**Title**
Examining Perspective Taking and its Relation to Map Use and Environment Learning



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**Publication Date**
2020

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Santa Barbara

# Examining Perspective Taking and its Relation to Map Use and Environment Learning

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Psychological and Brain Sciences

by

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ACKNOWLEDGEMENTS

There are many people I have to thank for their support and encouragement throughout my graduate career. Firstly, I would like to thank my advisor, Dr. Mary Hegarty, for her, patience, expertise, and good humor. You have an unmatched work ethic, strong critical eye, and have an enviable ability to do many things at once, and do them well. It has been a pleasure to work with you and to learn from you in myriad ways.

To my committee members, Dr. Tamsin German, Dr. Richard Mayer, and Dr. Daniel Montello, thank you all for your guidance over the years. Your knowledge has made my work more well-rounded, and my perspective more dimensional. You have reminded me of the importance of diversity in research, and to lift my head out of the perspective taking papers every once and a while.

To the academic advising staff, particularly Chris McFerron and Katherine Lowe, thank you for all that you do and for always lending a listening ear. To the members of the Hegarty Lab, past and present, particularly Alex Boone and Carol He, thank you for the support (both scientifically and emotionally), and for the good times. Both in Santa Barbara and away at conferences, you helped make graduate school a truly joyful experience.

To my family, Mom, Dad, Tijen, and Jemi, thank you for your endless support, patience, and generosity with me during graduate school. You have always cheered with me at the highs and supported me through the challenges. Thank you for always reading through drafts, listening to my rants, and allowing me the freedom to pursue my academic interests.

To my friends, both from the university and beyond, thank you for always sticking by me even when you’ve heard enough about my data analysis and latest experimental pursuits. James and Joseph, you have contributed invaluable comedy and guidance to me over the past five years, and your support has been elemental to my completion of this program.

And thank you to all of the other students, faculty, and advisors I’ve met throughout my graduate career. The small conversations, greetings, encounters, and friendships we’ve shared have made the last five years an experience I won’t soon forget.

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ABSTRACT

Examining Perspective Taking and its Relation
to Map Use and Environment Learning

by

Peri Nicole Gunalp

Spatial perspective taking is the process through which judgments (usually of distance) are made from an imagined perspective. For example, you may be sitting at a desk now, and I could ask you to image standing in front of the desk, facing your chair. Then I could ask you to point to the door nearest you. Spatial perspective taking allows you to imagine the standing position described and subsequently make a judgment about where the door is from that imagined perspective. Perspective taking is related to many other spatial abilities, including mental simulation of bodily rotations (Kessler & Wang, 2012), giving directions (Hegarty & Waller, 2004), and navigation (e.g. Holmes, Marchette, & Newcombe, 2017). There are also large individual differences in perspective taking performance (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001). This dissertation describes two lines of research focused on perspective taking: first, examining what factors influence perspective taking performance, and second, exploring the relationship between perspective taking and navigation tasks (map use and environment learning).

Spatial perspective taking is influenced by multiple factors, one of which is the agency of cues embedded in perspective taking task arrays (Tarampi, Heydari, & Hegarty, 2016). Previous research has used the Spatial Orientation Test (SOT; Friedman, Kohler, Gunalp, Boone, & Hegarty, 2019; Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001) to measure perspective taking ability. In this task, participants are shown an array of objects, and asked to imagine standing at one object in the array, facing a second, and then to point to a third. This is a judgement of relative direction (JRD) task (Shelton & McNamara, 1997). Work by Tarampi, Heydari, and Hegarty (2016) found that adding a human figure to the task array improves performance, and eliminates a previously robustly demonstrated sex difference in performance on this task favoring men.

In the present work, two hypotheses regarding the influence of the human figure were tested: first, if the agency of the human figure is the primary characteristic of importance, as suggested by previous research on agency and perspective taking (e.g. Shelton, Clements-Stephens, Lam, Pak, & Murray, 2012; Clements-Stephens, Vasiljevic, Murray, & Shelton, 2013; Tversky & Hard, 2009), then a cue that is agentive (a human figure) should yield improvements in performance above and beyond cues that are not agentive. Second, if the directionality of the human figure is what influenced performance on this task in previous research, then a cue that is only directional and not agentive (an arrow) should be sufficient to improve performance.

Experiments 1, 2a, and 2b of this dissertation compare how the agency and directionality of the cue could be influencing performance. Experiment 1, established that participants performed better with a human figure in the task array than without any additional cue, as in previous research. In Experiments 2a and 2b, an arrow (directional) was compared to a human figure (directional and agentive), and it was found that the arrow was sufficient to improve performance. These findings indicate that for this type of task display, directionality of an additional cue embedded in the task array is sufficient to improve performance. This suggests that cue characteristics in combination with display characteristics are both important factors to consider when measuring perspective taking performance.

In these experiments, other components of the perspective taking task were manipulated. Specifically, both magnitude of initial perspective shift and pointing direction to the target object were systematically varied across trials. Findings indicated that perspective taking was faster and generally more accurate when perspective shifts were small and when pointing to the front of the imagined heading. Target direction relative to actual heading (not imagined heading) was considered, though was not systematically varied per trial. Neither interaction between cue types and perspective shift nor pointing direction were significant. This suggests that additional cues do not make larger shifts easier to imagine or pointing to less visually accessible directions easier. Rather, findings from these experiments suggest that the benefit of the additional cue, either an arrow or human figure, is that it facilitates initial imagination of oneself in the array.

Experiments 3 and 4 of this dissertation focused on examining the connection between perspective taking and other spatial abilities: navigating using a map (Experiment

3), and learning the layout of an environment (Experiment 4). The relationship between perspective taking and various components of environment learning has been established in previous work (Allen, Kirasic, Dobson, Long, & Beck, 1996; Galati, Weisberg, Newcombe, & Avraamides, 2015; Holmes, Marchette, & Newcombe, 2017; Kozhenikov, Motes, Rasch, & Blajenkova, 2006; Muffato & Meneghetti, 2020; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014).

Experiment 3 examined the relationship between perspective taking and map use, specifically looking at how misalignment of the  map relative to the user influences navigation performance, and how perspective taking ability might ameliorate some of this alignment effects. During perspective taking one often engages in perspective-based transformations of the egocentric frame of reference (Zacks & Michelon, 2005), and doing this well relies on good underlying spatial transformation ability. Because using a misaligned map also requires similar transformations, it was predicted that good perspective taking would be correlated with more efficient navigation and also with less pronounced alignment effects. Good perspective takers were more efficient navigators than those with poor perspective taking ability, but the predicted interaction with map alignment was not observed. Findings from this experiment overall indicate that perspective taking is related to navigation using a map, but being good at perspective taking does not make someone immune to alignment effects.

Additionally, navigation performance was examined both when a map was present and when a map was absent. Performance on these different trials indicated that more able perspective takers were more efficient navigators than less able perspective takers, but only when a map was present. When the map was absent, there were no significant differences between more and less able perspective takers, though there was a general trend for more able perspective takers to be more efficient than less able perspective takers. This suggests that when navigating with a map, perspective taking ability might influence how easy it is to use the map. When navigating without a map, however, other abilities may be more influential to navigation efficiency than perspective taking. For example, participants could have been relying on a memory of the map or a memory of navigating in the environment during the no-map trials, but because memory is imperfect and often distorted (e.g. Friedman & Brown, 2000), perspective taking ability may not have been as influential on performance as memory for the map itself.

Experiment 4 explored the connection between perspective taking and environment learning, and more specifically the development of survey knowledge of a new environment. Survey knowledge is configural knowledge or representations with metric information about distances and directions (Chrastil & Warren, 2013). Two components of perspective taking that could also be important for the development of survey knowledge are the ability to imagine changes in orientation (heading) within an environment, and knowledge of the configuration of objects in the environment. In order to examine if both of these specific abilities were supporting the correlation between perspective taking and the development of survey knowledge when learning an environment, two measures of survey knowledge were employed. These tasks tested participant's ability to determine which headings were the same in an environment, and determine which objects were closest to each other in the environment based on Euclidean distance, which is one way of measuring participant's configurational knowledge of the environment. Perspective taking ability was examined in relation to the development of survey knowledge, and it was predicted that good perspective takers would perform better on these measures of survey knowledge than poor perspective takers. Findings from this experiment supported this prediction, and add support to the idea that being able to flexibly and continually update one's heading is fundamental to both perspective taking and environment learning. This in turn suggests that this ability facilitates development of survey knowledge of an environment.

This work contributes several important findings. First, it shows that perspective taking with an abstract display is influenced by cue directionality and not agency. Second it shows that additional cues facilitate initial imagination of oneself in a new position within a perspective taking task, but do not reduce the difficulty of shifting or pointing from an imagined perspective. Third, it shows that good perspective takers are better at using maps to navigate than poor perspective takers perhaps because of their fluency with perspective-based transformations. Finally it shows that both flexible updating of heading and configurational knowledge of the environment in part underlie the connection between perspective taking and survey knowledge.

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# I. Literature Review

Spatial perspective taking is the process of imagining how an object or scene would appear from a viewpoint other than one's current physical perspective. This can be contrasted with social perspective taking, which can be more intuitively understood as understanding the psychological perspective of another, as in empathy (Johnson, 1975). To understand spatial perspective taking, imagine the following example: imagine you are standing outside your house, facing your front door, and I could ask you to point to the nearest freeway on-ramp. The processes through which you imagine this perspective and subsequently make a pointing judgment comprise spatial perspective taking.

Perspective taking can be characterized in terms of multiple frames of reference, and imagined spatial transformations of certain reference frames relative to others. It is generally accepted that there are three primary frames of reference for spatial information: object-based, egocentric, and environmental (Zacks & Michelon, 2005). Object-based frames of reference are defined by an object, and can be thought of as the axes or planes that "cut-through" the object, or are the specific coordinates within planes on which that object resides. Egocentric frames of reference are based on axes that run through the body (e.g. front/back, right/left, top/bottom), and for the purposes of this paper will only be discussed in relation to head-based perspective (not eye-based or effector-based perspective). Environmental frames of reference define spatial relationships relative to the axes of a given space, for example the walls of a room or cardinal directions.

A mental transformation is required in the perspective taking example given above, unless your current perspective as your read this paper is outside your house, facing your front door. The transformation that must occur for you to then be able to make a judgment about the relative position of a freeway on-ramp is a perspective transformation (Zacks & Michelon, 2005). Perspective transformations like the example above that rely on a person's location and heading entail the real or imagined manipulation of the egocentric frame of reference of that person relative to the surrounding objects and environment. Spatial tasks can be done with other knowledge that is not egocentric, such as object- or environment-centered transformations (Zacks & Michelon, 2005). The configuration of objects in the environment can be described with an allocentric frame of reference, which locates objects relative to axes assigned to a fixed space, such as cardinal directions or the principle axes of a room (Zacks & Michelon, 2005). In the example described above, you would need to imagine transforming your own body's position within the frame of reference of the land your house is on, and relative to the object frame of reference for your front door; presumably you are currently positioned relative to the "inside" of your front door, and you need to imagine being positioned relative to the door's "outside." This kind of perspective transformation is what the perspective taking tasks discussed in the present work entail.

Foundational research on perspective taking has indicated that the transformations required when imagining a different perspective are analogous to real transformations, in that as the amount of transformation required increases, response time for the imagined transformation also increases (Hintzman, O'Dell, & Arndt, 1981; Rieser, 1989). Indeed, it is the rotational component of this process that is most challenging; we can imagine putting ourselves in a new spot as accurately and easily as if we actually move to that spot, but imagining the perspective from a new position is much less accurate and slower than if we actually physically adopt a new perspective (Presson & Montello, 1994). This is similar to, for example, mental rotation response time increasing as degree of rotation increases (e.g. Shepard & Metzler, 1971). This is dissimilar to mental rotation, however, in that in order to execute this kind of perspective transformation, one must override the proprioceptive, visual, and haptic cues they are receiving based on their current physical perspective (Presson & Montello, 1994; May, 2004).

Perspective taking is important for numerous cognitive processes, including understanding the layout of an environment (Fields & Shelton, 2006), navigation (e.g. Holmes, Marchette, & Newcombe, 2017), and giving directions (Hegarty & Waller, 2004). Extant research on perspective taking has illustrated the developmental trajectory of this skill (Epley, Morewedge, Keysar, 2004; Newcombe & Frick, 2010) originally measured through use of Piaget's three mountains task (Piaget & Inhelder, 1956). Research has also documented sex differences in performance (Lawton, 1994; Linn & Petersen, 1985; Tarampi, Heydari, & Hegarty, 2016; Gunalp, Moossaian, & Hegarty, 2019), and individual differences in performance (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001). Finally, prior work has also connected perspective taking to other skills like empathy (e.g. Ruby & Decety, 2004), mental simulation, and embodied cognition (e.g. Kessler & Wang, 2012). Neuroscience research on perspective taking also suggests that certain areas of the brain, including the posterior parietal cortex, posterior cingulate cortex, dorsal stream components of the posterior cortex, and the left lateral frontal cortex, are implicated relative to specific components of perspective transformations (Aguirre & D'Esposito, 1999; Creem, Downs, et al., 2001; Zacks & Michelon, 2005).

There are two levels of perspective taking that are distinguished within the field of spatial cognition, especially in developmental studies. With Level 1 perspective taking, "…the child can non-egocentrically infer what object another person does and does not see, given adequate cues," (Flavell, Everett, Croft, & Flavell, 1981, p. 99). With Level 2 perspective taking, "…the child further knows that an object simultaneously visible to both the self and the other person may nonetheless give rise to different visual impressions or experiences in the two if their viewing circumstances differ," (Flavell et al., 1981, p. 99). Some of this developmental research has indicated that by age three, children have not developed level 2 perspective taking abilities (Flavell et al., 1981) and level 2- perspective taking ability seems to appear from 4-6 years of age (Baron-Cohen, Leslie, & Frith, 1985; Frith & Frith, 2003). The present work focuses on Level 2 perspective taking, and specifically relates to the components of this process that require making judgments about imagined perspectives.

Perspective taking can also be executed at several scales of space (see Montello, 1993 for description), from figural-scale space where the setting of perspective taking is an array of objects, like that of the Spatial Orientation Test (SOT; Kozhevnikov & Hegarty, 2001), to larger vista-scale space, for instance when pointing between two learned routes in an environment (e.g. Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). Vista-scale space is as larger or larger than the body, but can be seen entirely without movement through the space, for example in a single room (Montello, 1993). Perspective taking can also occur in larger environmental-scale space, perhaps while navigating in a new city and attempting to imagine what a town square would look like from a museum you plan to visit. Importantly, there are differences between the processes that make up perspective taking at these scales of space.

For some perspective taking tasks at the figural scale of space, transformation of the display is not always required to begin perspective taking; at this scale participants may be shown an array of objects and told to imagine taking the perspective of one of them, as in the SOT. At this scale of space, the task can be completed by imagining a transformation of the array alone, or by executing a transformation of perspective. At vista scale space, however, a perspective transformation is necessary after apprehending the display in question; as in Shelton et al. (2012), in order to imagine the position from which a specific view of buildings could be seen, a representation of the buildings in relation to each other may need to be rotated to execute the perspective taking process. Further, at the environmental scale, when navigating a new city, the entire space cannot be apprehended from one view point, unless the city is represented or depicted on a map with an aerial view. Because of this, perspective taking at this scale requires not only time and movement through the environment, but also the transformation of existing representations of apprehended information (as in vista-scale PT) and transformation of *imagined* representations of information not yet gathered from the environment. Imagined transformation would need to occur for both seen and unseen views. The present work begins by focusing on pictorial-scale perspective taking (Experiments 1 and 2) and ends with consideration of pictorial-, vista-, and environmental-scale perspective taking.

All experiments discussed in the present work utilize the Spatial Orientation Test (SOT) developed by Kozhevnikov and Hegarty (2001) and Hegarty and Waller, 2004, which is a measure of spatial perspective taking performance. One crucial difference between mental rotation and spatial orientation that the development of this task helped to highlight was that mental rotation requires transformation of the target object, and therefore the object frame of reference, while spatial orientation often requires transformation of the egocentric frame of reference. The SOT requires transformation within the egocentric frame of reference, in that it defines the perspective to be imagined, and that perspective is never the current perspective of the participant. One way to execute the kind of transformation is though mental simulation. Indeed, many people who completed the SOT report using strategies that involve mentally simulating being in the task array (see Kozhevnikov &

Hegarty, 2001; Gunalp, Moossaian, & Hegarty, 2019). The original SOT was later refined by Hegarty and Waller (2004), who created trials that would enhance individual differences in perspective taking performance (selected such that the perspective shift was always greater than 90°, because most people can estimate directions after shifts of less than 90° accurately and more readily), and ensured that the task measured perspective taking performance reliably.

This task was originally conducted as a paper-and-pencil measure, but was recently revised and reformatted (and experimentally validated) to be conducted on a standard desktop computer (Friedman, Kohler, Gunalp, Boone, & Hegarty, 2019). The newest, computerized version of the SOT was implemented in each of the experiments discussed in the present work. This version clarified task instructions, controlled potentially influential extraneous variables (such as rotation of the test booklet by participants), automated scoring (reducing human error), added dots to objects in the array denoting object centers, and added practice trials with feedback to the task. Other improvements to the task included the ability to measure response time per trial, randomize trials, and employ a flexible time limit for task completion. In the original paper format, the same order of trials was presented to each participant, and one standardized time limit was used. However, with the computerized task, trial order could be fixed or randomized for each participant, and time limit could be set based on experimental needs.

Another substantial improvement of the computerized SOT was that it uses an array made up of non-directional objects. Given the nature of the task, it is intuitive to understand why the directionality (or the visible front/back of objects) might be important; if you are asked to imagine facing a specific direction from one object in the array of the SOT, but the object in question is facing a different direction than you are to imagine, more effort is required on your part to imagine your perspective for the trial, and your estimates of direction might be more cognitively demanding, slower, and less accurate. In previous versions of this task, directionality of the objects in the task array was not controlled, which could have influenced performance on this task. However, directionality was controlled in the computerized format, such that none of the objects included in the array have a clear front or back. No animate objects were included in the computerized test, which is another improvement over the paper version. In previous versions, a cat was included in the array, along with other objects that could possibly be anthropomorphized (e.g. a car, a house). This is another potential distraction that could influence judgments of relative direction based on this array, and hence only inanimate objects were included in the computer test array.

The SOT has been widely used as a psychometric measure of perspective taking ability. In order to understand individual differences in performance on this task, it is first necessary to understand the task demands. In this task, participants are shown a two-dimensional, black and white, array of objects from an aerial (overhead) view (see Figure 1 for a sample item of the SOT). On each trial of the task, participants are asked to imagine standing at one object in the array, facing a second, and to point to a third. The way participants "point" is by drawing a line on an answer circle. The task is then scored by finding the difference in degrees between the correct answer and the participant's answer. On original versions of this task, a five-minute time limit was imposed, and response time per trial was not measured. However, the present work utilizes a computerized version which collects response time data for each trial. Lower scores on this task therefore indicate better performance. Typically people complete this task with around 20-45 degrees of error (e.g. Tarampi, Heydari, & Hegarty, 2016).

*Figure 1.*

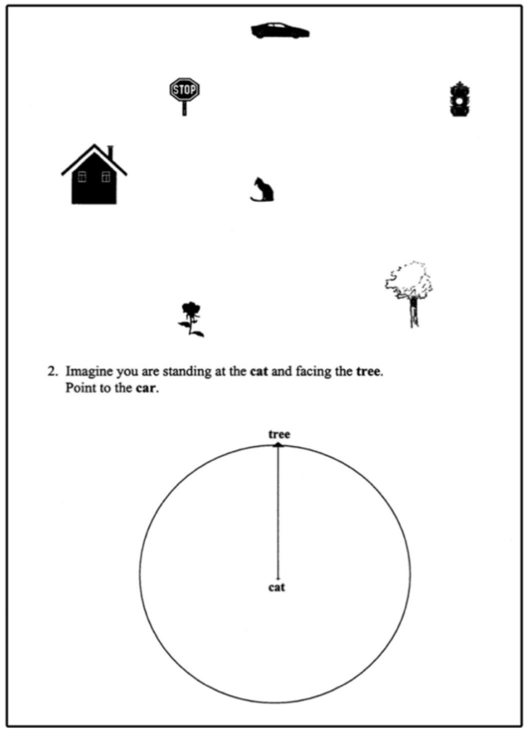


Figure 1. A depiction of one trial from the SOT used by Hegarty & Waller, (2004) and in the control condition of Tarampi et al (2016).

More recently though, the SOT was used in research that demonstrated one way to resolve this sex difference. Tarampi, Heydari, and Hegarty (2016) found that the inclusion of a human figure in the task array of the SOT improved performance relative to a control array. This finding echoes earlier research supporting the influence of agency in varying degrees on perspective taking performance (Shelton et al., 2012; Clements-Stephens et al., 2013). What is more, Tarampi et al. found that the human figure extended a specific benefit to women more so than men; women's performance on this task with a human figure included in the array improved to be equal to that of men.

The human figure added to a perspective taking task array could be influencing performance at three steps in the pictorial-scale perspective taking process (specific to this task): 1) during initial imagination of oneself in the array, 2) when imagining a facing direction, or 3) while making pointing judgments. Experiments 1 and 2 of the present work examine each of these three steps by systematically varying the magnitude of initial perspective shift and the pointing direction in a perspective taking task with either a human figure, an arrow (a directional but non-agentive cue), or a control task array. Thus, Experiments 1, 2a, and 2b of the present work examine how different cues added to the SOT influence perspective taking performance at three specific steps within the perspective taking process.

Previous research by Gunalp, Moossaian, and Hegarty (2019) has examined the influence of different cue types in a virtual reality (VR) version of the SOT. In this work, three different cues were employed to test different hypotheses regarding the influence of the human figure. The possible explanations tested were that the human figure improved performance either because it was agentive (is animate, has a perspective, is easy to embody), because it was directional (indicates facing direction to be imagined on each trial), or because it was interactive (it could be interacted with). To test these hypotheses, Gunalp et al. compared performance on the SOTs when either a human figure, an arrow, or a chair were included in the task array. A human figure is agentive, directional, and interactive, an arrow is only directional, and a chair is both interactive (in that we can imagine sitting in it) and directional, but not agentive. Thus, comparing performance across these conditions would help to isolate the critical characteristics of the cue.

It was found that the human figure improved performance relative to a control array, which replicated previous work (Tarampi et al., 2016). Additionally, a human figure improved performance significantly relative to an arrow, but a chair was sufficient to yield improvements in performance comparable to the human figure. Further, strategy data from these experiments indicated that a majority of participants in all versions of the task reported using strategies that relied on mentally simulating being in the array. Taken together, these findings indicated that interactive cues may be effective in this VR SOT partly because they facilitate the use of mental simulation strategies. In Experiments 1, 2a, and 2b of the present work I build on these findings, and continue to examine how the agency and directionality of cues embedded in the SOT array influence performance, specifically within the more abstract display similar to the original SOT (rather than in VR).

A second major aim of the present work is to explore the relationship between perspective taking ability and navigation ability is substantial (see Hegarty & Waller, 2005). For example, perspective taking is been correlated self-reported navigation skill and sense of direction (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), large scale/real-world navigation (Bryant, 1982; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Lorenz & Neisser, 1986), route encoding (Fields & Shelton, 2006), and mental rotation (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001). Much research has also illustrated a correlation between perspective taking performance and various measures of environment learning and survey knowledge (Allen, Kirasic, Dobson, Long, & Beck, 1996; Holmes, Marchette, & Newcombe, 2017; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). The size and valence of the correlation between perspective taking and environment learning is contingent on the measures used to examine each ability (see Table 1), but the general trend is the same: the better one is at perspective taking, the better one is at learning an environment, and vice versa.

For example, Kozhevnikov et al. (2006) found moderate correlations (ranging in magnitude from .29 to .43) of a perspective-taking test (similar to those used in the present experiments) with measures of environmental knowledge after learning of an environment in the field. Weisberg et al. (2014) had participants learn two routes in a virtual environment, and found that performance on the SOT correlated with onsite pointing both within ($r$ = 0.31), and between learned routes ($r$ = 0.49), as well as ability to reconstruct an aerial view of the learned environment ($r$ = - 0.36). See Table 1 for various correlations between navigation and perspective taking found in prior research.

As Allen et al. (1996) emphasized in their seminal work, perspective taking may mediate the relationship between small-scale spatial skills (measured by psychometric tasks) and environment learning (measured in the field). Both perspective taking and survey knowledge (sometimes measured by Euclidean direction estimation) require representations that contains information about the spatial relationships between objects in the environment.

Recent research has demonstrated that perspective taking is correlated with the accuracy of representations of a newly learned environment (e.g. Muffato & Meneghetti, 2020) and vice versa (Allen et al., 1996; Fields & Shelton, 2006). In one study, Muffato and Meneghetti (2020) walked participants through a park once, then from the lab asked them to complete a perspective taking task similar to the SOT, and a pointing task. This pointing task was based on imagined views from within the recently learned environment. Results indicated that performance on the perspective taking task predicted pointing performance; people with better perspective taking pointed with more accuracy (less error).

Table 1. Correlations between perspective taking and tasks related to survey/environmental knowledge.

| Reference | PT task | Learning Procedure | Survey/environmental knowledge task | Correlation |
|---|---|---|---|---|
| Allen, Kirasic, Dobson, Long, & Beck (1996) | TinyTown: subjects walk around a model town and later see a slide image. Have to decide if the image shows a possible perspective on the town. | Led on a 1,424-meter path through a city (path contained 9 turns) | Route reversal | 0.34 |
| | | | Euclidean direction | 0.32 |
| | | | Scene sequencing | 0.32 |
| | | | Intra-route distance | 0.39 |
| | | | Map placement (see pic and indicate where on map it is) | 0.58 |
| Kozhevnikov, Motes, Rasch, & Blajenkova (2006) | Pointing direction task, very similar to the SOT but with either a person or an arrow facing the target object | Led on an approximately 2.5-minute path through the building, then asked to retrace the route from beginning to end | Floor plans (trace route taken on given floorplan map) | 0.43 |
| | | | Shortcut | -0.3 |
| | | | Pointing | -0.29 |
| Weisberg, Schinazi, Newcombe, Shipley, & Epstein (2014) | SOT | Given as much time as needed to navigate two paths with eight buildings in a virtual environment | Model building | -0.36 |
| | | | Pointing within a route | 0.31 |
| | | | Pointing between routes | 0.49 |
| Galati, Weisberg, Newcombe, Avraamides (2015) | SOT | Studied a list of written route instructions/directions and then navigated the route in a virtual environment | Mean duration of both routes taken together | 0.5 |
| | | | Navigation errors | 0.51 |
| | | | Time spent pausing | 0.37 |
| Holmes, Marchette, Newcombe (2017) | SOT | Viewed a model of a landscape for 2.23 minutes and either saw static views, saw the landscape rotate, or walked around the landscape | Model building (recreate landscape in PowerPoint) | -0.33 |
| | | | Spatial judgments (JRDs) | -0.32 |
| | | | Free recall of any of the structures in the layout | -0.21 |
| Muffato & Meneghetti (2020) | sOPT (short Object Perspective Test) | Led on a single walk through a park, from North-South (NS) or South-North (SN) | Pointing task between objects based on imagined views within the park | .31 (SN)<br>.37 (NS) |

However, little research goes beyond a limited description of this connection to investigate which specific components of perspective taking are related to and may be predictive of specific components of navigation. Experiments 3 and 4 of the present work aim to further illuminate the connection between perspective taking and navigation, and further understand how this relationship may be influenced by components of the perspective taking array (described above), by systematically varying components of a perspective taking task and observing the influence that may have on a performance in a standard navigation task.

Frames of reference and spatial transformations are also relevant to navigation and environment learning. Firstly, egocentric reference frames are necessary for mindful navigation, in that if your goal is to navigate successfully to some target, you need to first know where that target is with respect to your current position and how far away it is (Zacks & Michelon, 2005). Additionally, while walking through an environment, we undergo perspective transformations (described above), in that our egocentric reference frames of reference are shifting with the stable and unmoving frame of reference of the environment, and relative to the frames of reference of other objects within the environment.

Another spatial property that is important to both perspective taking and navigation/environment learning is orientation specificity of spatial memories for large layouts. Waller, Montello, Richardson, and Hegarty (2002) describe it aptly, saying, “Spatial memory is said to be orientation specific when memorial representations are coded (and hence accessed) in a preferred direction,” (p. 1051). When the external environment does not provide a strong frame of reference, people often represent a space from the orientation in which the environment was first encountered (Shelton & McNamara, 2001), which is particularly true in room-sized environments (Waller et al., 2002). Orientation specificity of memories could influence perspective taking performance, perhaps making the learned orientation of an environment more difficult to inhibit when imagining a different orientation. However, previous research has shown that viewing an environment from multiple perspectives while learning, as often happens when moving through an environment, attenuates alignment effects caused by orientation specificity (Montello, Waller, Hegarty, & Richardson, 2004). It is also possible that perspective taking itself influences the orientation specificity of spatial memories. For example, the first imagined orientation from which perspective taking is performed may be given preferential status in memory (Shelton & McNamara, 1997; Shelton & McNamara, 2001), making it more difficult to accurately make judgments about other spatially disparate perspectives.

Orientation specificity also has clear implications for environment learning; if an environment is learned from one orientation, that orientation will be the preferred direction from which memories of that environment will likely be retrieved. Previous research also indicates that when learning an environment from a map, orientation specificity is particularly robust (Levine, Marchon, & Hanley, 1984; Montello et al., 2004; Presson & Hazelrigg, 1984), and the orientation of the map becomes the most salient orientation in memory (e.g. Meilinger, Frankenstein, Watanabe, Bulthoff, & Hölscher, 2015). This is particularly evident when using  you-are-here (YAH) maps, which are static reference maps that indicate the position of a user viewing the map (Montello, 2010). Given that these maps are most commonly static (do not change orientation or position within the environment), they can be defined by an object-based frame of reference. Problems can arise when using a YAH map, particularly if the map itself is misaligned with the environmental frame of reference. Misalignment occurs if the map does not follow the most psychologically functional alignment of forward-up orientation (Montello, 2010; Shepard & Hurwitz, 1984).

Indeed, misaligned map use during navigation is detrimental to navigation performance, and can even negate the positive effects distal landmarks may have (McKenzie & Klippel, 2016). Factors such as gender, discipline, and mental rotation ability all significantly impact one's ability to use YAH maps to navigate (Campos & Campos-Juanatey, 2020). This can all be complicated further by placing a YAH map in a virtual environment, which itself displays a unique scale of space with its own frames of reference (Montello et al., 2004).

It is important to consider why most people utilize a forward-up orientation when viewing YAH maps, as well as other visual displays (such as the array in the SOT). As Levine (1984) noted, manuals for horizontal map use often suggest that the easiest way to use a map is to align it with the terrain, such that your heading in the environment (facing forward) is paralleled by the map. For example, if you are walking west and consult your map, it will be easiest to use the map if it is aligned such that west on the map is forward to you (Levine, 1984; Levine, Jankovic, & Palij, 1984; Shepard & Hurwitz, 1984). However, when using vertical maps, which many YAH maps are, "forward" needs to be defined differently, and given that most YAH maps are static/fixed in the environment, will need to be transformed mentally rather than physically. In order for a YAH map to be aligned with the terrain, forward should be up on the map. If a vertical YAH map with this forward-up alignment were rotated 90° in the depth plane (away from the person using the map as if it were being laid on a table) so that it was horizontal, the terrain in front of the user would also be forward in the map. This forward-up alignment thus creates alignment between right and left in the environment and right and left on the map, which further increases ease of use of maps aligned in this way (Levine, 1984).

Given that forward-up aligned maps are used more effectively, and this alignment is thus preferred and (slightly) more commonly used in present day, we may implicitly apply the forward-up alignment to even sparse spatial representations that are not explicitly maps. For example, people viewing the array of objects used in the SOT may impose forward-up alignment on it, such that (in the case of the paper versions of the task) because the car is at the top of the array, the car is "forward" in the imagined environment. This is particularly important for step 2 of the perspective taking process, which entails imagining a shift in some direction relative to this forward-up alignment.

To conclude, perspective taking is influenced by many factors, including the agency, directionality, and interactivity of cues embedded in task displays (Tarampi et al., 2016; Gunalp et al., 2019). Previous research has also demonstrated that perspective taking performance is correlated with navigation and environment learning abilities. A brief overview has highlighted the importance of considering frames of reference, spatial transformations, orientation specificity, and map properties (as displays and learning tools) when examining the connection between perspective taking and environment learning or navigation. The following chapters will describe research aimed at examining specific components of this overview in greater detail. Chapter 2 examines the cue characteristics that could influence performance on the SOT. Chapter 3 investigates the connection between perspective taking and map use, particularly map use during navigation in a novel environment. This chapter begins to examine individual's development of survey knowledge of the environment. Chapter 4 focuses on further examining the relationship between perspective taking and the acquisition of survey knowledge. Lastly, Chapter 5 summarizes and discusses the findings from experiments presented in this dissertation.

## II. Experiments 1, 2a, & 2b

### *A. How Does a Human Figure Influence Specific Components of Perspective Taking?*

The Spatial Orientation Test (SOT) (Kozhevnikov & Hegarty, 2001; Hegarty & Waller, 2004) is a common measure of spatial perspective taking ability. A computerized version of this test has recently been developed and validated (Friedman, Kohler, Gunalp, Boone, & Hegarty, 2019), and here I took advantage of this computerized SOT to test a theoretical question about perspective taking. On each trial of the SOT, participants are asked to imagine standing at one object (station point) in an array, facing a second object, and then to point to a third (target) object (see Figure 2). These three-step, task-specific instructions for the SOT illustrate the three general steps in the perspective taking process: 1) initial imagination of oneself within an environment, 2) imagining the new view, and 3) making judgments about distance or direction. Importantly, while steps 1 and 2 of the perspective taking process entail singular processes, step 3 is more complex. In step 3, one needs to identify the target object and identify the direction to the target object from the imagined heading. The present experiment utilizes this three-step breakdown to examine which step (or steps) of the perspective taking process are facilitated by the addition of a human figure the task array. Different starting objects (or station points) are given for each trial (step 1), and the magnitude of initial perspective shift (step 2) and the pointing direction for each trial (step 3) are both systematically varied. For a graphic depiction of both imagined perspective shift and pointing quadrant, see Figure 3.

In this chapter, three experiments are presented. Experiment 1 examined how the addition of a human figure into an array of objects influences perspective taking performance relative to a control array. Experiment 2a compared a human figure, an arrow, and a control, and Experiment 2b addressed a confound in Experiment 2. Tarampi, Heydari, & Hegarty (2016) found that the inclusion of a human figure in the array improved performance relative to a control array. This finding supports earlier research on the influence of agency on perspective taking performance (Shelton et al., 2012; Clements-Stephens et al., 2013). Tarampi et al. suggest that the human figure improves performance because it helps participants imagine themselves embodying the position of the human figure within the array, affecting perspective taking at step 1 of the process.

*Figure 2.*

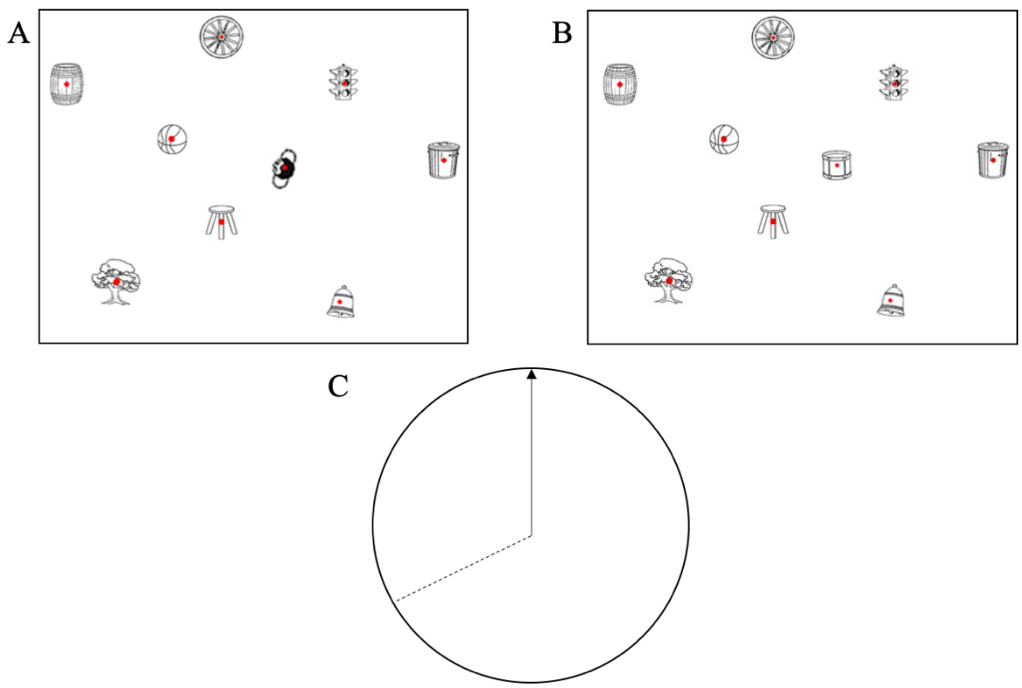


Figure 2. Array types used in Experiment 1 based on the computerized Perspective Taking Test (Friedman et al., 2019), with a sample trial reading, "Imagine you are standing at the drum/taking the perspective of the person, facing the basketball. Point to the bell." A) Human figure, and B) control. Also shown here is the answer on which participants input their pointing judgments (C).

*Figure 3.*

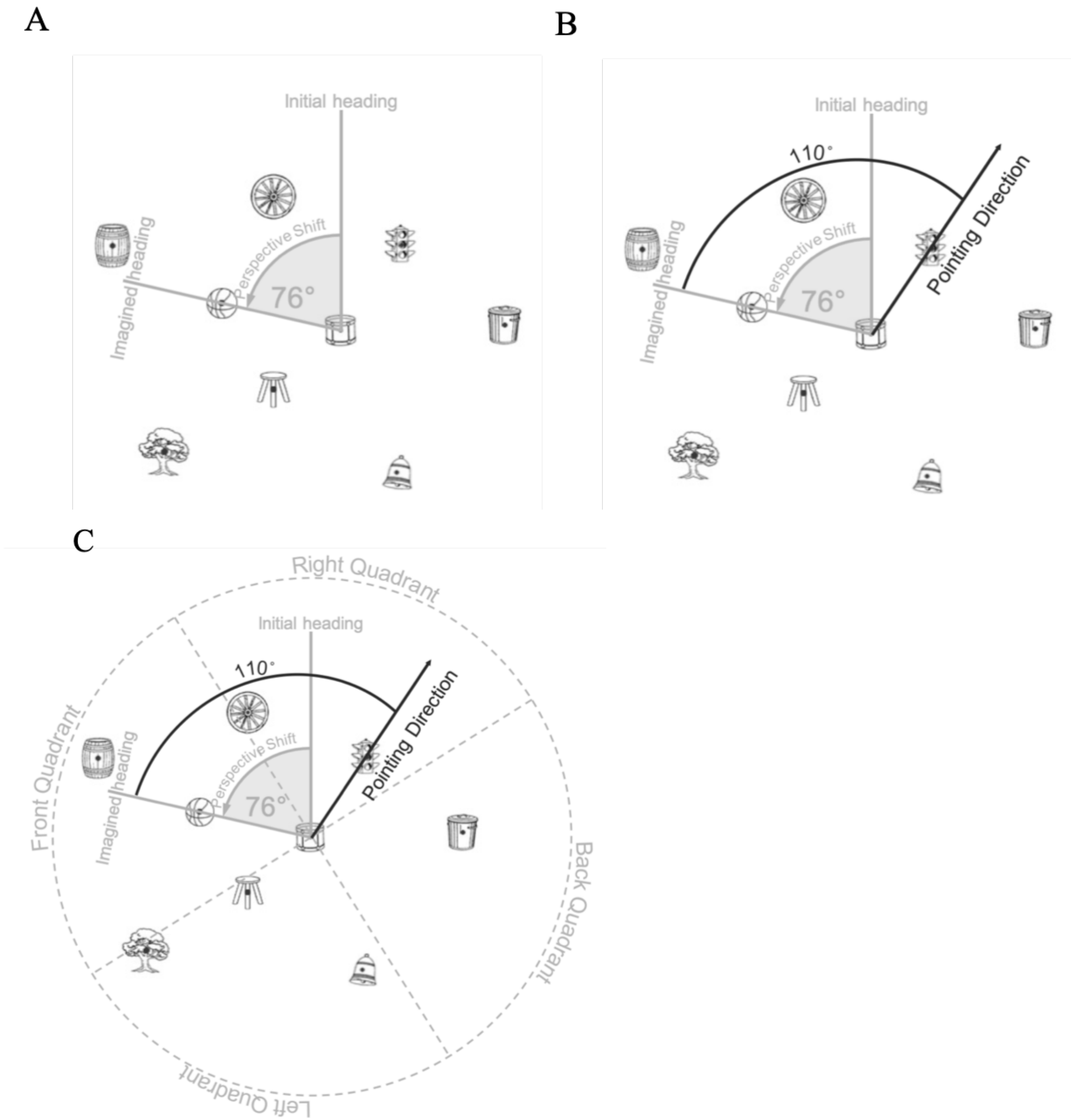


Figure 3. Graphic depiction of both imagined perspective shift and pointing quadrant for SOT trials. In this example, participants are to imagine standing at the drum facing the basketball, then point to the traffic light. If the initial heading is forward-up, reflecting the participant seated at the computer looking at the array, it takes a 76° shift in perspective to face the basketball. From that new perspective, the traffic light is 110° behind and to the right. Panel A represents step 2 of the perspective taking process, panel B represents step 3, and panel C represents the classification of pointing direction into quadrants relative to imagined heading.

With regard to step 2 of perspective taking – imagining a new facing direction – previous research shows that pointing error on the SOT is greater after a larger imagined perspective shift (Kozhevnikov & Hegarty, 2001). These findings suggest that perspective taking is an analog transformation (Rieser, 1989) like mental rotation (Shepard & Metzler, 1971) with the added difficulty of the current perspective interfering with the to-be-imagined perspective (May, 2004). This is consistent with reports of individuals completing perspective taking tasks by mentally simulating being in the array and performing transformations relative to their new perspective (Kozhevnikov & Hegarty, 2001; see also Zacks & Michelon, 2005; Zacks, Mires, Tversky, & Hazeltine, 2000; Gunalp et al, 2019). Step 2 is also theoretically based in ideas of grounded cognition and everyday experience (e.g. Barsalou, 2008). Taking the perspective of a human figure (or an actual person) likely engages grounded cognition in which we mentally simulate transforming our body position to match that of the target. Further, imagining taking the perspective of another person is something we do in everyday life. Our extensive familiarity with this shifting process coupled with grounded cognition processes may facilitate perspective taking performance by making imagined perspective shifts easier with a human figure array relative to arrays with no added cue.

Gunalp et al. (2019) suggest that the human figure influences perspective taking at both steps 1 and 2. The human figure provides both an anchor at which individuals can imagine standing *and* a directional cue because the human figure clearly faces a certain way. This makes performing larger imagined perspective shifts easier because the perspective shift end point (or goal), denoted by the human figure's facing direction, is already displayed within the task array. This could reduce the time it takes to perform an imagined shift, and make the imagined shift more accurate.

With regard to step 3 of the perspective taking process – making pointing judgments – some research indicates that pointing to a target that is in front of or behind the imagined heading is more accurate than pointing to an object that is to the right or left of the imagined heading (e.g. Franklin, Henkel, & Zangas, 1995; Franklin & Tversky, 1990; Franklin, Tversky, & Coon, 1992; Sholl, 1987; Hintzman, O'Dell, & Arndt, 1981; Werner & Schmidt, 2000), and other research suggests that pointing in front is easier than pointing behind (Horn & Loomis, 2004; Shelton & McNamara, 2001). Both of these findings were also evident in preliminary studies of the SOT (Kozhevnikov & Hegarty, 2001). It is likely that we parse the space around us into more than four sections or quadrants, but the present experiment did not have the precision to separately analyze this number of sections. Thus, in the present work, the space in which participants make pointing judgments is always divided into four quadrants.

Pointing to objects in specific positions (such as front, back, right, and left) relative to egocentric heading is an assessment of one's representation of a space (either real or imagined). This representation could include not only where objects are in relation to each other, but also what is visible from a given point and what is not. This is related to the two levels of perspective taking, originally described by Flavell, Everett, Croft, & Flavell (1981) summarized above.

Research on level 1 perspective taking often employs the dot perspective paradigm, in which a participant is required to indicate how many dots can be seen by something from a given point (e.g. Samson, Apperly, Braithwaite, Andrews, & Scott, 2010). Importantly, the judgment of what dots can be "seen" has been based on a target that is a human figure, a rectangle (Samson et al., 2010), and an arrow (Santiesteban, Catmur, Hopkins, Bird, & Heyes, 2014). This research is relevant to step 3 of the SOT, as both pointing to a specific quadrant based on an egocentric perspective and indicating what can be seen from a given point (i.e., what is in front of a target) are two ways of executing the same process: parsing the space around us into sections. Extant research has looked at how different targets (both agentive and not) have influenced level 1 perspective taking, but no research to date has examined how pointing to different quadrants (step 3 of perspective taking) is influenced by the degree of agency of the target. The present experiment addresses this question.

*Specific Predictions.* Based on previous research (Tarampi et al., 2017; Gunalp et al., 2019; Shelton et al., 2012; Clements-Stephens et al., 2013), I first predicted that a human figure should improve performance on the SOT relative to a control array. Second, I predicted that larger imagined shifts in perspective would lead to greater angular error and longer reaction times than smaller shifts (Kozhevnikov & Hegarty, 2001; Zacks et al., 2000). Third, I predicted that pointing to the front of the imagined position would lead to smaller pointing error and response times than pointing to other quadrants. This is the pattern generally found with this type of task (see Bryant & Tversky, 1999; Bryant, Tversky, & Franklin, 1992; Kozhevnikov & Hegarty, 2001), and could occur because the front quadrant allows use of level 1 perspective taking, that is, judging what would be in view from that perspective (e.g. Samson et al., 2010, Santiesteban et al., 2014). And fourth, based on previous research (Tarampi et al., 2017; Gunalp et al., 2019) I predicted that a human figure would affect all three steps of the perspective taking process, such that cue type (human figure vs control) would interact with perspective shift and pointing quadrant. Specifically, a human figure should give more advantage for perspective shifts that are larger and for pointing behind the imagined position than the control arrays. This would be because the human figure allows for an embodied/mental simulation approach, which might make imagining more difficult spatial transformations (i.e. perspective shifting or pointing) related to the human figure easier.

1. Experiment 1

## Method

### Participants

Sixty-four undergraduates from the University of California Santa Barbara participated in this study for course credit. Three (women) participants were excluded from the following analyses due to error above chance levels, and four participants' data were lost due to experimenter error. Analyses of the data of the remaining 57 participants (30 women, 27 men) ages 18-27 ($M$ = 20.0, $SD$ = 1.8) are presented below. A post-hoc power analysis for ANOVA was run using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) with an alpha level of .05 and an effect size of $f$ = .294, indicating that power for this experimental design was .86.

### Design

This study utilized a three factor within subjects design; factors were cue type (2 levels: control, human figure), absolute value of initial perspective shift (4 levels: 0-45, 45-90, 90-135, 135-180), and pointing quadrant (4 levels: front, left, right, back). Task order was counterbalanced between subjects such that there were two groups who completed the task as follows: control-human figure, human figure-control Absolute angular error and response times were dependent variables.

### Materials & Apparatus

This study employed a computerized perspective taking task (SOT) similar to a previously used computerized Spatial Orientation Test (SOT; Friedman, Kohler, Gunalp, Boone, & Hegarty, 2019). This task was displayed on Dell 24-inch P24124 (60 Hz refresh rate) monitors with Nvidia GeForce GTX (660) graphics cards. The computerized task was displayed through E Prime (2.0, Schneider, Eschman, & Zuccolotto, 2012). As in earlier versions of this task, the display included an array of objects and an arrow circle in which participants reported their direction estimates. The array contained nine non-directional objects (do not have a clear front or back or facing direction) dispersed roughly in a circle. The arrow circle contained a vertical arrow indicating the standing position and facing direction/imagined heading with written object labels for each trial. On each trial, participants were asked to imagine standing at one object in the array, facing a second, and then to point to a third. The way participants "point" using this arrow circle is by clicking on the arrow circle, which caused a line to appear. Using the mouse, the line could then be selected and dragged around the arrow circle to indicate the participant's estimate. The "Enter" key was pressed for participants to submit their pointing estimates. In the control cue type condition, a trial might read, "Imagine you are standing at the bell facing the tree. Point to the drum." In the human figure cue type condition a trial might read, "Take the perspective of the person facing the tree. Point to the drum," (see Figure 4).

*Figure 4.*

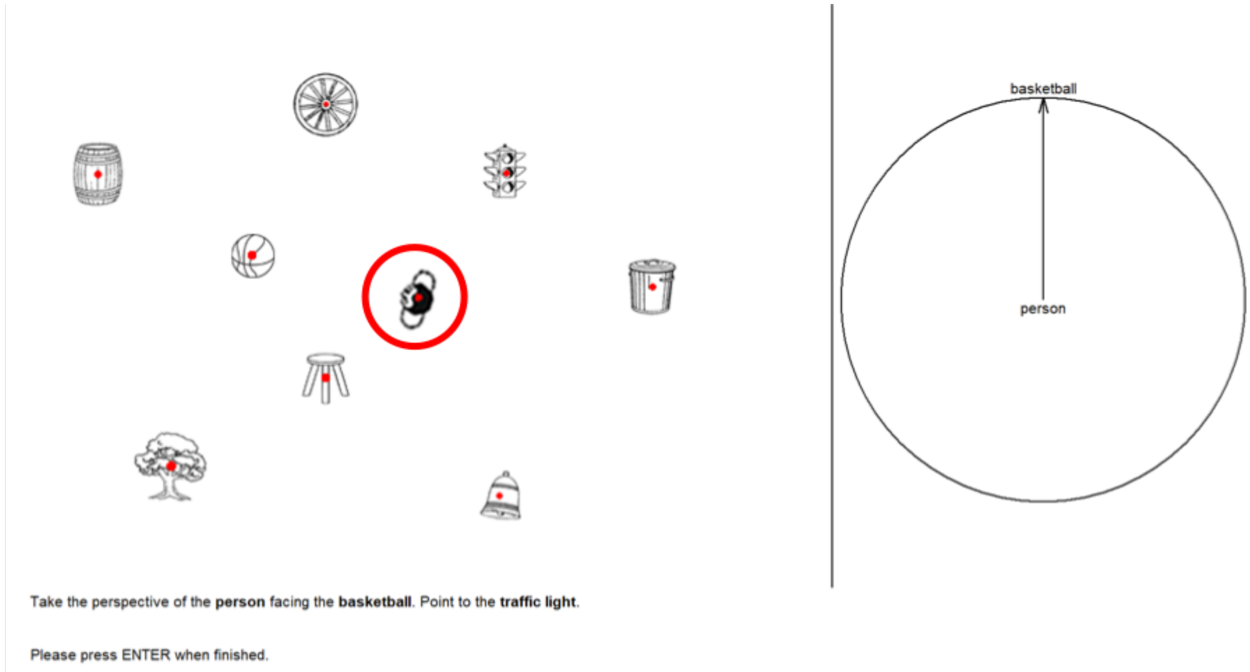


Figure 4. Sample SOT trial with the human figure (circled in red) cue type.

Participants completed 32 test trials. Both the magnitude of initial perspective shift and the quadrant in which the correct pointing response fell were systematically varied. Initial perspective shift was categorized into eight distinct bins with 45º increments (0-45, 45-90, 90-135, etc.). For each of these angle bins there were four trials, each with a final pointing direction falling into one of the four quadrants. Pointing quadrants were categorized as front, back, right, or left. The front quadrant encompassed 45 degrees clockwise or counterclockwise, and the right quadrant encompassed degrees 45-135, etc. No angle bin had final pointing quadrants repeated. For example, for the four trials that required an initial perspective shift within the range of 180-225º, the final pointing direction fell into each of the four quadrants once.

Participants also completed an online questionnaire using the Qualtrics survey platform. Questions included in the survey asked about mental strategy for solving each of the two versions of the perspective taking task and demographic information. A multiple-choice question listed four possible strategies (generated and categorized based on previous research; Kozhevnikov & Hegarty, 2001) and one text-entry option. Participants were asked to indicate which strategy most closely aligned with their own for solving the task, or if none of the options were representative could fill in their own strategy description in the text entry field. See Appendix A for complete strategy questions.

**Procedure**

Participants were run in groups of 1-3, and after giving informed consent began the first perspective-taking task (SOT) with one of the arrays (control or human figure). Participants were randomly assigned to a task order, with half of the participants completing the control version first and half completing the human figure version first. The experimenter read the instructions displayed on the computer aloud, one screen at a time. Participants were instructed to read the instructions on the screen along with the experimenter as the experimenter read aloud. After the instructions, participants completed one response sample item in which the computer mouse was used to match a response line to the correct answer displayed in the arrow circle. The experimenter ensured that each participant matched the correct answer shown and confirmed that each participant could satisfy themselves that the correct answer was logical. Participants then completed three practice trials with feedback, such that the correct answer was briefly shown in red next to their answer allowing for comparison between the submitted and correct answer. Participants then completed the 32 test trials.

After completing one version of the task, participants completed the second version. The instructions were again read aloud, and contained the exact same information as the previous version. As before, participants completed one response sample item, three practice trials with feedback, and 32 test trials. After completing both versions of the SOT, participants completed the online questionnaire and then were debriefed and released.

**Results**

The angular error and response time data were positively skewed and were thus natural log-transformed for subsequent analyses. However, raw error values are reported for ease of interpretation.

**Perspective Shift.**

*Angular Error*. A 2 (cue type: control, human figure) by 4 (absolute value of perspective shift: 0-45, 45-90, 90-135, 135-180) repeated measures ANOVA indicated a main effect of cue type $F(1, 56) = 8.79$, $p = .004$, $\eta_p^2 = .14$ such that, as predicted, participants had lower angular error in the human figure array ($M = 16.0$, $SE = 1.1$) than the control array ($M = 18.1$, $SE = 1.1$). There was also a main effect of perspective shift $F(3, 54) = 68.40$, $p < .001$, $\eta_p^2 = .79$. There was a significant positive linear trend, with error generally increasing as magnitude of perspective shift increased $F(1,56) = 87.92$, $p < .001$, $\eta_p^2 = .61$ as predicted. There was also a significant quadratic trend, $F(1,56) = 75.19$, $p < .001$, $\eta_p^2 = .57$ (see Figure 5). The interaction of cue type and perspective shift was not significant, $p = .97$. See Table 2 for all effects and effect sizes.

*Figure 5.*

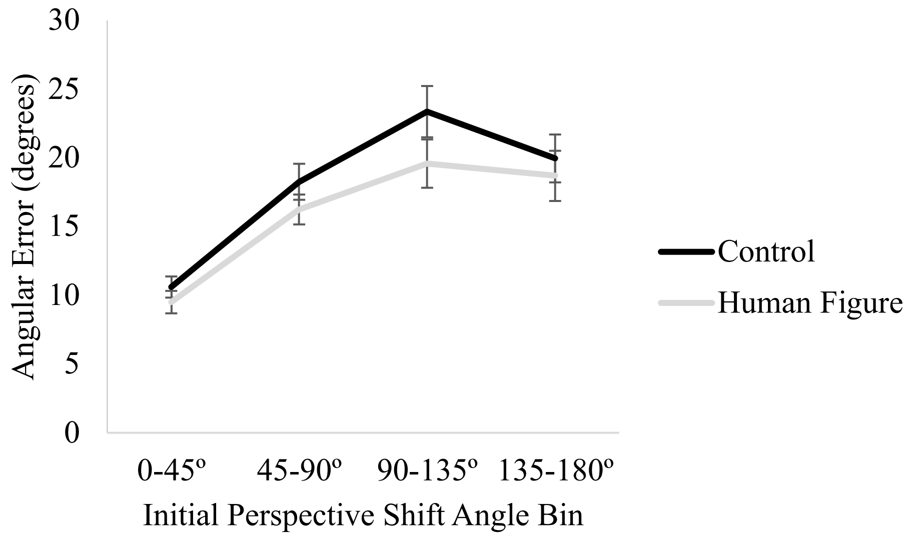


Figure 5. Results from Experiment 1 showing raw angular error as a function of magnitude of initial perspective shift and cue type, shown with standard error bars. Magnitude of initial perspective shift displayed here is the degree increment in both clockwise and counterclockwise direction. $N = 57$.

*Response Time.* A 2 (cue type: control, human figure) by 4 (absolute value of initial perspective shift: 0-45, 45-90, 90-135, 135-180) repeated measures ANOVA indicated a main effect of cue type $F(1, 56) = 13.95$, $p < .001$, $\eta_p^2 = .19$ such that as predicted, participants had faster response times in the human figure array ($M = 6.8$, $SE = .3$) than the control array ($M = 8.4$ $SE = .3$). There was also a main effect of perspective shift $F(3, 54) = 35.41$, $p < .001$, $\eta_p^2 = .66$ which conformed to a linear trend $F(1,56) = 81.61$, $p < .001$, $\eta_p^2 = .59$. (See Figure 6). Contrary to predictions, the interaction between cue type and perspective shift was not significant, $p = .79$ (see Table 2).

*Figure 6.*

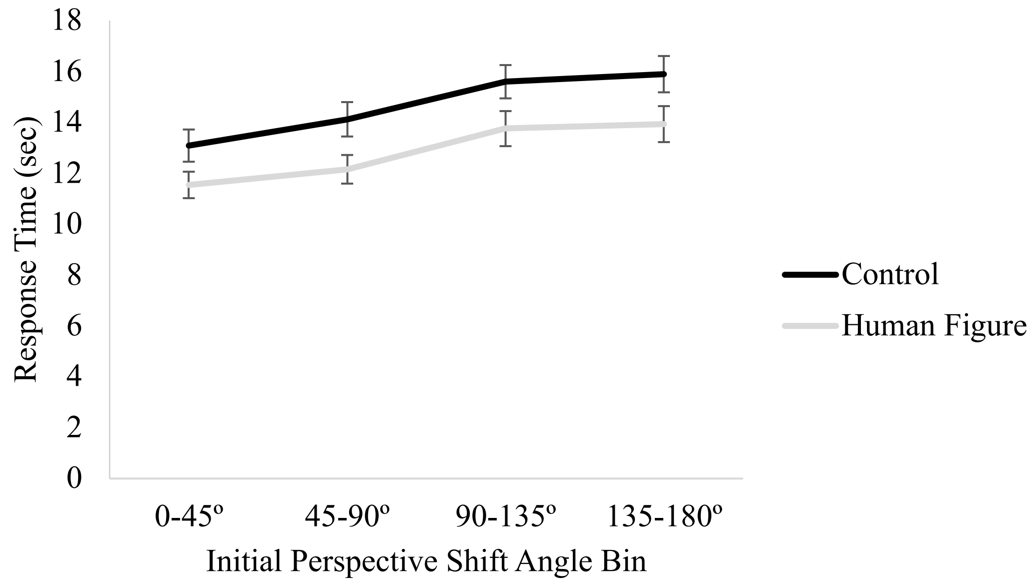


Figure 6. Results from Experiment 1 showing response time as a function of magnitude of initial perspective shift and cue type, shown with standard error bars. Magnitude of initial perspective shift displayed here is the degree increment in both clockwise and counterclockwise direction. *N* = 57.

**Pointing Quadrant.**

*Angular Error.* A 2 (cue type: control, human figure) by 4 (pointing quadrant: left, right, back, front) repeated measures ANOVA indicated a main effect of cue type $F(1, 56) = 7.60$, $p = .008$, $\eta_p^2 = .12$ such that, as predicted, participants were significantly more accurate in the human figure array ($M = 16.0$, $SE = 1.1$) than the control array ($M = 18.1$, $SE = 1.1$). There was also a main effect of pointing quadrant $F(3, 54) = 60.08$, $p < .001$, $\eta_p^2 = .77$. Post-hoc LSD pairwise comparisons revealed that participants were significantly more accurate pointing to the front ($M = 10.3$, $SE = .6$) quadrant than to any other quadrant, all *p*'s $< .001$. Pointing to the left ($M = 16.9$, $SE = 1.1$) was significantly more accurate than pointing right ($M = 20.7$, $SE = 1.7$), $p = .05$, but was not significantly different from pointing to the back ($M = 20.1$, $SE = 1.7$), $p = .78$. Pointing to the back was significantly more accurate than pointing to the right, $p$ = .04. There was a significant interaction between cue type and pointing quadrant, $F$ (3,54) = 3.60, $p$ = .019, $\eta_p^2$ = .17 (see Figure 7). A simple effects analysis indicated that for the control cue type, pointing to the left was significantly better than pointing to the back ($p$ = .007) and there was no significant difference between pointing left or right ($p$ = .178), however for the human figure cue type there were no significant differences in pointing to the back, left, and right ($p$'s > .08). This difference between the control and human figure cue types is thought to drive the significant interaction between cue type and pointing quadrant.

*Figure 7.*

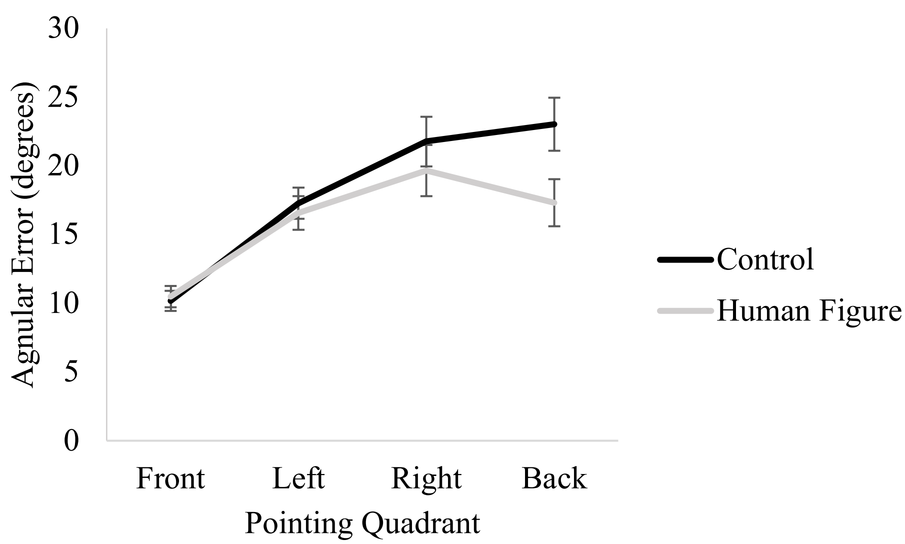


Figure 7. Results from Experiment 1 showing raw angular error as a function of pointing quadrant and cue type, shown with standard error bars. $N$ = 57.

*Response Time.* A 2 (cue type: control, human figure) by 4 (pointing quadrant: left, right, back, front) repeated measures ANOVA indicated a main effect of cue type $F$(1, 56) = 13.75, $p$ < .001, $\eta_p^2$ = .20 such that as predicted participants had faster response times in the human figure array ($M$ = 12.8, $SE$ = .6) than the control array ($M$ = 14.7, $SE$ = .6). There was also a main effect of pointing quadrant $F$(3, 54) = 38.00, $p$ < .001, $\eta_p^2$ = .68. Post-hoc

LSD pairwise comparisons revealed that pointing to the front ($M$ = 12.1, $SE$ = .5) was significantly faster than pointing to all other quadrants, $p$'s < .001. Pointing to the left ($M$ = 13.3, $SE$ = .5) was significantly faster than pointing to the back ($M$ = 14.9, $SE$ = .6), but was not significantly different from pointing to the right ($M$ = 14.7, $SE$ = .6). Contrary to predictions, there was no significant interaction of cue type and pointing quadrant, $p$ = .57 (see Figure 8).

*Figure 8.*

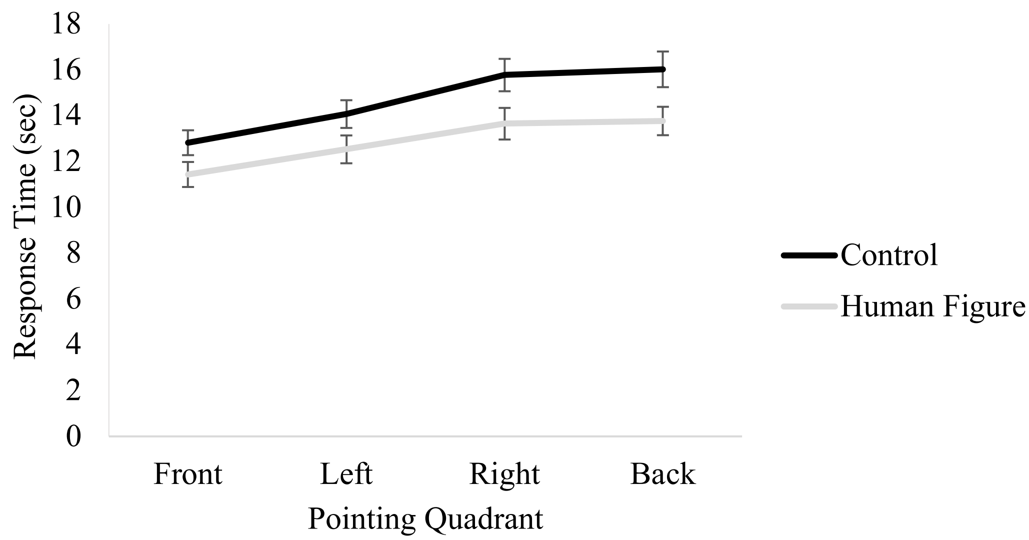


Figure 8. Results of Experiment 1 showing response time as a function of pointing quadrant and cue type, shown with standard error bars. $N$ = 57.

Table 2. Significance level (p-values) and effect sizes (partial eta-squared) for each effect in the Analyses of Variance (significant effect indicted in bold type).

| | Dependent Variable | |
|---|---|---|
| | Accuracy | Response Time |
| | p ($\eta_p^2$) | p ($\eta_p^2$) |
| **Perspective Shift (0°-45°, 45°-90°, 90°-135°,135°-180°) (Data Collapsed over Pointing Quadrant)** | | |
| Main Effects: | | |
| Perspective Shift | **.001 (.14)** | **.001 (662)** |
| Cue type (human vs. control) | **.001 (.79)** | **.001 (.20)** |
| Interactions: | | |
| Perspective shift*cue type | .97 (.005) | .79 (.02) |
| **Pointing Quadrant (Front, Back, Right, Left) (Data Collapsed over Perspective Shift)** | | |
| Main Effects: | | |
| Pointing quadrant | **.001 (.77)** | **.001 (.68)** |
| Cue type (human vs. control) | **.008 (.12)** | **.001 (.20)** |
| Interactions: | | |
| Pointing quadrant*cue type | **.019 (.17)** | .57 (.04) |

**Survey.** Following previous research (Gunalp et al., 2019), a majority of participants reported using mental simulation-based strategies rather than abstract strategies for both the control (abstract = 5, mental simulation = 53), and directional (abstract = 8, mental simulation = 48) cue types. Table 3 displays the number of participants who used mental simulation versus abstract strategies.

Table 3. Each cell shows the number of participants that reported using a particular strategy type as a function of cue type.

| Cue Type | Abstract | Mental Simulation |
|---|---|---|
| Control | 5 | 53 |
| Human Figure | 8 | 48 |

An independent samples t-test indicated that there was no significant difference in accuracy, $t(55) = -1.62$, $p = .87$, or response time, $t(55) = -1.17$ $p = .25$, between participants who used abstract versus mental simulation strategies for the control array. The same results were replicated with strategies for the human figure array; there were no significant differences in accuracy, $t(55) = .60$, $p = .55$, or response time, $t(55) = -.15$ $p = .89$. These results must be interpreted with caution, as the sample size here is likely too small to draw serious conclusions about performance of participants who use an abstract strategy for this type of task.

**Discussion**

The results suggest that, as predicted, the inclusion of the human figure in the array of objects reduced angular error in direction estimates and led to faster response times relative to the control array. The angular error data here replicate previous research that has used a human figure in the SOT task array (Tarampi et al., 2017; Gunalp et al., 2019). Response time data relative to perspective shift indicated that larger shifts did take longer to perform, which supports previous research suggesting that these imagined transformations are analogs of physical transformation (Hintzman, O'Dell, & Arndt, 1981; Rieser, 1989). With respect to pointing quadrant, the angular error data presented here partially replicate patterns shown in previous work (Kozhevnikov & Hegarty, 2001; Bryant & Tversky, 1999) in that pointing to the front was easier but pointing to the back was not easier than to the right or left. The accuracy data here thus suggest that pointing is not an analog process, because if that were the case then back should have been worse than left or right. However, response time data relative to pointing quadrant indicated that participants were faster when pointing to the left and right than when pointing to the back. This, in contrast, adds support to the idea of imagined translations being analogs of physical translations, in that pointing to the back quadrant did take significantly longer than pointing to the left or right. So, it appears that both the accuracy and response time data are telling conflicting stories regarding the nature of the pointing process, and thus conclusions about imagined pointing being an analog of physical pointing cannot be decisively made. The response time data are a novel addition to this body of work, adding support to the idea that the human figure speeds up perspective taking performance as measured by the SOT.

The significant interaction of pointing quadrant and cue type suggests that the human figure cue influences performance distinctly compared to a control array. This could be because it is easier to make judgments about front and back because these directions map to the front-back axis of the body, (e.g., Franklin & Tversky, 1990). Or, it could be that level 1 perspective taking can be leveraged when pointing to the front, as determining what is in one's line of sight is also determining what is in front of one's current position (e.g. Samson et al., 2010). Or, perhaps most intuitively, it makes sense that only when perspective taking is difficult would it be possible to see the positive effects of an additional cue (the human figure). If perspective taking is easy, as in the case of small imagined shifts or pointing to the front, performance will likely be at ceiling, and the addition of a cue might not have a significant positive impact on performance. In contrast, when the imagined shifts are larger and pointing is not to the front, performance will likely be much more variable across individuals, thus allowing an additional cue the opportunity to improve performance.

Apart from this one interaction, contrary to the predictions discussed earlier, a majority of the interactions between cue type and either perspective shift or pointing quadrant, for both accuracy and response time data, were not significant. If we consider three steps of the perspective taking process: 1) imagining standing in the array, 2) imagining a new facing direction, and 3) making a pointing judgment, these results suggest that the human figure is influencing step 1 of the process. This makes the initial imagination of oneself in the array easier and faster. Both the human figure and control conditions showed parallel patterns across perspective shift magnitudes and the different pointing quadrants, which fails to provide evidence for the hypothesis that a human figure would provide a benefit with larger shifts and more difficult pointing quadrants. Additionally, given that an imagined position is unlikely to be heading-free (it probably does include some representation of heading), the effect of the human figure on step 2 of the process cannot be ruled out. These results primarily suggest that the human figure does impact steps 1 (and probably 2) of the perspective taking process, but does not significantly impact step 3.

An overwhelming majority of participants (across cue types) in the present experiment reported using strategies based on mental simulation. It is possible that the human figure provides some other sort of facilitation in this task outside of factors that I have examined here, such as mental mapping/structuring of the array or clustering of objects (e.g. Gunzelmann & Anderson, 2006). It is also possible that the human figure provides an initial boost in this task, allowing participants to more quickly get used to the demands of/get in the mindset of perspective taking. The present study supports the latter account, with patterns of performance largely parallel across the control and human figure cue types.

However, one cannot be entirely sure of the mechanisms behind the human figure that provided this initial boost in performance. As discussed in earlier work (Gunalp et al., 2019), the human figure used here provides a directional cue by facing the correct direction on each trial, and by nature of being human is a component of the array that is easy to embody. The control array on the other hand contains objects that may take more time to imagine embodying. To further examine these points, the following study compares a human figure to an arrow, which serves as a directional cue but does not facilitate mental simulation in the same way as a human figure.

### *B. Comparison of Social and Directional Cues*

To further examine the influence of different cue types on perspective taking performance, this experiment compares a human figure array to both a control array and an arrow array. In contrast with a human figure, an arrow provides a directional cue by facing the correct direction on each trial, and provides a consistent station point, but may not facilitate mental simulation in the way a human figure does because it is inanimate (or non-agentive).

Gunalp et al. (2019) compared the effects of both an arrow and a human figure on a desktop Virtual Reality (VR) version of the SOT. They found that a human figure improved performance compared to an arrow, which supports the idea that the ease of simulating the new orientation of the cue is a crucial component of perspective taking. This result aligns with theories of grounded cognition (e.g. Kessler & Rutherford, 2010). If the facilitation of mental simulation that the human figure affords is crucial to the perspective taking processes observed in the SOT, previous findings (e.g. Gunalp et al., 2019) should be replicated and performance should be better with the human figure array than with the arrow array.

However, Gunalp et al. used a more naturalistic, three dimensional virtual environment than the original SOT, viewed through a head-mounted display. It is possible that the human figure may have improved performance relative to an arrow because a human figure is a more natural cue in this environment than an arrow, and therefore in this case there is more of a match between display and cue naturalism. The present experiment compares the efficacy of a human figure versus an arrow with a more map-like, abstract SOT array in order to examine whether the advantage of a human figure over an arrow generalizes to a map-like display. If directionality alone is sufficient to support perspective taking processes in a map-like display, then performance should be equal in the arrow and human figure arrays in the present study. Further, based on previous research, performance with the arrow array should be significantly better than performance with the control array.

I predicted that performance with the human figure would be more accurate, and faster, than with the arrow (agency hypothesis), based on previous research (Gunalp et al., 2019), but that this effect might be influenced by degree of display naturalism, as described above. If a directional cue is sufficient to improve performance in a map-like display (directionality hypothesis), then performance should be improved in both the person and arrow conditions relative to control.

1. Experiment 2a

## Method

### Participants

Eighty participants from the University of California Santa Barbara participated in this study for course credit. Five participants (all women) were excluded due to error above chance levels. The remaining seventy-five participants (35 women, 40 men) are included in subsequent analyses. Participants were ages 17-22 ($M$ = 18.5 $SD$ = .9). A power analysis for ANOVA was conducted using G*Power with an alpha level of .05 and power of .80, the minimum sample size of 72 would be needed (18 per group). The present sample size exceeds this minimum.

### Design

Similar to Experiment 1, this experiment employed a mixed factor design with array type (2 levels: control vs. directional cue), absolute value of initial perspective shift (4 levels: 0-45°, 45-90°, 90-135°, 135-180°) and pointing quadrant (4 levels: left, right, back, front) manipulated within subjects. Type of directional cue (cue type: arrow vs. human figure) was manipulated between subjects. Task order was counterbalanced between subjects such that there were 4 groups who completed the task as follows: (control-human figure, human figure-control, control-arrow, arrow-control). Absolute angular error and response time were measured as dependent variables.

**Materials & Apparatus**

This experiment used the same apparatus as Experiment 1. The same materials were used as in Experiment 1, with the addition of an arrow array (see Figure 9). As in the human figure array, the arrow changes location and replaces an object on each trial. The task instructions were improved from Experiment 1, with the first screen of instructions more clearly separating descriptions of the task and explanation of how to respond using the computer mouse (see Appendix B for complete instructions). Aside from this modification, all other instructions remained the same. Trials for the arrow array read, “Imagine you are standing at the arrow, facing X, point to Y.”

*Figure 9.*

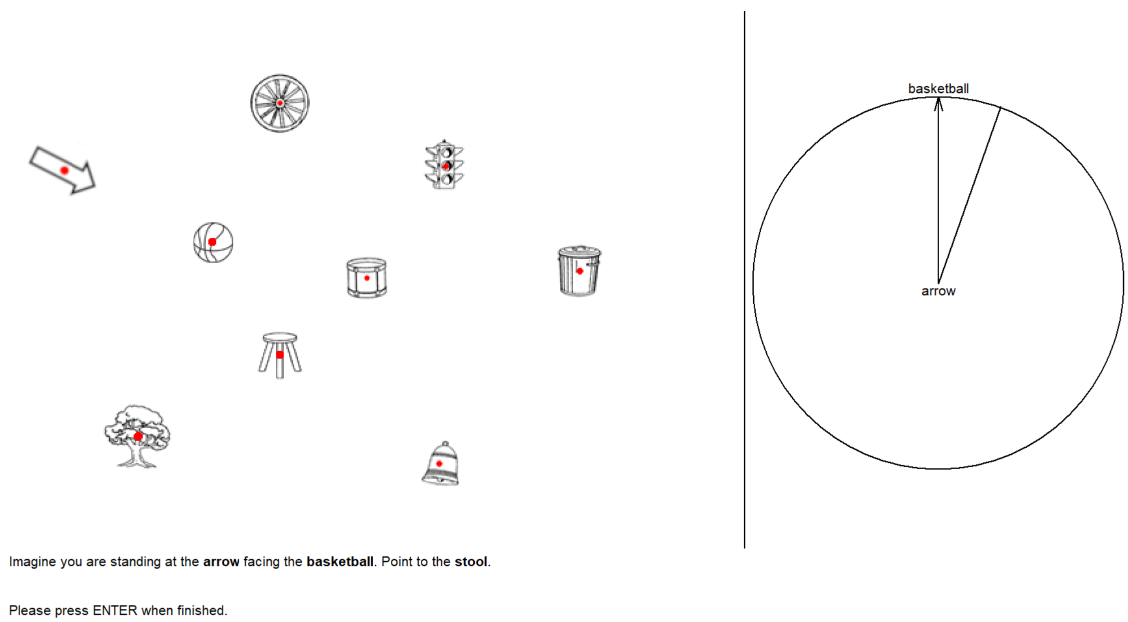


Figure 9. Sample SOT trial with the arrow cue type.

Qualtrics was used again for the questionnaire distributed at the end of the experimental task.

**Procedure**

Participants were run in groups of up to 5, each working independently on their own computer. The procedure was identical to that of Experiment 1.

**Results**

Accuracy data for this experiment were positively skewed, and therefore were natural log-transformed for subsequent analyses. Response time data were normally distributed, and therefore were not transformed. Though the control condition was identical regardless of what directional array participants were given (either arrow or human figure), the control task was completed between subjects. That is, one participant did not complete the control, arrow, and human figure conditions.

**Perspective Shift.**

*Angular Error*. A 2 (array type: control, directional) by 4 (perspective shift absolute value: 0-45°, 45-90°, 90-135°, 135-180°) by 2 (cue type: arrow, human figure) mixed factors repeated-measures ANOVA with post-hoc (LSD) pair-wise comparisons, corrected for multiple comparisons, revealed a significant main effect of perspective shift $F(3, 71) = 46.30$, $p < .001$, $\eta_p^2 = .39$, which conformed to a linear trend $F(1,71) = 81.07$, $p < .001$, $\eta_p^2 = .53$ (see Figure 10). Angular error increased with perspective shift as predicted. No other effects or interactions were significant, $p$'s > .156 (see Table 4).

*Figure 10.*

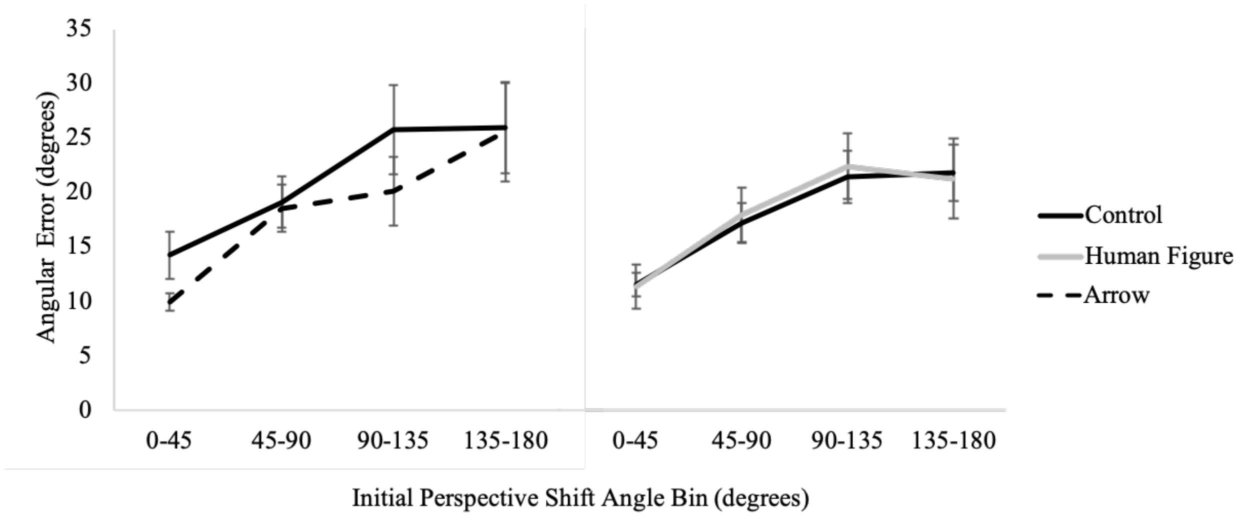


Figure 10. Results from Experiment 2a showing raw angular error as a function of cue type and initial perspective shift angle bin for control vs. arrow and control vs. human figure.

*Response Time.* A 2 (array type: control, directional) by 4 (perspective shift: 0-45°, 45-90°, 90-135°, 135-180°) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA indicated a main effect of array type $F(1, 73) = 14.05$, $p < .001$, $\eta_p^2 = .16$, with post-hoc pairwise comparisons indicating that participants were significantly faster with the directional array ($M = 14.1$, $SE = .4$) than with the control array ($M = 15.7$, $SE = .5$). There was also a significant main effect of perspective shift $F(3, 71) = 36.64$, $p < .001$, $\eta_p^2 = .61$, which conformed to a linear trend $F(1,71) = 110.05$, $p < .001$, $\eta_p^2 = .61$, (see Figure 11). No other interactions were significant, $p$'s > .143 (see Table 4).

*Figure 11.*

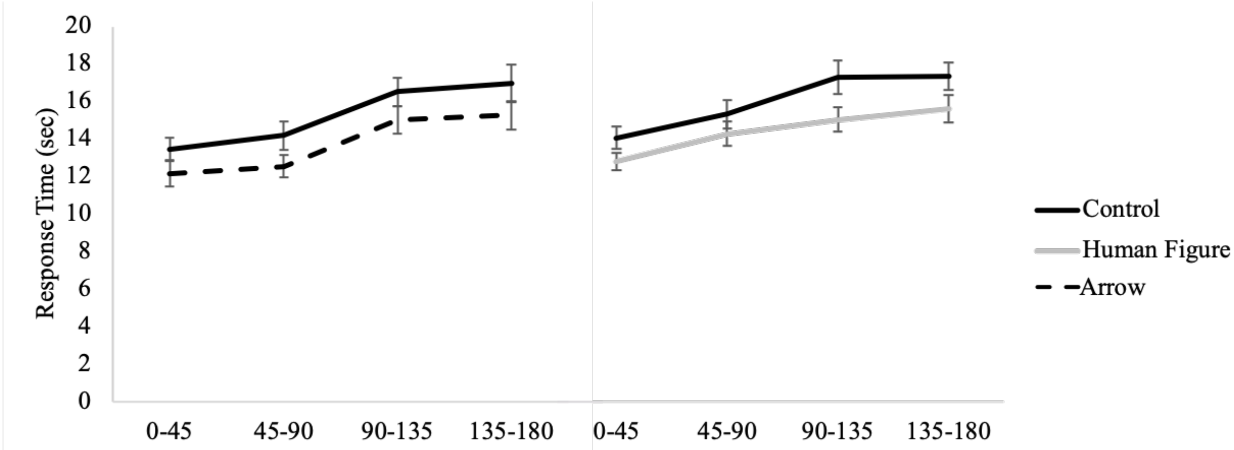


Figure 11. Results from Experiment 2a showing response time as a function of cue type and magnitude of initial perspective shift for control vs. arrow and for control vs. human figure.

**Pointing Quadrant.**

*Angular Error.* A 2 (array type: control, directional) by 4 (pointing quadrant: front, left, right, back) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA revealed a significant main effect of pointing quadrant $F(3, 71) = 61.58$, $p < .001$, $\eta_p^2 = .72$. Post-hoc pairwise comparisons indicated that, as predicted, participants were significantly more accurate for pointing to the front quadrant ($M = 2.3$, $SE = .1$) than the left ($M = 2.9$, $SE = .1$), right ($M = 2.8$, $SE = .1$), or back ($M = 2.8$, $SE = .1$) quadrants (see Figure 12). No other effects or interactions were significant, $p$'s > .162 (see Table 4).

*Figure 12.*

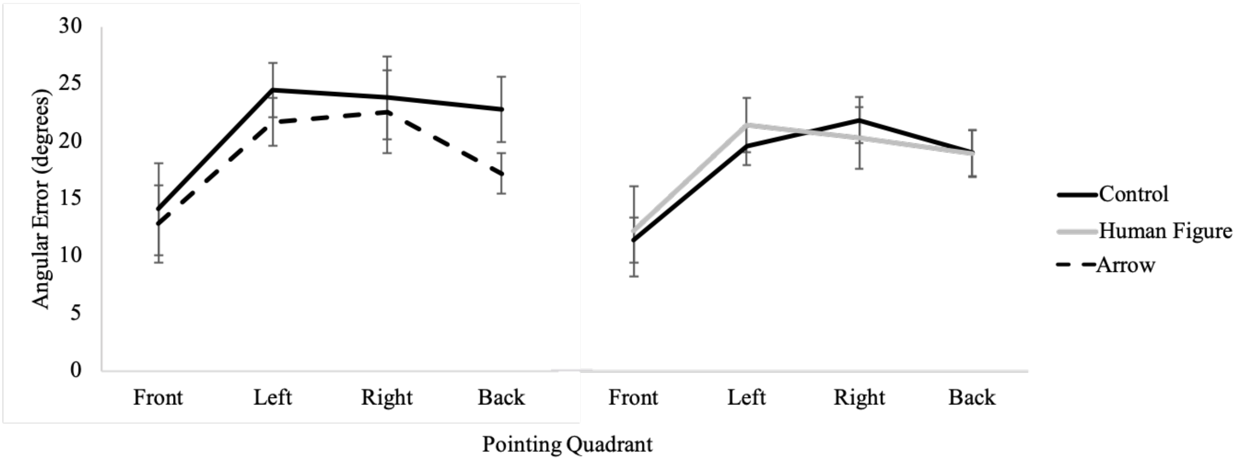


Figure 12. Results from Experiment 2a showing raw angular error as a function of cue type and pointing quadrant for control vs. arrow and for control vs. human figure.

*Response Time*. A 2 (array type: control, directional) by 4 (pointing quadrant: front, left, right, back) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA revealed a significant main effect of array type $F(1, 73)$ =14.05, $p < .001$, $\eta_p^2 = .16$ such that, as predicted, participants were significantly faster with the directional array ($M$ = 14.10, $SE$ = .40) than with the control array ($M$ = 15.65, $SE$ = .49). There was also a significant main effect of pointing quadrant $F(3, 71) = 37.20$, $p < .001$, $\eta_p^2 = .61$, with post-hoc pairwise comparisons indicating that participants were significantly faster for pointing to the front quadrant ($M$ = 13.17, $SE$ = .39) than the left ($M$ = 14.90, $SE$ = .44), right ($M$ = 15.52, $SE$ = .47), and back ($M$ = 15.90, $SE$ = .43) quadrants (see Figure 13). No other effects or interactions were significant, $p$'s >.183 (see Table 4).

*Figure 13.*

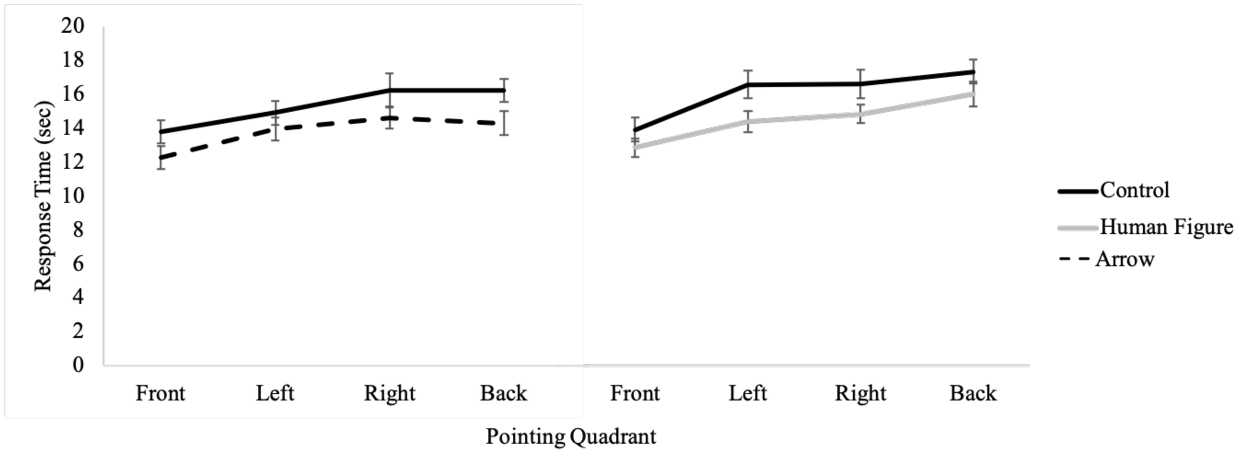


Figure 13. Results from Experiment 2a showing response time as a function of cue type and pointing quadrant for control vs. arrow and for control vs. human figure.

Table 4. Significance level (p-values) and effect sizes (partial eta-squared) for each effect in the Analyses of Variance (significant effect indicted in bold type)

| | Dependent Variable | |
|---|---|---|
| | Accuracy | Response Time |
| | p ($\eta_p^2$) | p ($\eta_p^2$) |
| **Perspective Shift (0°-45°, 45°-90°, 90°-135°,135°-180°) (Data Collapsed over Pointing Quadrant)** | | |
| Main Effects: | | |
| Perspective Shift | **.001 (.39)** | **.001 (.42)** |
| Presence of directional cue (directional vs. control) | .23 (.02) | **.001 (.16)** |
| Type of directional cue (human vs. arrow) | .68 (.002) | .38 (.01) |
| Interactions: | | |
| Type of directional cue*presence of directional cue | .58 (.004) | .95 (.00) |
| Perspective shift*type of directional cue | .16 (.02) | .23 (.02) |
| Perspective shift * presence of directional cue | .47 (.01) | .62 (.01) |
| Perspective shift*directional cue * type of directional cue | .72 (.01) | .61 (.01) |
| **Pointing Quadrant (Front, Back, Right, Left) (Data Collapsed over Perspective Shift)** | | |
| Main Effects: | | |
| Pointing quadrant | **.001 (.72)** | **.001 (.33)** |
| Presence of directional cue (directional vs. control) | .42 (.01) | **.001 (.16)** |
| Type of directional cue (human vs. arrow) | .28 (.02) | .38 (.01) |
| Interactions: | | |
| Type of directional cue*presence of directional cue | .29 (.02) | .95 (.00) |
| Pointing quadrant*directional cue | .09 (.03) | .14 (.03) |
| Pointing quadrant *type of directional cue | .87 (.00) | .87 (.00) |
| Pointing quadrant*directional cue * type of directional cue | 82 (.00) | .30 (.02) |

**Survey.** As in Experiment 1, a majority of participants in all conditions reported using a mental simulation-based strategy rather than an abstract strategy for both the control (abstract = 3, mental simulation = 77), and arrow (abstract = 5, mental simulation = 37), and human figure (abstract = 0, mental simulation = 38) array types (see Table 5). Interestingly, for the directional cues conditions, all participants who reported using an abstract strategy completed the arrow SOT. No participants in the human figure SOT reported using an abstract strategy in the directional cue condition (as opposed to the control) of the SOT. An independent samples t-test indicated that there was no significant difference between participants who reported using mental simulation strategies compared to those who reported using abstract strategies in the control condition, either in accuracy $t(73) = .75$, $p = .45$, or response time $t(73) = 1.25$, $p = .22$. Similarly, for the two directional cue conditions (collapsed over arrow and human figure), there was no significant difference between participants who reported using mental simulation strategies compared to those who reported using abstract strategies in the control condition, either in accuracy $t(73) = .10$, $p = .92$, or response time $t(73) = .57$, $p = .57$.

Table 5. Each cell shows the number of participants that reported using a particular strategy type as a function of cue type.

| Cue Type | Abstract | Mental Simulation |
|---|---|---|
| Control | 3 | 77 |
| Arrow | 5 | 37 |
| Human Figure | 0 | 38 |

**Discussion**

Results from this experiment suggest that a directional cue alone is sufficient to improve speed of response on the SOT perspective taking task. However, it is important to note that the instructions on each trial of the SOT differed between cue-types which was an accidental oversight on the part of the experimenter when devising the task instructions. For the human figure cue the trials read, “Take the perspective of the person…” while for the arrow cue the trials read, “Imagine you are standing at the arrow…”. The more active wording of “Take the perspective…” was used for the human figure to strengthen the chance that the human figure would provide a boost in perspective taking performance on this task. Further, because the arrow is an abstract object, it seemed more naturalistic to ask that participants imagine standing at the arrow rather than to take its perspective. In addition, previous work with arrows in the SOT array (Gunalp, et al., 2019) that used the wording, "Take the perspective of the arrow…" in one experiment and "Imagine you are standing at the arrow…" in another (tested with a between-subjects design and subsequent repeated measures ANOVAs) found that there were no significant differences between these two arrow conditions (see Gunalp et al., 2019 for relevant analyses). This suggests that these changes in wording do not significantly affect performance on this task.

Despite these justifications, this difference in wording between trials for different cue types in Experiment 2a was a confound. In order to address this confound, another experiment (Experiment 2b) was conducted that uses the same wording, "Imagine you are standing at the X…" for a human figure array, an arrow array, and a control array.

2. Experiment 2b

## Method

### Participants

Eighty-four participants from the University of California Santa Barbara participated in this study for course credit. Two participants (one woman, one man) were excluded, one due to error above chance levels, and one for missing data. The remaining 82 participants (51 women, 31 men) are included in subsequent analyses. Participants were ages 18-24 ($M$ = 19.25, $SD$ = 1.28).

### Design

The present experiment followed the same design as Experiment 2a. This experiment employed a mixed factor design with array type (2 levels: control vs. directional cue), absolute value of initial perspective shift (4 levels: 0-45°, 45-90°, 90-135°, 135-180°) and pointing quadrant (4 levels: left, right, back, front) manipulated within subjects. Type of directional cue (cue type: arrow vs. human figure) was manipulated between subjects. Task order was counterbalanced between subjects such that here were 4 groups who completed the task as follows: (control-human figure, human figure-control, control-arrow, arrow-control). Absolute angular error and response time were measured as dependent variables.

**Materials & Apparatus**

The materials used here were identical to those of Experiment 2a, apart from the instructions for the human figure array. In this experiment, the instructions for the human figure array type read, “Imagine you are standing at the person, facing the X, point to the Y,” rather than, “Take the perspective of the person, facing…”

**Procedure**

The procedure for this experiment was identical to that of Experiments 1 and 2a.

**Results**

The same transformations were applied to these data as in Experiment 2a; accuracy data were non-normally distributed, so subsequent analyses were conducted on log-transformed data. Response time data were normally distributed, and raw data were analyzed.

**Perspective Shift**

*Angular Error*. A 2 (array type: control, directional) by 4 (perspective shift absolute value: 0-45, 45-90, 90-135, 135-180) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA completed between participants revealed a significant main effect of array type, $F$ (1,80) = 16.49, $p < .001$, $\eta_p^2 = .17$, such that participants were significantly more accurate in the directional conditions ($M$ = 2.1, $SE$ = .0) than the control condition ($M$ = 2.3, $SE$ = .1). There was also a significant main effect of perspective shift, $F$ (3,78) = 47.32, $p < .001$, $\eta_p^2 = .65$, which conformed to a linear trend $F$ (1,80) = 51.18, $p <$ .001, $\eta_p^2 = .39$, (see Figure 14). All other effects and interactions were not significant, $p$’s >

.13. See Table 6 for significance and effect sizes for all analyses reported here.

*Figure 14*.

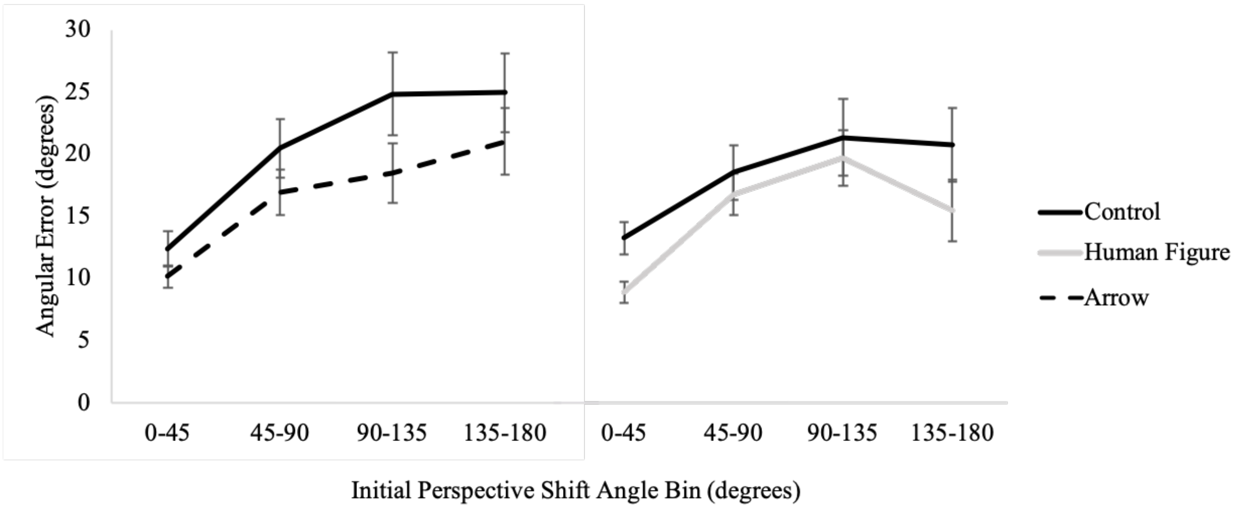


Figure 14. Results from Experiment 2b showing accuracy as a function of cue type and perspective shift for control vs. arrow and for control vs. human figure.

*Response Time.* A 2 (array type: control, directional) by 4 (perspective shift absolute value: 0-45, 45-90, 90-135, 135-180) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA revealed a main effect of array type $F(1, 80) = 18.97$, $p < .001$, $\eta_p^2 = .19$ such that participants were significantly faster in the directional conditions ($M$ = 14.9, $SE$ = .6) than in the control condition ($M$ = 17.4, $SE$ = .6). There was also a significant main effect of perspective shift $F(3, 78) = 36.64$, $p < .001$, $\eta_p^2 = .60$, which conformed to a linear trend $F(1,80) = 116.41$, $p < .001$, $\eta_p^2 = .59$ (See Figure 15). All other effects and interactions were not significant, $p$'s > .16 (see Table 6).

*Figure 15*.

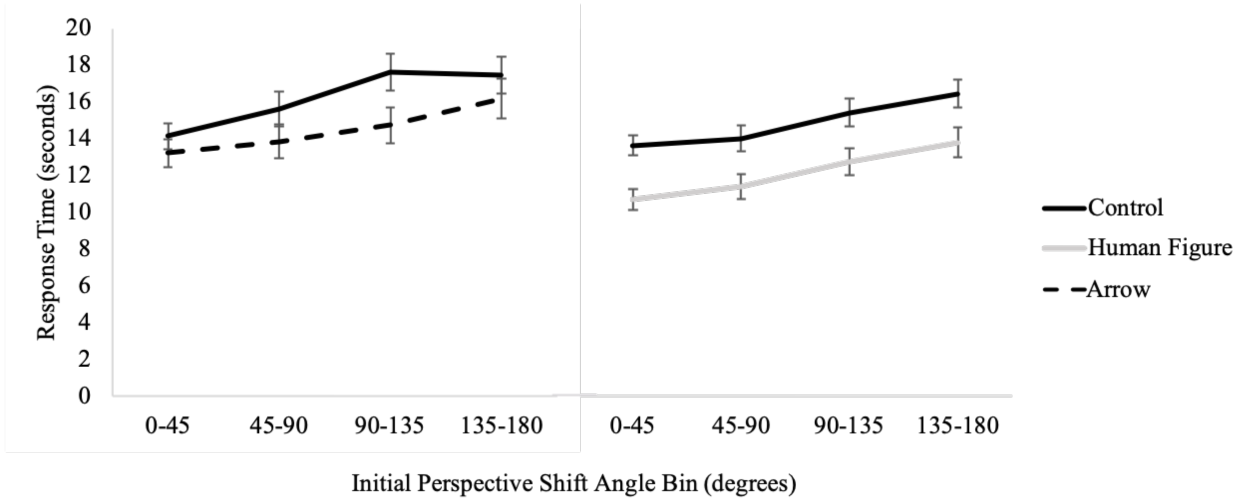


Figure 15. Results from Experiment 2b showing response time as a function of cue type and perspective shift for control vs. arrow and for control vs. human figure.

**Pointing Quadrant**

*Angular Error.* A 2 (array type: control, directional) by 4 (pointing quadrant: front, left, right, back) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA revealed a significant main effect of array type $F(1, 80) = 30.44$, $p < .001$, $\eta_p^2 = .28$, such that participants were significantly more accurate in the directional conditions ($M = 2.13$, $SE = .04$) than the control condition ($M = 2.31$, $SE = .05$). This ANOVA also revealed a significant main effect of pointing quadrant $F(3, 78) = 44.67$, $p < .001$, $\eta_p^2 = .63$, such that participants were significantly more accurate for pointing to the front quadrant ($M = 1.87$, $SE = .05$) than the left ($M = 2.30$, $SE = .04$), right ($M = 2.38$, $SE = .06$), or back ($M = 2.33$, $SE = .06$) quadrants (See Figure 16). There was a significant interaction of array type and pointing quadrant, $F(3, 78) = 4.16$, $p = .009$, $\eta_p^2 = .14$, such that the control array type conforms to a linear trend (as a function of pointing quadrant) whereas the directional array types follows a quadratic trend. There was also a marginally significant three-way interaction between array type, pointing quadrant, and directional cue type, $F(3, 78) = 2.54$,

$p$ = .06, $\eta_p^2$ = .09.Post-hoc simple effects analyses indicated that for the human figure and arrow cue types, pointing to the left, right, and back were not significantly different ($p$'s > .22), but for the control cue type pointing to the left was significantly better than pointing to the right ($p$ = .032). Additionally, for the human figure cue type pointing to the right was significantly better than pointing to the back ($p$ = .026), but for the arrow cue type pointing to the right and back were not significantly different ($p$ = .32). It is believed that these differences are driving the marginal significance of the three-way interaction between cue type, array type, and pointing quadrant. All other effects and interactions were not significant, $p$'s > .58 (see Table 6).

*Figure 16.*

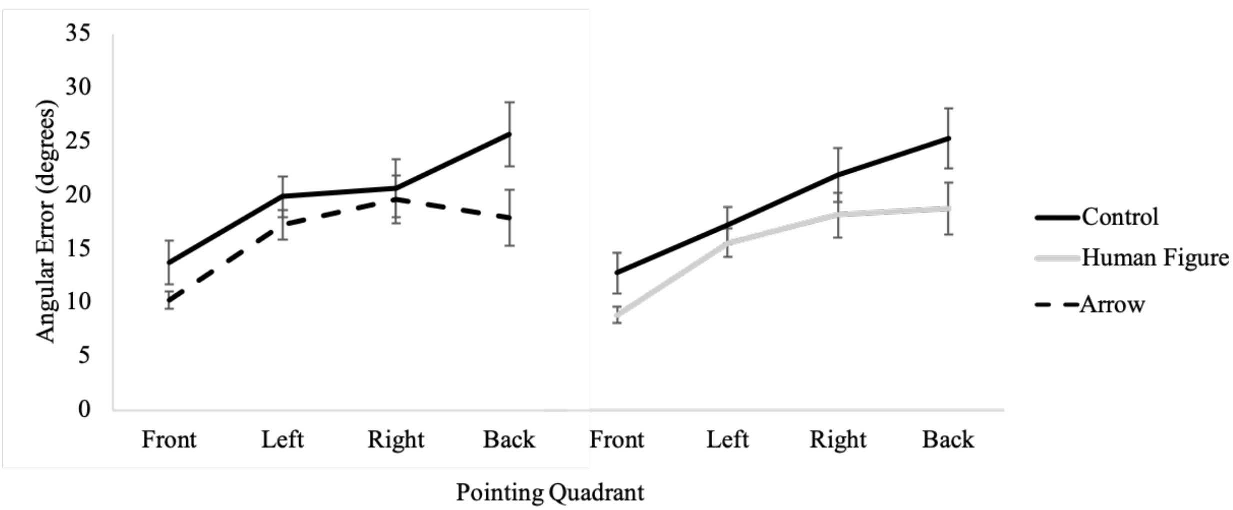


Figure 16. Results from Experiment 2b showing accuracy as a function of cue type and pointing quadrant for control vs. arrow and for control vs. human figure.

*Response Time.* A 2 (array type: control, directional) by 4 (pointing quadrant: front, left, right, back) by 2 (cue type: arrow, human figure) mixed factors repeated measures ANOVA revealed a significant main effect of array type $F(1, 80)$ =31.22, $p$ < .001, $\eta_p^2$ = .28, such that participants were significantly faster in the directional conditions ($M$ = 14.85, *SE* = .59) than the control condition (*M* = 17.41, *SE* = .57). There was also a significant main effect of pointing quadrant, $F(3, 78) = 39.31$, $p < .001$, $\eta_p^2 = .60$, such that participants were significantly faster for pointing to the front quadrant (*M* = 14.36, *SE* = .46) than the left (*M* = 15.93, *SE* = .55), right (*M* = 16.75, *SE* = .58), or back (*M* = 17.47, *SE* = .63) quadrants (See Figure 17). There was also a marginally significant interaction between array type and pointing quadrant, $F(3, 78) = 2.59$, $p = .059$, $\eta_p^2 = .09$., with somewhat flatter slopes as a function of pointing quadrant for the directional conditions compared to the control array type. All other effects and interactions were not significant, *p*'s > .09 (see Table 6).

*Figure 17.*

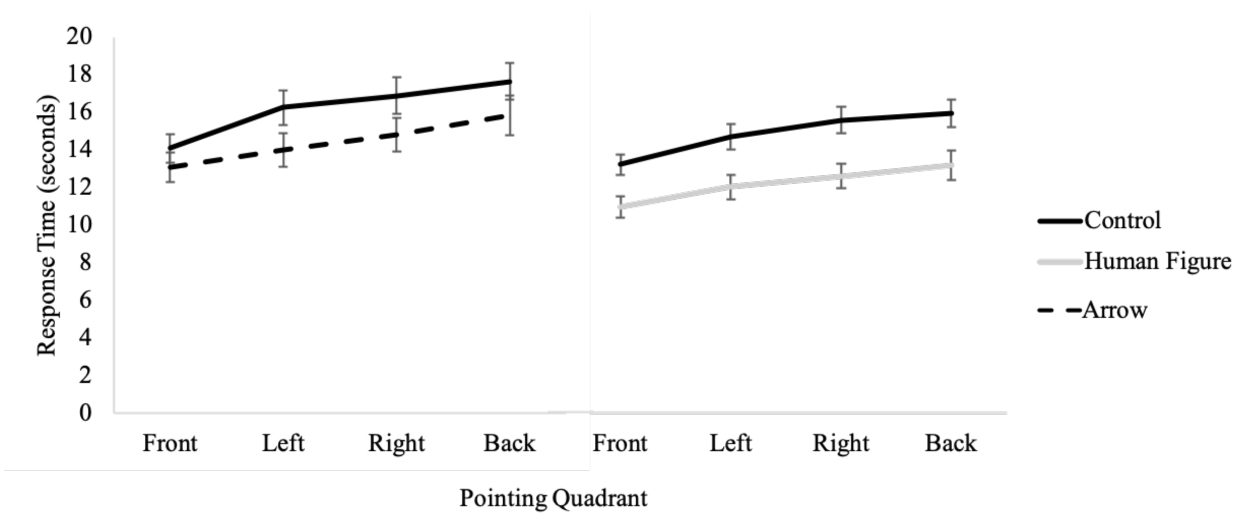


Figure 17. Results from Experiment 2b showing response time as a function of cue type and pointing quadrant for control vs. arrow and for control vs. human figure.

Table 6. Significance level (p-values) and effect sizes (partial eta-squared) for each effect in the Analyses of Variance (significant effect indicted in bold type). An asterisk (*) indicates where results diverge from Experiment 2a.

| | Dependent Variable | |
|---|---|---|
| | Accuracy | Response Time |
| | p ($\eta_p^2$) | p ($\eta_p^2$) |
| **Perspective Shift (0°-45°, 45°-90°, 90°-135°,135°-180°) (Data Collapsed over Pointing Quadrant)** | | |
| Main Effects: | | |
| Perspective Shift | **.001 (.64)** | **.001 (.60)** |
| Presence of directional cue (directional vs. control) | **.001 (17)*** | **.001 (.19)** |
| Type of directional cue (human vs. arrow) | .35 (.01) | .13 (.03) |
| Interactions: | | |
| Type of directional cue*presence of directional cue | .13 (.03) | .16 (.03) |
| Perspective shift*type of directional cue | .86 (.01) | .63 (.02) |
| Perspective shift * presence of directional cue | .35 (.04) | .49 (.03) |
| Perspective shift*directional cue * type of directional cue | .57 (.03) | .20 (.06) |
| **Pointing Quadrant (Front, Back, Right, Left) (Data Collapsed over Perspective Shift)** | | |
| Main Effects: | | |
| Pointing quadrant | **.001 (.63)** | **.001 (.60)** |
| Presence of directional cue (directional vs. control) | **.001 (.28)*** | **.001 (.28)** |
| Type of directional cue (human vs. arrow) | .78 (.001) | .14 (.03) |
| Interactions: | | |
| Type of directional cue*presence of directional cue | .73 (.00) | .09 (.04) |
| Pointing quadrant*directional cue | .58 (.03) | .95 (.00) |
| Pointing quadrant *type of directional cue | .01 (.14) | .06 (.09) |
| Pointing quadrant*directional cue * type of directional cue | .06 (.09) | .90 (.01) |

**Survey.** All findings from the survey data of Experiment 2a were replicated in the present experiment. A majority of participants in all conditions reported using a mental simulation-based strategy rather than an abstract strategy for both the control (abstract = 10, mental simulation = 72), and arrow (abstract = 5, mental simulation = 33), and human figure (abstract = 4, mental simulation = 40) array types (see Table 7). An independent samples t-test indicated that there was no significant difference between participants who reported using mental simulation strategies compared to those who reported using abstract strategies in the control condition, either in accuracy $t(80) = .83$, $p = .41$, or response time $t(80) = 1.49$, $p = .14$. Similarly, for the two directional cue conditions (collapsed over arrow and human figure), there was no significant difference between participants who reported using mental simulation strategies compared to those who reported using abstract strategies in the control condition, either in accuracy $t(80) = -.23$, $p = .82$, or response time $t(80) = 1.35$, $p = .18$.

Table 7. Each cell shows the number of participants that reported using a particular strategy type as a function of cue type.

| Cue Type | Abstract | Mental Simulation |
|---|---|---|
| Control | 10 | 72 |
| Arrow | 5 | 33 |
| Human Figure | 4 | 40 |

**Discussion**

All results from Experiment 2a were replicated here, indicating that the difference in instructions between the arrow and human figure conditions from Experiment 2a did not significantly impact performance on this task. Additional main effects of condition (control vs. directional) were found in the accuracy data from the present experiment, which were not found in Experiment 2a, indicating that participants in this experiment were significantly more accurate in the directional conditions than the control condition. Thus the directional conditions here were even more beneficial when the wording was matched in the arrow and human figure conditions. Fewer participants in this experiment were excluded from analyses due to error above chance levels, and accuracy in this experiment was higher than Experiment 2a (see differences in pointing accuracy by pointing quadrant comparing Figures 10 vs. 14, and 12 vs. 16). These factors suggest that the participants in this experiment had better perspective taking ability than Experiment 2a, and seem to have been able to take advantage of the directional cues even more than the participants in Experiment 2a.

It is also interesting to note that for both experiments 2a and 2b, the accuracy data (error scores) for the control conditions completed with the human figure are generally lower than the control conditions completed with the arrow. Given that task order (directional vs. control) was counterbalanced across participants, interpretation of the significance of these differences should be made with caution. However it is an interesting difference, which might indicate that for both experiments the participants who saw the human figure cue type were simply more able perspective takers in general. These differences in perspective taking ability should be examined with larger numbers of participants on this task to allow for valid statistical comparison. Indeed, in subsequent experiments of this dissertation, individual differences in perspective taking are considered in greater detail.

In both Experiments 2a and 2b, as predicted, a directional cue facilitated performance, but it did not matter whether this directional cue was an arrow or a human figure. The arrow and human figure both provide a directional cue, compared to all other objects in the display, which were chosen to have no directionality. It should also be noted that both the arrow and the human figure provide the same station points (and directional cues), which participants could locate without difficulty, thus acting as an “anchor” on each trial. The arrow and the human figure moved locations within the array from trial to trial, so there was still some updating required in these conditions. However, participants could always imagine standing at the arrow or person, and assume the direction of that cue, wherever they appeared in the array. In contrast, in the control condition, participants were required to locate a different object on each trial and imagine standing at that object, and locate another object to find the direction to be imagined.

The main effect – an improvement of the directional array types (both the arrow and the human figure) relative to the control found in both Experiments 2a and 2b– provides evidence in support of an anchoring effect, whereby the consistency and the directionality of a cue (whether a human figure or arrow) impacts performance. This anchoring is contrary to the agency hypothesis (and the results of Gunalp et al., 2019). Instead the present results indicate that any sort of directional cue improves the map-like abstract display used here. This suggests that step 1 of the perspective taking process, imagining being in the array, is a crucial point at which the task display can either facilitate or impede perspective taking performance. It is during step 1 that the human figure and the arrow confer their largest benefit.

It is possible that the directional cues also improved ease of imagined perspective shifts (during step 2 of the perspective taking process), even though the predicted interaction was not observed. Given the present significant main effects of directional cue type on response time data for perspective shifts, it was true that both an arrow and a human figure reduced response time relative to the control across the magnitudes of perspective shifts. This suggests that part of the benefit of a directional cue could be exerted during step 2 of the perspective taking process as well; the cue not only helps one imagine oneself in the array of objects, but also helps with imaging initial perspective shifts to reach the heading indicated by the directional cue.

As predicted, smaller perspective shifts were easier and faster than larger shifts. This finding suggests that the mental transformation involved in imagining a different perspective to one's current orientation is analogous to a physical transformation (c.f., Shepard & Metzler, 1971). Also as predicted, pointing quadrant influences performance; participants are faster and more accurate pointing to the front than the back, replicating previous findings (Horn & Loomis, 2004; Kozhevnikov & Hegarty, 2001; Shelton & McNamara, 2001). However, the pointing quadrant data do not show a clear pattern or evidence in favor of imagined pointing being analogous to physical pointing. Accuracy data generally suggest that imagined pointing is not an analog process, in that pointing to the front was easiest, and pointing to the right, left, and back were equally difficult. However, the response time data sometimes display patterns that would indicate that imagined pointing is an analog of physical pointing, with pointing to the back being the slowest. These conflicting results, across both perspective shift and pointing quadrant (and accuracy and response time), suggest that more research is needed to either support or oppose the idea that imagined rotations and pointing are analogs of the actual physical processes.

Additionally, it is interesting that for both Experiments 1 and 2a, all the subjects excluded were women. This might reflect the sex difference usually seen with this type of task (e.g. Kozhevnikov & Hegarty, 2001; Tarampi et al., 2016), with men typically pointing with lower error than women. This is important, given that the task used here was based on the most updated version of the SOT (Friedman et al., 2019), which included clarified instructions that seem to improve performance overall. Interestingly, even with improved instructions, a sex difference still might be occurring, particularly among individuals who perform very poorly on this task (almost chance levels of error) which, in Experiments 1 and 2a, were all women.

The present findings diverge from the results of Gunalp, et al., (2019), which found that an arrow was not sufficient to improve performance on a perspective taking task relative to a control condition. However, there are disparities between the displays used in this earlier research and the present experiment. Specifically, the display used by Gunalp et al. was a more naturalistic scene resembling a park, and the present experiment uses an abstract map-like array. Additionally, Gunalp et al. used a display in which the array of objects was viewed from a high (~130°) angle rather than from overhead (180°), and the array and answer circle were on different planes. These properties could have increased difficulty of the task using this display. A comparison of these studies suggest that different directional cues may be effective in different types of displays. An arrow is an abstract symbol and therefore may be more effective in a more abstract map-like display than a realistic scene.

Together, these three experiments indicate that directionality is the most important characteristic of a cue in this type of perspective taking task, rather than the degree of agency of a cue or how interactive a cue is. That is, a directional cue of any kind improves performance on this type of perspective taking task; it does not matter if this directional cue is an arrow or a human figure. Further, the directional cue mainly improves performance at steps 1 and 2 of the perspective taking process, which is imagining oneself in the array of objects or within the task-specific environment, and imagining a new heading in the environment. This may be related to display type, as discussed above. It would be interesting to examine, in future work, the symmetry of the human figure, each of the objects in the array, and the array configuration. Different properties of symmetry could be systematically varied in order to further examine how directional properties influence performance on this task. These experiments have helped to illuminate some of the factors important for perspective taking specifically, and the following experiments will focus on how perspective taking relates to performance of related, more day-to-day spatial tasks at larger scales of space.

## III. The Relationship Between Perspective Taking and Navigation Using a Map

Map use is one situation in which perspective taking is important in navigation. Perspective taking often occurs when navigating in a new environment and consulting a map of some kind. In order to plan a route or stay on a route successfully, it is often necessary to be able to imagine a location and perspective different from your current physical position. Research on  map use and navigation has considered perspective taking during navigation, as well as the issues that can arise during navigation (e.g. Levine, Marchon, & Hanley, 1984; Thorndyke & Hayes-Roth, 1982). Factors such as the components of the display (Gunzelmann & Anderson, 2004, 2006), how an individual is represented while moving through an environment (Pazzaglia & Taylor, 2007; Brunyé, Gardony, Mahony, & Taylor, 2012) and the orientation of map relative to the user's current facing direction (Levine et al., 1984) are all significant contributors to successful map use.

There are many situations while navigating using a map that perspective taking might be important, or rather, cognitive processes that are fundamental to both perspective taking and navigation may be particularly influential to navigation success. An overarching goal of the present experiment was therefore to examine how more and less able perspective takers navigate both when using a map and when relying on a mental representation of an environment learned through map-based navigation. More specifically, the present experiment set out examine two main questions: first, how participants navigate when using a map, specifically, how being misaligned with the map influences navigation, and second, how participants navigate from memory when the map is removed. With regard to the first question, orientation of the map, orientation specificity of memory, and misalignment with the map are important factors to consider. With regard to the second question, the nature of the representation that participants develop of the environment is central. These questions were both examined in relation to perspective taking ability, which has been found to be correlated with navigation performance in previous work. The following sections explore each of these factors in turn.

Previous work on perspective taking has implemented perspective taking tasks like the SOT used here, but with map displays of buildings (e.g. Richardson, Montello, & Hegarty, 1999) or environments (e.g. He & Hegarty, 2020; Kozhevnikov & Hegarty, 2001; Pazzaglia & Taylor, 2007) rather than arrays of objects, which more explicitly illustrates one connection between perspective taking and larger scale spatial abilities. In other work, perspective taking has been found to correlate with various elements of navigation, for example SOT performance is significantly correlated with navigation errors such as turning in the wrong direction at a decision point along a route (Galati et al., 2015), and reversing a learned route (Allen et al., 1996). Further, the ways in which an individual uses a map to navigate are likely also correlated with perspective taking performance. It is possible that more able perspective takers, because they are also frequently good navigators, will rely less on the map than poor perspective takers. If they rely on the map less while navigating, they may be more immune to the negative effects a misaligned map can produce. This may in turn highlight the differences in navigation performance between more and less able perspective takers.

With regard to map use, the orientation of the map itself is a particularly important factor that has been studied in depth, frequently with respect to vertical you-are-here (YAH) maps, as described above (see Chapter 1). Previous work by Levine, Marchon, and Hanley (1984) indicated that when a YAH map is misaligned with the environment by 90° or more, people were significantly less able to use the map to navigate to goals. This was true both in a lab setting and in the real world, and even if people were made explicitly aware of the misalignment. In real-world navigation, misaligned YAH maps made navigation to goals not only less successful, but also take longer (Levine et al., 1984). Importantly, this work also highlighted the counterproductive effect of misaligned maps; participants often navigated away from their goals when using a misaligned map.

In addition to orientation of the map itself, the orientation specificity of spatial memories is also relevant to the present experiment. Previous research on orientation specificity indicates that performance on pointing tasks and judgments of relative direction is more accurate when testing orientation matches or is parallel to study orientation (Shelton & McNamara, 1997). When the external environment does not provide a strong frame of reference, as in the maze environment used here which has no distal cues or landmarks, people often represent the space from the orientation that the environment was first encountered in (Shelton & McNamara, 2001). This is particularly true in room-sized environments (Waller, Montello, Richardson, & Hegarty, 2002).

Participants in the present experiment learned the environment layout through studying a map, so they should use the map, and the alignment of the map, to orient themselves in the environment while navigating. Further, prior research indicates that when learning an environment from a map, rather than through active navigation, the map orientation is the orientation specific memory for the environment, creating the frame of reference on which memory of the environment is built (Meilinger, Frankenstein, Watanabe, Bulthoff, & Hölscher, 2015; Richardson et al., 1999). Thus, I predicted that participants in this experiment would navigate more efficiently when they were aligned with the orientation of the map in the environment rather than misaligned.

Other elements that are fundamental to both perspective taking and navigation are transformations, such as translations and rotations (e.g. updating). In perspective taking, an imagined perspective transformation of the egocentric frame of reference is required when imagining perspectives that are different from one's current perspective. For example, you could be viewing a clock tower from your current position, and then be asked to imagine standing on the opposite side of the clock tower. Experiments 1 and 2 demonstrated that larger perspective shifts, which require larger mental transformations, lead to slower, more erroneous pointing performance. Indeed, previous work has shown that mental rotation ability does influence an individual's ability to accurately recall a recently-learned environment (mediated by visuospatial working memory ability; Meneghetti et al., 2016). Further, mental transformation is also important in map use and environment learning. If using a map while moving through an environment, one's location in the environment relative to a map must be updated, which requires coordination of egocentric heading with the allocentric representation of the environment (the map). Spatial updating with respect to the environment is considered to be an automatic process that occurs while moving through an environment (Farrell & Robertson, 1998; Rieser, 1989; Rieser, Guth, & Hill, 1986).

Moving through an environment while consulting a map also often requires updating the orientation of the map itself, further compounding the complexity of this seemingly simple activity. Thus, misalignment with the map, either in terms of the direction of travel misaligning with the primary orientation of the map, or based on the heading of the starting direction relative to the heading of the ending direction, has potential to influence the success with which an individual uses a map to navigate. The present experiment examines this relationship in order to determine how mental transformation ability influences perspective taking, map use, and navigation ability.

It is important to note that by providing a map, greater control of the representation of the environment is obtained, in that the individual using the map does not need to create their own cognitive map of the environment to navigate. There are large individual differences in the quality of internal representations of learned environments (cognitive maps) (Fields & Shelton, 2006; Ishikawa & Montello, 2006; Thorndyke & Hayes-Roth, 1982; Thorndyke & Stasz, 1980), and both between and within individuals these representations are prone to distortions and biases (Friedman & Brown, 2000; Tversky, 1981; Tversky & Schiano, 1989). Thus, the present experiment reduces the likelihood of these differences and distortions, providing a map of the environment that participants are explicitly instructed to use while they navigate to a goal.

In this experiment, participants completed a measure of perspective taking and a navigation task in which they had to travel to goal locations in a novel environment either using a map of that environment, or without a map. In the navigation task, two factors were systematically varied to manipulate the amount of mental transformation required for each navigation trial: goal alignment, and heading alignment. Goal alignment refers to the direction of the goal relative to the start being aligned with the forward-up orientation of the map. With goal alignment, the mental transformation required is between egocentric heading and the allocentric representation of the map. If a straight-line arrow drawn from the start to the goal objects pointed up, a trial was considered to be aligned with the forward-up orientation of the map. If the straight-line arrow drawn from the start to the goal objects pointed down, the trial was considered to be misaligned with the learned orientation of the map. If the straight-line arrow pointed to the right or left (or not definitively up or down), the trial was categorized as intermediate (see Figure 18).

*Figure 18.*

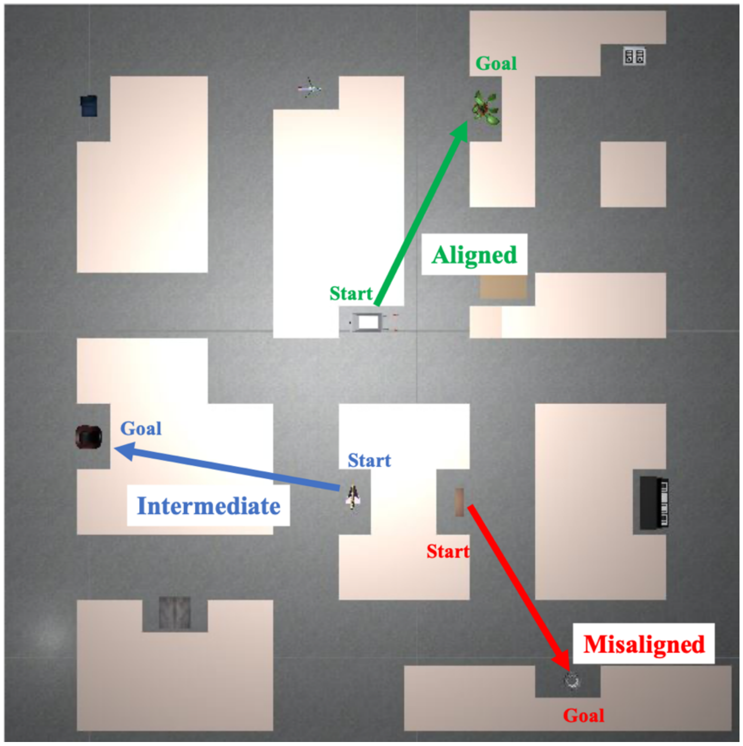


Figure 18. A depiction of three levels of goal alignment; aligned (green), intermediate (blue), and misaligned (red). The arrows here depict possible trials, with starting object at the base of the arrow and target (goal) object at the head of the arrow; for example the green arrow trial starts at wheelbarrow with the goal of navigating to the plant. The map is static, always shown with this orientation.

For example, in Figure 18, the green arrow is drawn starting at the wheelbarrow and extending to the plant. If a trial required participants to start at the wheelbarrow and navigate to the plant, to get to the plant they would need to ultimately spend more time traveling in the direction shown by the green arrow (at least proportionally), which is aligned with the forward-up orientation of the map. If, on the other hand, a trial asked participants to travel from the bookshelf to the trashcan (shown by the red arrow), to navigate successfully proportionally more time travelling would be 180° misaligned with the forward-up orientation of the map (contraligned). Lastly, if the trial asked participants to navigate from the harp to the chair (shown by the blue arrow), proportionally more travel time would be spent going to the left side of the map. This direction of travel is not completely contraligned with the forward-up orientation of the map, and was therefore categorized as intermediate.

Heading alignment was based on the goal heading relative to start heading, and was determined as the difference in heading direction when facing the start and goal objects. Facing any object in the environment sets one's heading in the environment. Facing a second object will then either set one's heading in the same direction as the first object, be rotated 90° to the right or left of the original object, or be 180° rotated from the original object, for example in Figure 19 the facing direction of the goal object (the wheelbarrow) is rotated to the left 90° (counter-clockwise) from the start object (-90°; see Figure 19).

*Figure 19.*


Figure 19. A depiction of heading alignment between start and goal positions for a trial in Experiment 3. The starting heading is indicated by the red arrow, pointing 90° clockwise from the forward (up) orientation of the map, or the right-hand edge of the map. The goal heading is indicated by the green arrow, pointing 90° counter-clockwise from the starting heading, or to the top edge of the map.

Both goal and heading alignment are important to consider because they both emphasize on the coordination of participant's egocentric heading and the allocentric representation of the environment. Given that these two factors of alignment emphasize the same type of frame of reference coordination, predictions about performance across these different types of alignment were the same.

I predicted that participants who performed well on the perspective taking task would take more efficient paths when navigating than participants who performed poorly on the perspective taking task. I also predicted that those who performed well on the perspective taking task would be less affected by both goal alignment and heading alignment than those who performed poorly on the perspective taking task. This is because the ability to transform and update position, either real (as in navigating through an environment) or imagined (as in perspective taking), is important for both navigation and perspective taking performance. Perspective taking relies on transformations of an imagined egocentric heading, and navigation while using a map requires coordination between the egocentric heading and allocentric representation of the environment (the map), which often requires transformations of either the egocentric or allocentric representations. Thus, individuals who are better at updating should also demonstrate resilience to misalignment (both with the map and between start/goal headings) *and* good perspective taking ability even when the magnitude of initial perspective shift is large. In contrast, individuals who have poor perspective taking ability will be less resilient to discrepancies in heading and thus show poorer navigation performance.

Participants also completed navigation trials without the map of the environment present. These trials were always completed after the trials with a map, and were included to examine if participants developed a survey representation of the environment based on their experiences navigating with a map. In these no-map trials, participants would have to rely on their own cognitive map of the environment that they had developed either through exposure to the environment itself or through study and use of the map.

A discussion of different possible learning experiences in an environment is relevant to these predictions (for example, see Chrastil & Warren, 2012 & 2013 for a discussion of active vs. passive learning). Much research has examined the different learning experiences possible within an environment and how different learning experiences contribute to knowledge of the environment. During the first phase of the present experiment, participants learn the environment by navigating through it with the help of a map. This knowledge of the environment could come from having studied the map, having moved through the environment, or a combination of the two. In the second phase, participants navigate through the same environment but without a map, therefore relying on whatever knowledge of the environment they developed during phase 1.

### *A. Experiment 3*

## Method

### Participants

Sixty-eight participants (34 women, 34 men) from the University of California Santa Barbara were recruited through the Psychology subject credit pool for this study. Two subjects (both women) were excluded from subsequent analyses for failure to complete all experimental tasks, and two participants' data were lost due to experimenter error. Thus, the analyses reported below include 66 participants (32 women, 34 men) ages 17-23 ($M$ = 19.02, $SD$ = 1.35). An a priori power analysis for f-tests for a repeated measures within-between interaction design conducted using G*Power with an alpha level of .05, power of .8, and small to medium effect size of f = .15 indicated that the minimum sample size for this design would be 62 participants. The current sample size exceeds this minimum.

## Design

This study employed a mixed-factor design, where goal alignment (3 levels: aligned, intermediate, misaligned), heading alignment (3 levels: 0°, |90°|, 180°), and map presence (2 levels: map, no map) were manipulated within subjects. A non-manipulated variable, perspective taking ability, was used as a between subjects variable (2 levels: poor, good). Navigation efficiency (number of steps taken divided by number of steps on the shortest possible path), time (travel time), and success (getting to goal) were measured as dependent variables.

## Materials & Apparatus

The navigation tasks were in a desktop environment designed using Unity software. The environment was a maze made up of high brick walls that the participant could not see above, and a plain textured floor surface. No distal cues were in the environment outside the maze of paths, and the sky was a continuous blue with no dimensionality or visible light source. There were 12 objects within the maze, all in recessed alcoves. Navigation in the environment was executed using keyboard controls. For the map trials of the navigation task, a 2D map of an aerial view of the environment was present on the screen while participants moved within the environment (see Figure 20). This map was static, always shown in the same orientation, shown in Figure 20, and presented constantly within the view of the environment as the participants navigated. Importantly, there was no depiction of participant position within the map; while participants navigated they needed to keep track of their position and orientation to determine their location within the environment.

*Figure 20.*

Figure 20. Sample of aerial view map participants view while navigating in the desktop environment.

Before completing any navigation trials, participants were first familiarized with the map and the objects in the environment. Participants were shown the map that would be present during with-map trials in a PowerPoint presentation, and were told that the map would be on the screen for some of the navigation trials. During this map familiarization, participants studied the aerial map and also saw a text label for each object, as well as a view of the object as if standing in the maze looking directly at the object (see Figure 21). This display was shown for each object in the maze, and on a final screen participants were allowed to study a map with all the objects labeled for as long as they wished.

*Figure 21.*


Figure 21. A depiction of one slide used in the map familiarization phase, showing the aerial view of the map and a callout showing the head-on view of the object. This slide was made for each object in the maze.

A with-map trial read, “You are now at the mailbox. Please navigate to the piano.” Trials for this task varied the misalignment of the goal with the map. There were eight aligned trials, 6 intermediate trials, and 10 misaligned trials, yielding a total of 24 with-map trials. The direction of the goal object relative to the start was roughly balanced across these trials. See Figure 22 for a depiction of the environment navigation display for trials with a map.

*Figure 22.*

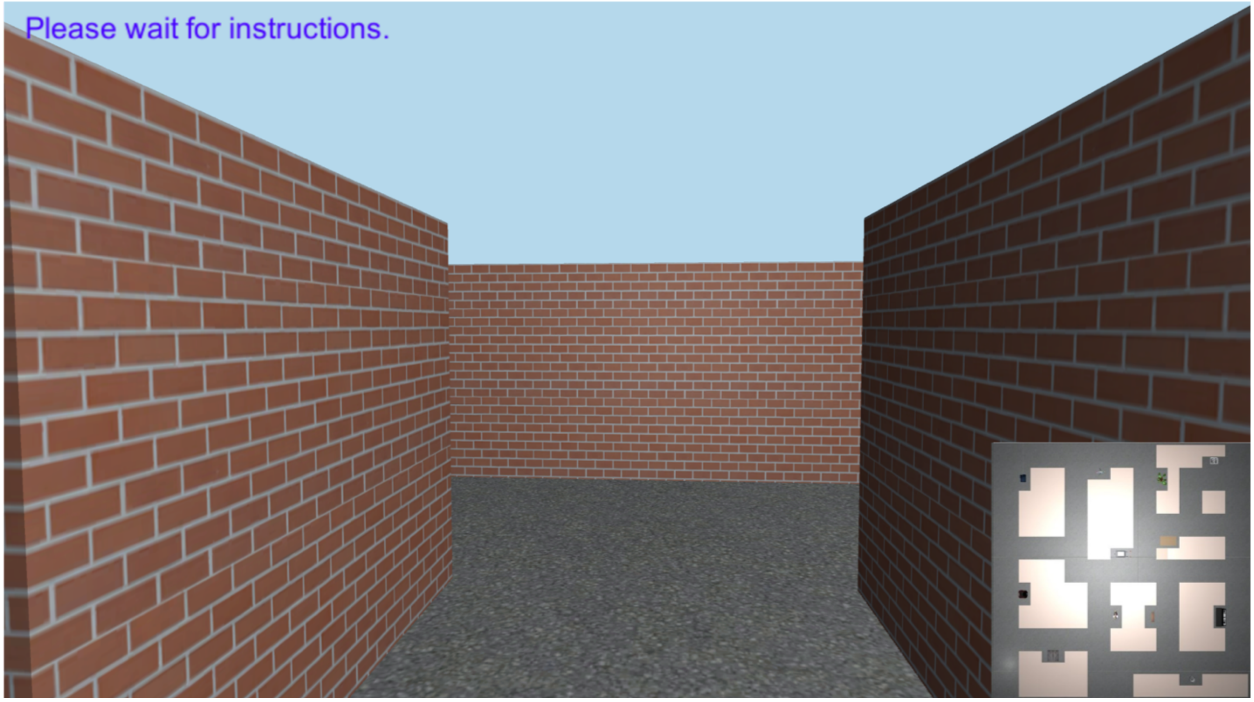


Figure 22. Sample view of the with-map navigation trials, showing the perspective while navigating in the environment, and the static aerial map in the bottom right of the display.

There were also trials within the same environment that did not have the static map present. This environment was identical to the environment used in the map trials, however no map was present on screen during the trials (see Figure 23). These no-map trials had the same instructions as the with-map trials, and read, “You are now at the harp. Please navigate to the wheelbarrow.” These trials were determined by taking the reverse of half of the with-map test trials. For example, if a with-map trial required participants to navigate from the chair to the telescope, a no-map trial might require participants to navigate from the telescope to the chair. For the no-map trials, the same metric of goal alignment was used. For the no-map trials there were six aligned trials, two intermediate, and 4 misaligned trials, yielding a total of 12 no-map trials.

*Figure 23.*

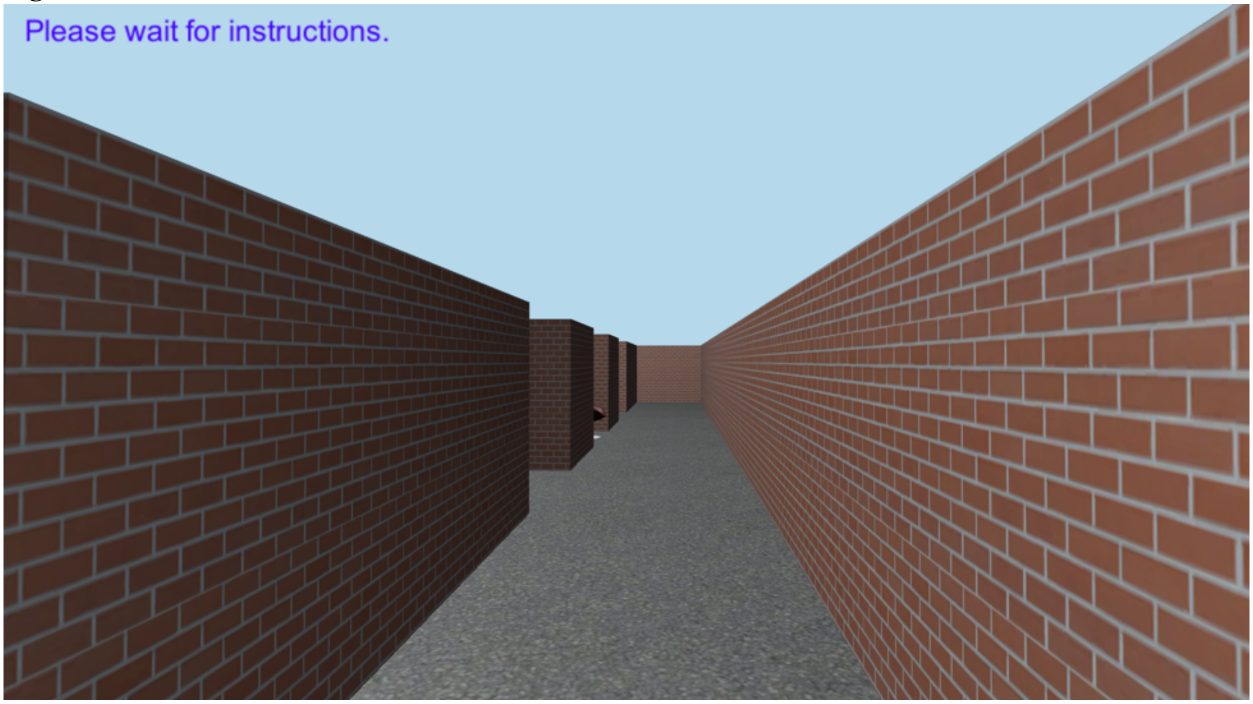


Figure 23. Sample view of the no-map navigation trials.

Heading of goal relative to the start position was also systematically varied for these trials. The potential misalignment between headings at the starting position (facing the start object), and the goal position (facing the goal object) had three possible levels: 0°, |90°|, and 180°. The 90° category collapses over 90° clockwise and 90° counter-clockwise, because the present experiment does not make predictions about misalignment to the right or left differently effecting performance.

The length of the path between start and goal objects was roughly balanced for with- and no-map trials. There was no time limit imposed for either the with- or no-map trials. Perspective taking ability was measured using the control condition SOTs used in Experiments 1 and 2. The Qualtrics survey platform was used to distribute an exit survey containing questions about navigation strategies and strategies for the SOT. The navigation strategy questions (listed in Appendix C) asked participants to describe their strategies during the maze task both when the map was present and when it was absent.

## Procedure

After giving informed consent, participants were instructed on how to use the keyboard to control their navigation in the environment. To practice with the controls, participants were put in a simplified practice environment with the same visual characteristics as the testing environment, but without any objects. There were also red arrows present on the floor of the environment. Participants were told to follow the arrows around the environment, which took them in a loop around the interior perimeter of the environment. The experimenter watched and offered guidance with the controls if it appeared that the participant was having difficulty using the controls. When the participant was comfortable with the controls (usually after 3 laps in the practice environment), they began the with-map trials. After completing the with-map trials, the no-map trials were completed. After completing the navigation test trials, participants completed the SOT, following the same procedure as in Experiment 2. Participants then completed the exit survey and were debriefed.

## Results

### SOT Median Split

A median split was conducted on the SOT data to categorize participants as more or less able perspective takers. Because this task includes trials with less than 90° imagined perspective shift, which have been found to be solved by mental rotation (Kozhevnikov & Hegarty, 2001), the median split was based on performance for the more difficult trials (those with an imagined perspective shift greater than 90°). Two participants' SOT data were lost due to experimenter error, so the analyses presented below are based on 64 participants. Participants completed this task with very low error, such that the median value was 16.75° (*SD* = 19.26).

## Navigation Success

Participants were successful in navigating to the goal location in both the map and no map trials. For the 24 with-map trials, the average number of trials ending in successful navigation to the goal was high (*M* = 23.9 *SD* = .5) with the minimum number of successful trials at 22, and for the 12 no-map trials, average successful navigation to the goal was perfect across participants (*M* = 12.0, *SD* = 0.0). This is likely due to the fact that the no-map trials always occurred after participants had completed all with-map trials, and therefore had much exposure in the environment allowing them to build a sufficient representation of the layout of objects.

## Navigation Efficiency

The maze itself was created on an 11 x 11 grid of unit squares, where one step in the environment was equal to one square. The navigation efficiency metric indicates the ratio of the number of steps the participant took relative to the number of steps on the shortest possible route between the start and goal objects. Thus, a smaller ratio (closer to 1) indicates more efficient navigation, in that the participant took a route closest to the shortest possible route between two objects.

### *With-Map Trials*

**Goal Alignment.** A 3 (goal alignment; aligned, intermediate, misaligned) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on navigation efficiency indicated that there was a significant main effect of perspective taking ability $F(1, 62) = 6.82$, $p = .01$, $\eta_p^2 = .10$, such that as predicted, participants who had good perspective taking ability took shorter paths (*M* = 1.4, *SE* = .1) than participants who had poor perspective taking ability (*M* = 1.6, *SE* = .1).

There was no main effect of goal alignment, $p = .26$, and no significant interaction of perspective taking performance and goal alignment, $p = .18$ (see Figure 24).

*Figure 24.*

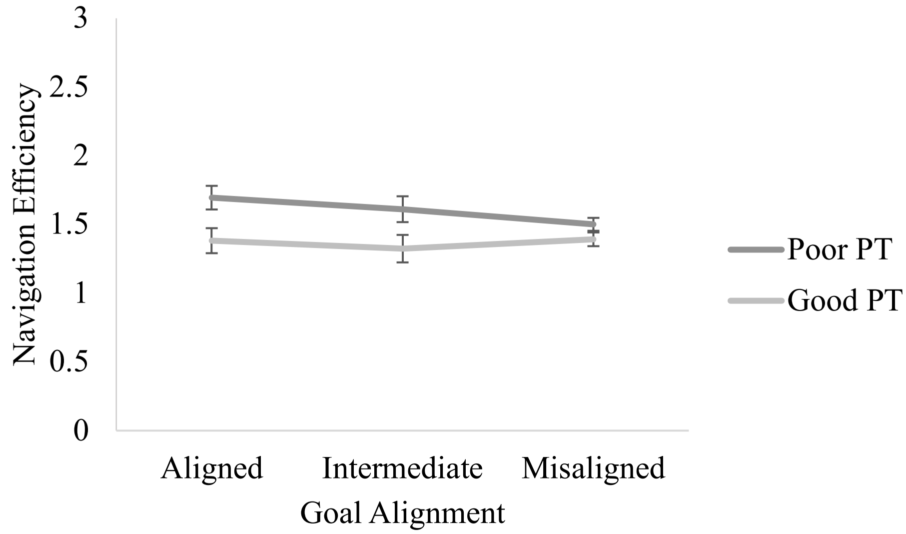


Figure 24. Data from Experiment 3 showing path efficiency as a function of goal alignment and perspective taking ability for the with-map trials.

**Heading Alignment.** It is important to note that the alignment of the goal relative to the start used here is based on the position of a viewer when looking at the start and goal objects head-on (see Figure 19). For example, if a trial started facing an object that entailed ultimately facing North in the environment, and facing the goal object entailed facing East, alignment for this trial would be 90°.

A 3 (alignment of goal relative to start: 0°, |90°|, 180°) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on navigation efficiency indicated that there was a significant main effect of perspective taking ability $F(1, 62) = 5.26$, $p = .03$, $\eta_p^2 = .08$, such that participants who had good perspective taking ability took shorter paths to goals ($M = 1.4$, $SE = .1$) than participants who had poor perspective taking ability ($M = 1.5$, $SE = .1$).

There was also a significant main effect of heading alignment $F(2, 61) = 12.64$, $p < .001$, $\eta_p^2 = .29$, following a significant linear trend $p < .001$, $\eta_p^2 = .28$, indicating that participants took shorter routes when the goal heading was more aligned with the start heading. There was no significant interaction of perspective taking and heading alignment, $p = .13$ (see Figure 25). This is consistent with the predictions made earlier.

*Figure 25.*

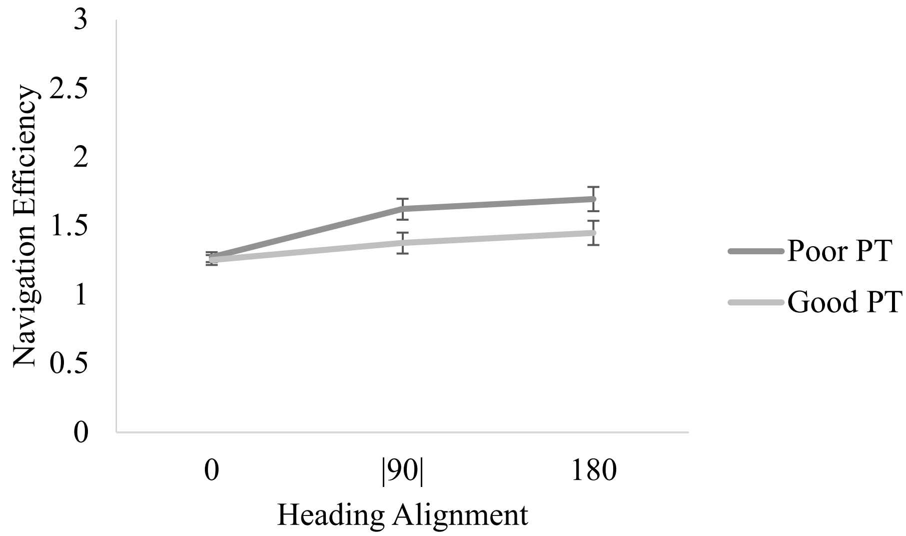


Figure 25. Data from Experiment 3 showing path efficiency as a function of heading alignment and perspective taking ability for the with-map trials.

***No-Map Trials***

**Goal Alignment.** A (goal alignment; aligned, intermediate, misaligned) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on navigation efficiency indicated that there was a significant main effect of goal alignment, $F(2, 61) = 15.66$, $p < .001$, $\eta_p^2 = .34$. Post-hoc pairwise comparisons indicated that, contrary to prediction, participants took significantly shorter routes when they were misaligned with the map ($M = 2.0$, $SE = .1$) than when they were aligned with the map ($M = 2.4$, $SE = .1$), $p < .001$, or when travelling in an intermediate direction ($M = 2.6$, $SE = .2$), $p < .001$ (see Figure 26).

There was no main effect of perspective taking performance, $p = .15$, and no significant interaction of perspective taking and goal alignment, $p = .35$. This is in contrast to the predictions made earlier.

*Figure 26.*

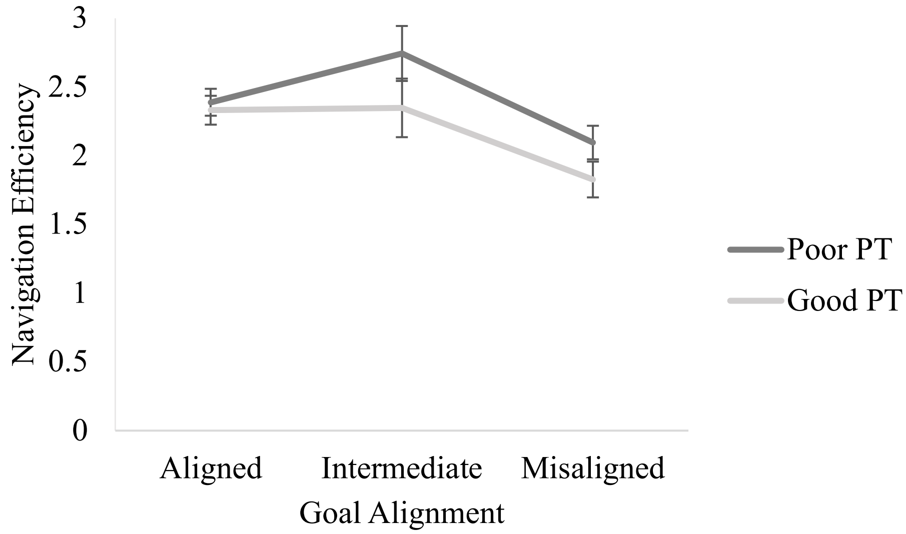


Figure 26. Data from Experiment 3 showing path efficiency as a function of goal alignment and perspective taking ability for the no-map trials.

**Heading Alignment.** A 3 (alignment of goal relative to start: 0°, |90°|, 180°) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on navigation efficiency indicated that there was a significant main effect of heading alignment $F(2, 61) = 10.74$, $p < .001$, $\eta_p^2 = .26$. Post-hoc pairwise comparisons indicated that being aligned actually lead to the longest routes ($M = 2.5$, $SE = .1$), which were significantly longer than routes when misaligned by |90°| ($M = 2.0$, $SE = .1$) $p < .001$, or when misaligned by 180° ($M = 2.2$, $SE = .1$) $p = .002$. This contrasts with predictions made previously.

There was no main effect of perspective taking ability, $p = .34$ on navigation efficiency. There was a marginally significant interaction of perspective taking and heading alignment $F(2, 61) = 2.71$, $p = .08$, $\eta_p^2 = .08$ (see Figure 27).

*Figure 27.*

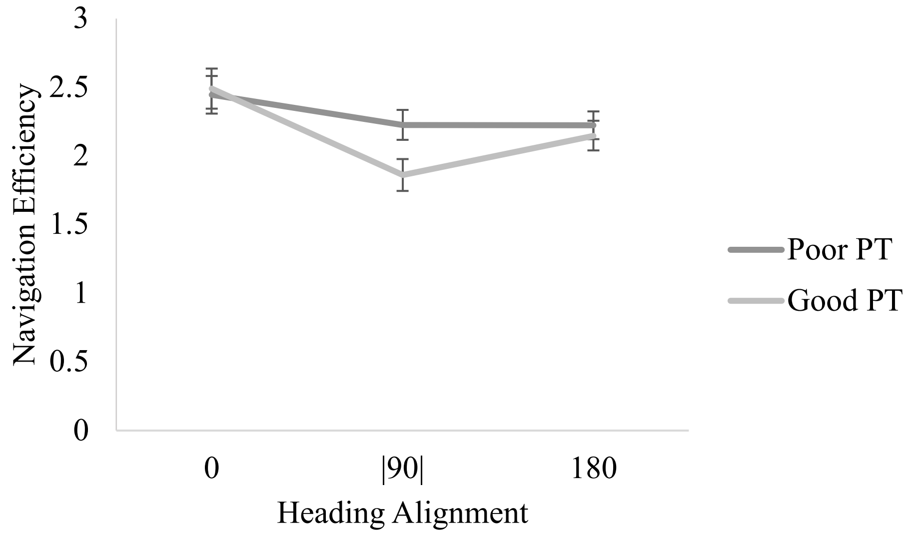


Figure 27. Data from Experiment 3 showing path efficiency as a function of heading alignment and perspective taking ability for the no-map trials.

**Travel Time**

The travel time metric used in the analyses below is based on the amount of time (seconds) it took for participants to navigate from the start position to the goal object.

***With-Map Trials***

**Goal Alignment.** A 3 (goal alignment; aligned, intermediate, misaligned) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on travel time indicated that there was a significant main effect of perspective taking ability $F(1, 59) = 5.82$, $p = .02$, $\eta_p^2 = .10$ on travel time, such that as predicted, participants who had good perspective taking ability spent less time navigating ($M = 22.5$, $SE = 1.6$) than participants who had poor perspective taking ability ($M = 27.9$, $SE = 1.5$).

There was also a significant main effect of goal alignment $F(2, 58) = 6.91$, $p = .002$, $\eta_p^2 = .19$. Post-hoc pairwise comparisons indicated that being aligned with the map ($M = 24.2$, $SE = 1.3$) or at an intermediate alignment while travelling to the goal ($M = 24.07$, $SE = 1.34$) were not significantly different from each other, $p = .91$, but both were significantly faster than being misaligned with the map (*M* = 27.4, *SE* = 1.1), *p*'s < .004. There was no significant interaction of perspective taking performance and goal alignment, $p = .18$ (see Figure 28). These results support the predictions made previously.

*Figure 28.*

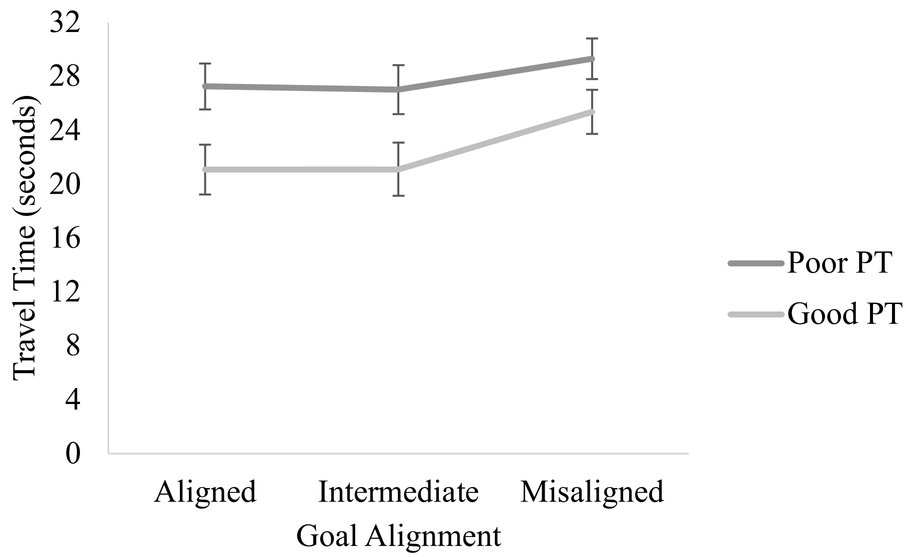


Figure 28. Data from Experiment 3 showing travel time (seconds) as a function of goal alignment and perspective taking ability for the with-map trials.

**Heading Alignment.** A 3 (alignment of goal relative to start: 0°, |90°|, 180°) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on travel time indicated that there was a marginal main effect of perspective taking ability $F(1, 60) = 3.17$, $p = .08$, $\eta_p^2 = .05$, such that participants who had good perspective taking ability spent less time navigating to goals (*M* = 23.3, *SE* = 1.4) than participants who had poor perspective taking ability (*M* = 26.9, *SE* = 1.4).

There was also a significant main effect of heading alignment $F(2, 59) = 6.34$, $p = .003$, $\eta_p^2 = .18$, following a significant linear trend $p < .001$, $\eta_p^2 = .17$, indicating that participants spent less time navigating when the goal heading was more aligned with the start heading. There was no significant interaction of perspective taking and heading alignment of goal relative to start, $p = .79$ (see Figure 29).

*Figure 29.*

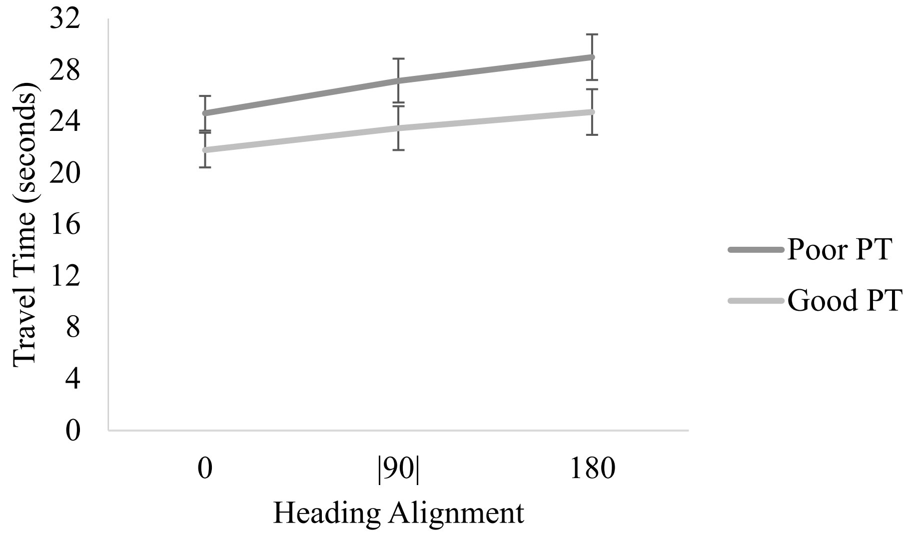


Figure 29. Data from Experiment 3 showing travel time (seconds) as a function of heading alignment and perspective taking ability for the with-map trials.

***No-Map Trials***

**Goal Alignment.** A 3 (goal alignment; aligned, intermediate, misaligned) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on travel time indicated that there was a marginally significant main effect of perspective taking ability $F(1, 60) = 3.14$, $p = .08$, $\eta_p^2 = .05$ on travel time, such that participants who had good perspective taking ability spent less time navigating ($M = 18.5$, $SE = 1.1$) than participants who had poor perspective taking ability ($M = 21.1$, $SE = 1.0$).

There was also a significant main effect of goal alignment $F(2, 59) = 7.74$, $p = .001$, $\eta_p^2 = .21$. Post-hoc pairwise comparisons indicated that being aligned with the map ($M = 20.2$, $SE = 0.8$) or at an intermediate alignment while travelling to the goal ($M = 21.5$, $SE = 1.3$) were not significantly different from each other, $p = .31$, but both were significantly slower than being misaligned with the map ($M = 17.7$, $SE = 0.8$), $p$'s $< .003$. There was no significant interaction of perspective taking performance and goal alignment, $p = .25$ (see Figure 30). These results do not support the predictions made previously.

*Figure 30.*

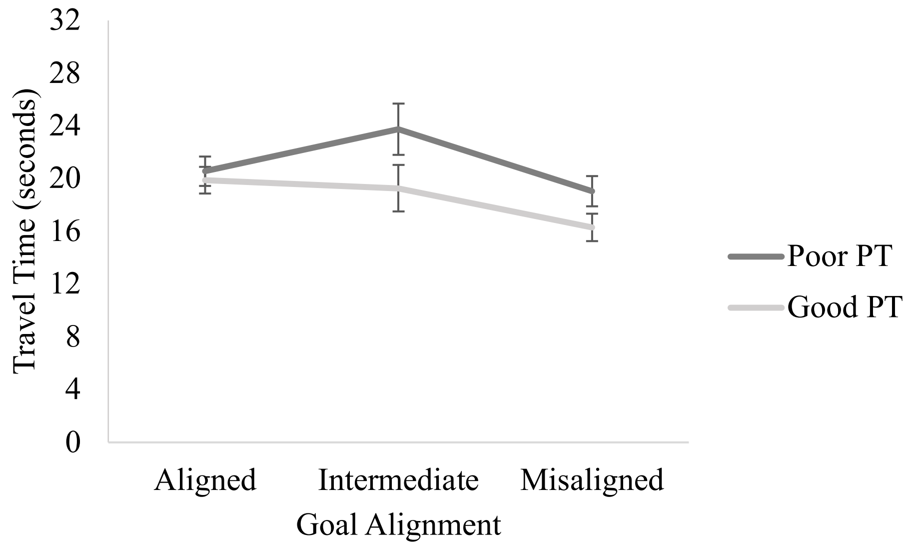


Figure 30. Data from Experiment 3 showing travel time (seconds) as a function of goal alignment and perspective taking ability for the no-map trials.

**Heading Alignment.** A 3 (alignment of goal relative to start: 0°, |90°|, 180°) by 2 (perspective taking ability: poor, good) mixed model repeated measures ANOVA on travel time indicated that there was no significant main effect of perspective taking ability*,* $p$ = .45, such that participants who had good perspective taking ability spent the same amount of time navigating to goals ($M$ = 18.8, $SE$ = .9) than participants who had poor perspective taking ability ($M$ = 19.8, $SE$ = .9) for the no-map trials.

There was a significant main effect of heading alignment $F(2, 60) = 4.41$, $p = .016$, $\eta_p^2 = .13$, following a quadratic linear trend $p = .008$, $\eta_p^2 = .11$, indicating that participants spent more time navigating when the goal direction was 0° misaligned ($M$ = 20.4, $SE$ = .8) and 180° misaligned ($M$ = 19.5, $SE$ = .8) with the start direction than when 90° misaligned ($M$ = 18.1, $SE$ = .7). There was a marginally significant interaction of perspective taking and heading alignment of goal relative to start, $F(2, 60) = 2.89$, $p = .06$, $\eta_p^2 = .09$ (see Figure 31).

*Figure 31.*

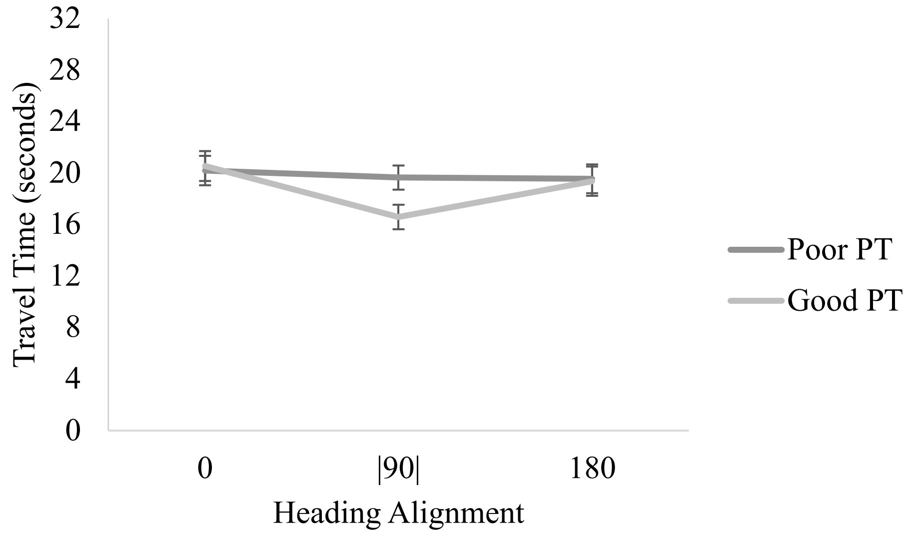


Figure 31. Data from Experiment 3 showing travel time (seconds) as a function of heading alignment and perspective taking ability for the no-map trials.

**Survey**

Strategy reports were collected for both the SOT and the navigation tasks (with-map and no-map trials). Two independent viewers coded strategy data, and agreed upon all strategy categorizations. As in previous experiments, a majority of participants (n = 57) reported using mental simulation strategies on the SOT task, with only 3 participants reporting abstract strategies (n = 3).

Strategies for the map trials were categorized into two groups: those that mentioned relying on the map to orient themselves (n = 45), and other (n = 20). An example of an "other" strategy is, "Looking at the object closest to me and then figuring out where the object I needed to go to was.." Independent samples t-tests found that there were no significant differences between those who mentioned using the map and those who did not on navigation efficiency or travel time for the with-map or no-map trials, *p'*s > .26.

Strategies for the no-map trials were also categorized into two groups: those that mentioned trying to recall or visualize the map (n = 8) and other (n = 57). Independent samples t-tests found that there were no significant differences between those who mentioned trying to visualize the map and those who did not on navigation efficiency or travel time for the with-map or no-map trials, *p'*s > .22.

**Discussion**

In the present experiment, two predictions were tested. The first prediction was that more able perspective takers would perform better on the navigation task (with and without a map) than less able perspective takers. Second, it was predicted that more able perspective takers would be less affected by misalignment, either of the goal with the map or the heading of the start relative to the heading of the goal, than less able perspective takers. These predictions were tested based on both navigation efficiency and travel time data, which are each discussed in turn below.

***Navigation Efficiency***

Results from this experiment partially support the central prediction that more able perspective takers are more efficient navigators than less able perspective takers. Critically, the difference between more and less able perspective takers was only significant for the with-map trials; in contrast there was no significant difference between more and less able perspective takers for the no-map trials. This suggests perspective taking may ability may not be the only influential factor when navigating based on memory, either of first-person views of the environment or the aerial map.

When using a map to navigate to a goal in an environment, if relying on the map, repeated attempts to compare the current first-person view of the environment seen by a navigator to the corresponding position on the map. During this comparison, the navigator can determine if what is visible from her first-person perspective aligns with what should be visible from that position on the map. This is a perspective taking process. When navigating without a map, these same processes may be occurring because navigation could be based on a memory of the map. However, it is unlikely that such a memory of the map is a precise representation of the environment free of distortion. Indeed, when making judgments based on memory of learned spatial configurations, for example the latitudes of different cities, previous research shows that these memories are often distorted in systematic ways (Friedman & Brown, 2000).

Thus, it could be the case that though participants relied on a memory of the map during navigation in the no-map trials, because that memory was not a precise representation of the environment, translation between current position in the environment and imagined position on the map might have been more erroneous than when the map was on screen. Being a good perspective taker might not have had a beneficial effect on navigation efficiency if perspective taking was being done on a distorted memory of the map. Indeed, navigation was less efficient in the no-map trials for both more and less able perspective takers (compare Figures 24 vs. 26). Thus, using a distorted memory of the map could have led to the discrepancy in significant main effects of perspective taking ability between the with- and no-map trials. However, strategy data for the no-map trials suggests that many participants were not explicitly attempting to recall the map during navigation, and thus this explanation of the difference in perspective taking ability for the with- vs. no-map trials should be taken with a grain of salt.

It is also likely that in addition to using memories of the map itself, participants recalled their first-person memories of navigating with the environment from the with-map trials during the no-map trials. Each participant had different first-person experiences in the environment, given that navigation was not controlled or constrained. Good navigators may have wandered less, and therefore seen less of the environment during the with-map trials.

Poor navigators on the other hand would have wandered more, taking less efficient paths to goals, and therefore could have gotten much more exposure to the environment during the with-map trials. If this were the case, it is possible then that the poor navigators, who could have also been less able perspective takers, had built up enough first-person experience during the with-map trials to supplement their poor navigation skills. Thus, this might have caused the difference between more and less able perspective takers to be reduced (and not significant) for the no-map trials.

Further, the navigation efficiency data indicate that being a more able perspective taker does not implicitly make you better at learning an environment from a map. If that were the case, there should have been a significant difference between more and less able perspective takers for the no-map trials, which was not shown in the present data.

Evidence in support of the prediction that more able perspective takers would be less effected by misalignment was not found consistently in the navigation efficiency data. For the with-map trials, there was a main effect of heading alignment, such that being more aligned when facing the start and goal objects was significantly better (more efficient and faster) than being less aligned at these two positions. There was no effect of goal alignment for the with-map trials. For the no-map trials the data are opposite to predictions, such that both having a goal position that was misaligned with the map and having start and goal headings misalign lead to more efficient navigation. This is puzzling, because even though the map was not on screen for these trials, one would assume that participant's cognitive maps of the environment that were developed during the map trials would have some orientation specificity for the forward-up orientation of the map. However, this does not seem to be the case. Rather, these findings suggest that participants did not learn and remember the environment based on the orientation of the map. These findings contrast previous work on orientation specificity, which suggest that the first orientation from which and environment is encountered is often better remembered than other orientations (e.g. Meilinger et al., 2015; Richardson et al., 1999; Shelton & McNamara, 1997; Shelton & McNamara, 2001; Waller et al., 2002). This could be because the number of exposures to the environment in the present study was too few, though given the rate of successful navigation to goals in the no-map trials and relatively short travel times this seems unlikely.

It should be noted that the median split-approach used to categorize participants as more or less able perspective takers is imperfect. By splitting participants in this way, variability in the sample is inherently reduced. Additionally, because the majority of participants did fairly well on the SOT and performed close to the median level, splitting people who are just below the median and just above the median into two different groups, who were ultimately categorized as more and less able, is somewhat arbitrary. To better examine differences between groups of truly more able and less able perspective takers, it would be ideal to sample participants at the ends of the spectrum of performance on this task (given sufficient sample size). Alternatively, examining perspective taking performance in a correlational design with, for example, other navigation and environment knowledge measures. This correlational approach was taken in Experiment 4.

***Travel time***

Travel time analyses partially supported the prediction that more able perspective takers would be faster navigators than less able perspective takers. For the with-map trials, more able perspective takers were faster than less able perspective takers at navigating when the goal was misaligned with the map. More able perspective takers were also marginally faster than less able perspective takers when navigating and start and goal headings were misaligned. For the no-map trials, more able perspective takers were marginally faster than less able perspective takers at navigating when the goal was misaligned with the map. However, there was no significant difference in travel time between more and less able perspective takers when start and goal headings were misaligned. These results partially echo the navigation efficiency data, which is to be expected; if participants are taking more efficient routes they are also likely taking less time to get from start to goal. However, the travel time data are inconsistent, and given that these data do not control for length of the path participants took, these results should not be over-emphasized.

With respect to alignment effects, for the with-map trials the results are clear: for goal misalignment with map and start and goal heading alignment, more alignment leads to faster travel times than misalignment. Interestingly, for the no-map trials the results are different: participants were faster when the goal was misaligned with the map, and when start and goal headings were either aligned, or 180° misaligned. Perhaps by default of completing the with-map trials first, participants learned the environment sufficiently to be able to quickly notice when their goal for a trial was misaligned with the map, which thus allowed them to navigate more quickly in these cases. Or, it is possible that being misaligned on some of the no-map trials was a type of desirable difficulty, in that it challenged participants to consult and transform their memory of the map or environment that they had developed during the with-map trials. During the no-map trials, participants could have referred to their memory of the map, noticed when they were misaligned, and therefore corrected for that misalignment or tried harder to navigate quickly to goal.

A similar principle might also explain the faster travel time when start and goal headings were misaligned by 180° than by 90°. As the navigation success data indicates, all participants knew the map (or environment) sufficiently well by the time they were completing the no-map trials that they were able to get to the goal on every trial. It is possible that participant's cognitive map of this environment at this stage included axes, such that objects were remembered as being on certain "sides" of the environment. Thus, when placed at an object and then asked to navigate to a second object that had a heading 180° different (the opposite) from the start, participants could have noted that the start object was on one end of an axis and the goal object was on the other end of the axis. It could be that this type of axis-based memory facilitated navigation between these objects. However, this would not explain why misaligned trials were faster or more accurate than aligned trials.

***Survey***

Survey data on navigation strategies differed between with-map and no-map trials. A majority of participants in the with-map trials reported trying to use the map, while in the no-map trials a majority reported using strategies not based on recalling the map. It is understandable that when the map was removed from the display many participants shifted their strategies and did not focus on the formerly present map—instead, many participants reported using nodes in the environment, such as the bounding walls, corners, and intersections of hallways, to guess at or determine their starting position. This could indicate that either participants had developed survey knowledge (a cognitive map) of the environment learned through study of the map and exposure to the environment, or that they had at least developed some less comprehensive understanding of the spatial relationships of some objects in the environment. It is also possible that participants did use a memory of the map during the no-map trials, but did not conceptualize their strategies as based on the map given that the map was no longer present during these trials.

It should be noted that survey responses about navigation and navigation strategies have limited reliability. It is often difficult for participants to articulate, or even access, their navigation strategies. Further, given that a map was present for the with-map trials and participants were explicitly instructed to use the map to aid their navigation, it is understandable that many people would report using the map (and therefore following instructions) for the with-map trials. In contrast, in the no-map trials, because there was no map present in the display it is understandable that participants would not report using a map as part of their strategy. Thus, though self-reported strategies add dimensionality to the experimental data presented here, one should be cautious of over-interpretation of strategy reports.

### *Final Points*

In summary, the findings from the present experiment most substantially provide evidence in support of the predictions regarding perspective taking ability. More able perspective takers were more efficient navigators when using a map than less able perspective takers. Differences in perspective taking ability did not have an effect when navigating without a map. Having the goal misaligned with the map or having start and goal headings misaligned inconsistently affected performance.

One factor that could be seen as a limitation of this experiment was that the proposed connection—good heading updating ability—between perspective taking and navigation was not explicitly examined. It is possible that the ability to flexibly transform and update one's heading is fundamental to both perspective taking and navigation or environment learning, however this experiment did not include a direct measure of participant's understanding of heading and orientation within the environment. Such a measure was included in the following experiment to more directly examine this theory. Additionally, rather than using a median split to separate the sample in to more and less able perspective takers, a correlational design was used in the following experiment to better examine how performance on the SOT is related to performance on measures of survey knowledge.

## IV. The Relationship Between Perspective Taking, Survey Knowledge, and Environment Learning

In addition to having accurate mental transformation/updating ability, having robust perspective taking ability may offer specific advantages that are useful during navigation. Being a good navigator is often attributed to possession of a cognitive map of an environment, as well as having good updating abilities (Simons & Wang, 1998; Wang & Simons, 1999). A thorough and sophisticated cognitive map includes survey knowledge (Ishikawa & Montello, 2006), which is described as configural knowledge or representations with metric information about distances and directions. Survey knowledge is separable from route knowledge, in that with route knowledge an individual can remember a sequence of turns to follow a route (e.g., Siegel & White, 1975), and may even be able to calculate a rough approximation of the distance between objects in the environment based only on the route they learned, but fail to understand global spatial properties of the environment, like the absolute (or Euclidean) distance or direction between objects along their learned route. There is contention in the field regarding whether survey knowledge contains precise and metric information, but the present work does not aim to inform that debate.

The primary aim of this study is to examine how perspective taking is related to acquisition of survey knowledge. Compared to the task of using a map to navigate a novel environment (as in Experiment 3), the process of acquiring actual environment knowledge is more sophisticated and more naturalistic. We frequently navigate places we know and have learned over time, and experience fewer instances of being in/learning entirely new environments. That is, an environment can only be “novel” to us once (further, true novelty of places is unlikely to exist); in subsequent exposures to that environment we are by default navigating somewhere we at least have seen part of once. Thus, to make the present research more representative of the type of navigation we more frequently engage in (in an environment we have repeated exposure to), the following study examines the connection between perspective taking and ability to construct survey knowledge after repeated exposure to an environment. The present experiment examines perspective taking performance in relation to three measures of survey knowledge, two of which were created for this experiment.

Importantly, extant research already suggests that perspective taking and environment learning are related. As summarized in Table 1 (page 19), perspective taking has been found to be correlated with various measures of environment learning and navigation, such as estimations of Euclidean direction (Allen et al., 1996), shortcutting while navigating (Kozhevnikov et al., 2006), building models of a learned environment (Holmes et al., 2017; Weisberg et al., 2014), pointing along learned routes (Muffato & Meneghetti, 2020), within and between learned routes (Weisberg et al., 2014), and navigation errors (turning in the wrong direction at a decision point; Galati et al., 2015). Based on this previous research, I predicted that individuals who are good at perspective taking tests with low error will also acquire more knowledge of the layout of an environment (i.e. survey knowledge) from navigation experience, because the ability to imagine changes in and update heading direction within the environment is important for both developing a survey representation of the environment and perspective taking. Both perspective taking and the development of survey knowledge require repeated updating of one's heading, whether after an imagined (as in a perspective taking task) or real (as in a navigation task) change in position. To test this prediction, the present experiment utilized a heading matching task, similar to other heading-based tasks used in previous research (Burte

& Hegarty, 2012; Sholl, Kenny, & DellaPorta, 2006). For this task, participants were shown three views of a recently learned environment, and asked to indicate which of the two views display the same heading direction within the environment. Thus, one specific prediction for this experiment was that participants with better performance on the SOT (a measure of perspective taking) would also have better performance on the heading matching task after learning a route through the environment.

The second measure of survey knowledge was the distance estimation task, similar to other tasks used to measure distance estimates (e.g. Nasar, Valencia, Omar, Chueh, & Wang, 1985). For this task, participants were shown three objects from the learned environment and asked to indicate which two objects were closest to each other within the environment. Good performance on this task would indicate that the individual has a better understanding of the configuration of objects in the environment, rather than knowledge of the spatial relationships of the objects along the learned route (route knowledge). Estimating distances between objects on a learned route may be fairly easy if the objects in question were close together on the learned route and could be remembered as being within one segment of the route. However, if the task is to estimate the distance between objects that were not close to each other on the route, and therefore on different segments of the route (as in the present experiment), then it would be considerably more difficult. This would be more difficult because it would require integration of the different segments of the route into one more cohesive representation of the space as a whole. Indeed, survey knowledge has been characterized in previous work as the integration of separately learned spaces into a representation of the configuration of the environment as a whole (e.g. Chrastil & Warren, 2013; Ishikawa & Montello, 2006; Wiener, Büchner, & Hölscher, 2009). Knowledge of the configuration of objects in an environment would not only help with estimating distances between objects (or ranking distances between certain object pairs as in the present experiment) but also with being able to point to objects within the environment (as in the SOT). Thus a second specific prediction for this experiment was that individuals that perform well on the SOT would perform better on the distance estimation task than individuals who perform poorly on the SOT.

For consistency with previous work (Kozhevnikov et al., 2006; Weisberg et al., 2014; Galati et al., 2015; Holmes et al., 2017; Muffato & Meneghetti, 2020) a pointing task was also implemented to measure survey knowledge. The pointing task specifically examines the accuracy of individual's representations of the directional relationships between objects in the learned environment (as opposed to distances). The pointing task used in this experiment, though similar to the SOT, is more cognitively demanding, in that participants did not view a map of the environment while completing each trial, and therefore were required to reference their memory of the locations of objects to make their pointing judgments. However, it is important to note that the response method is the same for both pointing measures (within the environment and on the SOT). For both tasks, participants make pointing estimates by dragging a line around an arrow circle. For the SOT, this is executed with a computer mouse, and for the pointing task this is done on a tablet (see detailed description in Materials below).

In order to test these specific predictions and examine the overall relationship between perspective taking and the development of survey knowledge, participants completed several measures: a standard computerized version of the Spatial Orientation Test (Friedman et al., 2019) to measure extra-environment (and more abstract) perspective taking, an object recall task, and the Santa Barbara Sense of Direction Scale (SBSOD: Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). The object recall task required participants to name each of the objects on an abstracted map of the learned environment checked participant's basic landmark knowledge of the environment. This measure was included to examine participant's route knowledge of the environment at the end of the experimental session, which was predicted to be fairly accurate given the number of exposures to the route in the environment.

***A. Experiment 4***

## Method

### Participants

Sixty-eight undergraduates (34 women, 34 men) ages 18-23 ($M$ = 19.09, $SD$ = 1.16) from the University of California Santa Barbara were recruited through the Psychology Subject Pool and participated in exchange for course credit. Three participants (1 woman, 2 men) were considered as potential cases for exclusion, due to missing data (n = 1) and error above chance levels on the SOT (n = 2). Analyses were conducted with all possible variations of including and excluding these three participants, and the patterns of significance do not change with various filtering criteria. Thus, the total sample was used in all analyses presented below. A power analysis for F-tests (repeated measures, within-between interaction) conducted using G*Power with a small effect size f =.1 alpha level of .05 and power of .80 indicated that the minimum number of participants to detect an interaction between heading matching misalignment and perspective taking ability for the proposed design was 32. The present sample size exceeds that minimum.

### Materials & Apparatus

The SOT and the two measures of survey knowledge were programmed using E Prime. All computerized tasks were completed on the same desktop computer as was used in all previous experiments (see Chapter 2 for computer specifications).

The SOT used in this experiment was the computerized standard version developed by Friedman et al. (2019), which is slightly different from the SOTs used in Experiments 1 and 2. This task showed an array of objects and an arrow circle, similar to the SOT used in Experiments 1, 2a, and 2b (described above). The array consisted of seven non-directional (had no front or back), black and white objects, with red dots demarcating the center of each object (see Figure 32). On each trial, participants were given the following instruction: “Imagine you are standing at the X, and facing the Y. Point to the Z.” where X, Y, and Z were each unique objects within the array. Participants responded by moving a line on the arrow circle using the computer mouse to indicate their estimate of the direction to the target object. Participants pressed the “Enter” key to submit their responses, and the trial ended. There are 12 trials in this task and participants were given the standard time limit of five minutes.

*Figure 32.*

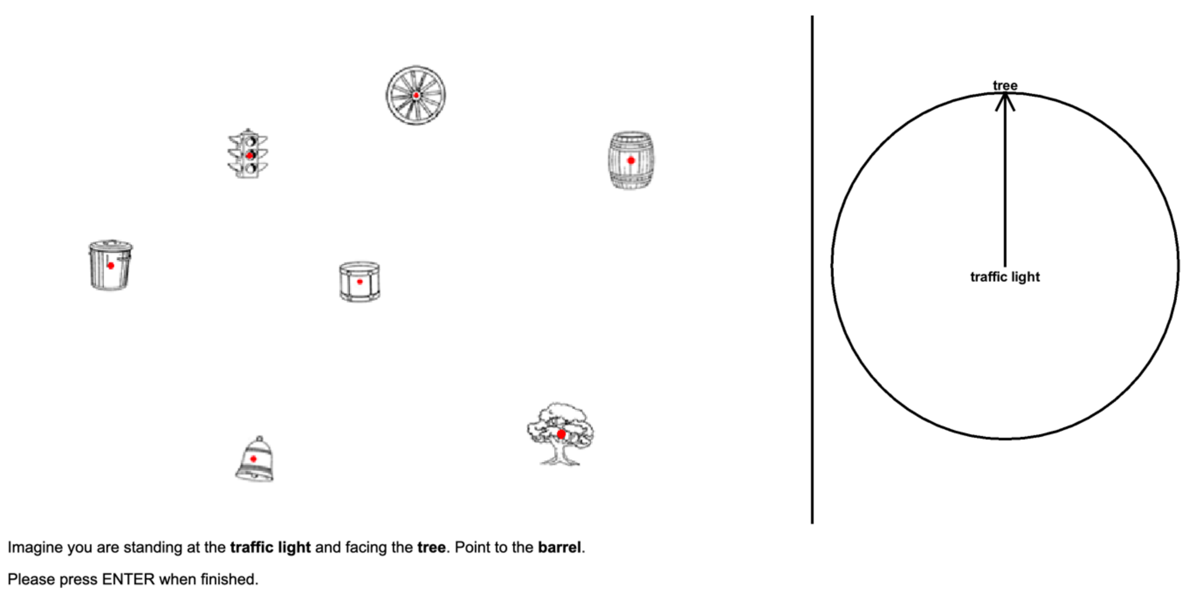


Figure 32. The standard, computerized, 12-item Spatial Orientation Test (SOT; Friedman et al., 2019) used in Experiment 4.

The environment shown in the videos used for this experiment was the same environment from Experiment 3 (described in Chapter 3). The learning phase for the maze environment utilized two videos. One video, called the “stop-look” video showed the route through the environment, and paused to view each of the 12 objects within the maze when they are encountered. This video is called the “stop-look” video because the view in the video pans to look directly at each object along the route. The second video, called the “walk-through” video, presented the same route through the environment, but without stopping to view each object in the maze.

One measure of survey knowledge was the heading matching task, in which participants were shown three images of objects within the maze environment. The images were head-on views of an object in the maze. One main image was presented centered on the screen in the first “row”, and two images of different objects were presented below the main image in a second row (see Figure 33). On each trial, participants were asked to indicate which of the two objects in the second row had the same heading as the object shown in the first row. A trial in this task read, “Which of the two images below shows the same heading as the main image above?” The maze environment was contained within a square, and heading for this task essentially meant which of the four walls of the square you would be facing if you stood in front of an object looking at it head-on. This additional explanation of heading was given to participants before they completed this task. The foil image was systematically misaligned from the heading of the other two images by -90° (90° counterclockwise), 90° (clockwise) or, 180°. There were 11 trials in which the foil was -90° misaligned, nine in which the foil was 90° misaligned, and 20 in which the foil was 180° misaligned. Thus, participants completed a total of 40 heading matching trials. The position of the foil was also counterbalanced between the left and right positions of the second row on screen.

*Figure 33.*

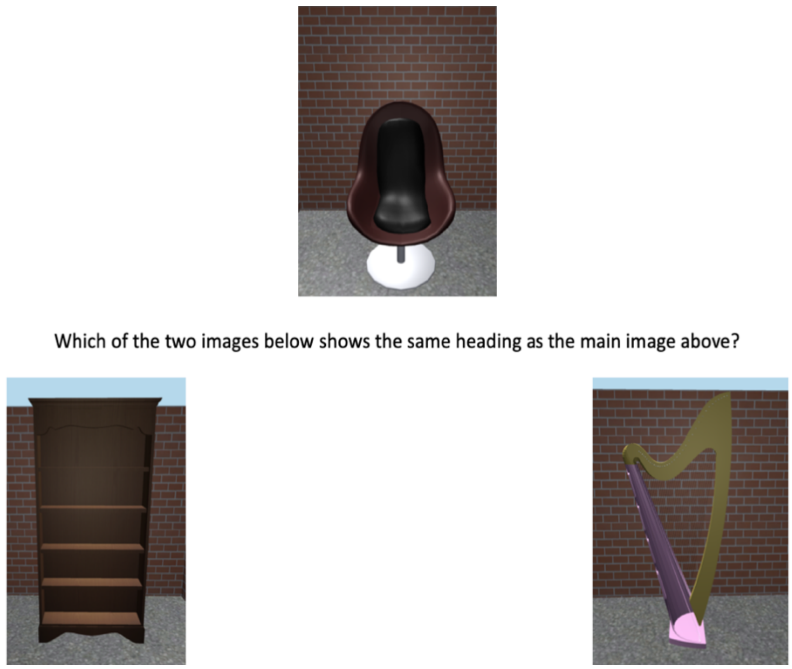


Figure 33. A depiction of the heading matching task.

A second measure of survey knowledge had the same structure as the heading matching task; participants were shown three images of objects in the environment, and were required to indicate which two objects are closest within the environment. For these trials it was emphasized to participants that they were to make their judgments based on straight-line distance between the objects, not the distance between the objects based on the route they learned through the environment. A trial read, “Which of the two images below shows the object that is closer in the environment to the object shown in the main image above?” See Figure 34 for a depiction of a distance estimation trial. Again, position of the foil was balanced between the right and left positions in the second row on the screen.

The environment distance between the main object and the correct answer object was measured based on a 7.3 x 7.3 inch print-out of the aerial map of the environment. A distance was considered short if it was less than 3 inches on this printout, and long if it was over 3 inches. Distance was balanced such that the correct object was a short distance from the main object for 30 trials, and a long distance from the main object for 30 trials. Thus, participants completed a total of 60 distance estimation trials. It was not possible to completely counterbalance how frequently an object was in each of the three possible positions (main or either of the two answer choices). Each object appeared as one of the three possible images on each trial between nine and 23 times.

*Figure 34.*

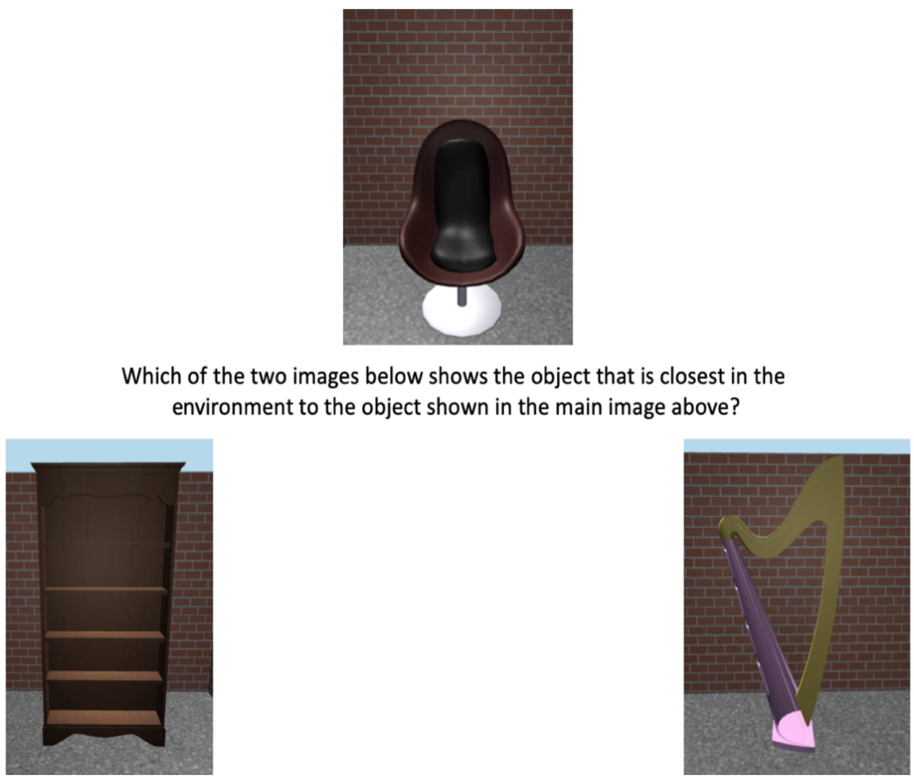


Figure 34. A depiction of a distance estimation trial.

The pointing task utilized the stop-look video in which a video of the route through the environment is shown pausing to look at each object along the way. For the pointing task, the video was paused at each of the 12 objects along the route and participants pointed to two other objects within the maze. Thus, there were 24 trials in the pointing task. Each object in the maze was pointed to twice, once as the first object from a given starting point and once as the second object from a given starting point. For each trial participants were standing at and facing one of the objects in the maze, and then were instructed to point to a second object from that position. For example, a trial read, “You are now standing at the X and facing the X. Please point to the Y.” See Figure 35 for a depiction of a pointing trial. Participants used a tablet with an arrow circle (the same arrow circle used in the SOT) to input their pointing responses. The tablet used was an 8-inch Samsung Galaxy Tab E with 1280 x 800 resolution. Participants used their finger to drag a line around the arrow circle (no stylus used), and clicked a “Submit” button to submit their response.

*Figure 35.*


Figure 35. A depiction of a pointing trial, showing the participants view directly facing one object in the environment in the computer monitor (left) and the arrow circle (right) with a pointing estimate (for display purposes highlight in green).

Participants also completed an object recall task, in which they were given a map showing an aerial view of the maze environment. This map had the object that the learning videos started at, which was the chair, labeled in text (see Figure 36). In this task participants were asked to write down the names of the rest of the objects in the environment (11 total).

*Figure 36.*

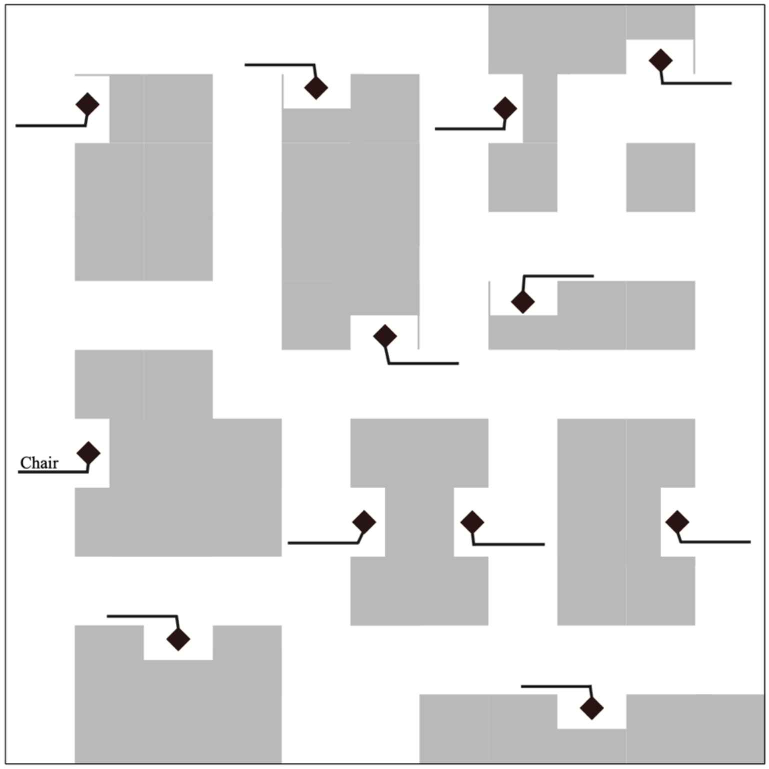


Figure 36. The object recall task used in Experiment 4 to test participant's knowledge of the layout of objects learned within the maze environment.

The Qualtrics survey platform was used to distribute a survey containing items about demographic information, strategy for the SOT (same as Experiments 1, 2a, and 2b; see Appendix A) and for learning the maze environment, the Santa Barbara Sense of Direction Scale (SBSOD; Hegarty et al., 2002), and video game experience. The SBSOD is a 15-item scale that measures self-reported sense of direction. Seven of the items are reverse coded (numbers 1, 3, 4, 5, 7, 9 , and 14), and then using the reverse coded items an average across all 15 items is calculated (see Appendix D). Lower average scores on this measure indicate poor sense of direction.

**Procedure**

After giving informed consent, participants first completed the standard, 12-trial SOT. Participants had five minutes to complete this task. Then participants learned the maze environment. The maze learning task procedure started with the stop-look video, which was played twice. For the first playing of the video, the experimenter named each object aloud when the view of the video panned to look at the object. For the second playing of the video, the experimenter asked participants to name each object when the view in the video panned to look at an object, to ensure that each participant knew the correct name for each object. If a participant did not know the name of the object, this video was replayed until all objects were named correctly. This occurred with 4.6% of participants ($n = 3$), who all needed to watch this video and name the objects only one additional time to correctly name each object (three times total if including first play of video with experimenter naming objects). Then the walk-through video was shown five times, looping automatically, such that after one iteration of the route was shown the video restarted at the beginning of the route.

After learning the environment, participants completed the heading matching and distance estimation tasks (order counterbalanced between participants), and the pointing task. There was no time limit for any of these tasks. Then participants completed the object recall task, which had a five-minute time limit. After completing all of the experimental tasks, participants completed the exit survey and were debriefed.

## Results

### *Descriptive Statistics*

Descriptive statistics for all measures included in this experiment are reported below in Table 8.

Table 8. Descriptive statistics (mean, SD, minimum, maximum, skewness, kurtosis) for all measures included in Experiment 4 (SOT, Heading Matching [HM], Distance Estimation [DE], Pointing, and Object Recall). All participants were included here (n = 68).

| | Mean | Minimum | Maximum | Standard Deviation | Skewness | Kurtosis |
|---|---|---|---|---|---|---|
| SOT Error | 34.41 | 4.42 | 98.08 | 23.29 | 1.02 | 0.38 |
| HM | 24.71 | 16.00 | 40.00 | 6.05 | 0.87 | 0.16 |
| DE | 36.01 | 25.00 | 55.00 | 5.34 | 0.78 | 1.84 |
| Pointing | 82.70 | 21.03 | 146.25 | 23.74 | -0.19 | 0.55 |
| Object Recall | 9.57 | 4.00 | 12.00 | 2.63 | -0.69 | -0.86 |

**SOT.** Participants performance on the SOT was measured such that the angular error between their response and the correct response was calculated for each trial, then averaged across all 12 trials of the task. Note that low angular error indicates good performance. Mean angular error on this task was 32.62° (*SD* = 20.94), with only two participants exceeding chance levels of error (90°), though angular error ranged from 4.42°-89° across individuals. Data for the SOT were positively skewed, and therefore for remaining analyses were log transformed.

**Heading Matching.** Participants completed 40 trials for this task, with number of correct responses ranging across individuals (# correct: 16-40). Participants performed at roughly 62.5% accuracy (*M* = 25, *SD* = 6), indicating that this task was sufficiently difficult to demonstrate variability between individuals, but not so difficult as to yield floor effects with a majority of participants (n = 51) performing above chance (50%) (see Table 8).

**Distance Estimation.** Participants completed 60 trials for this task, with number of correct responses ranging across individuals (# correct: 25-55). Participants performed at roughly 60% accuracy on average (*M* = 36.02, *SD* = 5.37), indicating that this task was also sufficiently difficult to demonstrate variability between individuals, but not so difficult as to yield floor effects with a majority of participants (n = 57) performing above chance (50%). This task had lower average accuracy across participants relative to the heading matching task, indicating that it was slightly more difficult (see Table 8).

**Pointing Task.** Participants' performance on the pointing task was measured the same way as the SOT, such that the angular error between their response and the correct response was calculated for each trial, then averaged across all 24 trials of the task. Angular error on this task was generally high across participants, ($M = 81.96$, $SD = 23.95$), with 23 participants (34%) exceeding chance levels of error (90°) (see Table 8). Performance did range considerably (average angular error: 21.03°-146.25°) across individuals.

**Object Recall Task.** Participants completed 12 trials for this task, with number of correct responses ranging across individuals (# correct: 4-12). Participants performed at roughly 80% accuracy ($M = 9.6$, $SD = 2.61$), indicating that this task was sufficiently difficult to demonstrate variability between individuals. A sizeable portion of participants (n = 27, or 40% of the sample) completed the task with 100% accuracy (see Table 8). This proportion is not large enough to suggest that there were strong ceiling effects for performance on this task.

**Correlations Between Measures**

All experimental tasks were entered in a correlation analysis, which revealed that all correlations between all performance measures were significant (see Table 9). This generally provides evidence in support of the predictions described above, indicating that good perspective takers are also good at the measures of survey knowledge used here.

Table 9. Correlations between SOT scores, heading matching (HM), distance estimation (DE), the pointing task, the object recall task, and the SBSOD from Experiment 4 showing Pearson's r.

| | HM | DE | Pointing | Object Recall | SBSOD |
|---|---|---|---|---|---|
| Ln SOT | -.40** | -.41** | .34** | -.30* | -.05 |
| HM | | .48*** | -.51*** | .30* | .21 |
| DE | | | -.37** | .35** | -.08 |
| Pointing | | | | -.35** | -.33** |
| Object Recall | | | | | .00 |

** p < .05, ** p < .01, *** p < .001*

Performance on the SOT was significantly negatively correlated with the heading matching, distance estimation, and object recall tasks, as SOT score is an error score and higher scores indicate worse performance. The SOT was significantly positively correlated with performance on the pointing task, as performance on both of these tasks are error scores. This indicates that as predicted, perspective taking ability is related to the ability to construct survey knowledge of a new environment.

The two measures of survey knowledge, heading matching and distance estimation, were significantly positively correlated ($r$ = .480, $p$ < .001), and both the heading matching and the distance estimation tasks were significantly negatively correlated with performance on the pointing task ($r$ = -.514, $p$ < .001; $r$ = -.365, $p$ = .002, respectively, as expected). Again, this correlation is negative because the metric of performance on the pointing task is an error score, and lower scores therefore indicate better performance. This suggests that the measures of survey knowledge used here do indeed measure survey knowledge as intended, and reflect the same kind of survey knowledge that is measured in a pointing task.

The pointing task was significantly correlated with all other experimental tasks, which parallels the pattern found with the SOT. This was expected, as the pointing task is a measure of survey knowledge and has the same response format as the SOT. Lastly, performance on the object recall task was significantly correlated with performance on all experimental tasks, but was only marginally correlated ($r$ = -.209, $p$ = .088) with perspective taking ability (not shown in Table 9). Of the experimental tasks, the SBSOD scores were significantly correlated with only the pointing task.

**Survey.** Participants reported their strategies for completing the SOT, which were categorized as being abstract or using mental simulation. An example of an abstract strategy is, "I mentally superimposed the whole array of objects on the answer circle to formulate my answer." An example of a mental simulation-based strategy is, "I imagined myself being in the array, at the location I was told to imagine, turning my body to the imagined facing direction and figured out where the target object would be in relation to my body." A majority of participants reported using mental simulation strategies for the SOT in this experiment (abstract = 7, mental simulation = 61). An independent samples t-test on SOT strategy indicated that there was no significant difference in strategies used by individuals with good perspective taking ability (abstract = 2, mental simulation = 32) compared to those with poor perspective taking ability (abstract = 5, mental simulation = 29), $t(66)$ = 1.19, $p$ = .24.

An open-ended strategy question was included in the exit survey, which asked about participant's strategy for learning the environment. Two independent viewers coded strategy data, and agreed upon all strategy categorizations. A majority of responses ($n$ = 48, 71%) mentioned an attempt to remember the order of objects along the route, including paying attention to turns in the route. Eleven participants (16%) mentioned paying attention to the heading/orientation/facing direction of objects within the environment, and only one participant (1%) reported trying to imagine themselves walking through the environment as a memorization strategy. Eight participants used a separate, uncodable strategy (12%). Based on these categorizations, the participants could be subsequently grouped as those who used a route-based strategy versus those who used another strategy during the environment learning phase. After dichotomizing participants in this way, a series of independent samples t-tests were conducted to determine if performance on any of the experimental measures differed significantly between participants who used a route-based strategy ($n$ = 48) versus those who used a different strategy ($n$ = 20). It was found that there was no significant difference in performance on any experimental task between these strategy groups, all $p$'s > .38. The difference in performance on the object recall task between strategy groups was marginally significant $t(66) = 1.91$, $p = .06$, such that participants who used a route-based strategy labelled more objects correctly on the map ($M$ = 9.96 , $SD$ = 2.41) than the participants who used another strategy ($M$ = 8.65, $SD$ = 2.96). Though this was only marginally significant, it is a logical result, as it would be expected that participants who tried to learn the route through the environment might therefore by default learn more of the objects in the environment.

**Discussion**

Findings from the present experiment substantiate the relationship between perspective taking and environment learning/navigation tasks that has been demonstrated in prior research (e.g. Allen et al., 1996; Kozhevnikov et al., 2006; Weisberg et al., 2014; Holmes, Marchette, & Newcombe, 2017). The predictions made above were supported, indicating that better perspective takers performed better on the measures of survey knowledge included in this experiment. These results add evidence in support of the idea that being able to flexibly and continually update one's heading is a process or ability that is fundamental to both perspective taking and environment learning. Further, integrating information about the Euclidean distances between objects in an environment into one's representation of the environment is significantly correlated to perspective taking performance. Being able to estimate distances accurately might be linked to perspective taking performance because it is suggestive of a greater understanding of the spatial relationships (or configuration) of objects in the environment. This does not mean that perspective taking is a predictor of distance estimation in a broad sense, rather it suggests a specific relationship between perspective taking ability and distance estimation based on a learned spatial configuration of objects. It thus seems that both heading updating and integration of distance knowledge, at least in part, facilitate an individual's ability to later develop survey knowledge of that environment.

Perspective taking performance (measured by the SOT) was also significantly correlated with pointing performance, which is consistent with previous research (Holmes et al., 2017; Kozhevnikov et al., 2006; Muffato & Meneghetti, 2020; Weisberg et al., 2014). At first glance this result may not be surprising; there are many similarities between these tasks, primarily that they both are essentially judgments of relative direction. However, the memory demand is much higher in the pointing task, because unlike the SOT the target objects (to be pointed to) are not visible. In addition, the view at test in the pointing task provides very little spatial or visual information. Data from these tasks provide support for this idea; error was much higher on the pointing task than the SOT. During the pointing task participants simply viewed an object head-on, with continuations of hallways in the periphery and the alcove that contained the object in the center. This sparse visual display is closer to what we encounter when navigating in the real world, for example when trying to find a particular office in a building. The SOT on the other hand presents an abstract, map-like display of several objects that remains visible during the task. This is more similar to looking at a map of a mall and making judgments solely about the map, which is a much less quotidian experience than in situ navigation. However, despite these differences the present work demonstrated that performance on these two types of tasks is strongly correlated.

Additionally, performance on the pointing task was significantly correlated with SBSOD scores. This adds support to the idea that maintaining orientation in an environment is related to one's ability to update one's representation of and heading within an environment, and replicates findings from previous research using this measure (e.g. Hegarty et al., 2002; Hegarty et al., 2006; Kozhevnikov & Hegarty, 2001; Weisberg et al., 2014). Interestingly, SBSOD scores were not significantly correlated with the measures of survey knowledge used in this experiment. This could be because a desktop virtual environment was used here, rather than actual in situ navigation, and because both heading matching and distance estimation are not metric tasks. It is important to note that correlations observed here were likely higher than what would be observed if in situ navigation (with actual locomotion) was included in the experiment (see Hegarty et al., 2006).

Despite the good performance on the measures of survey knowledge used in this experiment, a majority of participants reported using a route-based strategy for learning the environment. Of course, self-report measures are limited in that people cannot always access or articulate their own strategies. Still though, it is surprising that most participants reported using a route-based strategy, as one might guess that if a person has good survey knowledge of an environment that they would use more survey-oriented strategies for learning, such as trying to remember where object was in a particular section of the environment, or where objects were in relation to each other. It is also possible that because the environment learning procedure used here showed a route through an environment, and not a survey representation of the environment, that participants were primed to use a route-based strategy.

Or, perhaps participants thought their task was to learn the route through the environment. In this case, development of survey knowledge could have been more implicit, developing without conscious effort on the participant's part. Indeed, previous research has shown that not only do people do better on route knowledge tasks when they learned with route representations and better on survey knowledge tasks when they learn with survey representations, but also specific knowledge-type goals matter. Taylor, Naylor, and Chechile (1999) found that giving participants a route knowledge goal ("…learn the fastest routes between rooms," p. 311) led to improved performance on route knowledge based tasks, and giving survey knowledge goals ("…learn the spatial layout of the building," p. 311) led to better performance on survey knowledge tasks. Thus, if participants in the present experiment thought that the route exposures in the environment learning implied that they were to develop route knowledge of the environment, this implicit goal could have inspired more participants to use route-based strategies for learning the environment.

Use of a route strategy for learning the environment does not invalidate participant's performance on the measures of survey knowledge. It does, however, suggest an interesting disparity; one's cognitive map may contain survey knowledge, but one's preferred environment learning strategy may rely on route-based information. Indeed, much research has shown that there are great individual differences in both navigation ability (e.g. Chrastil & Warren, 2015; Hegarty et al., 2006) and navigation strategy choice (e.g. Boone, Gong, & Hegarty, 2018). It is also possible that the measures of survey knowledge themselves require further refinement to more truly test survey knowledge. This is an interesting dynamic between learning strategy and environment learning ability that should be examined in future work.

One limitation of the present experiment was that naturalism of environment and the environment learning protocol was sacrificed for greater experimental control. The most ecologically valid way to examine navigation and environment learning would be in the field. The present study did control for novelty of environment, number of exposures, and minimized number of extraneous distractors during the task, but in order to do so utilized a virtual environment. Future work should conduct a similar study using in situ navigation in the real world and incorporate the measures of survey knowledge employed here, taking participants to an environment and controlling type, duration, and frequency of exposure (e.g. Ishikawa & Montello, 2006; Lawton, Charleston, & Zieles, 1996; Muffato & Meneghetti, 2020). This would be an even more ecologically valid way to examine the research questions presented here.

Despite this limitation, the present findings are a valuable contribution to the body of work examining the connection between perspective taking and environment learning. Importantly, the present experiment utilized two measures of survey knowledge acquisition and demonstrated that they correlated strongly with perspective taking ability at the same level as more established measures of environment learning. This suggests that these measures can be useful if employed in other experimental paradigms.

## V. General Discussion

Spatial perspective taking is the process by which one makes judgments (often about distance or direction) about a perspective (real or imagined) that is different from one's current physical perspective (e.g. Kozhevnikov & Hegarty, 2001; Hegarty & Waller, 2004; Tarampi et al., 2016). This kind of perspective taking is distinct from social perspective taking, which focuses more on understanding the psychological perspective of another person.

This dissertation focuses on one task that has been used to measure spatial perspective taking, the Spatial Orientation Test, originally developed as a paper-and-pencil test (Kozhevnikov & Hegarty, 2001; Hegarty & Waller, 2004), and recently translated to computer format (Friedman et al., 2019). In this task, participants are required to imagine standing at one object among an array of objects, facing a second object, and then to point to a third object. This task measures the accuracy of pointing estimations (judgments of relative direction) through the metric of angular error (and in the computer version response time is measured as well), and has demonstrated robust sex differences favoring men (Gunalp et al., 2019; Tarampi et al., 2016).

Previous research has examined in detail the factors that influence perspective taking performance, much of which highlights the importance of cue agency (Clements-Stephens et al., 2013; Santiesteban et al., 2014; Gunalp et al., 2019; Shelton et al., 2012; Tarampi et al., 2016; Tversky & Hard, 2009). Specific to the SOT, it was found that including a human figure in the task array not only influenced individual's performance, but also resolved the sex difference such that women performed as well as men (Tarampi et al., 2016).

Experiments 1, 2a, and 2b of this dissertation examined characteristics of the human figure to better understand why it resolved a previously robust sex difference on the SOT.

Perspective taking process can be broken down into three distinct steps: first imagining a new station point, then imagining a new facing direction, and lastly making a pointing judgment. Separating these three steps of the perspective taking process, and examining the influence of additional cues at each of these steps, is a theoretical contribution of the present work. The primary aim of Experiments 1, 2a, and 2b of this dissertation was to systematically vary the difficulty of each of these three steps while also comparing the influence of both an arrow (a directional cue) and a human figure (a directional *and* agentive cue) within the task array. Findings from these experiments indicated that contrary to predictions, for this type of display the arrow improved performance as much as the human figure, which suggests that directionality alone was sufficient to improve performance.

Importantly, these findings contrast previous research on different cues in perspective taking arrays, which indicated that directionality alone was insufficient to improve performance (Gunalp et al., 2019). This contrast is likely due to the difference in display types used in the present work compared to the display used by Gunalp et al. (2019). In the present work, an abstract display was used, and therefore an abstract cue, such as an arrow, may have been more effective to facilitate perspective taking. However, in the virtual reality (VR) version of this task used by Gunalp et al., directionality of the cue was insufficient and only interactive cues (a person and a chair) improved performance. This could be because the VR task implicitly engaged more embodied (Kessler & Wang, 2012) or grounded (Barsalou, 2008) cognition by nature of being immersive.

Another important contribution from these experiments was the finding that cues appear to have the most influence during the first step of the perspective taking process. Regardless of cue type, having either an arrow or a human figure in the array of objects helps to imagine oneself in the array. This may be because the cue provides a station point that is consistent from trial to trial that facilitates imagination of oneself in the array, which in turn improves accuracy and response time on this task.

Additional exploratory analyses were conducted to examine sex differences in these data. Interestingly, no significant sex differences were found in perspective taking performance for either the control or human figure cue types. This contrasts previous work using the SOT which did find a sex difference on control versions of this task (e.g. Kozhevnikov & Hegarty, 2001), as well as the resolution of a sex difference with the inclusion of a human figure (Tarampi et al., 2016). However, the lack of significance here should not be over stated, as a larger sample size is likely necessary to truly examine sex differences.

Experiments 3 and 4 of this dissertation focused on the connection of perspective taking to other spatial abilities, namely navigation using a map (Experiment 3) and environment learning (Experiment 4). In a general sense, perspective taking is important for things like using a map, giving directions, and understanding an environment. Previous work has demonstrated the correlation between perspective taking and learned-route reversal (Allen et al., 1996), shortcutting (Kozhevnikov et al., 2006), pointing within (Kozhevnikov et al., 2006; Muffato & Meneghetti, 2020; Weisberg et al., 2014) and between learned routes (Weisberg et al., 2014), and navigation errors such as turning in the wrong direction at a decision point (Galati et al., 2015).

The primary aim of Experiments 3 and 4 was to examine what specific abilities or processes are fundamental to both perspective taking and map use, as well as perspective taking and environment learning. Findings from these experiments indicated that more able perspective takers are also good at navigating using a map and learning a new environment, and that people who are more able to learn an environment also have better perspective taking ability. Experiment 3 demonstrated that, contrary to predictions, more able perspective takers are not less affected by or immune to misalignment effects that occur when a user is misaligned with the map being used to navigate. However, more able perspective takers were more efficient and faster while navigating than less able perspective takers, indicating that there is a relationship between these abilities. This seems to suggest that updating of ones heading, or perhaps greater ease in imagined perspective-based transformations of the egocentric frame of reference (see Zacks & Michelon, 2005), are important components of this relationship. Alternatively, it is possible that participants in this experiment used route-knowledge rather than survey knowledge of the environment to complete the navigation tasks. The data from strategy reports adds evidence in support of this idea.

Experiment 4 in this dissertation examined two components that could be fundamental to both perspective taking and the development of survey knowledge while learning an environment: flexible updating of heading, and integration of metric distance estimation into the spatial representation of the environment. A heading matching task was used to specifically test participant's ability to remember different headings experienced on a learned route in the environment. A second task, distance estimation, was used to test participant's knowledge of Euclidean distance between objects in the environment. Again, more and less able perspective takers were compared across each of the experimental measures. Findings from this experiment indicated that more able perspective takers performed better on the heading matching and distance estimation tasks than less able perspective takers. This supported predictions, suggesting that the ability to flexibly update heading and integrate metric information about the spatial layout of an environment are both fundamental to perspective taking *and* the development of survey knowledge.

Overall the findings from this dissertation suggest that perspective taking is influenced by multiple factors (display type, cue characteristics), that more able perspective takers seem to be better at using maps to navigate than less able perspective takers perhaps because they make perspective based transformations well, and that more able perspective takers develop survey knowledge more easily/quickly due to both flexible updating of heading and integration of distance information in their spatial representation of the environment.

Additionally, with each experiment included in this dissertation, self-reported strategy data were analyzed. These data, while important for helping to understand the mindset of the participants, need to be interpreted cautiously. Particularly for Experiments 3 and 4, questions about navigation strategies and survey knowledge tasks can be difficult to answer. Firstly, it is likely that many individuals do not have access to their strategies for these types of task, or have difficulty articulating them. This is true of most self-report measures, and particularly for the strategy questionnaire included in Experiment 3. Thus, these data can be interpreted but should not be over emphasized.

Future work should extend the findings presented here, examining other cues related to perspective taking, for example varying the visual access of human figures, using non-directional human figures, using arrays of all human figures, or even using misaligned human figures. Future work should also continue to examine the connection between perspective taking and larger scale spatial abilities like navigation and environment learning. To that end, future studies could utilize different perspective taking tasks and examine performance on those measures in relation to the survey knowledge measures presented here. Future work should also tie together these two aims, examining how different cues embedded in tests of either ability influences both perspective taking *and* navigation or environment learning. This would be highly relevant to the general public, as user-representation is particularly prevalent in many navigation aids and mapping software used today. This is a rich area for further exploration, and this dissertation serves as a starting point for these future endeavors.

**A. Implications**

1. Theoretical Contribution

As noted above, separating and systematically varying the three steps of the spatial perspective taking process is a major theoretical contribution of the present work. Previous research on perspective taking has precisely examined factors that influence performance on perspective taking tasks, as reviewed earlier, but none have examined how and when these factors exact their influence. The findings from Experiments 1 and 2 of this dissertation vary factors that could influence perspective taking performance while simultaneously varying the difficulty of each of the three steps in the perspective taking process.

2. Empirical Contribution

The tasks for assessing survey knowledge presented in Experiment 4 provide an empirical contribution to the canon of spatial cognition experimentation. The heading matching and distance estimation tasks provide an efficient and direct measure of an individual's survey knowledge for a learned environment. These tasks are easy to employ in a variety of modalities. Here, they are based on a desktop computer display, but these tasks could easily be translated to virtual environment systems, or even to paper for practicality and applications in real world environments, potentially even in remote field work.

Additionally, Experiments 3 and 4 of this dissertation provide findings in support of the connection between perspective taking, navigation, and survey knowledge. Though this relationship is established in extant research, the present work adds to our understanding of this connection. Findings from Experiment 3 indicate that the connection between perspective taking and navigation abilities is particularly important to consider when navigation involves use of a map, and that more able perspective takers are affected by misalignment as much as less able perspective takers. This suggests that either more testing with other types of alignment needs to be conducted, or that the relationship between perspective taking and navigation is not driven primarily by alignment effects. Lastly, findings from Experiment 4 help to further elucidate the connection between perspective taking and survey knowledge, which we know to be correlated. This work shows that the ability to update heading and configurational knowledge are two factors that underlie both perspective taking and survey knowledge.

3. Practical Contributions

This research adds to the growing body of work on perspective taking, and its connection to navigation tasks (such as using a map to navigate and learning an environment). Much extant research indicates that there is a relationship between spatial perspective taking ability and environment learning. However, the nature of this relationship is underspecified. In the research presented here, a series of experiments examined this relationship in closer detail, further clarifying specific components that may unite perspective taking and navigation tasks (map use and environment learning). This is in turn has wide practical implications, a few being: mapping and navigation interface research, and potential applications for training perspective taking or environment learning ability. The insight gained from Experiments 3 and 4 can be used to inform both design of new navigation aids and modification of existing navigation aids, by demonstrating what components of navigation are facile and challenging specifically relative to the first-person perspective of the user.

Further, the insight gained from these experiments (specifically from Experiments 1 and 2) can be used to inform training for perspective taking, specifically at the pictorial scale and in terms of characteristics of cues used in the tasks. This research can also be used to inform navigation and environment learning training schemes, as Experiments 3 and 4 shed light on perspective taking as a potential source for indirect navigation and environment learning improvement. Findings indicate that perspective taking and navigation/environment learning are comorbid, and as such training of perspective taking could lead to improvement in map-based navigation or environment learning.

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# Appendices

Appendix A

Survey Strategy Questions—for all computerized SOTs

1. Other students have reported a range of strategies that they used to do these tasks. Please indicate which strategy is closest to the one that you used when doing each of the tasks. For this task what strategy did you use the most:
    a. I mentally superimposed the whole array of objects on the answer circle to formulate my answer.
    b. I superimposed the answer circle on the array of objects to formulate my answer.
    c. I imagined drawing the angle between the object I was facing, my imagined location and the target object. I then moved and rotated that angle and superimposed on the answer circle to formulate my answer.
    d. I imagined myself being in the array, at the location I was told to imagine, turning my body to the imagined facing direction and figured out where the target object would be in relation to my body.
    e. I did not use any of these strategies. I used the following strategy:

*Note*: The strategy questions were scored as follows: strategy choices a and b were coded as abstract, while choices c and d were coded as mental simulation. Any text entries were coded by two independent raters as either abstract or mental simulation.

Appendix B

Complete instructions for the three versions of the computerized SOT task. The bolded sections indicate a divergence from the control condition.

Control Task Instructions

This is a test of your ability to imagine different perspectives or orientations in space. In this task, you will see a picture of an array of objects with a statement below it, together with an “arrow circle”. You will be asked to imagine that you are standing at one object in the array and facing another object. Your task is to draw a line showing the direction to a third object from this perspective. On each trial, you will be asked to imagine standing at a different first object, facing a different second object, and then to draw a line to a different third object.

You respond by “drawing” a line on the arrow circle using the computer mouse. The center of the arrow circle represents your imagined location (at the first object) and the vertical arrow represents your imagined perspective (facing the second object). You need to draw the direction to a third object from this facing direction.

Look at the sample item below. In this example you are asked to imagine that you are standing at the bell facing the tree. Your task is to draw a line indicating the direction to the drum. In the sample item this line has been drawn for you. In the test items, your task is to draw this line on the arrow circle using the computer mouse. Can you see that if you were at the bell facing the tree, the drum would be in the direction shown by the dotted line? Please ask the experimenter now if you have any questions about what you are required to do.

Now you will begin practicing on the computer.

Press the SPACE BAR to continue.

Human Figure Task Instructions

This is a test of your ability to imagine different perspectives or orientations in space. In this task, you will see a picture of an array of objects with a statement below it, together with an “arrow circle”. You will be asked to imagine that you are standing at the location of a person in the array and facing an object. **Note the location of the person in the bottom right of the array. It is a top-down view of a person’s head and shoulders, and you can see the person’s nose which indicates their facing direction.** Your task is to draw a line showing the direction to a second object from this perspective. On each trial, you will be asked to imagine standing at the location of the person and taking the person’s perspective, facing a different object, and then to draw a line to a different second object.

You respond by “drawing” a line on the arrow circle using the computer mouse. The center of the arrow circle represents your imagined location (at the person) and the vertical arrow represents your imagined perspective (facing an object). You need to draw the direction to a different second object from this facing direction.

Look at the sample item below. In this example you are asked to imagine that you are taking the perspective of the person facing the tree. Your task is to draw a line indicating the direction to the drum. In the sample item this line has been drawn for you. In the test items, your task is to draw this line on the arrow circle using the computer mouse. Can you see that if you took the perspective of the person facing the tree, the drum would be in the direction shown by the dotted line? Please ask the experimenter now if you have any questions about what you are required to do.

Now you will begin practicing on the computer.

Press the SPACE BAR to continue.

Arrow Task Instructions

This is a test of your ability to imagine different perspectives or orientations in space. In this task, you will see a picture of an array of objects with a statement below it, together with an "arrow circle". You will be asked to imagine that you are standing at the location of an arrow in the array and facing an object. **Note the location of the arrow in the bottom right of the array. The arrow has a red dot, and should not be confused with the arrow in the "arrow circle".** Your task is to draw a line showing the direction to a second object from this perspective. On each trial, you will be asked to imagine standing at the location and in the direction of the arrow, facing a different object, and then to draw a line to a different second object.

You respond by "drawing" a line on the arrow circle using the computer mouse. The center of the arrow circle represents your imagined location (at the arrow) and the vertical arrow represents your imagined perspective (facing an object). You need to draw the direction to a second object from this facing direction.

Look at the sample item below. In this example you are asked to imagine that you are standing at the arrow facing the tree. Your task is to draw a line indicating the direction to the drum. In the sample item this line has been drawn for you. In the test items, your task is to draw this line on the arrow circle using the computer mouse. Can you see that if you were at the arrow facing the tree, the drum would be in the direction shown by the dotted line? Please ask the experimenter now if you have any questions about what you are required to do.

Now you will begin practicing on the computer.

Press the SPACE BAR to continue.

Appendix C

Navigation strategy questions presented to participants after completion of the experimental tasks from Experiment 3. Questions were formatted to allow for text-entry responses.

1) This is what some of the trials you completed in the first task looked like. In these trials, there was a map present on the screen during the maze task. In a couple of sentences, describe what your strategy was in the maze task when the map <u>was</u> present on the screen.
2) This is what some of the trials you completed in the first task looked like. In these trials, a map <u>was not</u> present on the screen during the maze task. In a couple of sentences, describe what your strategy was in the maze task when the map <u>was not</u> present on the screen.

## Appendix D

Instructions and items on the Santa Barbara Sense of Direction (SBSOD; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002).

This questionnaire consists of several statements about your spatial and navigational abilities, preference, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions
2. I have a poor memory for where I left things.
3. I am very good at judging distances.
4. My "sense of direction" is very good.
5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).
6. I very easily get lost in a new city.
7. I enjoy reading maps.
8. I have trouble understanding directions.
9. I am very good at reading maps.
10. I don't remember routes very well while riding as a passenger in a car.
11. I don't enjoy giving directions.
12. It's not important to me to know where I am.
13. I usually let someone else do the navigational planning for long trips.
14. I can usually remember a new route after I have traveled it only once.
15. I don't have a very good "mental map" of my environment.

*Note: each of the items above was shown with the following scale response option:*

strongly agree 1 2 3 4 5 6 7 strongly disagree