DEPARTMENT OF PSYCHOLOGY

SENSORIMOTOR INFLUENCES ACROSS ENVIRONMENTS IN SPATIAL PERSPECTIVE TAKING

DOCTOR OF PHILOSOPHY DISSERTATION

HATZIPANAYIOTI ADAMANTINI

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The present Doctoral Dissertation was submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy at the ***Department of Psychology*** *and was approved on the 02nd of May 2017 by the members of the* ***Examination Committee****.*

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The present doctoral dissertation was submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy of the University of Cyprus. It is a product of original work of my own, unless otherwise mentioned through references, notes, or any other statements.

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ABSTRACT IN GREEK

Σε 4 πειράματα εξέτασα παράγοντες που τυχόν επηρεάζουν τον τρόπο με τον οποίο οι άνθρωποι λαμβάνουν προοπτικές στο χώρο όταν είναι εξωτερικοί παρατηρητές της αντιληπτικής σκηνής. Οι συμμετέχοντες φαντάστηκαν να λαμβάνουν προοπτικές γύρω από ένα στρογγυλό τραπέζι και στη συνέχεια καλέστηκαν να δείξουν τη θέση ενός ατόμου-στόχου που καθόταν επίσης στο τραπέζι. Στο Πείραμα 1 συνέκρινα την επίδοση των συμμετεχόντων είτε όταν η σκηνή τους παρουσιάστηκε μέσα από εικονική πραγματικότητα αλλά οι συμμετέχοντες ήταν μέρος της , είτε όταν έβλεπαν την σκηνή δισδιάστατα μέσα σε άλλο εικονικό περιβάλλον. Στο Πείραμα 2, η σκηνή παρουσιάστηκε στους συμμετέχοντες σε κανονική οθόνη προβολής στο εργαστήριο και καλέστηκαν να δείξουν προς τη θέση του στόχου είτε τεντώνοντας το χέρι τους προς την κατεύθυνση του στόχου είτε μέσω ενός μοχλού. Στα Πειράματα 3 και 4 η σκηνή προβλήθηκε στους συμμετέχοντες μέσω μιας οθόνης ηλεκτρονικού υπολογιστή. Επίσης, στο Πείραμα 4, χειρίστηκα τη σειρά με την οποία παρουσιάζονταν οι πληροφορίες της φανταστικής προοπτικής και του στόχου. Συνολικά, τα αποτελέσματα έδειξαν ισχυρή επίδραση της ευθυγράμμισης μεταξύ της πραγματικής προοπτικής των συμμετεχόντων και της φανταστικής προοπτικής. Αυτό σημαίνει ότι οι συμμετέχοντες ήταν πιο ακριβείς και πιο γρήγοροι στις απαντήσεις τους όταν οι φανταστικές προοπτικές ήταν ευθυγραμμισμένες με τους ίδιους από ότι όταν ήταν μή ευθυγραμμισμένες με το σώμα τους. Σημαντικά, η επίδρση της ευθυγράμμισης του σώματος μειώθηκε όταν οι συμμετέχοντες έπρεπε να εκτελέσουν το έργο σε συνθήκες πραγματικού κόσμου από ότι σε συνθήκες εικονικής πραγματικότητας. Επίσης, η επίδραση της ευθυγράμμισης και η επίδοση γενικότερα, δεν επηρεάστηκαν από πληροφορίες αναφορικά με την φανταστική θέση που δώθηκαν εκ των προτέρων στους συμμετέχοντες, πριν την εμφάνιση του στόχου, για να τους βοηθήσουν. Τα ευρήματα προτείνουν ότι (1) οι δυσκολίες του να λαμβάνουμε φανταστικές προοπτικές στο χώρο μάλλον σχετίζονται με αισθητηριο-κινητικές παρεμβολές από ότι με κόστος νοητικών μετασχηματισμών και (2) η οπτική πρόσβαση σε πληροφορίες του σώματος πιθανών να είναι ένας σημαντικός παράγοντας όταν λαμβάνουμε φανταστικές προοπτικές στο χώρο.

Λέξεις κλειδιά: Θεωρία του Νου, αντίληψη θέσης, επίδραση ευθυγράμμισης, άμεσο περιβάλλον, απομακρυσμένο περιβάλλον, εκ των προτέρων πληροφορίες

ABSTRACT IN ENGLISH

In four experiments I examined factors that may influence how people carry out spatial perspective taking when being external observers to a perceptual spatial scene. Participants imagined occupying positions around a round table and indicated by pointing the position of a person also sitting around the table. Experiment 1 contrasted performance for when participants experienced the scene either as immediate to them in immersive Virtual Reality or as a 2D projection within another virtual environment. In Experiment 2 participants viewed the layout projected on an actual screen in the laboratory and carried out pointing either by extending their arm or by deflecting a joystick. In Experiment 3 and 4 participants were presented with the layout on a small computer screen. Also, in Experiment 4 the order of information about the imagined perspective and the target was manipulated. Overall, results showed the presence of strong alignment effects in all experiments; that is, participants were more accurate and fast to point to targets when adopting a perspective that was aligned than misaligned with their own body. Importantly, the alignment effect was reduced when the task was carried out in the real world conditions than in Virtual Reality. Also, the alignment effect, and performance in general, was not affected by advance perspective information. These findings suggest that (1) difficulties with perspective taking most likely reflect sensorimotor interference than mental transformation costs, and that (2) visual access to the body may be an important factor for perspective taking.

Keywords: theory of mind, perspective taking, alignment effect, immediate, remote environment, advance information.

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1. Chapter 1 - Introduction

1.1. Perspective taking and Theory of Mind

A distinctive attribute of humans is their inherent ability to understand the actions and intentions of those around them. This ability allows them to adjust their behavior according to the situation they are in. Imagine for example that you are sitting opposite to a friend in a coffee shop when he asks you to indicate which of the two cups on the table in front of you is his coffee. In order to make things easier for your friend, you will most likely adopt his perspective and respond with something like "it's the one on your left". This suppression of your own position and orientation in order to adopt your friend's, is one form of the concept referred to in the literature as perspective taking. Despite the fact that we engage in perspective taking quite often in daily life, it is usually an effortful and time demanding task because it requires processing of information that is not directly observable such as goals, intentions and beliefs (Epley, Morewedge, & Keysar, 2004; Flavell, Everett, Croft, & Flavell, 1981). As such, perspective taking has been broadly examined under the scope of the Theory of Mind (Frith & Frith, 2007; Leslie, 1987), which I discuss next.

Theory of Mind is the ability to understand the mental state (e.g., thoughts, motives, perceptions, and beliefs) of others. The term 'Theory of Mind' was introduced at first by Premack and Woodruff (1978) in an original study that examined the social behavior of chimpanzees. The main finding was that chimpanzees, although non-human, were able to predict human goals and -to some extent- infer human intentions (e.g., when people were unwilling vs. when they were unable to do something; Call, Hare, Carpenter, & Tomasello, 2004; see also Call & Tomasello, 2008 for a review).

As already mentioned, perspective taking refers to imagining ourselves in a position other than our own, which is of great importance in situations that require understanding of the intentions of others. In such situations, we seem to engage in simulatory processing that puts ourselves into the shoes of other people in order to reason about the world from their perspective, to interpret their thoughts and actions and to predict their future behavior (Baron-Cohen, 2005). Therefore, by definition, the concepts of Theory of Mind and perspective taking are inextricably linked so that the first is a prerequisite of the second for successful social interaction (Premack & Woodruff, 1978). Deficits in Theory of Mind lead to difficulties in communication and prevent successful social interaction; a typical case is children on the Autistic Spectrum Disorder who exhibit difficulties in understanding the mental state of others and in grasping that not all people share the same thoughts, goals and beliefs (Cohen, Leslie, & Frith, 1985; Frith, 2001).

Although perspective taking is a general term that encompasses several aspects of perspective taking process, the present research will focus on spatial perspective taking, which refers to reasoning about objects after adopting a visuospatial perspective other than the one occupied physically. I discuss this aspect of perspective taking next.

1.1.1. Spatial perspective taking: 2 types

Studies in children have shown that certain types of knowledge can be acquired from successful visual perspective taking. Flavell and colleagues (Flavell et al., 1981; Flavell et al., 1986) made a distinction between Level-1 and Level-2 knowledge of visual perspective taking. Level-1 refers to visual experiences, that is, *what* is visible to another person, and can be examined though occlusion tasks. Typically in these tasks the child is required to occlude an object so that is not visible to another person, or respond to questions about whether an object is visible from another person's point of view. Level 2 on the other hand involves mentally taking the perspective of someone else in order to reason about *how* objects look like from his/her perspective. A typical example of Level-2 knowledge is the seminal work of Piaget and Inhelder (1956), who studied first the development of awareness about the view of others. Piaget and Inhelder used a spatial perspective taking task, known as the 3 mountain task, in which children were initially presented with a physical model of a layout containing 3 different mountains followed by pictures of the layout taken from different vantage points. Their task was to indicate which of the pictures shown matched the view of a doll that was placed next to the layout across from them. Results showed that children between the ages of 4 and 7 responded egocentrically, in that they chose pictures which represented their own view instead of the doll's. In contrast, the ability of adopting the perspective of the doll was evidenced around the ages of 7 and 8 years old. However, follow-up studies by others, have provided evidence that Level-2 perspective taking is developed earlier in childhood, between the ages of 4 and 5 (Hamilton, Brindley, & Frith, 2009; Perner, 1991), whereas Level-1 appears even earlier, at around the age of 2 (Flavell, Shipstead, & Croft, 1978).

Michelon and Zacks (2006) investigated factors that may influence performance in Level-1 and Level-2 tasks, providing some interesting results. Using spatial tasks equivalent to those of Level-1 and Level-2 knowledge, in adults, they found that when participants had to judge the visibility of objects (Level-1) from another person's perspective, their performance depended on the distance between the target object and the person. That is, the greater the distance between the person and the object, the more time was needed to trace the line of sight of the person to the object. But, when participants made left-right judgments about an object relative to a virtual character, their performance depended on the angular difference between the viewpoints of the viewer and the virtual character. Michelon and Zacks concluded that different processes support each task and are dependent upon the goal and the task at hand. However, what seems clear, is that Level-2 tasks are more complex and effortful compared to Level-1 because they entail ignoring our physical perspective and engaging in mental in transformations (Kessler & Wang, 2012). In the next section, I briefly discuss the research on the mental transformations that allow adopting imagined spatial perspectives.

1.2. Mental transformations

In the literature of spatial cognition, two kinds of transformational processes have been proposed: the *object-based transformations* and the *egocentric transformations*. These processes differ in the dynamic inter relations that are being updated during transformations. Specifically, in object-based transformations the object's reference frame is transformed relative to the viewer and the environment. In these transformations, the relations between the observer and the various parts of the object are updated, while the environment and the reference frame centered on the observer remain stable. In contrast, in egocentric transformations the reference frame centered on the observer is transformed relative to fixed object-centered and environment-centered reference frames (Mou & McNamara, 2002; Zacks, Mires, Tversky, & Hazeltine, 2002). The fact that different spatial relations are updated with each type of transformational process, has led many theorists to argue that the two transformations are distinct processes that rely on different neural systems (Keehner et al., 2006; Zacks et al., 2002). Nevertheless, both types of transformations can be used to achieve an imagined perspective. Using an object-based transformation one can rotate the reference frame that is centered on another person in alignment to his/hers, while with an egocentric transformation, one can rotate his/her egocentric reference frame in alignment with the viewpoint of another person.

1.2.1. Mental rotation of objects

A large body of literature on mental transformations provides support for the distinct mechanisms underlying the mental transformation of external objects vs. one's own viewpoint (Zacks & Michelon, 2005). Object-based transformations are typically employed in mental rotation tasks that require participants to make same vs. different judgements about pairs of objects (Shepard & Metzler, 1971) or characters (Cooper & Shepard, 1973) presented at different orientations. The general finding from such tasks is that the time needed to perform the judgments increases monotonically with the angular difference in the orientation of the two objects. Similarly, in tasks requiring normal vs. mirror judgments on a single alphanumeric character, response time increases as a function of the character's angular deviation from its typical upright orientation. These findings support the conclusion that in such tasks, most people resort to object-based transformations that involve mentally rotating an object to either its upright orientation or until is aligned with another object (Cooper & Shepard, 1973; Shepard & Metzler, 1971).

1.2.2. Mental Rotation of the self

While object-centered transformations are predominantly used in same vs. different and normal vs. mirrored judgments, egocentric transformations are typically employed in tasks requiring spatial judgments such as left vs. right. Studies requiring laterality judgments typically present participants with schematic human figures at different orientations. The figures could also be facing towards (front-facing orientation) or away (back-facing orientation) from participants. Participants are called to make a left vs. right judgment for an attribute in the human figure such as to indicate which of the hands of the figure has a mark (Blanke et al., 2005; Gardner & Potts, 2011; Zacks et al., 1999) or is outstretched (Parsons, 1987). The typical finding from these studies is that response latency is longer for front-facing judgments than back-facing judgments. Most participants carry out the task by mentally rotating their body in alignment with the figure's perspective.

Other studies have employed tasks with virtual characters (i.e., Avatar in Scene-AIS) in which participants had to decide whether a target is to the left or to the right of the character (Amorim, 2003). The main finding from these studies converge with studies that employed schematic human figures instead of virtual, in that performance is worse for front-facing virtual characters compared to back-facing virtual characters (Blanke et al., 2005; Gardner & Potts, 2011; Parsons, 1987; Zacks et al., 1999). Moreover, findings from these studies indicate a monotonic increase in reaction time as the angular difference between the virtual character and the observer increases. The long reaction times might reflect the time needed to adopt the character's perspective through egocentric transformational processes (Kessler & Rutherford, 2010; Kessler & Thomson, 2010; Michelon & Zacks, 2006).

A study by Zacks, Mires, Tversky and Hazeltine (2002) compared directly tasks requiring laterality judgments with tasks entailing same versus mirror reversed judgments on the same stimuli. Specifically, participants viewed pairs of schematic figures that differed in orientation and responded to whether schematic figures were same or mirror reversed or to which arm of the figure was outstretched. Results showed a correlation between response time and orientation in the same vs. mirror-reversed judgments but not in the left vs. right judgments. This finding converges with the results from other studies (Wraga, Creem, & Profitt, 2000), showing that mental rotation and perspective taking are distinct processes that rely on different types of mental transformation.

Perspective taking can also take place with stimuli that are held in memory as opposed to being available to perception. A number of studies have examined perspective taking by comparing how well people can locate memorized objects after physical or imaginal movement to a new a point of observation (May, 1996, Rieser, 1989). In these studies, participants first observe and memorize a layout of objects from a particular standpoint and then point to them from memory. Then, they are asked to move either physically or imaginally to a new position and/or orientation and point to the objects again (Rieser, 1989; May, 1996; 2004). The typical result from a number of studies is that participants can point to the memorized objects with ease after adopting a new perspective, provided that they adopt the new perspective by physical movement (Rieser, 1989; Rieser, Guth, & Hill, 1986). In contrast, when participants respond from a new perspective that is adopted by imaginal movement, their pointing performance is substantially impaired (Easton & Sholl, 1995; May & Wartenberg, 1995; Presson & Montello, 1994; Rieser, 1989). In one example study using this paradigm, Rieser (1989) had participants memorize an array of objects placed around them and then point to each object location from novel perspectives adopted by physical or imaginal movement. Results showed that participants pointed faster and more accurately to objects after physical than after imagined rotations. Additionally, response latencies increased as a function of the magnitude of the to-be-imagined rotation. Rieser (1989) attributed the performance advantage of physical rotations over imagined rotations to the idiothetic information (e.g., proprioceptive cues and vestibular signals) that is generated during physical self-movement. According to Rieser, this information allows the moving observer to continuously monitor during movement the changing self-to-object relations. Instead, when idiothetic information is lacking, as in the case of adopting a perspective through imaginal movement, deliberate and effortful computations – that most likely include mental rotation -- are needed to determine spatial relations from the imagined perspective (Rieser, 1989).

1.2.3. Neural underpinnings of mental transformations

A vast amount of research has focused on identifying the neural mechanisms that support perspective taking mostly by directly comparing perspective taking with the process of mental rotation. Numerous neuroimaging studies that employed object transformation tasks have documented the involvement of temporoparietal junction (TPJ) during mental rotation of self (Blanke et al., 2005; Creem et al., 2001; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999) and not during mental rotation of objects (Blanke et al., 2005). The temporoparietal junction is usually involved in social cognition, and along with other brain areas including the prefrontal cortex, superior parietal lobule, occipito-temporal junction, precuneous and retrosplenial cortex, is associated with perspective taking (Blanke et al., 2004; Blanke et al., 2005; Decety & Sommerville, 2003; Sulpizio, Commiteri, Lambrey, Berthoz, & Galati, 2016; Vogeley & Fink, 2003). Studies that used functional magnetic imaging have reported activation in right intraparietal sulcus when participants performed a mental rotation task (e.g., array rotation), whereas the perspective taking task (e.g., imagined rotation around the array) was associated with activation in left superior temporal sulcus and parieto-temporo occipital junction and retrosplenial cortex (Lambrey, Doeller, Berthoz, & Burgess, 2011; Zacks, 2008; Zacks, Vettel, & Michelon, 2003). Electrophysiological measures replicate the activation of intraparietal sulcus during mental transformation of objects in 400-600ms after stimulus onset (Blanke et al., 2005). Activation of the right hemisphere during object transformations is consistent with other neuroimaging studies which also showed high activation in the right inferior and posterior parietal areas (Zacks, et al., 1999). Similarly, areas in left hemisphere including left parietal temporal occipital junction were more active during egocentric transformations (Creem, et al., 2001a; Zacks et al., 1999). Finally, left posterior parietal cortex seems to be involved during egocentric transformations, especially in egocentric coding of information acquired through vision and heading orientation (Andersen, Snyder, Bradley, & Xing, 1997; Semmes et al., 1963).

Overall, neuroimaging data seem in agreement with behavioural views in that egocentric transformations are mediated by mechanisms that are not activated in object transformations providing further support for the dissociation between the mental rotation of objects and perspective taking.

2. Chapter 2 - Experiment 1

2.1. Introduction

As described in Chapter 1, the term perspective taking is used to define our understanding of the mental state of others. Spatial imaginal perspective taking refers to our ability to mentally adopt a spatial perspective other than the one we physically occupy. For example, when providing route directions to others we need to imaginally reposition ourselves at certain locations and orientations on the route we describe in order to indicate a left or a right turn. Although there is ample evidence that people spontaneously adopt the perspective of others in social interaction situations (Kessler & Wang, 2012; Tversky & Hard, 2009), findings from research in spatial memory and perception converge in that imaginal perspective taking is effortful (Gardner & Potts, 2011; May, 2004; Rieser, 1989; Rierer, Guth, & Hill, 1986; Sohn & Carlson, 2003). This is documented by the presence of an *alignment effect*: performance is slow and prone to error as the angular disparity (i.e., the difference between one's actual and imagined orientation) increases (Avraamides, Theodorou, Agathokleous, & Nicolaou, 2013; May, 1996; Presson & Montello, 1994; Rieser, 1989; Rieser, Guth, & Hill, 1986; Sohn & Carlson, 2003; Wang & Simons, 1999; Wraga, Creem, & Proffitt, 2000; Zacks, Vettel, & Michelon, 2003).

Two explanations have been proposed about the alignment effect. The first explanation is that the alignment effect reflects processing costs associated with mental transformations (Rieser, 1989). According to this mental transformation account, access to spatial knowledge from novel imagined perspectives is not direct. Instead, it requires deliberate computational processing, most likely in the form of mentally rotating one's self to the novel perspective. As such mental transformations are time demanding and prone to error, performance in perspective taking tasks decreases as a function of the extent of mental transformation required (e.g., the magnitude of the angle of rotation).

Indeed, findings from studies in which participants located objects from memory after actual vs. imagined movements to a new standpoint, revealed slow and reduced performance for imagined movement, especially when it entailed a change of perspective (Easton & Sholl, 1995; May & Wartenberg, 1995; Presson & Montello, 1994; Rieser, 1989). This performance disadvantage could be due to the fact that, unlike physical movement, imagined movement does not generate idiothetic information (i.e., proprioceptive cues and vestibular signals) that presumably allows people to continuously track the changing egocentric spatial relations during movement (Klatzky, Loomis, Beall, Chance, & Golledge, 1998). In the case of adopting an imagined perspective, participants had to perform offline mental transformations to adopt the imagined perspective and to compute an object's location from it (Rieser 1989; Rieser, Guth, & Hill, 1986). Hence, according to this account, pointing to the locations of objects from memory after imagining occupying a new perspective requires effortful and time demanding mental transformation processes.

In line with the mental transformation account, as described in Chapter 1, findings from perceptual studies in which participants made laterality judgments about the handedness of a schematic human figure have shown that performance was less accurate for front-facing figures than back-facing figures (Blanke et al, 2005; Parsons, 1987; Zacks et al., 1999; Zacks et al 2002), suggesting that for front-facing figures participants might have carried out mental rotations to align their own view with that of the figure.

A second account for the alignment effect is based on the presence of spatial conflicts at the time of response computation and execution. According to May's sensorimotor interference hypothesis (2004), responding from imagined perspectives is difficult due to knowing where objects are relative to our actual position and orientation. Such information must be suppressed for the observer to compute and execute a response to a location from an imagined perspective. Evidence for this account comes from an experiment in which participants first memorized a layout of objects and then pointed towards their locations after adopting a new standpoint either by an imagined rotation or an imagined translation. In this experiment, information about the to-be-imagined perspective was provided ahead of target information and within varied time intervals (SOAs of 1, 3 and 5 sec). May (2004) hypothesized that if the difficulties with perspective taking occur at the early stage of the imagination process as the mental transformation hypothesis implies, then response latency should decrease with increasing SOAs and alignment effects should be eliminated, or at least be reduced. That should be the case because large SOAs would provide participants with sufficient time to process information and adopt the imagined perspective in anticipation of the target. However, results showed that although overall response latencies decreased with increasing SOAs, there was no interaction between SOA and angular disparity. Instead, participants' pointing errors and response latency showed a monotonic increase of response latencies as a function of angular disparity in all SOAs. Thus, it seems that participants had used the advance information about the imagined perspective to carry out some of the cognitive processing required by the task leading to an overall speed-up in performance, but this did not reduce the relative difficulty of responding from imagined perspective with large angular disparities. Although the finding of poorer overall performance with larger angular disparity is consistent with the transformation hypothesis, the finding that the alignment effect was not affected by advance perspective information suggests, according to May, that the main difficulty with imaginal perspective taking does not arise from the mental transformation processes required for adopting the perspective. Instead, this finding can be accounted for the sensorimotor interference account, which posits that the difficulty of responding from imagined perspectives stems primarily from spatial conflicts during response computation and execution.

The mental transformation and the sensorimotor interference accounts are not mutually exclusive. Indeed, results from a study by Sohn and Carlson (2003) suggest that both mental transformation processes and spatial conflicts contribute for the presence of alignment effect. In contrast to May's (2004) remembered environments, participants in Sohn and Carlson's study (2003), viewed a display depicting a table with names arranged around it, and then indicated the position of a target person after adopting the perspective of another reference person. Responses were made by pressing keys on keyboard that corresponded to the verbal labels "near–left", "far–left", "near–right", and "far–right". In an advance perspective condition, information about the perspective was given ahead of the presentation of the target with varied SOAs, so as to provide participants with sufficient time to adopt the imagined perspective. Results revealed that the alignment effect documented in response latency was reduced, but not completely eliminated, with increasing SOAs. This finding provides at least partial support to the mental transformation account which posits that the alignment effect arises during the imagination process. However, the fact that the alignment effect was reduced but not completely eliminated suggests that mental transformations alone cannot account for it. Therefore, in a follow-up experiment, Sohn and Carlson (2003) included a condition in which participants responded with keys on the keyboard (the W, S, L, and P keys) that were arbitrarily associated with the positions of targets. Results from this condition showed that the alignment effect in the advance perspective condition was completely eliminated with this non-spatial response set. Taken together, the findings from the two experiments of Sohn and Carlson (2003) indicate that (1) providing advance information about the imagined perspective reduces the alignment effect, possibly by allowing participants to commence the imagination process ahead of target presentation, and (2) using non-spatial responses completely eliminates the alignment effect, most likely by removing the sensorimotor conflicts associated with a spatial response. Thus, at least with a perceptual task, both mental transformation processes and sensorimotor conflicts seem to contribute to the difficulties associated with responding from imagined perspectives.

Although the studies of May (2004) and Sohn and Carlson (2003) provide somewhat contradictory results, they differ methodologically in various aspects. Not only did May's (2004) study involve a memory task (compared to the perceptual task of Sohn & Carlson, 2003), but it also had participants carry out the task while immersed in the learning environment. Previous findings have shown that when people reason about immediate environments, alignment effects are greater possibly due to the presence of sensorimotor influences, which are absent when reasoning about remote locations (Kelly, Avraamides & Loomis, 2007). Based on this outcome, Avraamides et al (2013) investigated the alignment effect by comparing reasoning about immediate environments where participants were part of the spatial scene vs. remote environments where participants were located in a different room for testing. Participants in this study first memorized the locations of objects placed around them in various directions within a virtual environment. In an immediate testing condition participants pointed towards the objects' locations from imagined perspectives while standing in the same environment in which they had previously memorized the objects (Experiment 3), whereas in a remote testing condition participants carried out the pointing trials after moving to a different virtual environment (Experiment 2). As in Sohn and Carlson's study (2003), Avraamides et al. varied the order in which information about the perspective and the target was provided. Results showed that for the immediate testing condition, advance perspective information replicated the findings of May (2004) showing an overall reduction of response latency but no effect on the alignment effect. Interestingly, in the remote testing condition results were more in line with those of Sohn and Carlson (2003): advance perspective information eliminated the alignment effect but only for objects located at orthogonal angles, whereas for all other angles the effect was only reduced. Based on these findings Avraamides et al. (2013) concluded that both the mental transformation and the sensorimotor interference accounts seem to account for the presence of alignment effect. Moreover, they argued that sensorimotor conflicts appear to be more pronounced in immediate testing conditions compared to remote testing conditions.

Collectively, the findings described above, provide two possible explanations for the presence of alignment effect when reasoning about imagined perspectives. One explanation is provided by Rieser's (1989) findings which lend support for the mental transformation account. Specifically, the documented decline in performance when adopting imagined perspectives at large angular disparities might result from the more extensive mental rotation that is needed during the imagination process. The other explanation comes from May's studies (1996; 2004) and is more in line with the sensorimotor interference account. May (2004) suggested that conflicts might arise when responding from an imagined perspective due to knowing where objects' actual location is relative to ourselves. As such, this information needs to be suppressed in order to respond from an imagined perspective. However, this might be the case, only when reasoning about remembered environments. For perceptually experienced environments, Sohn and Carlson (2003) showed that providing information about the imagined perspective in advance gave time to participants to perform the time demanding mental transformations and reduced the alignment effect, whereas using non-spatial responses completely eliminated the effect most likely by reducing any sensorimotor conflicts. Hence, both the mental transformation and the sensorimotor interference hypotheses might account for the alignment effect. In line with Sohn and Carlson's study, Avraamides et al. (2013) also showed that advance perspective information eliminated the alignment effect but only in remote testing situations and not in immediate ones. According to Avraamides et al. (2013; but see also Avraamides & Kelly, 2008), when we are immersed in the environment sensorimotor influences emerging from knowing the real location of objects relative to our position in space, hinder performance when reasoning about imagined perspectives. If sensorimotor conflicts are present when we are immersed in an environment, and especially in situations where we are internal to the spatial scene (e.g., being surrounded by objects) compared to when we are external to the layout (e.g., when viewing the objects from a position outside of the layout) or viewing the scene on a computer monitor or a projector which are more perceptually based, then sensorimotor conflicts should have less or no influence in adopting imagined perspectives. This would be because the self-to-object codes which define the spatial relations between the observer and the objects around him and are present in immersive situations or when the observer is part of the scene, would be absent or of a lesser extent in non-immersive occasions or when the observer is external to the somewhat immediate layout.

The goal of Experiment 1 was to investigate whether sensorimotor interference effects are greater when reasoning about immersive compared to non-immersive environments using a perceptual perspective taking task. In contrast to previous studies (e.g., Avraamides & Kelly, 2008; May 2004) in which participants were internal to the spatial scene surrounded by the objects they had to memorize, my interest here was for situations in which the participant is an external observer to a perceptual scene. Such situations are closer to the Level-2 tasks used in perspective taking (Chapter 1) and the task of Sohn and Carlson (2003). Specifically, Experiment 1 aimed to examine whether the alignment effect is greater in situations where participants are immediate to a spatial scene but are external observers to it, compared to situations in which they reason about a remote scene that is available to their perception. The task required that participants imagine themselves occupying various positions around a round table and indicate by pointing the position of a person also sitting around the table. The layout was experienced using immersive virtual reality but, depending on the environment condition, it was either adjacent to participants (immersive environment condition) or was displayed on a projector screen in the virtual world (virtual projector environment condition). If being an external observer to an adjacent scene causes egocentric encoding (i.e., encoding self-to-object vectors) but observing the scene as a 2D display on a screen does not, then a larger alignment effect (i.e., poorer performance with increasing angular disparity of the imagined perspective), should be expected in the immersive environment condition compared to the virtual projector environment condition. This outcome would be in line with findings from a previous study suggesting that mental rotations in 3D environments rely on an egocentric reference frame, whereas environments presented on 2D displays involve an allocentric reference frame instead (Kozhenikov & Dhond, 2012).

2.2. Method

2.2.1. Participants

Forty-eight students from the University of Cyprus participated in the experiment in exchange for course credit. Twenty-four participants were randomly assigned to each of the immersive and virtual projector environment conditions.

2.2.2. Materials, Stimuli and Apparatus

Stimuli constituted of a virtual environment depicting a round table with 7 empty sitting positions, one highlighted empty seat and a female virtual character sitting on one of the 8 seats. The highlighted empty seat indicated the imagined perspective to be adopted, whereas the virtual character served as the target person towards which participants pointed to from the imagined perspective. Participants experienced the layout either directly by standing adjacently to the 3D scene or indirectly by viewing the scene as a 2D projection on a virtual screen. In both conditions, participants experienced the virtual environments in an Oculus Rift DK2 head-mounted display with a 960 x 1080 resolution per eye and a 75Hz refresh rate. A script written in the Unity game engine was used to present the virtual content and control the experiment during the testing phase. Participants pointed with their dominant arm and clicked a handheld air mouse to log their response. The orientation of their arm was tracked by a Myo Gesture Control Armband (Thalmic Labs) that participants wore on their arm.

In addition to the experimental task, participants completed the revised version of Spatial Orientation Test (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001) and filled out the Santa Barbara Sense of Direction Scale (SBSOD) questionnaire (Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002). The Spatial Orientation Test is a paper and pencil tool that measures perspective taking. It requires participants to draw a line indicating how they would point to an object from an imagined perspective in a schematic scene with drawings of objects. The Santa Barbara Sense of Direction Scale (SBSOD) is a self-report measure of environmental spatial ability.

2.2.3. Design

The experiment followed a mixed 2 (environment condition: immersive vs. virtual projector) x 8 (imagined perspective: 0^o, 45^o, 90^o, 135^o, 180^o, 225^o, 270^o and 315^o) design with imagined perspective manipulated within subjects and environment condition between.

2.2.4. Procedure

Participants signed an informed consent form before the start of the experiment and started by completing the Santa Barbara Sense of Direction Scale (SBSOD) and the Spatial Orientation Test.

Prior to the experimental phase participants were familiarized with the virtual environment and were provided with instructions about the pointing. They wore the head-mounted-display and were asked to aim and point towards the position of a chair that appeared in various locations in space using Myo Armband and the wireless mouse. Participants then carried out a practice block of 10 trials randomly chosen from the all possible combinations of imagined perspectives and pointing locations.

Upon completing the practice trials participants proceeded to the experimental trials. In each trial, a round table was presented with a female avatar sitting on one of the 8 seats. The remaining 7 remained empty but one them was highlighted in red. Participants were instructed to imagine sitting on the highlighted chair facing the center of the table and point from that perspective with their arm towards the female avatar. Participants were asked to point as fast as possible without sacrificing accuracy. All participants carried out 2 blocks of 56 trials each. Participants' pointing response and response latency were recorded by the computer and analysed offline. The task was identical in the two conditions and the only difference was that participants in the immersive environment condition stood in a virtual room that contained the table while those in the virtual projector environment condition stood in a room that contained a projector screen on which the table was shown.

2.3. Results

Data were analysed using Repeated-measures Analyses of Variance (ANOVAs) that were carried out separately for pointing error and response latency, with imagined perspective as the within subject factor and environment condition (immersive vs. virtual projector) as the between subject factor. The analysis was followed by planed contrasts to evaluate the size of sensorimotor alignment effect in each condition. Pointing errors and response times deviating 3 standard deviations or more from the mean of each participant were considered outliers and were removed from the analyses.

Pointing Error.

Results revealed that pointing error varied as a function of the imagined perspective adopted at testing, $F(7, 322) = 12.30$ $p < .001$, $\eta^2 = .21$. As shown in Figure 1, the error was overall smaller when the imagined perspective at testing was aligned with their physical orientation (0°) compared to the remaining imagined perspectives. Neither the main effect of environment condition nor the interaction between the environment condition and imagined perspective were significant, $F(1,46) = 1.14$, p = .29, $\eta^2 = .02$ and $F(7, 322) = 1.36$, $p = .21$, $\eta^2 = .02$ respectively.

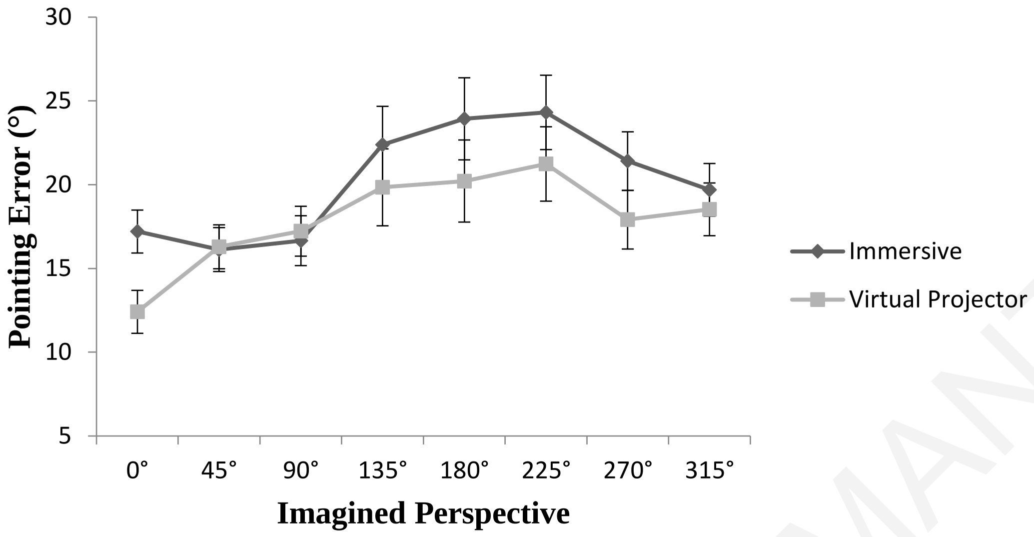

Figure 1. Pointing error as a function of imagined perspective across environment conditions (Immersive vs. Virtual Projector) in Experiment 1.Error bars represent standard errors from the ANOVA.

Planed contrasts revealed a significant alignment effect in both environment conditions (Figure 2), $t(23) = 2.87$, $p = .009$ for the immersive environment condition and $t(23) = 4.71$, $p < .001$ for the virtual projector environment condition. The alignment effect was numerically smaller in the immersive environment condition but the difference did not reach significance, $t(46) = 1.61$, $p = .11$.

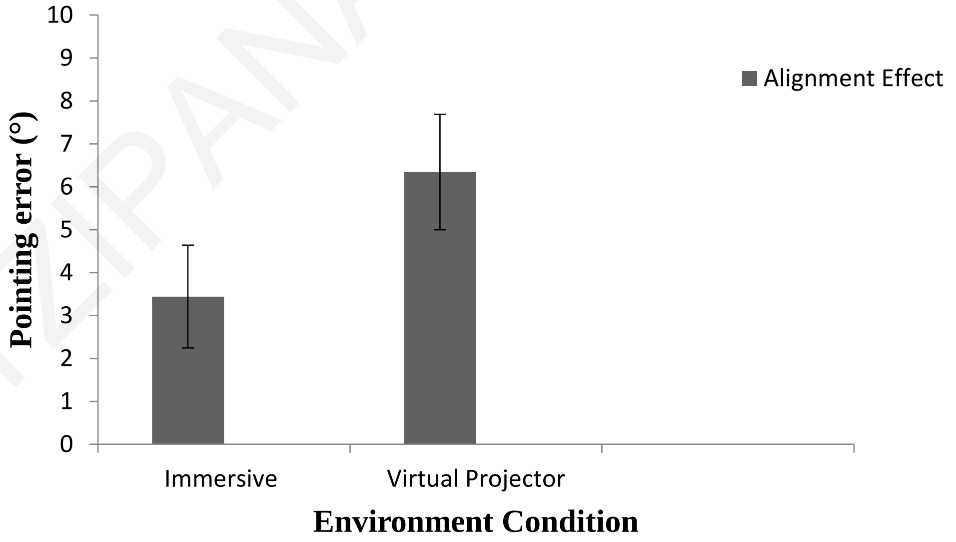

Figure 2. Alignment effects for pointing error across environment conditions in Experiment 1.Error bars represent standard errors from the t-test.

Response Latency.

Participants' response latency also varied as a function of the imagined perspective, $F(7, 322) = 29.86$, $p < .001$, $\eta^2 = .39$. Overall, participants responded faster when the imagined perspective adopted at testing was aligned with their physical orientation (0°) compared to the remaining imagined perspectives, (Figure 3). As with pointing error, the analysis revealed neither a significant main effect for environment condition, nor a significant interaction between the environment condition and the imagined perspective, $F(1,46) = 0.00$, p = .99, $\eta^2 = .00$ and $F(7, 322) = 0.88$, $p = .51$, $\eta^2 = .02$ respectively.

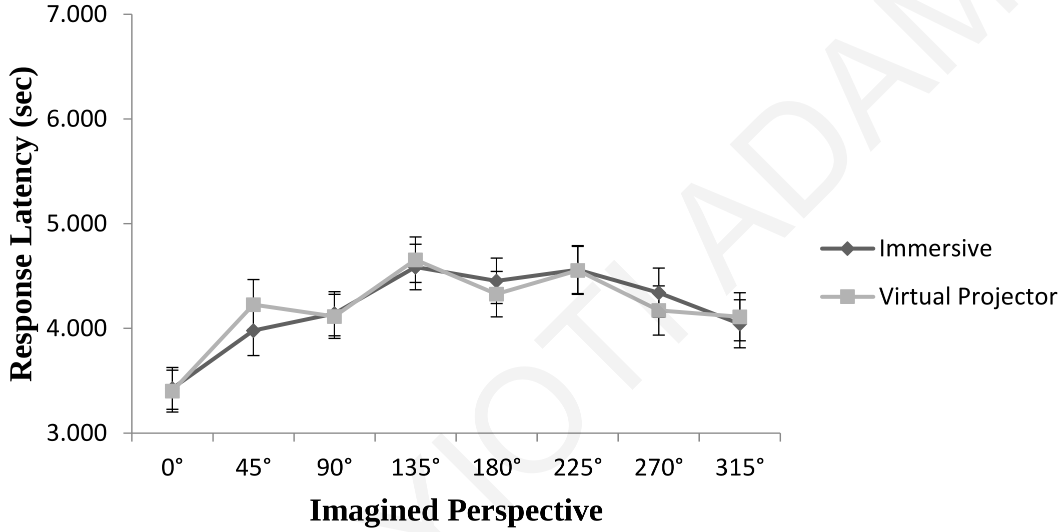

Figure 3. Response latency as a function of imagined perspective across environment conditions (Immersive vs. Virtual Projector) in Experiment 1. Error bars represent standard errors from the ANOVA.

Planed contrasts revealed a significant alignment effect in both the immersive condition, $t(23) = 6.46$, $p < .001$ and the virtual projector condition, $t(23) = 9.52$, $p < .001$ (Figure 4). The size of the alignment effect was equal in the two environment conditions $t(46) = 0.20$, p = .83.

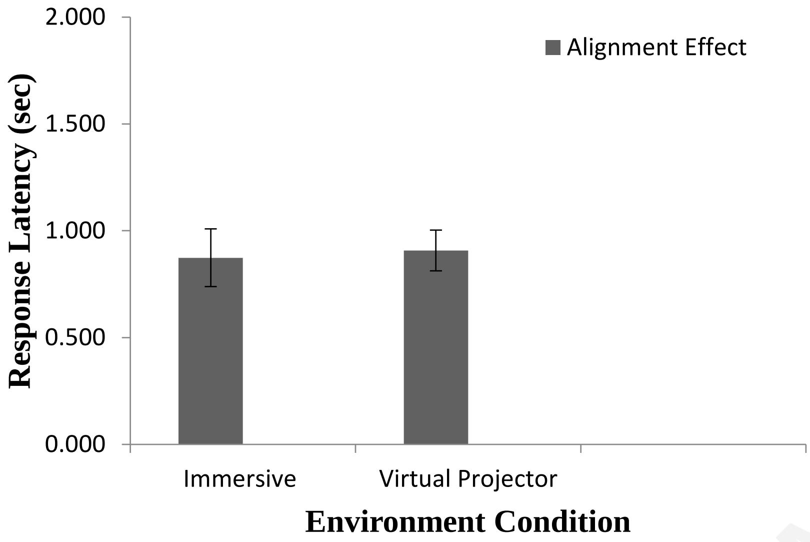

Figure 4. Alignment effects for response latency across environment conditions in Experiment 1. Error bars represent standard errors from the t-test.

Correlation results.

Correlational analyses were also conducted to examine the relation between performance and perspective taking skills as measured with the Spatial Orientation Test and the Santa Barbara Sense of Direction Scale (SBSOD). The analysis included participants from all experiments to increase its statistical power. Therefore, results from the analysis are described and discussed at the end of Experiment 4 (Chapter 6).

2.4. Discussion

Results from Experiment 1 revealed that participants produced fewer errors and were faster in their responses when the imagined perspective to be adopted at testing was aligned with their body orientation. Notably, an alignment effect was found in pointing error and response latency for both immersive and virtual projector environment conditions. Although for pointing error this effect was numerically smaller in the immersive environment condition, statistically there was no difference in either pointing error or latency across environment conditions. This finding goes against my expectation for a greater alignment effect in the immersive environment condition resulting from more salient self-to-object relations. Instead, it suggests that being an external observer to an immediate scene does not create any additional difficulties for pointing from imagined perspectives compared to being remote to the scene.

Previous research on spatial perspective has claimed that the alignment effect might reflect (1) mental transformation costs during the imagination process, or/and to (2) sensorimotor conflicts at the time of response computation and execution (May, 2004; Sohn & Carlson, 2003). According to Avraamides et al. (2008) the extent of these conflicts is greater when we are embedded in the spatial scene due to salient self-to-objects codes that define our relations to the surrounding objects and which cannot be easily ignored when adopting imagined perspectives. If this is also the case when we are immediate to a spatial scene albeit external to it, then a greater alignment effect should have been observed in the immersive environment condition than the virtual projector environment condition. However, the present results revealed an equivalent alignment effect in the two environment conditions. What could account for this finding?

One possibility is that when we are external observers to a spatial layout we simply don't experience any spatial conflicts from the actual locations of objects. This could be the case if we don't automatically encode egocentric relations to individual locations in the layout but we instead treat the layout as a uniform entity and only encode a general self-to-layout relation. In that case the documented alignment effect might reflect only the costs entailed by the mental transformation processes employed to align one's perspective with the imagined one. However, the results of Sohn and Carlson (2003) are at odds with this possibility; in their study, evidence for the presence of spatial conflicts was provided in a task that involved a scene viewed on a computer screen.

Another possibility is that spatial conflicts were present but equally so in the two conditions. This could have occurred if both conditions presented an immersive experience to participants. Although I designed the virtual projector condition expecting that participants would regard themselves as disengaged from the depicted scene, it is possible that this was not the case. The fact that in both conditions participants could not see their own body might have rendered the distinction between the scene and their body as less salient.

Yet another possibility is that strong sensorimotor conflicts were present in both conditions due to the nature of the response mode. In previous studies participants responded by pressing keys on the keyboard corresponding to verbal labels (e.g., Sohn & Carlson, 2003) or by deflecting a joystick (e.g., Avraamides et al., 2013). These modes of response can be regarded as less body-dependent than the response mode used in the present experiment. Perhaps, pointing to objects from an imagined perspective by extending one's arm is too unnatural of a task, causing much sensorimotor interference.

Although we may use a joystick from an imagined perspective at some instances of daily life (e.g. during gaming), how often do we use our arms to point from an imagined perspective?

Given the possible accounts outlined above, I designed Experiment 2 to examine whether visual access to one's body and the response mode influence reasoning from imagined perspectives. In order to investigate the possibility that the alignment effects documented were due to the strong body-dependence of the response mode we used, in Experiment 2, I compared pointing towards objects locations by extending the arm vs. deflecting a joystick. To examine whether visual access to one's body influences perspective taking, in Experiment 2 I had participants view the virtual table projected onto a real projection screen. This allowed me to examine – by comparing the pattern of results with those of Experiment 1 -- whether having visual access to your own body during the task influences performance.

3. Chapter 3 - Experiment 2

3.1. Introduction

In Experiment 2, participants stood in the middle of the laboratory and viewed the layout on an actual projection screen that was mounted on the wall in front of them. Depending on environment condition, participants responded either by extending their arm as in Experiment 1 or by deflecting a joystick that was placed in front of them. If sensorimotor conflicts in Experiment 1 were present due to the strong body-dependence of the response medium, the alignment effect should be smaller in the joystick than the arm pointing condition. Also, if having visual access to your own body influences perspective taking, then differences should be observed between the arm condition of Experiment 2 and the virtual projector environment condition of Experiment 1. In particular, if visual access to one's body functions to make egocentric relations more salient, then a greater alignment effect is expected in the arm condition of Experiment 2 than in the virtual projector environment condition of Experiment 1. In contrast, if visual access to one's body makes the distinction between the observer and the scene more salient, then a smaller alignment effect is expected in the real projector condition compared to the virtual projector environment condition.

3.2. Method

3.2.1. Participants

Fifty students from the University of Cyprus participated in the experiment in exchange for course credit. Twenty-five participants were randomly assigned to each of the real projector-arm condition and real projector-joystick condition. Pointing errors and response times deviating 3 standard deviations or more from the mean of each participant were considered outliers and were removed from the analyses.

3.2.2. Materials and Procedure

Materials and procedure were identical to those of Experiment 1 with two notable differences. First, while in Experiment 1 participants experienced the layout via immersive VR, in Experiment 2 they view the layout on an actual projector screen. This allowed them visual access to their own body. Second, participants responded either by extending their arm (as in Experiment 1) or by deflecting a joystick placed in from them on a stool, while standing in the middle of the laboratory room.

3.3. Results

Data were analyzed with separate repeated measures ANOVAs for pointing error and response latency with imagined perspective as the within subject factor and environment condition (real projector-arm condition vs. real projector-joystick condition) as the between subject factor. Planned contrasts were conducted to evaluate the extent of the alignment effect across environment conditions. Moreover, cross experiment analyses were conducted to compare the size of alignment effect between the real projector-arm condition of Experiment 2 and the corresponding virtual projector environment condition of Experiment 1.

Pointing Error.

Results from the ANOVA revealed that pointing error varied as a function of the imagined perspective adopted at testing, $F(7, 336) = 7.66$, $p < .001$, $\eta^2 = .13$. As illustrated in Figure 5, participants error was significantly smaller when the imagined perspective at testing was aligned with their physical orientation (0^o) compared to the remaining imagined perspectives. However, neither a significant main effect for condition nor a significant interaction between condition and imagined perspective were found, $F(1, 48) = 0.12$, $p = .73$, $\eta^2 = .00$ and $F(7, 336) = 1.27$, $p = .26$, $\eta^2 = .02$ respectively.

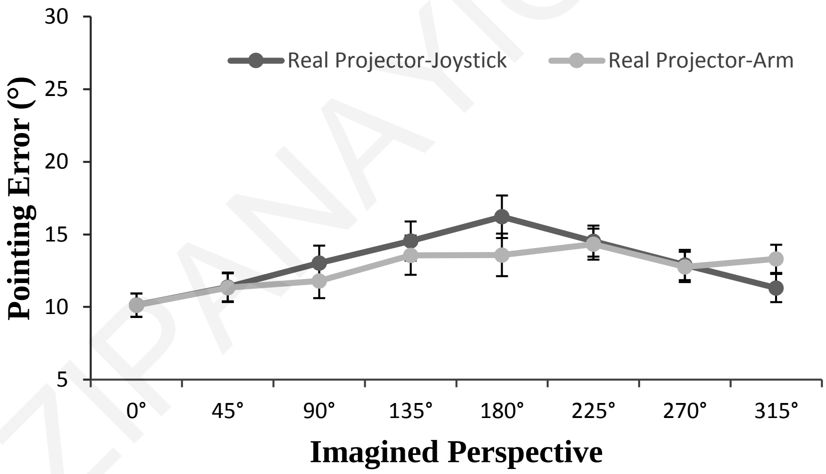

Figure 5. Pointing error as a function of imagined perspective across environment conditions (Real Projector-Joystick vs. Real Projector-Arm) in Experiment 2. Error bars represent standard errors from the ANOVA.

Planned contrast for pointing error revealed a significant alignment effect in both conditions, $t(24) = 4.90$, $p < .001$ for the real projector-arm condition and $t(24) = 3.73$, $p = .001$ for the real projector-joystick condition (Figure, 6). The size of the alignment effect was equal for the two conditions, $t(48) = 0.42$, $p = .67$.

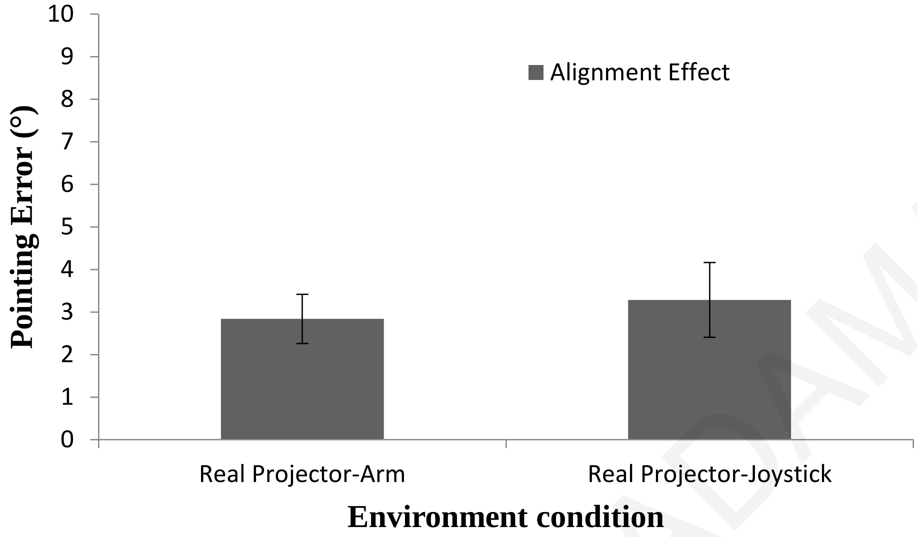

Figure 6. Alignment effects for pointing error across environment conditions in Experiment 2. Error bars represent standard errors from the t-test.

An independent samples t-test was then employed to compare the magnitude of the alignment effect between the virtual projector environment of Experiment 1 and the real projector-arm condition of Experiment 2. The test revealed that the size of the alignment effect was smaller in the real projector-arm condition compared to the virtual projector condition $t(47) = 2.42$, $p = .01$. This seems to be due primarily to participants being substantially less accurate when reasoning about misaligned perspectives in the virtual projector condition (M = 18.75) than in the real projector-arm condition (M = 12.95), but only slightly less accurate in the aligned perspectives (M = 12.40 in the virtual projector-arm condition vs. M = 10.12 in the real projector-arm condition).

Response Latency.

The ANOVA on response latency also showed that participants' performance varied as a function of the imagined perspective, $F(7, 336) = 16.40$, $p < .001$, $\eta^2 = .25$. Overall, participants responded significantly faster when the imagined perspective adopted at testing was aligned with their physical orientation (0^o) compared to the remaining imagined perspectives (Figure, 7). Similar to pointing error, the analysis showed neither a significant main effect for environment condition nor a significant interaction between environment condition and imagined perspective $F(1, 48) = 1.76$, $p = .19$, $\eta^2 = .03$ and $F(7, 336) = 1.10$, $p = .36$, $\eta^2 = .02$, respectively.

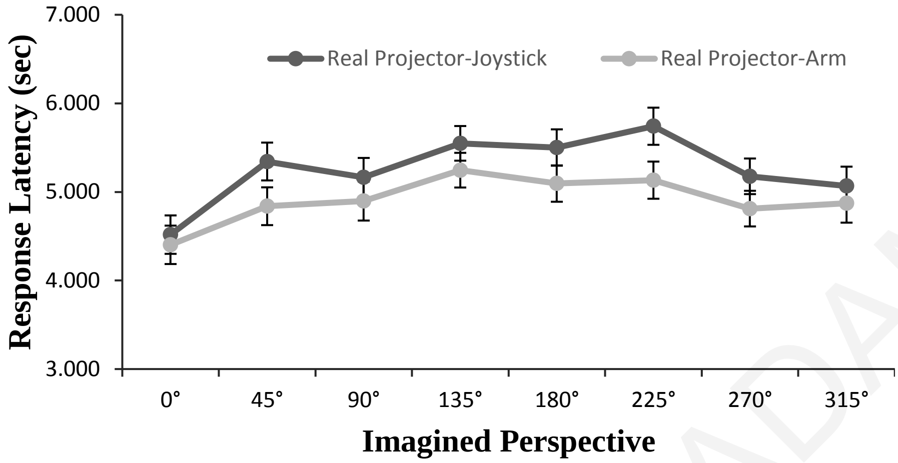

Figure 7. Response latency as a function of imagined perspective across environment conditions (Real Projector-Joystick vs. Real Projector-Arm) in Experiment 2. Error bars represent standard errors from the ANOVA.

Planned contrasts for response latency revealed a significant alignment effect in both the real projector-arm and the real projector-joystick environment conditions, $t(24) = 5.24$, $p < .001$ and $t(24) = 6.80$, $p < .001$ respectively (Figure 8). The alignment effect was somewhat smaller in the real projector-arm condition, but the difference did not reach significance, $t(48) = 1.58$, $p = .12$.

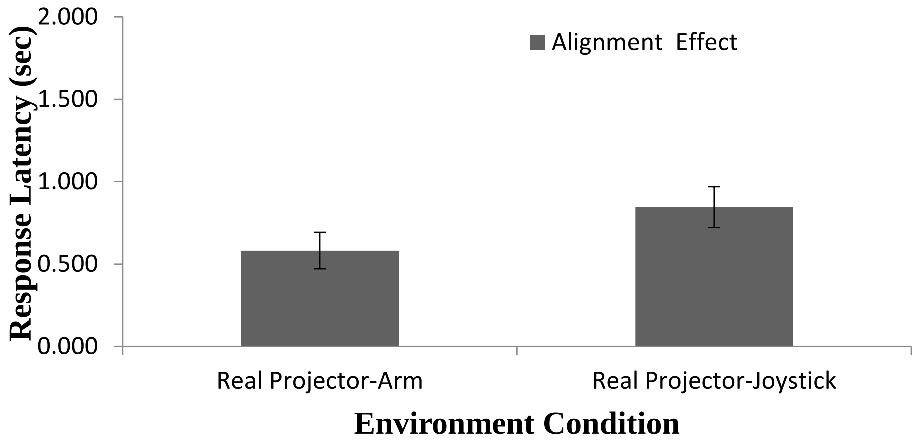

Figure 8. Alignment effects for response latency across environment conditions in Experiment 2. Error bars represent standard errors from the t-test.

Finally, an independent samples t-test revealed that the alignment effect was smaller in the real projector-arm condition of Experiment 2 than in the virtual projector environment condition of Experiment 1, $t(47) = 2.22$, $p = .03$. This was due to participants being slower to respond from aligned perspectives in the real (M = 4.40) compared to the virtual projector environment condition (M = 3.40).They were also slower to respond to misaligned perspectives in the real than in the virtual projector environment condition but the difference was smaller (M = 4.98 vs. M = 4.30).

3.4. Discussion

As with Experiment 1, results from Experiment 2 showed that participants' performance was best when the imagined perspective to be adopted at testing was aligned with their physical orientation, compared to the remaining orientations. Moreover, an alignment effect was found for both the real projector-arm and real projector-joystick conditions, in both pointing error and latency. However, the size of the alignment effect and performance overall were similar for when participants pointed by outstretching their arm or by deflecting the joystick. This finding shows that even if pointing with the arm is more dependent on one's body that pointing with a joystick, it does not create any additional difficulties for reasoning from imagined perspectives. Thus, the alignment effect found in Experiment 1 cannot be attributed to the pointing device.

Notably, results revealed that the alignment effect was smaller in the real projector-arm condition of Experiment 2 compared to the virtual projector environment condition of Experiment 1 in both pointing error and response latency. A possible account for this finding is that seeing themselves standing in the middle of the laboratory and at distance from the spatial scene might have served as a constant reminder to participants that they were external to the projected layout. In contrast, experiencing the projected layout in VR without visual access to their body, might have blurred the boundaries between their body and the spatial scene. This elevation immersion could account for the bigger alignment effect in the virtual projector environment condition, and in particular for (1) the less accurate performance in the misaligned trials, and (2) the faster performance in the aligned trials. That is, it could be that not having visual access to our body such as in the virtual projector environment condition, facilitates adopting imagined perspectives aligned with our body and interferes with adopting misaligned perspectives due to producing an elevated feeling of presence in the scene.

If indeed visual access to one's body in the real projection conditions of Experiment 2 helped to emphasize the detachment of the participant to the scene, perhaps carrying out the task on a smaller screen would further disengage participants, reducing thus further the alignment effect.

That is, it could be that the large size of the layout that was projected on the screen elicited the encoding of self-to-object relations at least by some participants, causing sensorimotor interference. For this reason, in Experiment 3, I ran a condition in which participants viewed the spatial scene as a 2D representation on a desktop monitor. If the size of the screen influences the type of spatial encoding and the presence of sensorimotor conflicts, then using a computer screen to present the virtual layout might reduce further the alignment effect.

4. Chapter 4 - Experiment 3

4.1. Introduction

In Experiment 3, participants carried out the task on a desktop computer, viewing the scene with the round table as a 2D environment on the small screen. If the large visual size of the display in Experiment 2 has caused some feeling of presence or immersion for some participants, presenting the layout on a computer screen could reduce the alignment effect by highlighting further the disengagement of the observer from the scene.

4.2. Method

4.2.1. Participants

Twenty-four students from the University of Cyprus participated in the experiment in exchange for course credit.

4.2.2. Materials and Procedure

Materials and procedure were identical to those of Experiment 2 with two notable differences. While in Experiment 2 participants viewed the layout through the laboratory's projector, in Experiment 3 they were presented with the layout on a 21" computer screen. Moreover, since in Experiment 2 I found no differences between pointing with the arm or a joystick, in Experiment 3 only the joystick response was used.

4.3. Results

As in the previous experiments, data were analyzed with separate ANOVAs for pointing error and latency. The analysis was followed by planed contrasts to evaluate the presence of an the alignment effect while an independent samples t-test compared the size of the effect between the desktop condition of Experiment 3 and the real projector-joystick condition of Experiment 2. Pointing errors and response times deviating 3 standard deviations or more from the mean of each participant were considered outliers and were removed from the analyses.

***Pointing Error*.**

Results revealed that pointing error varied as a function of the imagined perspective adopted at testing, $F(7, 161) = 4.70$, $p < .00$, $\eta^2 = .17$. As shown in Figure 9, pointing errors were smaller when the imagined perspective at testing was aligned with participants' physical orientation (0^o) than when it was not, $t(23) = 7.13$, $p < .001$.

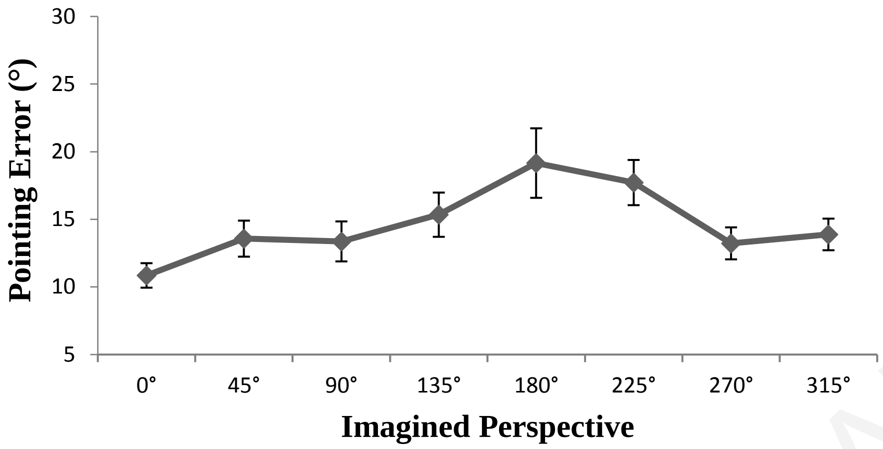

Figure 9. Pointing error as a function of imagined perspective in Experiment 3. Error bars represent standard errors from the ANOVA.

The across-experiment comparison showed that the alignment effect was equal in the real projector-joystick condition of Experiment 2 and the desktop environment condition of Experiment 3, $t(47) = 0.97$, $p = .33$ (Figure, 10).

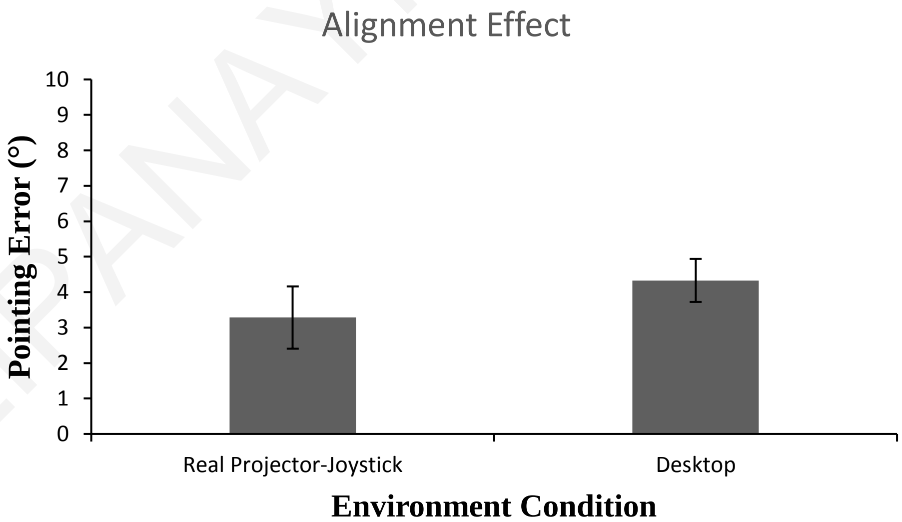

Figure 10. Alignment effects for pointing error for the Real Projector-Joystick condition (Experiment 2) and the Desktop condition (Experiment 3). Error bars represent standard errors from the t-test.

Response Latency.

Participants' response latency also varied as a function of the imagined perspective adopted at testing, $F(7, 161) = 7.16$, $p < .001$, $\eta^2 = .23$. The planned contrast showed that participants pointed significantly faster when the imagined perspective adopted at testing was aligned with their physical orientation (0^o) compared to the remaining imagined perspectives, $t(23) = 9.22$, $p < .001$ (Figure, 11).

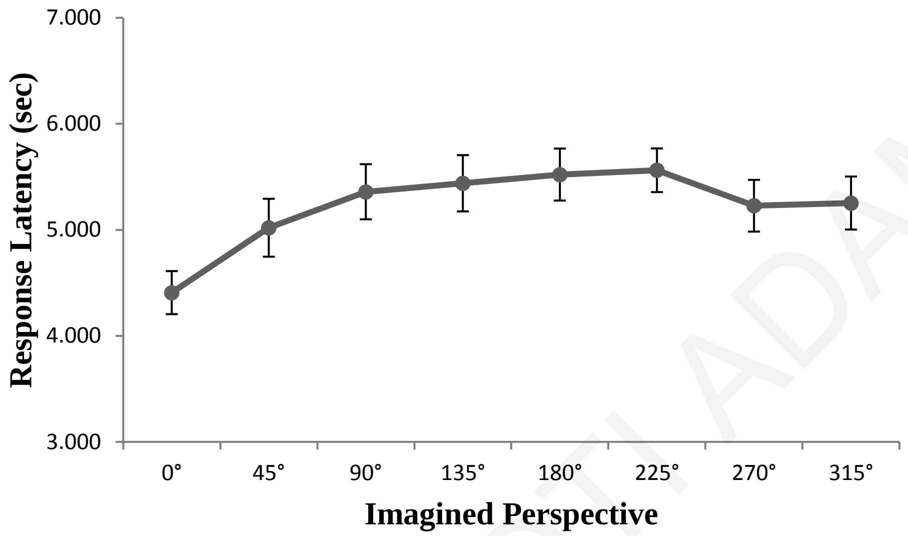

Figure 11. Response latency as a function of imagined perspective in Experiment 3. Error bars represent standard errors from the ANOVA.

As with pointing error, the size of the alignment effect was equal between the real projector-joystick condition of Experiment 2 and the desktop condition of Experiment 3, $t(47) = 0.54$, $p = .58$ (Figure, 12).

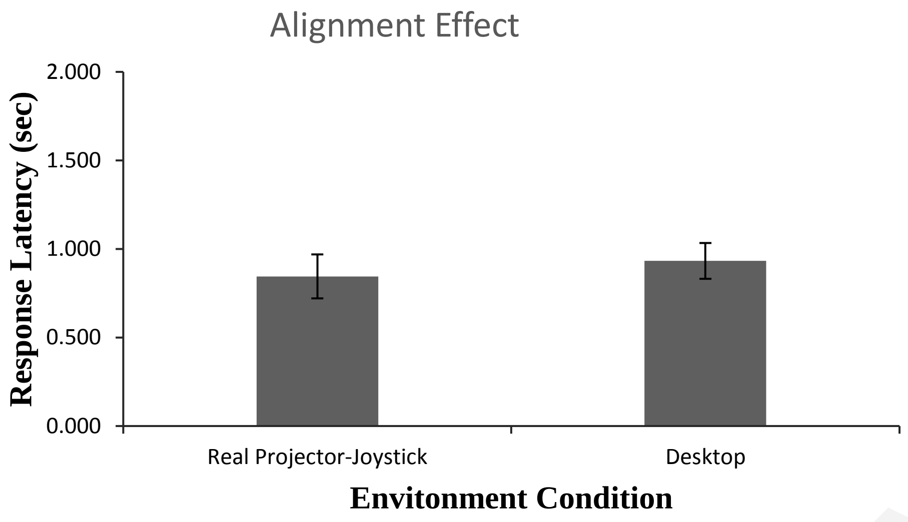

Figure 12. Alignment effects for response latency across Real Projector-Joystick condition (Experiment 2) and desktop condition, Experiment 3. Error bars represent standard errors from the t-test.

4.4. Discussion

As in Experiment 1 and Experiment 2, Experiment 3 showed that participants' performance was superior when the imagined perspective to be adopted at testing was aligned with their body orientation. Moreover, a significant alignment effect of the same size was found for the pointing error and response latency of the real projector-joystick condition (Exp.2) and the desktop environment condition (Exp.3). This finding suggests that viewing the layout on a screen of a small size does not disengage the observer from the layout any more than viewing it on a big screen, so as to ease reasoning from imagined perspectives.

Taken together, the findings from the 3 experiments demonstrate that regardless of the conditions under which the layout was depicted, participants still encountered difficulties in responding from imagined perspectives. As discussed in Experiment 2, the alignment effect was reduced for participants who viewed the layout through the real projector in the laboratory compared to those viewing the layout on a virtual projector. This might be because when we are external observers to a spatial scene and have visual access to our body we have perceptual support for the distinction of our body and scene. In contrast, when visual access to our body is lacking, such as in scenes that are presented virtually, the distinction between our self and the scene might be less obvious. This might blur the boundaries between our body and the scene, resulting in conflicts when we try to imagine ourselves occupying imagined perspectives within the virtual environment. Experiment 3 aimed to examine whether reducing the size of the scene by presenting it on a small computer screen would further highlight the distinction of the body from the scene, and further reduce the alignment effect. Results showed that this was not the case.

One possibility is that the alignment effect was not reduced further with the small screen because it reflects mental transformation costs, and not sensorimotor interference. According to the mental transformation account, difficulties in perspective taking are associated with large mental rotations that are carried out when we try to align our current perspective with the imagined one (Rieser, 1989). Previous studies have examined the contribution of mental transformation processes in perspective taking task by providing perspective information in advance of target information. The rationale was that if the alignment effect is caused by mental transformation then providing advance perspective information would allow people to adopt the imagined perspective ahead of the target, reducing thus the alignment effect. Results from these studies have been mixed.

In one study, Wang (2005) had participants point to the locations of memorized objects after providing them with perspective information that preceded the target by 0 to 10 seconds. Results showed that the alignment effect was not reduced in any SOA and overall performance did not benefit from advance information. In contrast to Wang (2005), Avraamides et al., (2013) showed that advance perspective information could reduce the alignment effect. In that study, participants pointed to the location of memorized objects while standing in a different virtual environment from the one they memorized. Results showed that the alignment effect was reduced at least for perspective that were aligned with the geometric structure of the environment. Similar findings were reported by Sohn and Carlson (2003) in a study that used a perceptual environment. Participants in that study viewed on a computer monitor a round table with names arranged around it and were asked to indicate the position of a target name after adopting a perspective around the table. Responses were made by choosing among verbal labels assigned to keys of the keyboard and the order in which information was given (i.e., advance perspective vs. advance target) was manipulated. Results showed that advance perspective information reduced the alignment effect and sped up overall performance.

Although these previous studies with advance perspective information provide contradictory results, based on the findings of Sohn and Carlson (2003), whose task is most similar to the one I use, I hypothesized that providing information about the imagined perspective ahead of the presentation of the target may lead to a reduction of the alignment effect, if mental transformations costs contribute to the alignment effect. Therefore, in Experiment 4, I examined this possibility by manipulating the order in which information about the perspective and the target became available.

5. Chapter 5 - Experiment 4

5.1. Introduction

In Experiment 4 I examined whether costs during the mental transformation process can account for the persisting alignment effect documented in Experiment 3.Participants were provided with advance information about the to-be-imagined perspective which could allow them to initiate mental transformation processes ahead of receiving information about the target location. Based on the rational of previous studies (e.g., Rieser, 1989; Sohn & Carlson, 2003), if the residual alignment effect is due to transformation costs, providing participants with sufficient time to adopt the imagined perspective ahead of the target's presentation would reduce or even eliminate the alignment effect. If however the alignment effect is due to spatial interference then its size – and performance in general -- would be unaffected by advance perspective information.

5.2. Method

5.2.1. Participants

Twenty-six students from the University of Cyprus participated in the experiment in exchange for course credit.

5.2.2. Materials and Procedure

Materials and procedure were similar to those of Experiment 3. As in Experiment 3, participants viewed the layout on a 21" computer screen. However, while in Experiment 3 information about the imagined perspective and the target appeared simultaneously, in this experiment, in half of the trials the imagined perspective (i.e., highlighted empty seat) was presented ahead of the target (i.e., virtual character), whereas in other half the target appeared first. The time interval between the presentation of the imagined perspective and the target (and vice versa) was fixed at 2 seconds. Reaction time was recorded starting when both pieces of information were available, (i.e., when the target was presented at advance perspective trials and when the perspective was presented at advance target trials). Participants were explicitly instructed to adopt the imagined perspective when information was presented before the target. The order in which information was presented was blocked. One block contained only trials in which the perspective appeared first whereas another block consisted of trials in which information about the target was presented first. The order in which the two blocks were presented was counterbalanced across participants. As in Experiment 3, participants responded with the use of a joystick and were asked to point as fast as possible without sacrificing accuracy.Overall, each participant carried out 2 blocks of 56 trials resulting in a total of 112 trials.

5.2.3. Design

The experiment followed a 2 (advance information: advance perspective vs. advance target) x 8 (imagined perspective: 0^o, 45^o, 90^o, 135^o, 180^o, 225^o, 270^o and 315^o) within-subjects design.

5.3. Results

Data were analyzed using repeated measures ANOVAs with terms for the nature of the advance information (advance perspective vs. advance target) and imagined perspective. They analyses were followed by planned contrasts that were conducted to investigate the extent of alignment effect in the two advance information conditions. As in previous experiments, pointing errors and response times that deviated 3 standard deviations or more from the mean of each participant were considered outliers and were removed from the analyses.

Pointing Error.

Results from the ANOVA revealed that pointing error varied as a function of the imagined perspective adopted at testing, $F(7,175) = 6.05$, $p < .001$, $\eta^2 = .19$ (Figure, 13). Pointing error was significantly smaller when the imagined perspective at testing was aligned with participants' physical orientation (0^o) compared to the remaining orientations in both the advance perspective condition, $t(25) = 3.46$, $p = .002$ and the advance target condition, $t(25) = 2.79$, $p = .01$ (Figure 14). The alignment effect was somewhat largest in the advance perspective than the advance target condition but the difference was not significant, t(25)= 0.97, $p = .34$. Participants were slightly more accurate in advance perspective condition (M = 12.44) compared to advance target (M = 12.89), however, neither a main effect of advance information nor an interaction between advance information and imagined perspective was found, $F(1,25) = 0.20$, $p = .65$, $\eta^2 = .00$ and $F(7,175) = 0.86$, $p = .53$, $\eta^2 = .03$ respectively.

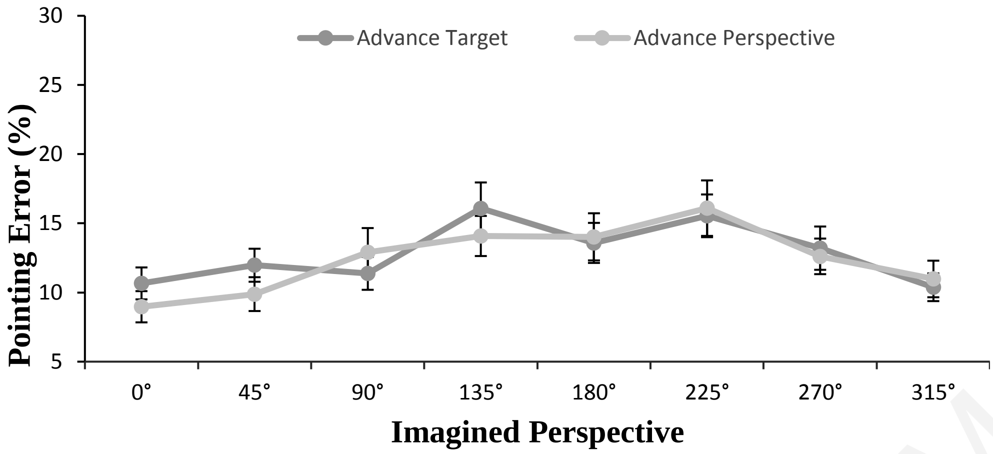

Figure 13. Pointing error as a function of imagined perspective and advance information in Experiment 4. Error bars represent standard errors from the ANOVA.

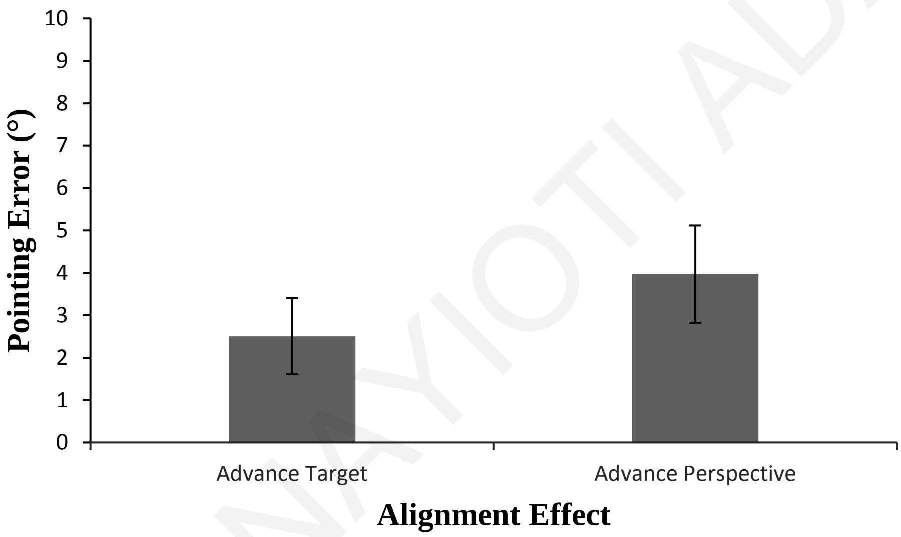

Figure 14. Alignment effects in pointing error for advance perspective and advance target in Experiment 4. Error bars represent standard errors from the t-test.

Response Latency.

Participants' response latency also varied as a function of the imagined perspective, $F(7, 175)= 20.91$, $p < .001$ $\eta^2 = .45$ (Figure, 15). Participants responded significantly faster when the imagined perspective to be adopted at testing was aligned with their physical orientation (0°) compared to the remaining orientations in both the advance perspective condition $t(25) = 6.04$, $p < .001$ and the advance target condition, $t(25) = 7.49$, $p < .001$ (Figure 16). The alignment effect was somewhat largest in the advance perspective than the advance target condition but the difference was not significant, t(25) = 0,69, p = .49. Participants were somewhat faster to respond in the advance perspective condition (M = 4.73) compared to the advance target condition (M = 4.89), but the analysis revealed no significant main effect of advance information or interaction between advance information and imagined perspective, $F(1,25) = 0.73$, p = .39, $\eta^2 = .02$ and $F(7,175) = 0.73$, $p = .63$, $\eta^2 = .02$ respectively.

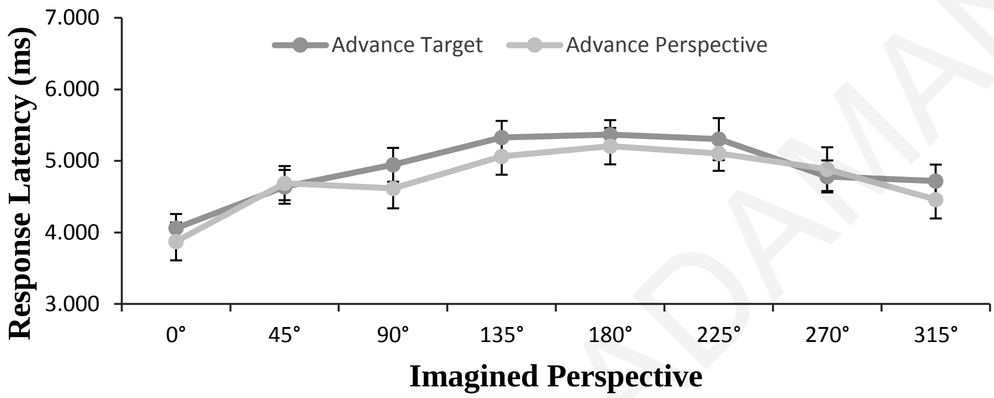

Figure 15. Response latency as a function of imagined perspective and advance information in Experiment 4. Error bars represent standard errors from the ANOVA.

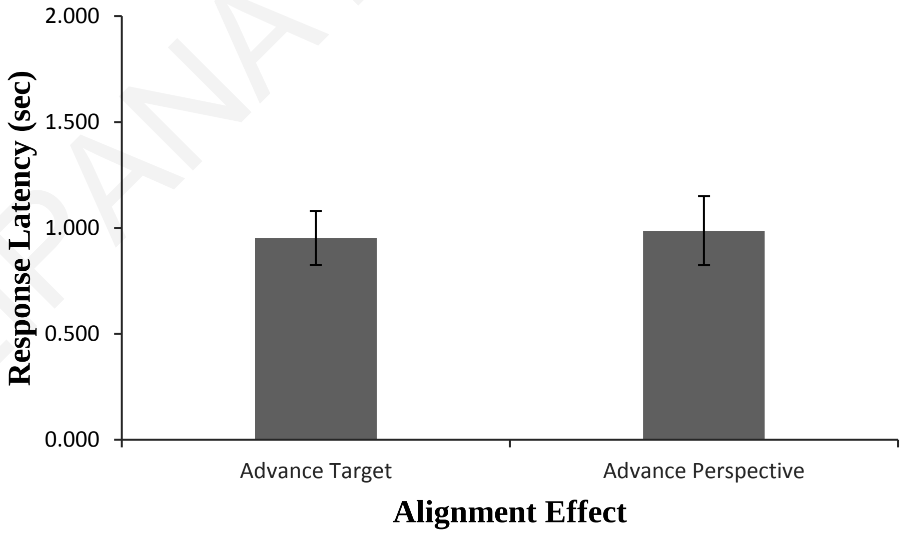

Figure 16. Alignment effects in response latency for advance perspective and advance target in Experiment 4. Error bars represent standard errors from the t-test.

5.4. Discussion

Similar to previous experiments, results from Experiment 4 showed that participants' performance was best when the imagined perspective to be adopted at testing was aligned with the body orientation. Notably, results revealed that advance information did not affect performance; participants were slightly faster in their responses and produced fewer errors when the information about the imagined perspective was presented prior to target information but these differences were not significant.

That providing information about the imagined perspective in advance of the target did not reduce the alignment effect is compatible with the findings of Wang (2005). In this study in which participants responded from imagined perspectives adopted in an environment held in memory showed that providing advance information about the perspective had no effect in performance. That is, participants did not respond faster or more accurately than when the two pieces of information were provided simultaneously nor was the alignment effect reduced. This was the case for various SOAs, including a self-paced condition.

The results of Experiments 4 are at odds with the findings of Avraamides et al. (2013) and Sohn and Carlson (2003) who showed that the alignment effect can be reduced with advance perspective information when reasoning about memorized and perceptual environments respectively. It seems that methodological details in each experiment may be responsible for the discrepancy of findings across studies. I return to this issue in the General Discussion.

Correlations results.

To attain statistical power, correlational analyses were conducted after collapsing data across all experiments (N=151). These analyses aimed to examine whether performance in the computerized perspective taking task I used in the current experiments is captured by individual differences in perspective taking as captured by the Spatial Orientation Test (Hegarty & Waller, 2004). As shown in Table 1, participants' overall error correlated positively with accuracy on the Spatial Orientation Test, $r = .48$, $p < .001$. This result suggests that the novel task used in the current experiments can indeed capture differences in perspective taking ability. However, no significant correlations were found for the scores on the Santa Barbara Sense of Direction Scale.

Table 1. *Correlations and Descriptive Statistics for variables of Experiment 1,2,3 and 4*

	M(SD)	*SOT*	*Resp.Lat.*	*Align.Eff.*	*P.Error*	*SBSOD*
SOT	45.03 (32.58)	1	.08	-.07	.48***	-.09
Resp.Lat.	4.79 (1.05)		1	.11	.03	-.00
Align.Eff.	0.84 (0.57)			1	-.00	-.00
P.Error	15.34 (6.37)				1	-.06
SBSOD	4.19 (0.95)					1

Ns = not significant (p > .05), *p < .05, ** p < .01, *** p < .001
Note. Align.Eff. = Alignment Effect, SOT = Spatial Orientation Test, P.Error = Pointing Error, Resp.Lat. = Response Latency, SBSOD = Santa Barbara Sense of Direction Scale.

6. Chapter 6 - General discussion

The findings of the present thesis provide important insights about the difficulties that people encounter during spatial perspective taking. In four experiments I examined various factors that may affect performance in responding from imagined perspectives in perceptual situations in which the observer is external to the spatial scene (i.e., viewing the whole scene from an external vantage point). Specifically, I investigated performance in immersive vs non-immersive environments (Experiment 1) and when the environment is presented on a large projector screen in the laboratory (Experiment 2) or on a small computer screen (Experiments 3 and 4). Across experiments, I manipulated the response medium (armband vs. joystick) while in Experiment 4, I also manipulated the order in which information about the perspective and the target were presented to participants. Results showed that conflicts were reduced when the layout was presented on a real projector in the laboratory or on a desktop monitor, compared to when the environment was experienced in VR. Moreover, findings showed that the alignment effect found with the desktop monitor was not affected by providing advance information about perspective that could serve to start the imagination process ahead of target presentation. This finding supports the idea that the alignment effect does not reflect transformational costs during the imagination process (Rieser, 1989), but that it stems instead from sensorimotor conflicts during response computation and execution (May, 2004). Notably, the response medium did not seem to make a difference for the size of the alignment effect.

Several studies in spatial cognition have investigated the difficulties that are associated with adopting imagined perspectives (Avraamides et al., 2013; Creem-Regehr, 2003; Easton & Sholl, 1995; May, 2004; May & Wartenberg, 1995; Presson & Montello, 1994; Rieser, 1989; Sohn & Carlson, 2003; Wraga, Creem, & Proffitt, 2000). Findings from these studies converge in that performance is worse as the angular disparity between one's actual and imagined orientation increases (i.e., alignment effect), especially after imagined self-rotations. This is corroborated by the findings of all four experiments reported here.

One explanation for the alignment effect put forth in the literature (e.g., Rieser, 1989; Rieser, Guth, & Hill, 1986) is that it reflects costs associated with mental transformations. According to this account, the alignment effect exists because it takes more time, and is more prone to error, to mentally align our perspective with an imagined one that is offset by a large angular extent. Therefore, providing information about the imagined perspective prior to the presentation of the target could in theory provide the necessary time to perform in advance any mental transformations, reducing thus the alignment effect (Avraamides et al., 2013; Sohn & Carlson, 2003). My findings here indicate that although performance was somewhat more accurate and fast -- but not significantly so -- when information about the imagined perspective was presented prior to the target than the other way around, the alignment effect was not reduced (Experiment 4). This finding is at odds with the mental transformation account and replicates previous findings from Wang (2005) who examined perspective taking in remembered environments. Participants in the study of Wang (2005) pointed to the locations of memorized objects after they were presented with advance perspective information, with SOAs ranging from 0 to 10 seconds (Experiment 1). Results showed neither a benefit in overall performance from advance viewpoint information nor a reduction of the alignment effect. Wang (2005) interpreted this findings as support of the sensorimotor interference account which posits that difficulties in reasoning from imagined perspectives arise because of conflicts between the objects' actual and imagined locations in space (see May, 1996; 2004).

Although my results converge with those of Wang (2005), they contrast findings from other studies done with memorized (Avraamides et al., 2013) and perceptual environments (Sohn & Calrson, 2003) that also manipulated the order of perspective and target information.

Specifically, Avraamides et al. (2013) had participants memorize the location of objects placed around them and then carried out testing trials after having moved to a different room (Experiment 2). Depending on condition, trials provided advance information either about the perspective or the target. In contrast to our results, Avraamides et al (2013) showed that providing information about the perspective prior to the target reduced overall response time as well as the size of the alignment effect. This finding, along with the fact that testing took place at a remote location, led the researchers to conclude that conflicts in perspective taking are at least partially due to costs during the imagination process. Several methodological differences between the experiment of Avraamides et al. and my Experiment 4 exist that could potentially account for the discrepancy in findings. First, while the study of Avraamides et al. tested perspective taking in memory mine tested it in perception. Second, in Avraamides et al. study participants were immersed in the scene surrounded by objects while in mine they were external observers. Third, while in my study I presented the spatial scene within a featureless environment, Avraamides et al. used an information-rich scene by presenting objects in a rectangular room with distinct sides and external information (e.g., windows on one side). This could have allowed participants to maintain a memory based on an allocentric reference frame that is immune to sensorimotor interference. These methodological differences, which could be responsible for the differences in results, should be explored in future research.

In contrast to Avraamides et al. (2013), Sohn and Carlson (2003) used a perceptual task that was conceptually similar to the one I used in the current experiments. In that experiment, participants viewed a table with names arranged around it and had to imagine sitting at the position of a given name and indicate the position of a second name by choosing among verbal labels assigned to keys on the keyboard. Their findings showed that the alignment effect was reduced with increasing SOAs as did overall response time; this finding is in stark contrast with those from the present study. Again, differences in the methodological details between the studies could account for the discrepant results. For example, participants in the study of Sohn and Carlson (2003) responded by pressing keys on a keyboard that corresponding to spatial verbal labels. Previous research has documented that responding with spatial language is more flexible and reduces errors in responding from imagined perspectives than doing so with body-dependent mediums such as pointing with arm or a joystick (Avraamides, Klatzky, Loomis, & Golledge, 2004; Wraga, 2003). Although when I examined in Experiment 2 whether performance is influenced by a strong body-dependent mode of response such as pointing by extending the arm versus deflecting the joystick I found no differences, it could well be the case that responding with spatial language is associated with less sensorimotor interference during response execution. Another difference is that Sohn and Carlson presented a schematic scene from a top-down view while I used a more realistic scene made with graphics and experienced from a side view, providing the perspective of an external observer. Also, in Sohn and Carlson, the scene included names that were always presented in an upright view; this could have provided an advantage for the low disparity angles -- as reading the names would entail adopting first an upright viewpoint – causing a larger than usual alignment effect. This larger effect could have provided more room for reduction in the advance perspective condition. Notably, in pilot research I conducted -- in collaboration with Sohn -- using a schematic layout with no names, I found no evidence for the reduction of the alignment effect with advance perspective information.

Despite the fact that my findings deviate from those of Avraamides et al. (2013) and Sohn and Carlson (2003), but are in line with those of Wang (2004), it seems that the alignment effect I obtained in the particular task I used is more easily explained by the sensorimotor interference account, which posits that sensorimotor conflicts occur at response computation and execution. Based on this account, difficulties in responding from imagined perspectives result from suppressing information about the actual position of objects relative to ourselves in order to localize them from an imagined perspective (May, 1996; 2004). Findings from previous studies on perspective taking (Avraamides et al., 2013) and on mental rotation of objects (Kozhevnikov & Dhond, 2012) have shown that sensorimotor conflicts are greater when we are immersed in a 3D environment than when we are remote to it. This might be because in immersive situations we might be more likely to encode the locations of objects using an egocentric reference frame. As a result, self-to-object codes must be suppressed in order to respond from an imagined perspective in an immediate environment. In contrast, as previous research has shown (e.g., Mou, McNamara, Valiquette, & Rump, 2004) enduring memories about remote environments are held in allocentric reference frames. Therefore, no suppression of conflicting egocentric codes is necessary when reasoning about spatial relations in distal environments (see also Kelly, Avraamides, & Loomis, 2007; Avraamides & Kelly, 2008 for a review).

In the present research, Experiment 1 also examined reasoning about immediate and remote spatial relations albeit in situations that the observer is external to the scene. Notably results showed that the alignment effect was the same when participants pointed towards object locations within the immediate and the non-immersive environment viewed in immersive VR. Given the results from previous studies, it seems that being external to a scene, even if it is immediate, does not induce any additional difficulties for perspective taking compared to reasoning about a remote scene perceived indirectly on a screen. Thus, whether the observer is embedded or is external to the layout, might be an important factor determining the presence of sensorimotor interference; I will explore this possibility more rigorously in my future research. My conjecture is that, in contrast to being embedded in a scene surrounded by objects, being external to it does not promote egocentric encoding in that no individual self-to-object vectors are maintained. As a result, sensorimotor interference is less when being an external observer to the scene than being embedded to it and it doesn't matter if the scene is immediate or remote. This is in line with findings from mental rotation showing that being disengaged from the layout such as when viewing 2D stimuli on a computer screen promotes allocentric encoding (Kozhevnikov & Dhond, 2012).

However, it should be noted that my findings showed that even when the layout is depicted on a computer screen, the alignment effect persist (Experiment 3 and Experiment 4). This could be the case if in situations in which we are disengaged from the layout and carry out allocentric encoding of object relations, we still encode the egocentric relation between our body and the layout as a whole. That is, instead of encoding the location of each object relative to our self, we encode object-to-object relations but also the scene as a single object relative to our self. Such combination of allocentric and egocentric encoding is compatible with recent theories of spatial memory (e.g., McNamara, 2003; see also Avraamides & Kelly, 2008) and can explain 1) the lack of a difference in the size of the alignment effect between the two immersive conditions of Experiment 1, and 2) the presence of a alignment effect even when viewing the scene on a projector or a desktop screen.

An intriguing finding from Experiment 2 was that the alignment effect was smaller when participants viewed the layout on a real projector screen compared to the immersive conditions of Experiment 1. Although this could be a general effect of viewing real vs. virtual stimuli, this possibility seems unlikely given that previous studies document no substantial differences in spatial reasoning about location in VR vs. the real world (Williams, Narasimham, Westerman, Rieser, & Bodenheimer, 2007). A more interesting possibility relates to the fact that by default in VR you don't see your own body. Thus it could be that having visual access to body information in the real world, reduces conflicts during reasoning about imagined perspectives compared to virtual situations in which we do not have this information. This could be the case if the distinction between the self and the layout can become even more prominent when visual information about the position of the observer's body is available. While several studies have claimed that imagined self-rotations are hard to perform due to lack of proprioceptive information that allows us to track the changing spatial relations in our surroundings (Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Rieser 1989; Rieser, Guth, & Hill, 1986), it could also be that viewing our body at a certain location detached from the spatial scene helps to anchor us to the real world, facilitating thus performance about a depicted environment. In other words, it is possible that when visual access to our body is lacking -- as in the case of immersive VR -- the boundaries between the self and the environment become blurred and immersion is increased, causing greater sensorimotor conflicts than in real situations where information about the body is available. This possibility is compatible with previous findings showing that sensorimotor conflicts are reduced following disorientation presumably because when losing track of orientation relative to salient characteristics of the surrounding environment, one's body is rendered less relevant to the task. Similarly, it might be case that positioning ourselves outside of the environment we reason about, such as when we are external observers to a scene, with visual information supporting the distinction between our body and the environment we reason about, we make our body less relevant and are able to reason from imagined perspective with less sensorimotor interference. Future research may examine this possibility by manipulating systematically the presence of visual information in VR environments by having, for example, observers wear a motion capture suit to animate the body of the participants in the virtual world. Research on distance judgments that used self-avatars within virtual environments showed that when the avatar was present participants made better estimates than when there was no avatar, most likely by relating themselves to the depicted body (Mohler, Bülthoff, Thompson, & Creem-Regehr, 2008; Mohler, Creem-Regehr, Thompson, & Bulthoff, 2010). Thus, there is a possibility that the presence of a virtual body might create more interference in responding from imagined perspectives within virtual environments because it can serve as a frame of reference to anchor the observer into the virtual world.

Overall, findings from the present study add to the literature on perspective taking by examining a situation that, to the best of my knowledge, has not been examined before in the context of perspective taking, that is, reasoning from imagined perspective on a layout observed from an external vantage point. My findings extend to perception, previous results from memory (Wang, 2005), showing that mental transformation costs cannot account for the difficulties people encounter in reasoning about spatial relations from imagined perspectives. These findings suggest that sensorimotor conflicts during response computation and execution (May, 2004) are responsible for the alignment effect documented in all four experiments. An interesting novel finding from my research is that being an external observer to an immediate scene does not create additional difficulties in perspective taking compared to viewing the scene remotely on a screen. A possible reason for this is that when we are external to the scene we may not encode locations egocentrically but simply encode the spatial relation between our self and the layout as a whole. Another novel finding is that the alignment effect was reduced when the spatial scene was experienced in the real world where visual access to body information is present by default. Perhaps, being aware of our body makes the distinction between the real and the to-be-reasoned-about environment more explicit, reducing thus sensorimotor conflicts in spatial perspective taking.

In closing, it should be noted that the findings from the present study have important implications for real-world situations that entail spatial reasoning about remote environments. For example, when tele-operating robots, drones or remote cameras people must reason in a fast and accurate manner about space from perspectives other than their own. This is also true for tele-surgery or the remote operation of search-and-rescue robots, where perfect performance is of vital importance. If, as shown here, factors such as the visibility of one's body or the user's body position and orientation influences perspective taking, this should be taken into account for the design and improvement of such technologies. The findings presented here showed that it is not necessary to be part of the environment to be able to reason about it effectively; spatial reasoning is accomplished as fast and as accurately even if we are external to the environment or we experience it remotely. This supports that tele-surgery and other situation that require the remote operation of technologies by means of perspective taking can be tackled by the human brain.

7. Chapter 7 - References

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8. Chapter 8- Appendix: Images from testing

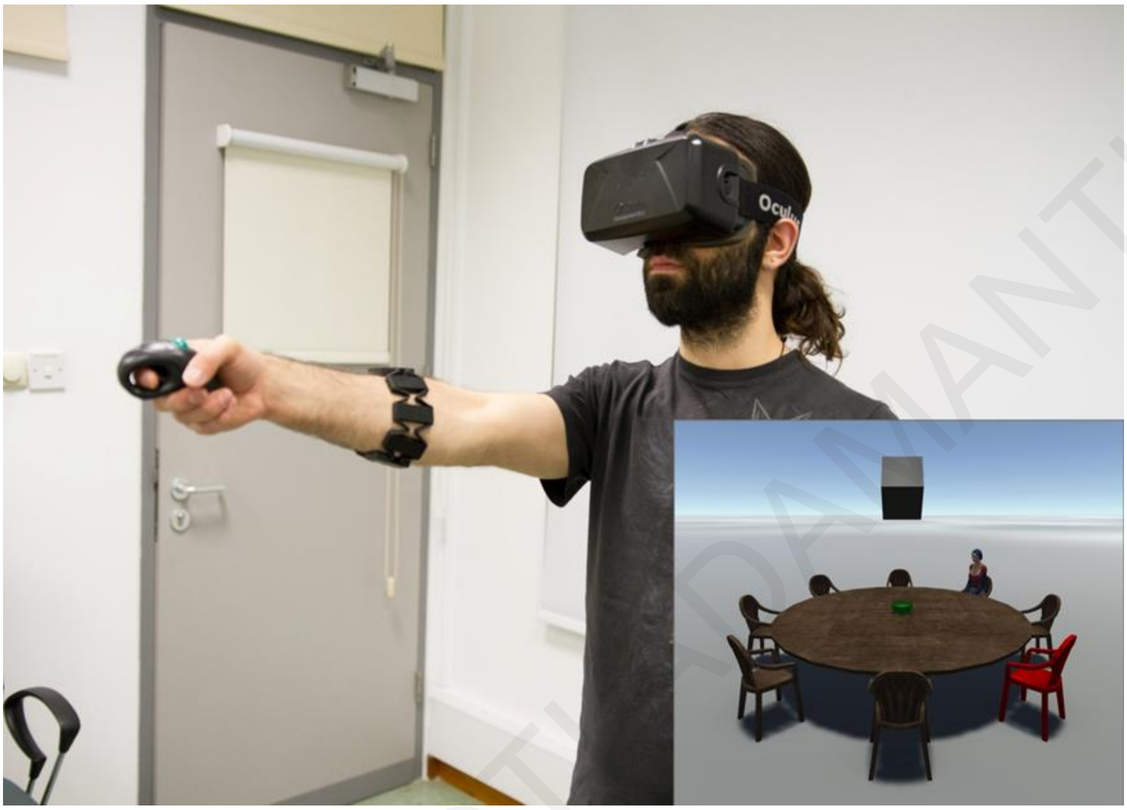

Image 1. Example of a participant carrying out the pointing task in the immersive VR condition of Experiment 1.

Image 2. Example of a participant carrying out the task in the virtual projector condition of Experiment 1.

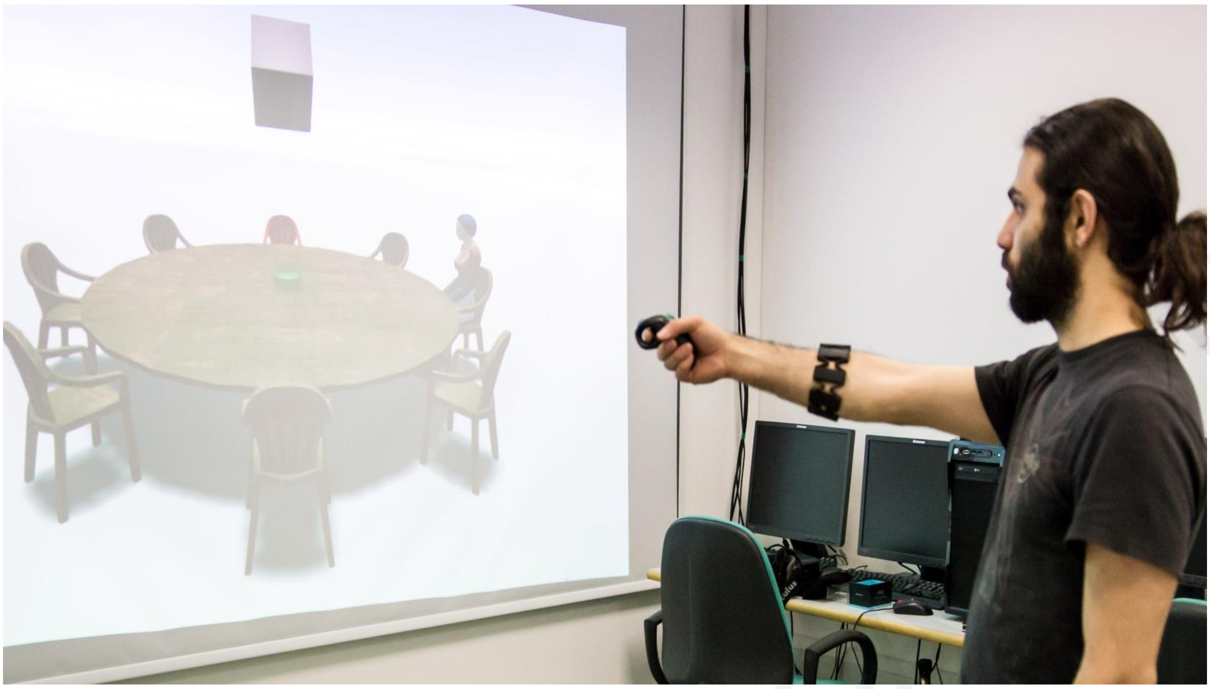

Image 3. Example of a participant carrying out the task in the Real projector-arm condition of Experiment 2.

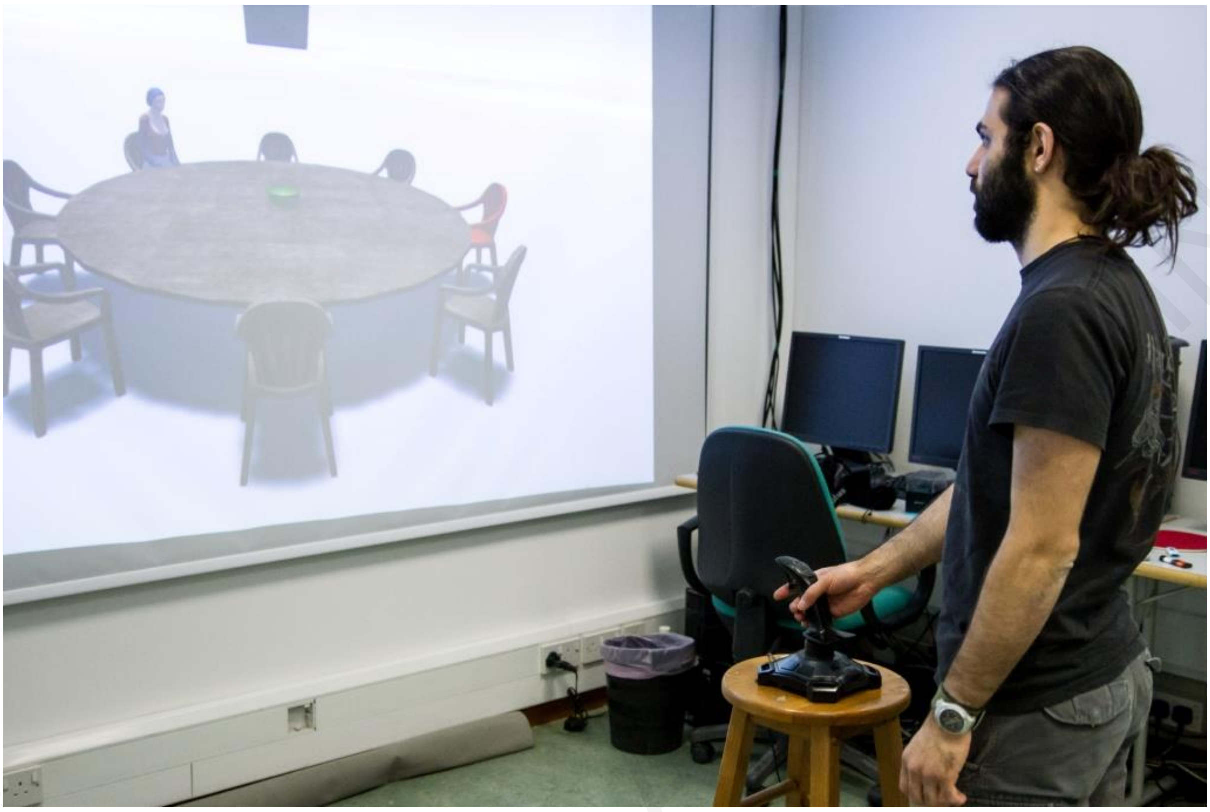

Image 4. Example of a participant carrying out the task in the Real projector-joystick condition of Experiment 3.

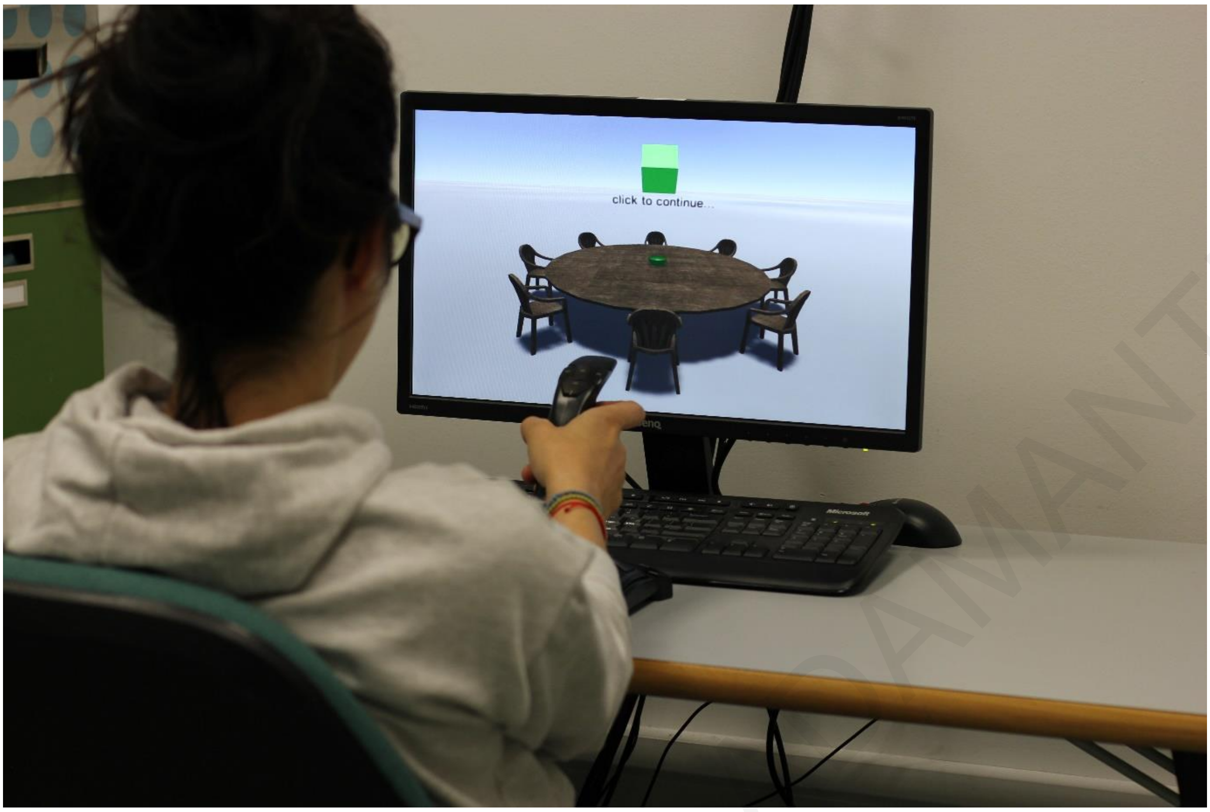

Image 5. Example of a participant carrying out the task on a computer screen in Experiments 3 and 4.