to be statistically significant, although the order x imagined perspective approached significance, \( F(1,65) = 2.05, p = .087, \eta^2 = .16 \). As seen in Table 1, the pattern of orientation latencies was somewhat different in the two order conditions. Although in the advance target condition orientation latency remained relatively stable across imagined perspectives, in the advance perspective condition it followed a pattern suggestive of mental rotation. That is, orientation latency was shorter for the 0° learning perspective, increased until 180°, and then decreased after that. To examine whether orientation latency reflects

![Figure 6](image_url)

*Figure 6. Response latency as a function of order of information, Experiment 2.*
primarily the time needed to retrieve locations from memory, we have also analyzed the data from the advance target condition relative to the targets’ egocentric locations. Although times tended to be somewhat slower for the 225° direction than all other directions, no main effect of egocentric direction was obtained, \( p = .14 \).

3.3. Discussion

In Experiment 2 participants were tested in a different environment than the one in which they had studied the layout. Based on previous studies (e.g., Kelly et al., 2007; Wang & Brockmole, 2003) we assume that no sensorimotor influences were present with this remote testing.

Compared to the findings of Experiment 1, providing advance perspective information in Experiment 2 seemed to benefit performance more. First, as in Experiment 1 overall latency was shorter for the advance perspective condition than for the advance target condition despite the fact that the amount of information to be processed during the response interval was the same. Second, advance perspective information completely eliminated the alignment effect for imagined perspectives that were orthogonal to the learning orientation. This result shows that participants could adopt and maintain these imagined perspectives. Third, advance perspective information reduced the alignment effect for oblique angles. This result suggests either that participants were able to sometimes maintain the oblique imagined perspective, or that they could quickly re-adopt it when target information became available. We return to this issue later in the General Discussion.

The results of Experiment 2 differ markedly from those of Wang (2005) who found no effects of advance perspective information on either overall latency or on the magnitude of the alignment effect. However, in contrast to
Table 1. Mean orientation latencies (and standard deviations) in ms as a function of imagined perspective and order of information

<table>
<thead>
<tr>
<th>Imagined perspective</th>
<th>0°</th>
<th>45°</th>
<th>90°</th>
<th>180°</th>
<th>225°</th>
<th>270°</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advance perspective</td>
<td>4,467 (2,140)</td>
<td>4,620 (2,215)</td>
<td>4,795 (2,182)</td>
<td>5,893 (2,795)</td>
<td>5,363 (2,735)</td>
<td>4,754 (1,919)</td>
</tr>
<tr>
<td>Advance target</td>
<td>5,020 (2,805)</td>
<td>5,124 (2,093)</td>
<td>4,451 (1,277)</td>
<td>5,214 (2,117)</td>
<td>4,643 (1,903)</td>
<td>4,904 (2,445)</td>
</tr>
<tr>
<td><strong>Experiment 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advance perspective</td>
<td>3,314 (1,187)</td>
<td>3,431 (1,175)</td>
<td>3,791 (1,374)</td>
<td>4,003 (1,332)</td>
<td>3,831 (1,385)</td>
<td>3,635 (1,201)</td>
</tr>
<tr>
<td>Advance target</td>
<td>3,819 (1,250)</td>
<td>3,511 (1,061)</td>
<td>3,587 (1,151)</td>
<td>3,690 (1,525)</td>
<td>3,755 (1,687)</td>
<td>3,685 (1,400)</td>
</tr>
</tbody>
</table>
Wang’s experiment in which participants remained embedded to the layout during testing, participants in the present experiment were tested after having moved to a different environment. Thus, it is possible that the presence of sensorimotor interference in Wang’s study had masked the effects of advance-perspective information. To examine whether it is the absence of sensorimotor interference that allowed observing the effects of advance perspective in Experiment 2, we conducted Experiment 3 in which perspective-taking was carried out while participants remained in the learning environment during the testing phase.

4. EXPERIMENT 3

Experiment 3 was conducted to examine whether advance perspective information may eliminate or reduce alignment effects when sensorimotor influences are present. The learning phase was identical to that of Experiment 2. However, participants completed the testing phase while standing in the learning room. If the absence of sensorimotor influence in Experiment 2 was responsible for the enhanced benefits of advance perspective information then no such benefits should be observed in Experiment 3.

4.1. Method

4.1.1. Participants. Participants were 16 students from an introductory psychology course at the University of Cyprus who participated in the experiment in exchange of course credit.

4.1.2. Stimuli and Design. The VE and the spatial layout presented during learning was the same as in Experiment 2. In contrast to Experiment 2, testing was carried out while participants remained immersed in this environment but after all critical objects were removed from the scene. The design was identical to that of Experiment 2.

4.1.3. Procedure. The design and procedure were identical to those of Experiment 2 with the exception that participants carried out the testing trials while in the virtual room in which they had previously studied the layout. As in Experiment 2, participants were rotated by means of a short disorienting movement to a new orientation that deviated 135° from the learning orientation. No participant was able to determine how their new orientation related to the geometry of the physical room. When participants opened their eyes they saw the same room that was used for learning without any objects. Their orientation in the virtual room was the same as their initial learning orientation (i.e., they faced the wall with the windows). The testing phase was then proceeded in the same fashion as in Experiment 2.
4.2. Results

As in the previous experiments, no evidence was found for a speed-accuracy trade-off. The between-participant correlation of accuracy and latency was not significant, $r(15) = .07, p = .79$. However, the average within-participant accuracy-latency correlation was negative ($M = -.27$) and differed significantly from zero, $t(15) = -2.65, p < .05$.

An ANOVA with terms for order (advance-perspective, advance-target) and imagined perspective ($0^\circ$, $45^\circ$, $90^\circ$, $180^\circ$, $225^\circ$, and $270^\circ$) was used to analyze latencies. Mean latency was overall shorter for the advance-perspective condition ($M = 4512, SD = 1004$) than for the advance-target condition ($M = 4883, SD = 1052$), although the main effect for order fell short of significance, $F(1, 15) = 3.34, p = .09, \eta^2 = .19$. A significant main effect for imagined perspective was obtained, $F(5, 75) = 17.83, p < .001, \eta^2 = .54$. The order x imagined perspective interaction was, however, not significant, $p = .39$. Figure 8 presents the average latencies as a function of order and imagined perspective.

To test whether alignment effects were present in the two order conditions, we carried out planned contrasts comparing perspectives at either orthogonal or oblique angles with the learning perspective. All contrasts differed significantly from zero verifying that significant alignment effects were present for both orthogonal and oblique perspectives in both orders of information, $p$’s < .01.\footnote{As seen in Figure 8, the latency for the $180^\circ$ imagined perspective was longer than either the $90^\circ$ and $270^\circ$ perspectives. Contrasts using only the $90^\circ$ and $270^\circ$ as orthogonal angles were also carried out. Results are identical to those obtained with the $180^\circ$ angle included.}
Figure 9. Alignment effects as a function of the order information and the imagined perspective type, Experiment 3.

To compare the magnitude of these effects in the two orders we carried out contrasts analyses across conditions using alignment scores. The contrast for imagined perspectives at orthogonal angles did not differ from zero, \( t(15) = .91, p = .38 \). The contrast for imagined perspectives at oblique angles was marginally significant, \( t(15) = -1.94, p = .07 \). As seen in Figure 9, the alignment effect for oblique angles was somewhat larger in the advance-perspective than in the advance-target condition.

As in Experiment 2, orientation latency was recorded and analyzed. Although, none of the effects were statistically significant, the pattern of orientation latency as a function perspective appeared different in the two order conditions (Table 1). Like Experiment 2, orientation latency was relatively stable across imagined perspectives in the advance target condition but followed the trend expected of mental rotation in the advance-perspective condition. Analyzing latency data relative to the egocentric directions of targets in the advance target condition revealed no significant effect, \( p = .82 \).

4.3. Discussion

In contrast to Experiments 1 and 2, results from Experiments 3 showed no reduction of the alignment effect for either orthogonal or oblique angles. Overall latency was, however, shorter for advance perspective than advance target information, albeit the difference was not significant. These results suggest that participants adopted the imagined perspectives when advance perspective information was provided but could not maintain them until information about the target became available. Maintaining an imagined perspective could be difficult in this experiment due to the presence of interference from the automatic activation of sensorimotor codes (May, 2004).
5. GENERAL DISCUSSION

Taken together, the results from the three experiments showed that advance perspective information reduces alignment effects but only under certain conditions. In Experiment 1, where participants retrieved spatial relations from an environment encoded through desktop VR, the alignment effect for orthogonal, but not oblique, angles was reduced. In Experiment 2, in which immersive VR was used and testing took place remotely, the alignment effect was reduced for oblique angles and was eliminated completely for orthogonal angles. Finally, in Experiment 3 where immersive VR was used again but testing took place in the same environment, no reductions in the alignment effects were observed. Importantly, in all three experiments the overall latency was shorter when information about the imagined perspective was provided before target information than the opposite.

The overall difference in latency between the advance-perspective and advance-target condition, particularly in Experiments 1 and 2, extends the findings of Sohn and Carlson (2003) and Hintzman, O’Dell, and Arndt (1981) with perceptual scenes to spatial scenes that are held in memory. As the amount of information processed in the two conditions was equal, the difference most likely reflected participants’ ability to adopt an imagined perspective in the advance perspective condition. Findings of reduced and eliminated alignment effects in the first two experiments are also more in line with the findings from these studies, which also reported reductions of alignment effects with advance-perspective information. Notably, a decrease in overall latency, albeit not significant, was also found in Experiment 3, where testing took place in the immediate environment. This trend contrasts with the complete absence of such an effect in immediate environments in the study of Wang (2005). However, like Wang (2005), we found no reductions of the alignment effect in this experiment.

Overall, our findings suggest that people may benefit from advance perspective information but only when reasoning about remote environments. The benefit may stem either from adopting and maintaining an imagined perspective ahead of target information or from initially adopting the perspective and then re-adopting it quickly when target information becomes available. The pattern of orientation latencies in Experiment 2 and Experiment 3 suggests that participants adopted imagined perspectives ahead of target information.

Although noisy, orientation latencies for the advance perspective condition were in both experiments shorter for the 0° imagined perspective and increased with greater angular disparity. The fact that this was not the case in the advance target conditions suggests that the pattern in the advance perspective condition reflects participants’ using a mental rotation strategy to carry out viewpoint alignment, with the learning perspective serving as the starting point. However, the response latencies from the first two experiments indicate that maintaining an imagined perspective might be possible for angles
Maintaining Imagined Perspectives

orthogonal to the initial learning perspective but not for angles that are oblique to it. This might have been caused by the fact that the environment used in the experiments had a salient geometric structure.

Previous studies from the spatial memory literature have documented that the environmental reference frame of the enclosing space determines the preferred direction from which a layout is remembered (e.g., Mou & McNamara, 2002). Retrieval is often facilitated, not only when the imagined perspective is aligned with the preferred direction, but also when it is aligned with directions orthogonal to it. This is evidenced by the sawtooth pattern of results that is typically reported by spatial memory studies, indicating superior performance for orthogonal than oblique angles.

In some cases, performance from orthogonal angles is as good as performance from the preferred direction. This has led McNamara and colleagues (McNamara, 2003; Mou & McNamara, 2002) to argue that a layout is sometimes represented not only from one preferred direction, but from all 4 directions of the environmental reference frame. Based on this, the effect of providing advance information about perspective in the first two experiments could be described as an enhancement of the sawtooth pattern that is typically observed in spatial memory studies. Thus, participants in Experiments 1 and 2 might have represented the layout along the two axes of the environmental reference frame and were then able to maintain an imagined perspective only when it was aligned with one of its axes.

Because in Experiment 3, participants were tested while in the same environment occupying the learning perspective, this might have introduced a different kind of alignment effect caused by the misalignment of the actual and the imagined perspectives (e.g., Rieser, 1989). Kelly et al. (2007) used the terms sensorimotor alignment effect and encoding alignment effect to differentiate between alignment effects caused by the discrepancy of the imagined perspective from the actual perspective at retrieval and from the perspective aligned with the preferred direction from which the memory was stored.

As Kelly et al. (2007) and Avraamides and Kelly (2010) showed, while an encoding alignment effect is found with both immediate and remote testing, a sensorimotor alignment effect is typically observed only when reasoning about locations in the immediate surroundings. Based on these findings, the advantage for the 0°-perspective in Experiment 3 was most likely caused by both its alignment with the learning perspective and the physical perspective of the participant.

Although overall latency was also reduced in Experiment 3, suggesting that participants adopted the imagined perspective before the response interval, no effects of advance perspective information were found on the alignment effect. It seems that maintaining the imagined perspective was difficult in this experiment for both oblique and orthogonal angles. Perhaps this is the case because when reasoning about immediate surroundings people are faced with interference caused by the automatic activation of sensorimotor
codes (May, 2004). No such interference exists when reasoning about a remote environment as in this case no self-to-object relations are maintained.

Avraamides and Kelly (2008) proposed a model for how people reason about immediate and nonimmediate spatial relations, which may account for the present results. In line with other theories (Mou et al., 2004; Sholl, 2001; Waller & Hodgson, 2006), the model posits that upon experiencing a spatial layout people construct both allocentric and egocentric representations. The allocentric representation provides a stable and enduring memory by encoding object-to-object relations in long-term memory (Sholl, 2001) from a preferred direction (McNamara, 2003). The egocentric representation provides a transient memory by continuously monitoring self-to-object relations (Wang & Spelke, 2000).

According to Avraamides and Kelly (2008), when participants reason about remote environments, they do so solely on the basis of the allocentric representation as the self is detached from the remote environment. Therefore, retrieval is influenced only by the organizational structure of the enduring memory, i.e., the preferred direction. When reasoning about immediate environments the origin of the egocentric representation (i.e., the current location of the self) is represented as a location in the allocentric representation. This provides an interface between the two representations, which could be aligned or misaligned, depending on the physical orientation of the observer. Based on May’s (2004) sensorimotor interference hypothesis, Avraamides and Kelly (2008) argued that the self-to-object relations of the egocentric representation are automatically activated. Thus, in order to respond from perspectives misaligned to the facing direction, people need to suppress these relations.

The model of Avraamides and Kelly (2008) would attribute the alignment effect observed in Experiment 1 and Experiment 2 to the discrepancy between the imagined perspectives and the direction from which the enduring memory was formed. Providing advance perspective information allowed participants to adopt an imagined perspective—using the preferred direction as the starting point for viewpoint alignment—but maintaining it was difficult, unless it involved an angle that was perpendicular to the learning orientation and aligned with the room axes. Based on Avraamides and Kelly (2008) and May (2004), adopting and maintaining an imagined perspective in Experiment 3 entailed that participants overcome the continuous sensorimotor interference stemming from the automatic activation of self-to-object relations in their egocentric representation. Even if participants were able to adopt the imagined perspective before the response interval, strong sensorimotor interference prevented them from maintaining it in anticipation of the target.

It should be pointed out that in Experiment 3, participants’ actual perspective at the time of test coincided with the learning perspective. Although participants were differently oriented in the actual space during learning and testing, they were oriented towards the same direction in the virtual
environment. This was done to equate Experiment 3 with Experiment 2. Previous studies with remote environments suggest that even when people are not aware of the relation between their facing direction and the remote environment, they establish a subjective orientation (Avraamides & Kelly, 2010; Mou, McNamara, Rump, & Xiao, 2006).

As Avraamides and Kelly (2010) report, this subjective orientation is typically aligned with the learning perspective. The drawback of confounding the learning and testing perspectives in Experiment 3 is that we cannot determine whether the alignment effect observed was an encoding effect or a sensorimotor effect. Although previous research (e.g., Kelly et al., 2007) suggests that it might be a combination of the two, this remains to be examined by future research. The current research provides the first evidence in spatial memory that, under certain circumstances, people are capable of adopting and maintaining imagined perspectives in anticipation of target information.

AUTHOR NOTES

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