Characterizing Landmark/Turn Preferences in Spatially Ambiguous Conditions through Navigation in Immersive Virtual Environments

An honors thesis for the Department of Psychology

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Abstract

Turn decisions of participants under conditions in which instructed turn and landmark information were inconsistent with the actual environmental layout were assessed through simple virtual environments using a head mounted display. In particular, their tendency to prefer turn or landmark-based decisions as well as response time were correlated with measures of spatial ability, such as the FRS (German Questionnaire of Spatial Strategies) (Münzer & Hölscher, 2011); Questionnaire of Spatial Representation (Pazzaglia, Comoldi, & De Beni, 2000); and an abridged version of the Need for Closure (NFC) scale (Roets & Van Hiel, 2011). Results show that decision preferences and reaction time of participants depends on the distance between turns; individual spatial abilities and need for closure; positioning of landmarks; and order of presentation of trials. This study represents one of the first in characterizing such spatially ambiguous settings. Therefore, future directions in order to better capture relationships between individual differences and decisions made under this paradigm are discussed.

Keywords: *spatially ambiguous*, *turn/landmark-based decisions*, *virtual environments.*

1. Introduction

1.1. A Spatially Ambiguous Scenario and its Scarcity of Previous Investigation

Whether through walking or driving, one of the most cognitively demanding but regular tasks faced by people is way-finding in unfamiliar environments. Oftentimes, one may not have the appropriate technological arsenal to aid in navigation and may often rely on provided directions, either in a verbal or visual format, which may sometimes be incomplete or ambiguous. Let us take the former format in constructing a hypothetical scenario. You have been instructed, from your starting location, to turn right at the church to get to the school. After walking for a while, you see a church, but it is on your left. Further ahead, there is a right turn, but the building beside it is a sporting goods store, not a church. Which turn would you take in order to get to the school?

One can see that the discrepancy present in the above example is that the referred[1] landmark (i.e., the church) was actually by a left turn instead of being on the right in accordance with the directions. Thus, there is an incongruity between the instructions and the actual environmental layout. This conundrum seems to be a common human experience but is scarcely mentioned within the spatial cognition literature. Mani & Johnson-Laird (1982) studied the differences in mental representation of indeterminate versus determinate spatial relations; however, the ambiguity could be seen in the statements describing the positioning of various objects. Our example is one of, as referred to by Schneider & Taylor (1999), an emergent indeterminacy; that is, the individual does not realize the true nature of the instructions until he or she is within the environment. Schneider & Taylor (1999) varied the ambiguity by deliberately withholding in the instructions, for instance, landmark names that would normally guide participants to make the appropriate turn. Instead of stating *Turn at the high school*, the directions might read *Turn at the corner.* Thus, the individual was unsure of whether to turn left or right at a particular point. This indeterminacy, however, was studied in the context of determining the nature of learning and memory of the participants when placed in different degrees of spatial ambiguity. While the overall amount of errors was assessed, the pattern of behaviors taken by individuals at these decision points was not analyzed. Finally, spatial uncertainty has been studied in the context of path planning, which involves determination of the order of paths to take to reach a goal in the most efficient manner, where the efficiency is governed by probabilistic considerations (Weiner, Lafon, & Berthoz, 2008). Participants had to find an object, which could be in one of four spatial locations, before proceeding to the destination. Yet, the probability of the object at any one location was fixed. Furthermore, participants were sufficiently trained on the environment so that, on test trials, most visited the locations in a particular order based on their likelihood of containing the object. In the present study, participants are not provided with any information about whether or not they have correctly reached the destination; thus, there is no “best” decision.

1.2. An Overview of the Present Study

The present study is directly inspired from the scenario illustrated above. Namely, it involved a manipulation of ambiguity by displaying written directions to participants prior to their navigation through immersive virtual environments that either had landmark-turn congruency or landmark-turn incongruity (see Appendix F for examples of the latter). A concomitant study with the same procedure but involving decision choices based on a two-dimensional map was also conducted in the Spatial Cognition Lab at Tufts University, but this paper will mainly focus on the virtual environment study. A brief comparison between the two studies will be elucidated in the general discussion.

In all cases, the instructions to get to an unmarked destination were present on a wall in each environment; thus, the directions were not explicitly linked to any person. The environments were simplified from real-world analogues to simply include two turns from a straight path, each turn marked by a labeled landmark. Naturally, the turn that participants took on each ambiguous trial was recorded (i.e., the incorrect turn by the landmark referred to in the directions or the correct turn by the landmark not mentioned in the instructions). Equivalent trials of clear and ambiguous trials were present and intermixed in a pseudorandom fashion.

Furthermore, clear and ambiguous trials were split between ones with a short distance and those that had a long distance between turns. One might expect differences between decision choices as a function of distance. For example, using the original scenario, imagine that the left turn where the church is situated is far away from the right turn. The person may conclude that the turn instructions are incorrect and therefore will take the left turn (i.e., the landmark-congruent decision). However, if the left and right turns are close to each other, he or she may decide that the church is close enough to the right turn and thus take that turn (i.e., the turn-congruent decision). Furthermore, the long distance trial does not allow for initial viewing of the further landmark relative to the starting point, whereas the short distance trial immediately shows its ambiguity. Indeed, by the time the subject can identify the landmark at the second turn on the long trial, he or she is already halfway between both landmarks, and the cost of turning around becomes relevant to consider. That being said, after some initial trials, participants may discover that the two labeled landmarks are never the same, and so the ambiguity in the long inter-turn distance trial is revealed immediately, simply by viewing the turns and one of the labeled landmarks, in subsequent trials. Nevertheless, it is predicted that individuals on long-distance trials may be more inclined to choose one strategy[2], whereas on short-distance trials, less consistency in decision-making may be noted due to the lack of navigational cost in altering one's current strategy as well as the proximity of the landmarks to both turns, making both types of decisions appealing.

Apart from the decisions people make on ambiguous trials, other measures were collected. Reaction time and degree of horizontal head motion (yaw) were noted, as the virtual environment navigation employed a head mounted display for turning. In particular, one might expect participants to look from side to side more during at least the first ambiguous trial in order to ensure that no other landmarks or turns are present in the environment. Finally, participant's responses on a battery of administered questionnaires were compared to the behavioral data in order to see if any relationships occurred. Each of these questionnaires will be discussed in turn, with specific predictions of the relation between individual differences assessed by the psychometric measures and decisions on ambiguous trials suggested. Furthermore, the repercussions and benefits of conducting a navigational study in a virtual environment will be discussed, with emphasis placed on seeking to characterize and prevent the maladaptive effects from occurring.

1.3.Need for Closure

Naturally, the navigation trials of interest in this study involve directions framed in such a manner that no correct route to a destination can be determined. This ambiguity interacts with the nonspecific need for closure, defined as a motivational desire to seek a definite answer to a problem (Kruglanski & Webster, 1996). Specifically, the need for cognitive closure comprises two stages: (1) urgency, which involves seizing onto a conclusion, and (2) permanence, which results from maintenance of this belief, even in the face of inconsistent evidence (Kruglanski & Webster, 1996; Roets & Van Hiel, 2007). While this construct can be induced by time pressure, dullness of the task, or environmental noise, need for closure can be appreciated as an individual-differences variable (Webster & Kruglanski, 1994; Kruglanski & Webster, 1996). The original NFC scale has been abridged to a 15-item scale (Roets & Van Hiel, 2011) that still preserves the different features of the one-dimensional construct, namely dislike of ambiguity; predictability; order; decisiveness; and close-mindedness.

In the context of the study, individuals with a high need for closure, when placed in an ambiguous condition, may feel frustrated and be emotionally motivated to reach a quick conclusion and not alter their judgment or seek more extensive information processing (Van Hiel & Mervielde, 2002), with an opposite result expected for those with a low need for closure. When placed into a situation where the correct turn is unclear, those with a high need for closure may leap to consideration of heuristics, which has indeed been shown in the context of its social analogue, stereotypes (Webster & Kruglanski, 1994). For instance, those people may immediately call the validity of the instructions into question and then determine the likelihood of an incorrectly tabulated landmark or turn. The heuristic of availability may be employed in which the probability can be measured from prior experiences (Tversky & Kahneman, 1974). If the individual traditionally has viewed turns as more difficult to remember correctly, he or she may be propelled to choose the turn by the landmark, assuming that the instructions likely erred with the turn, but not the landmark.

Van Hiel & Mervielde (2002) operationalized information processing as the propensity to search for more additional information. Differences in information processing between individuals could be seen in alternative explanations for the ambiguity in the directions. Instead of immediately categorizing the directions as wrong, some subjects may conclude that they were meant for someone coming from the opposite direction. This spatial orientation (Hegarty & Waller, 2004) involves an egocentric positional transformation of oneself, while preserving the relations between objects and the environment. For instance, if the instructions of the original example referred to a person coming from the opposite side of the straight path, then the church would now be by the right turn. Thus, there is no ambiguity anymore. So, perhaps, individuals with low need for closure may have a greater propensity for this spatial perspective-taking. Notice, however, that this prediction would cause low need for closure individuals to predominantly choose the landmark-based turn on ambiguous trials, resulting in a one strategy stance as expected to be seen with high need for closure individuals. However, perhaps the spatial perspective-taking could be modulated based on distance between intersections. Thus, one may still expect differences in self-reported need for closure to manifest in the degree to which individuals alternate their decisions on ambiguous trials. Furthermore, it seems unlikely that high need for closure individuals will exhibit differences in turn choices on trials with short versus long distances between intersections, whereas low need for closure individuals are more likely to incorporate distance into their decision process, seeking out additional information under these ambiguous conditions (Van Hiel & Mervielde, 2002).

1.4. Survey vs. Route Representation

The other two questionnaires used in this study include the relatively recent German Questionnaire of Spatial Strategies (FRS, Münzer & Hölscher, 2011) and the Questionnaire on Spatial Representations (Pazzaglia et al., 2000). The latter allows for a differentiation of spatial representation tendencies between individuals, such as survey-centric, route-centric, or landmark-centric strategies. The former is similar to the Santa Barbara Sense of Direction Scale (SBSOD; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), except that it views mental map formation and proficiency in cardinal directions as separate constructs from general confidence in one's orientation abilities within an environment (Münzer & Stahl, 2011). Finding behavioral associations with survey-centricity may seem ill-advised since the main measure of the study involves assessing people's tendencies to select a destination based on a landmark or turn, both of which are more in line with route representations. Nevertheless, since the left-right distinction depends on an egocentric view, survey-minded individuals may be more likely to believe the instructions have erred on the turn rather than the landmark. Thus, less survey-centric individuals (i.e., more route-centric) individuals will be more likely to choose turns based on the instructed turn.

Nevertheless, from developmental studies (Siegel & White, 1975), knowledge of landmarks appears a basic aspect of the spatial representation of an environment for humans. Experiments have shown that people rely on landmarks when available for way-finding (Heft 1979; Foo, Warren, Duchon, & Tarr, 2005), and thus, in the absence of consistent spatial information, subjects may simply fall back to consideration of mainly landmarks under ambiguous conditions, regardless of their spatial representation tendencies. Other aspects of consideration include that survey-centric individuals likely have reasonably strong route representations, since configurational knowledge seems to involve integration of landmarks and routes into a holistic, externalized reference (Siegel & White, 1975). Finally, the directions are given in an egocentric fashion, encouraging the formation of at least an initial route representation. Nonetheless, mental representations from instructions have been shown to be somewhat independent of perspective (Taylor & Tversky, 1992). However, route representations generated from reading egocentric instructions have been shown to be somewhat inflexible, at least initially (Brunyé, Rapp, & Taylor, 2008), although this inflexibility as a function of individual differences in spatial preferences has not yet been studied. Nevertheless, when one considers spatial perspective-taking (Hegarty & Waller, 2004), one might consider that people with allocentric tendencies may have a greater propensity to view the environment from multiple individual orientations, producing more flexible representations and a set of decisions that appear landmark-based, which is in-line with the decision predictions outlined in the previous paragraph.

Furthermore, it is well-established that people with different spatial representations have differential performances on spatial tasks, due to their selective attention to certain environmental features (Thorndyke & Hayes-Roth, 1982; Pazzaglia & De Beni, 2001). For instance, people with a survey-centered representation may be better versed in judging distances between landmarks compared to people with route-centered representations. However, since both types of individuals will undergo first-person navigation, it is likely that both will incorporate distance into their decision, the degree to which may depend on their need for closure.

1.5. Positive and Negative Effects of Immersive Virtual Navigation

The use of virtual environments (VE) for navigation was done in order to better externalize to real-world navigation (Richardson, Montello, & Hegarty, 1999). For instance, the distance between intersections will likely produce a greater effect in decision choices on a first-person navigation task as opposed to a map, for participants can appreciate the distance in the former format through the time required for traversal. Turning in each environment was accomplished through rotation of the head, allowing the user to take a more active role in navigation. However, VE navigation, particularly with a head mounted display, can invariably produce sickness, particularly in a population that has traditionally not been screened for motion-sickness susceptibility (e.g., compare the Air Force to the civilian population). However, since no actual translational motion of the subjects is involved, the probable symptoms exhibited do not correspond to motion-sickness, but closely-related simulator-sickness (Kolasinski, 1995). This polysymptomatic syndrome can be quantified through the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993), which splits this construct into different dimensions, such as nausea; oculomotor (e.g., eye strain); and disorientation factors. McCauley & Sharkey (1992) found that longer exposure times to the VEs increased the likelihood of reporting symptoms. Indeed, Regan (1993) noted that the sickness symptoms increased in severity from initial exposure to 20 minutes post-exposure. Thus, it was thought that a reduction of the amount of continuous exposure to the VE would help ameliorate the malaise brought on by the immersive experience. As a result, participants completed off-the-VE tasks at certain points, which were unrelated to the present study. Furthermore, while the SSQ was originally designed to be assessed post-exposure only, it was done so with an Air Force population in mind, who are vastly different from the civilian population (Kolasinski, 1995). Thus, the SSQ was administered pre- and post-exposure.

1.6. Predictions of the Present Study

Ultimately, it is hoped that this discussion revealed the exploratory nature of the study. Since this specific type of paradigm is underrepresented in the literature, only general predictions about people's behaviors and their relation to spatial abilities may be drawn, which no doubt represents an important and necessary first step. Clearly, although need for closure has been traditionally viewed as a non-spatial construct, it seems to offer the most straight-forward applicability to the current study, while the other constructs remain more speculative. An additional ancillary investigation can be done into the validation of the FRS questionnaire in comparison to the Questionnaire for Spatial Representation, as the former is relatively new in its use and shares similar subscales to the latter. The important predictions are outlined below as follows:

(1) A difference should be seen between people's turn choices on short, as compared to long, distances between intersections. Specifically, people should be less inclined to change strategies on long distances between intersections.
(2) High self-reported need for closure individuals should vary their choices less than low self-reported need for closure individuals (i.e., consistently choose the turn that either coincides with the instructed landmark or turn) and should be less likely to change their decision preference based on the distance between intersections.
(3) Survey-centric individuals should tend to select turns based on the referred landmark more so than route-centric individuals.
(4) Ambiguous trials should take longer to navigate on average than clear trials, an effect that should be modulated by need for closure, with high need for closure individuals having less of a relative increase in reaction time for ambiguous trials, indicating lesser information processing.

2. Method

2.1. *Participants*:

Twenty undergraduate students from Tufts University (*M*= 20.45 years, *SD*=1.57), nine males and eleven females, performed this study for monetary compensation. Prior to the study, a common video game experience questionnaire had to be completed (Basak, Boot, Voss, & Kramer, 2008). There were 9 self-reported gamers (6 males and 3 females) and 11 non-gamers (3 males and 8 females) who differed in their video game exposure (*M*=1.98 and *M*=0.886, respectively, on a scale from 0-3). The difference was statistically significant ($t(18) = 3.29$, $p= 0.0041$).

2.2. *Materials*:

2.2.1 Virtual Environments

Sixteen different virtual environments were employed for the study. Each environment was created using the Unreal Tournament video game editor (Unreal Engine 2 by Epic Games, Raleigh, NC) (see Appendix F for a 2-D images of a sample environment). Each environment contained an enclosure where the participant would begin his or her navigation. The walls of the enclosure were of a height to prevent viewing the rest of the environment. Directly in front of the subject's starting position was instructions, all of which were of the same format: To get to *X* [name of destination], turn left/right at *Y* [name of landmark]. The actual environment could be reached by passing through the wall containing instructions. Each environment consisted of a linear path with two turns, each of which was fronted by a labeled building. The exterior of all the buildings was homogeneous and non-salient. Thus, the only means of differentiation between buildings lay in the labels, all of which were generic, everyday places (no proper nouns were used). One of the buildings by the intersections corresponded to building *Y* in the instructions, while the other building was not previously referred. The two turns proceeded in different directions from the linear path, so there was a right turn and left turn in every environment. The end of each turn had a building marked by a question mark. Immediately preceding each "mystery" building was a flag that served as a trigger to record the intersection decision of the participant when he or she walked through the flag.

2.2.2. Controls

In order to closely simulate real-world immersion, navigation was accomplished through Vuzik Wrap 310XL video goggles, with a 55-inch virtual screen. This eyewear allowed for rotational movement of the user's head to translate into the environment. So, in order to turn left, the subject simply had to turn his or her head left. Note that the stereoscopic function of the goggles was disabled. To allow for translational motion, a Nintendo WiiMote was paired via Bluetooth and an emulator software Dolphin to the computer. An additional program, Glovepie 3.0, mapped the directional pad on the controller to the W, A, S, and D keyboard keys, which are traditionally the controls for in-game navigation. Thus, the participant simply had to press the appropriate directional button on the WiiMote to proceed in that direction. It is important to note that participants were standing while navigating through the environments, a product of the controls used.

2.2.3. Video Game Experience

A video game experience questionnaire was slightly modified from its previous use (Basak et al., 2008). Given the use of head turning for rotation in the environment, a question assessing the extent of participants' experience with motion-control video game systems (e.g. Kinect) was deemed prudent, measured on the same scale as the other questions. Furthermore, a forced-choice, yes-no question involving any previous experience with virtual reality was added, since this entertainment medium consists of immersion into an environment with similar intensity as is accomplished by the Vuzik goggles.

2.2.4. Simulator Sickness Measures

The Simulator Sickness Questionnaire (Kennedy et al., 1993) (see Appendix D) was administered to obtain the extent of nausea, oculomotor, and disorientation symptoms before and after the virtual navigation. To reduce the length of continuous exposure to the immersive virtual environment, paper-and-pencil distracter tasks were implemented at certain time periods and consisted of Hidden Picture Puzzles, where items to be searched are blended within a complex visual stimulus (see Appendix E for one of the Hidden Picture Puzzles used).

2.2.5. Post-Experiment Questionnaires

A variety of spatial ability questionnaires were administered on SuperLab after participants had completed the navigation portion of the experiment, including the German Questionnaire for Spatial Strategies (FRS; Münzer & Hölscher, 2011), Questionnaire of Spatial Representation (Pazzaglia et al., 2000), and the abridged form of the Need for Closure Scale (Roets & Van Hiel, 2011). Additionally, questions directly regarding aspects of the navigation were asked (forming the Retrospective Questionnaire) (see Appendix B), requiring ratings on a Likert 1 to 7 scale. The questions of primary interest were: (1) *To what extent did you attend to the turn information (left/right) (1- not at all… 7-very much)*? (2) *To what extent did you attend to the landmark information (such as buildings) (1- not at all… 7-very much)?* (3) *If the instructions were inconsistent or ambiguous, to what extent did you prefer the landmark or turn (1-turn…4-no* *preference…7-landmark)?* and (4) *To what extent did you imagine yourself walking through the environment (1-not at all…7-very much)?* An additional question was intermixed with the Questionnaire of Spatial Representation (see Appendix C): *To what extent do you tend to mix up left and right* (*1- not at all… 7- very much*)? Finally, a short answer question queried as to the general strategies that people used to locate the destination and the rationales for their decisions.

2.2.6. Automated Measures

The Unreal software outputs the three-dimensional coordinates of the player during navigation, the corresponding time, and pitch; roll; and yaw motions. Additionally, messages about when participants entered the actual environment (through the enclosure) and when they touched a trigger to designate the destination were recorded in the user log.

2.3. *Design*

For eight of the sixteen environments, instructions gave information consistent with the environment. The other half gave ambiguous directions, where the instructed turn did not correspond to the available turn by the named landmark in the actual environment. Furthermore, within the clear and ambiguous trials, half had short distances between the two intersections, while the other half had the intersections separated by a long distance. Indeed, in the long condition, the subject would not be able to read the landmark label until he or she was at least halfway between the two intersections. The directional ordering of turns along the path relative to the starting point (that is, a left followed by right turn versus a right followed by left turn) and the positioning of the landmark referred to in the instructions on either the first or second turn relative to the starting point were both controlled. Thus, this study was a 2 (ambiguity: consistent, ambiguous) x 2 (distance between intersections: short, long) x 2 (directional ordering of the turns: right-then-left, left-then-right) x 2 (positioning of referred landmark: named landmark by first turn, named landmark by second turn) within-subjects design. Each condition was represented by one environment in the study. The order of the sixteen environments was pseudo-randomized to create one participant group, with the other group undergoing experimental trials in the opposite order.

2.4. *Procedure*

During recruitment, participants completed the video game experience questionnaire via email. Once they arrived at the lab, subjects completed a consent form. Subjects also filled out the SSQ, with any significant results indicating sickness symptoms unrelated to virtual environment exposure. They were told that the study was interested in how people used route directions to get to a destination, with the general layout of each environment and specific task (i.e., *touch the flag by the mystery building that you feel best represents the correct location of the destination*) elucidated. Importantly, subjects were instructed that they had to make a choice within a given environment, even if they were not sure. However, there was no explicit mention that some of the directions would provide inconsistent information. After this brief explanation, participants placed the goggles over their eyes and looked straight ahead in an upright posture to calibrate the goggles to their eye level via the Vuzik computer program.

Participants were then placed in a practice environment to familiarize themselves with the controls and the environmental layout, namely the intersections and the triggering flags. Practice trials started in an enclosure initially, as in the actual trials, but with no instructions. Additionally, the practice environment buildings did not have labels. After the participant navigated through both turns successfully, the actual experiment was started. Each time the participant touched the flag by the chosen intersection, they were placed into a new environment. After every four trials, they were given a break from the goggles, whereupon subjects were asked to complete a paper-and-pencil Hidden Pictures Puzzle. They had to find as many of the instructed items in the picture as they could within one minute (see Appendix E). After the time elapsed, subjects continued the experimental trials. A different Hidden Pictures Puzzle was used for each break (three in total).

After the last trial, participants again filled out the SSQ to evaluate their post-exposure symptoms. They then completed a series of questionnaires on the computer, and upon completion, were thanked for their participation and compensated. No debriefing form was provided, although participants were asked if they had any questions about the experiment.

3. Results

3.1. Validation of Spatial Questionnaire Subscales

The FRS questionnaire was split into the Global-Egocentric (G-E) scale, the survey scale, and cardinal directions scale in accordance with Münzer and Stahl (2011). Furthermore, the Questionnaire of Spatial Representations was divided into five factors as outlined by Pazzaglia and De Beni (2001): general sense of direction, survey perspective, route perspective, landmark perspective, and compass orientation. A differential score was created for participant's responses to survey and landmark-centered questions (Survey-LM) as well as survey and route-centered questions (Survey-Route). Developmental evidence has shown that an allocentric representation emerges last (Siegel & White, 1975), and thus people who tend to exhibit a survey representation may also have strong route and landmark representations. Thus, the differentials may prevent confounds from emerging in categorizing people as landmark-centered or route-centered based simply on consideration of the individual landmark or route subscales. As for the abridged NFC scale, it could be equally split into its different realizations of ambiguity, predictability, decisiveness, order, and close-mindedness, but the items that represent each facet (e.g., ambiguity) were selected from the original questionnaire based on their representation of the overall NFC construct rather than their specific category. Thus, the abridged NFC scale does not lend itself to consideration of individual factors, but rather to the overall construct only (Roets & Van Hiel, 2011).

As both the FRS G-E and Sense of Direction factors involve general confidence in one's ability to orient in an environment, it is unsurprising that a high correlation was seen in participants' responses on both factors (R^2=0.7907, p<0.01). Furthermore, the responses to the Survey subscale of the FRS was strongly predictive of scores on the survey-centered factor of the Questionnaire for Spatial Representations (R^2= 0.6263, p<0.01). Interestingly, there was no inverse relationship between the scores on the landmark-centered factor and the survey factor (R^2=0.01, p=0.67), while a moderate curvilinear relationship was seen between the route-preferential factor and the survey factor (R^2= 0.3203). Based on these findings, people with high survey scores may tend to respond favorably to landmark-centered and route-centered questions regarding one's spatial representations, while the opposite pattern does not hold. When regression analyses were conducted with the differential scores, a moderate, positive correlation was seen with Survey-LM and the survey subscale of the Pazzaglia questionnaire (R^2=0.4066, p<0.01). Furthermore, scores on the survey subscale were found to be a good predictor of the Survey-Route dimension (R^2=0.62702, p<0.01). Both of these correlations justify the use of these differential scores. Finally, there was a strong correlation between the FRS cardinal directions and compass orientation subscale within the Spatial Representation Questionnaire (R^2=0.7062, p<0.01).

3.2. Regression Analyses of Average Intersection Choices on Ambiguous Trials

Unsurprisingly, every participant chose the correct destination when given directions congruent with the environment. To assess destination choice for ambiguous trials, we coded destinations consistent with the instruction's turn direction as 1 (turn-congruent decision), and those by the named landmark were scored as -1 (landmark-congruent decision). We then averaged the ambiguous trial choices for a given participant (either -1 or 1). This average decision tendency was compared to the self-reported scores on the retrospective questionnaire. Naturally, a negative correlation was seen between average intersection choice (range from -1 to 1) and self-reported preference for landmarks under ambiguous trials (R^2=0.42633, p<0.01) (see Figure 1 in Appendix A). That is, on the ambiguous trials, people with a higher preference for landmarks had a greater tendency to choose landmark-congruent turns. Additionally, the average decision turn choice ranging from -1 to 1 was found to positively predict a subject's self-reported attention to turns (R^2=0.3559, p<0.01). Only a weak positive correlation was found between turn choice and overall attention to landmarks (R^2=0.1633, p=0.086), indicating that perhaps landmarks serve as a more salient guide for route choice than turns. Participant's decisions, on average seemed unrelated to their tendency to mix up left and right (R^2=0.0043, p=0.78).

3.3. Within-Subject Comparisons on Distances between Intersections, Positioning of Landmarks, and Order of Directionality of Turns

Across all participants, there was a significant difference ($t(19)$=-3.47, p<0.01) between decision choices for long (M=-0.675) and short distance trials (M=-0.15), the former of which involved more landmark-congruent turns. The differences between long and short distances between turns became more pronounced (*M*=-0.625 as compared to *M*=0.25, respectively), when only those participants that switched their decisions between instructed landmark or turn congruency at least once during ambiguous trials (12 subjects) were considered ($t(11)=-4.47$, $p<0.001$) (see Figure 3 in Appendix A). Thus, people were far more likely to predominantly choose landmark-congruent turns on trials that contained long distances between turns. Interestingly, comparison of the absolute value of the choices on the different inter-turn distances only trended towards significance (*M* of long=0.71 and *M* of short=0.5; $t(11)=1.45$, $p=0.17$) (see Figure 4 in Appendix A), suggesting that, on average, subjects may have decided on the turn in the same direction as was mentioned in the directions more often than not for short intersection trials, whereas on long intersection trials, they may have been more inclined to choose the landmark-congruent turn. Paired t-tests revealed no difference in people's choices for ambiguous trials that varied in the order of direction of turns ($t(19)= 0.27$, $p= 0.79$) but did reveal a trend towards significance for those trials that varied in positioning of landmarks ($t(19) = 1.93$, $p=0.069$). There was a trend towards subjects being more likely, on average, to choose the turn corresponding to the referred landmark in ambiguous trials when that landmark was on the second turn (*M*= -0.55) than when the landmark was on the first turn (*M*= -0.275). The absolute value of the average decision choice for ambiguous trials overall was compared between the two types of trials. A paired t-test revealed a significant difference regarding the position of the referred landmark in tendency of subjects to choose one strategy (*M*=0.8 when landmark on second turn compared to *M*=0.575 when landmark on first turn, $t(19)=2.44$, $p=0.025$) (see Figure 5 in Appendix A). Finally, a positioning of landmark x distance between turns Generalized Linear Model ANOVA revealed no interaction ($F(1,1) = 2.021$, $p=0.171$).

3.4. Between-Subject Comparisons for Experimentally Assigned Groups

Participants were randomly assigned to either one of two experimental conditions, which differed in the order of presentation of the environments (one was a complete reversal of the other). Group 1 had a lower average tendency to choose turns based on the instructed landmark (M= 0.175) as compared to Group 2 (M= -0.7), a difference that was significant ($t(18) = 2.44$, p=0.0253) (see Figure 6 of Appendix A). This pattern extended towards comparison of choices on ambiguous long distance trials ($t(10) = 2.43$, p=0.0357) but trended on short distance trials ($t(18) = 1.82$, p=0.085). A mixed modal ANOVA revealed no interaction of inter-turn distance (within-subjects variable) and experimental groups (between-subjects variable) ($F(1,1) = 0.060$, p=0.809). The absolute value of the decision choices between experimental groups showed that Group 2 tended to exhibit decisions based on consideration of only one factor (M=0.85) more so than Group 1 (M=0.55) on trials with short inter-turn distances ($t(18)$=2.15, p=0.045), with a trend towards significance seen on trials with long inter-turn distances ($t(13)$=2.06, p=0.060). Experimental group x intersection distance mixed modal ANOVA for tendency to choose one strategy revealed no main effect of intersection distance ($F(1)$=1.923, p=0.182) and no interaction ($F(1,1)$=0.077, p=0.785). Group 2 had a greater self-reported preference to landmarks than Group 1 on ambiguous trials ($t(11) = 3.03$, p=0.0114). In a somewhat counterintuitive fashion, Group 2 also had a higher FRS Survey subscale score than Group 1 ($t(18) = 2.15$, p=0.046). Finally, experimental group x landmark position mixed modal ANOVA for average decision choice produced no significant interaction ($F(1,1)$=1.547, p=0.229), but significant interaction was present for tendency to choose one strategy ($F(1,1)$=10.565, p=0.004), where Group 2 seemed to choose one strategy irrespective of landmark position, while Group 1 was more variable in their strategy at the first landmark position but not at the second landmark position (see Figure 7 of Appendix A).

3.5. Median Splits of Average Decision Choices for Comparison to Questionnaire Scores

A 7-7 split on average decision choice was made, with one group consisting of those that had only chosen turns congruent to the referred landmark (decision score of -1) and the other comprising subjects that had frequently chosen alternate types of turns (decision score of either 0 or -0.25). Groups were compared across the different subscales assessed, with the landmark-based strategy group appearing to have a lower need for closure score than the multiple strategy group ($t(12)=-2.08$, $p= 0.05957$). With the retrospective questions, it comes to perhaps little surprise that the landmark group was associated with more overall attention to landmarks ($t(6)=2.83$, $p= 0.0300$) and tended to prefer landmarks to turns when given ambiguous directions (t(6)=2.83, $p= 0.0300$).

Performing a median split on the absolute value of decision scores for ambiguous trials overall results in one group with alternating strategies (scores of 0 to 0.5) and another that chose mostly only either landmark or turn-congruent decisions (scores of 0.75 and 1). A significant result is seen for number of strategies on short intersection distances only ($t(18)=4.87$, $p<0.01$), where the single-strategy group tends to consistently choose the same type of turn for short intersection distances ($M=0.95$) as compared with the alternating-strategy group ($M=0.45$). A trend towards significance in the same manner is seen with long distances between turns only ($t(13)=2.06$, $p=0.060$).

3.6. Gender Differences on Decision-Based Turn Choices and Questionnaire Responses

11 females and 9 males participated in this study, which does not provide equivalent gender groups and thus may have affected the power of some of the statistical analyses performed. No differences were found with respect to the behavioral data. Males had a greater FRS cardinal directions score and Pazzaglia compass factor score than females ($t(18)=2.36$, $p= 0.03$ in both cases). In contrast to the established literature (Biocca, 1992; Kennedy & Frank, 1995), males reported more simulator sickness symptoms ($M= 22.9$) due to virtual environment exposure than females ($M= 3.06$), a difference that was statistically significant ($t(9)=2.24$, $p= 0.047$).

3.7. Response Time Differences on Ambiguous and Clear Trials

Each line of the Unreal software's user log outputs contain the time, given up to the millisecond value, and rotational data for every movement of the user. Thus, the time elapsed from the beginning of each trial to the entrance of the actual environment (that is, after the subject passed through the initial enclosure containing the directions) was noted, which was thought to provide a measure of the time required for reading the directions (henceforth to be called "reading RT", where RT is response time). Additionally, the time from the entrance to the environment to the activation of the endpoint trigger at the end of a particular turn (henceforth to be called "navigation RT") could also be tabulated. It was thought that participants might spend more time reading the directions on the trial subsequent to the first ambiguous trial in order to ensure that the directions were not misread. However, no such difference was noted; reading RT for the critical trial was 4.23 seconds, while mean reading RT of the remaining trials was 3.73 seconds ($t(19)=1.54$, $p= 0.14$).

A paired t-test comparing the average navigation RT of ambiguous and clear trials revealed that participants took significantly longer ($t(19)=6.16$, $p<0.01$) to complete ambiguous trials ($M= 21.5$ s) than clear trials ($M= 15.1$ s) (see Figure 8 of Appendix A). This relationship also occurred when comparing only trials with short distances between turns or long distances between turns. A differential navigation RT score was computed by subtracting the average RT of clear trials from that of ambiguous trials in order to control for individual differences in speed of completion as well as differences in environmental length. This measure represents relative increase in RT, on average, for ambiguous trials as compared to control trials. This computation was extended towards trials with only short inter-turn distances and only long inter-turn distances. When these values were compared against one another, participants significantly differed ($t(19)=-3.32$, $p<0.01$) on the magnitude of their average increase in RT for ambiguous trials compared to control trials that were matched on their length. Namely, people spent less additional time relative to unambiguous analogues navigating ambiguous, short distance trials ($M= 3.35$ s) than ambiguous, long distance trials ($M= 9.42$ s) (see Figure 9 of Appendix A).

A median split was conducted for the average relative increases in RT on ambiguous trials overall, creating two equivalently-sized groups. People with a low increase in RT have a significantly greater tendency ($t(18)=3.73$, $p<0.01$) towards consistently making a decision ($M=0.85$) based on congruency to either the landmark or turn referred to in the directions as opposed to those with a greater increase in RT ($M= 0.325$) (see Figure 10 in Appendix A). The high RT group tended to imagine themselves walking through the given environments more so than the low RT group (M= *5.2* compared to $M= 3.7$, respectively; $t(18)=2.02$, $p=0.059$). Finally, the low RT group trended towards reporting a greater attention to landmarks than the high RT group ($t(18)=1.88$, $p= 0.07664$), a pattern that makes sense since the low RT group tended to be comprised of individuals that chose based on one strategy, which is then mostly congruency with the instructed landmark, as far as long distance trials are concerned. Interestingly, a significant between-groups difference is seen with relative RT increases on long distance trials only ($p<0.01$) but not on short distance trials only ($p=0.44$).

A mixed modal ANOVA looking at high/low overall RT increase x intersection distance revealed a significant interaction ($F(1,1) = 11.597$, p=0.003) (see Figure 11 in Appendix A). There was a much larger difference in relative RT between long and short ambiguous trials for the individuals with high overall relative RT compared to those with low overall relative RT. Looked at another way, the difference in RT for short distance ambiguous trials was not as pronounced between the two groups as it was for the long distance ambiguous trials.

Interestingly, when a similar median split is conducted for relative increases in RT for ambiguous trials with short distances between intersections, a trend towards significance ($t(11)=1.89$, $p=0.086$) is observed with respect to decision preferences for ambiguous trials with long inter-turn distances. Its direction is in the manner by which people with a high RT for ambiguous, short trials have a much greater tendency to choose the landmark-congruent turn on ambiguous, long trials. Unlike the overall RT split, no relationship was seen with overall attention to landmarks, although people with high RT for short intersections tended to imagine themselves walking through the environment more so than those with low RT (M= 5.3 and M= 3.6, respectively; $t(18)=2.37$, $p=0.03$). It is important to note that 20% of the participants had either equivalent or lower RTs on average for short, ambiguous trials as compared to matched unambiguous trials. Obviously, a median split for long distance RT increase produced a significant relationship between groups for overall RT increase ($t(12)=4.69$, $p<0.01$), but not for RT increase on short distances between intersections ($t(18)=0.3984$, $p=0.70$). A trend towards significance ($t(18)=-1.83$, $p=0.08$) is observed for people with a low RT increase on ambiguous long trials making a greater proportion of decisions based on the referred landmark ($M=-0.45$ compared to $M=0.15$). As expected, low long intersection RT increase leads to choosing a predominantly singular strategy ($t(18)=2.68$, $p=0.015$) as compared to the other group on overall ambiguous trials. Considering the preference of landmarks to turns in the average decision distribution, it is unsurprising that the low long intersection RT increase group reported more overall attention to landmarks than the other group ($p=0.026$) and a greater preference to landmarks than turns on ambiguous trials ($p=0.039$).

In comparing the two experimentally assigned groups on their relative navigational RT for ambiguous trials, Group 1 trended towards having a higher RT ($M=$ 7.86 s) than Group 2 ($M=4.91$ s). While the difference is not statistically significant ($t(18)=1.47$, $p=0.16$), more subjects may provide greater statistical power, and the result would make sense in the context of Group 2 tending towards a landmark-based, singular strategy more so than Group 1. Subjects had a lesser relative increase in RT for ambiguous trials containing the referred landmark on the second intersection ($M=4.02$ s) compared to those containing the referred landmark on the first intersection ($M=$ 8.74 s), a difference that was statistically significant ($t(19)=-2.17$, $p=0.043$).

3.8. Video Game Experience Differences on Behavioral and Self-Report Measures

Again, 9 gamers and 11 non-gamers prevented equivalent sizes of groups for comparison. On average, gamers trended towards a lower increase in response time for ambiguous as compared to control trials for environments that had large distances between turns ($t(18)=-1.79$, p= 0.09102). Finally, there was a trend towards more males being gamers than females ($\chi^2(1,1) = 3.841$, $0.10<p<0.05$). Unfortunately, the proportion of different responses to the added questions regarding experience with motion control gaming and a virtual reality machine prevented assignment into groups for a median split.

3.9. The Characterization of SSQ Responses and the Effects of Different SSQ Levels on Navigation Behavior and Spatial Abilities

The nausea, oculomotor, and disorientation scores for each participant were determined, from which a weighted score for each category and an overall SSQ score could be accomplished, as outlined by Kennedy, Lane, Berbaum, & Lillenthal (1993). Scores were determined for before and after the virtual environment navigation. Paired t-tests revealed significant increases in oculomotor weighted scores ($t(19)=2.15$, $p=0.045$), disorientation weighted scores ($t(19)=3.13$, $p<0.01$), and SSQ weighted scores ($t(19)=2.61$, $p=0.017$) post-exposure. An SSQ difference score was tabulated for each participant (SSQ weighted score pre-exposure subtracted from the SSQ weighted score post-exposure), all of which was subjected to a 9-9 median split (median was 3.74, which were two data points and were thus not considered in either group). Interestingly, this split revealed one group that either had no difference in their pre- and post-exposure symptoms or had less post-exposure symptoms. However, no difference was seen between the two groups on any self-report or behavioral data, indicating that although simulator sickness was seen due to VE exposure, it did not affect any of the measures of interest.

3.10. Yaw Differences in Ambiguous as Compared to Control Trials

Yaw is defined as lateral head motion, which was expected to be greater in participants during their first exposure to an ambiguous trial as compared to a matched control[3]. However, the standard deviation of the yaw was not significant, although it actually trended towards increased variability for the matched control ($p=0.076$).

3.11. Comparison across Spatial Abilities Scales through Median Splits

A median split of participants (median of 4.75) into equal groups of low FRS global-egocentric scores and high FRS global-egocentric scores was conducted. The former group was found to have significantly ($t(18)$-4.85, $p<0.001$) lower Pazzaglia sense of direction scores (M=3.33) than the latter group (M=4.95), which makes sense considering both subscales are highly correlated and measure similar factors. A trend towards significance ($t(18)=1.80$, $p=0.088$) was seen with participants with low FRS global-egocentric scores having a greater tendency to mix up left than right (M=3.9) than those with high FRS global-egocentric scores (M=2.1). Interestingly, significant differences between the two groups was seen with the FRS survey ($p=0.037$) and cardinal directions ($p<0.001$) subscales, with the high FRS global-egocentric group having higher scores across both factors. Thus, even though the FRS is explicitly meant to separate these different aspects of spatial proficiency, it seems that they are still closely linked. Indeed, regression analyses conducted between FRS global-egocentric scores and survey reveals a moderate positive correlation (R^2= 0.3837, $p<0.01$), with a similar result for the cardinal directions scores (R^2=0.3052, $p=0.01$).

A median split of participants into high and low FRS survey scores showed an interesting difference between the group's decisions, on average, for only ambiguous trials with long inter-turn distances. There was a trend towards significance ($t(11)=-1.89$, $p=0.086$) for the high FRS survey group to tend to choose the landmark-based turn (M= -0.9) more so than the low FRS survey group (M= -0.45). When the FRS survey factor and survey perspective subscale of Pazzaglia et al. (2000) questionnaire were averaged for each subject to form a composite survey score, the above relationship became significant ($t(10)= -2.43$, $p=0.036$). By contrast, the decision preferences for short ambiguous trials were insignificant ($p=0.78$) (see Figure 12 in

Appendix A). A median split produced a trend towards significance ($t(13)=2.06$, $p=0.060$) with high survey composite group tending towards one strategy ($M=0.95$) more so than low survey group ($M=0.7$) for long distance trials. In contrast, short distance trials produced no differences in tendency to employ alternative behaviors ($p=1$, respectively). However, a mixed modal ANOVA of intersection distance x survey composite group showed no significant interaction ($F(1,1)=2.36$, $p=0.142$). A greater NFC score of the high FRS survey group ($M= 3.98$) as compared to the low survey group ($M=3.51$) approached significance ($t(18)=1.89$, $p=0.075$). Median splits of both the FRS survey score and FRS cardinal directions score showed significant relationships with the sense of direction subscale, along with the FRS global-egocentric subscale as mentioned before. The former result can be explained by the encompassing nature of the sense of direction subscale.

Splitting the Sense of Direction scores among its median, expected mean differences between each of the subscales of the FRS were found (e.g., the higher sense of direction group had higher FRS survey scores, $t(18)=2.78$, $p=0.0121$). However, only the compass subscale of the Pazzaglia questionnaire produced a close to significant finding ($t(18)=2.01$, $p= 0.059$); the higher sense of direction group showed higher compass scores ($M=4.67$) compared to the poorer sense of direction group ($M=3.23$). Since the Pazzaglia questionnaire has been divided into five separate factors for analysis (Pazzaglia & De Beni, 2001), one might expect no significant relationships between the other four factors upon doing a median split on one factor, although sense of direction is a broad factor. Nevertheless, the survey composite factor yielded significant group differences ($t(18)=2.24$, $p=0.038$). Those people with a lower sense of direction reported a greater likelihood of mixing left and right ($M=4$ compared to $M=1.67$; $t(18)=2.90$, $p<0.01$).

Finally, the higher sense of direction had a significantly ($t(18)=2.18$, $p=0.043$) higher need for closure ($M=4.01$) compared to the lower sense of direction group ($M=3.49$).

The median split among the Survey-Route scores produced one group that either had a greater route perspective score or had equivalent tendencies to engage in survey and route-specific processing; the other group had higher preferences for survey representations. Thus, the latter was survey-centric, while the former was not survey-centric, but for the purposes of the median split, could be considered route-centric. An analogous explanation can hold for the differential groups formed by performing a median split on the Survey-Landmark scores. In comparing between Survey-Route groups, there was a trend towards significance ($t(18)=1.80$, $p=0.088$) for the survey-centric group to report more mixing of left and right ($M=3.9$) than the non survey-centric (route-centric) group ($M=2.1$) (see Figure 13 of Appendix A). Interestingly, differences in FRS survey scores between the two groups was non-significant ($p=0.14$), in contrast to the survey subscale of the Pazzaglia questionnaire ($t(12)=2.69$, $p=0.010$).

The bottom 7 and top 7 Survey-Landmark scores were placed into groups, as the division allowed the former to be better comprised of subjects that were landmark-centered (e.g., stronger landmark representations than survey representations) and the latter for subjects that were survey-centered. Differences between the FRS and Pazzaglia survey scores were seen in the expected direction, where the survey-centered group had significantly higher scores ($p<0.01$ in both cases) than the landmark-centered group. Furthermore, the landmark-centered group had significantly stronger landmark representations as evidenced by the landmark subscale ($M=6.14$ as compared to $M=4.29$; $t(12)=3.58$, $p<0.01$). Additionally, differences were seen in the survey-route scores, with the landmark-centered group having greater tendencies to predominate in route representations ($M=-1.67$) as compared to the survey-centered group ($M=0.5$), $t(12)=-2.76$;

p=0.02. Finally, the survey-centered group had higher need for closure (*M*=4.08) as compared to the landmark-centered group (*M*=3.31), a difference that was significant (*t*(12)=2.65, *p*=0.021). Interestingly, the survey-centered group reported significantly stronger preferences for landmarks on ambiguous trials compared to the landmark-centered group (*t*(6)=3.58, *p*=0.0117) and trended to making landmark-congruent decisions more so (*M*=-0.9286) than the landmark-centered group (*M*=-0.3571) on long distance trials (*t*(7)=-1.84, *p*=0.11).

A 9-9 split of the compass scores into two groups, where the middle two data points were ignored, showed the low compass oriented group having lower FRS global-egocentric scores than the high compass oriented group (*M*=4.12 compared with *M*=5.14; *t*(16)=-2.77, *p*=0.0136). Since FRS global-egocentric scores are highly correlated with sense of direction, it is no surprise that significant differences were seen with the sense of direction subscale (*M*=4.74 in the high compass oriented group as compared to *M*=3.52 in the low compass oriented group; *t*(16)=2.59, p=0.02).

Finally, a median split between the NFC average scores into two groups showed between-group differences in absolute value of average decision preference for only ambiguous short intersection distances. Namely, the low need for closure group tended to stick with one strategy (*M*=0.85) as compared to the high need for closure group (*M*=0.55), a difference that was significant (*t*(18)=2.15, *p*=0.045). For ambiguous long distance trials, need for closure groups did not differ in strategies employed (*t*(18)=1.15, *p*=0.27) (see Figure 14 in Appendix A). There was no interaction between need for closure group and intersection distance on number of strategies employed (*F*(1,1)=0.717, *p*=0.408). Additionally, the low need for closure group tended to be landmark-centered (*M* of Survey-Landmark= -2.03) compared to the high need for closure group that was less landmark-centered (*M*=0.033), which was a significant difference

($t(18)= 3.72$, $p<0.01$) (see Figure 15 in Appendix A). While the abridged NFC scale is not designed for analyses of its five features, it is interesting that significant differences between the two groups occurred on all but decisiveness ($p=0.78$).

4. Discussion

4.1.General Relationships between Spatial Questionnaires

Primarily, regression analyses of participant's responses demonstrated high reliability between subscales of different questionnaires that sought to measure similar spatial capacities, such as the FRS Global-Egocentric scale and the sense of direction factor of Pazzaglia et al. (2000); the FRS survey scale and Pazzaglia survey representation factor; and FRS cardinal directions scale and compass orientation factor. However, significant relationships were also seen within the different questionnaires, shown by both median splits and correlations. For instance, subjects with high FRS global-egocentric scores tended to also have high FRS survey and cardinal direction scores, likely due to the encompassing nature of the global-egocentric construct. Namely, it includes queries of confidence in general spatial ability (i.e., *My sense of direction is very good*). Furthermore, the questions determining one's ability to point towards unseen locations in an environment may also be scored high by a person with a strong capacity for forming mental maps and exhibiting knowledge of cardinal directions. In order to account for situations involving proficient scoring in multiple categories, such as survey and route perspective factors, differential scores, such as Survey-Landmark or Survey-Route, were created. One cited advantage of the relatively recent FRS measure over the more traditional Santa Barbara Sense of Direction Scale (Hegarty et al., 2002) is its ability to be split into more specific constructs than simply sense of direction (Münzer & Stahl, 2011). Yet, the apparently close relationship between these factors may still validate the continued use of the SBSOD. The results from the median split and regression analyses with the FRS global-egocentric scale must be interpreted with caution, as the scores had a limited range (minimum-3.1; maximum-6.4; range-3.3 on a scale from 1-7).

A median split conducted with the sense of direction factor of the Pazzaglia et al. (2000) questionnaire produced between-group differences only with the compass factor. As this construct is broad, assessed by such questions as *Do you consider yourself to have a good sense of direction?,* one would expect differences to occur in other spatial representation comparisons, such as a positive relationship with Survey-LM or Survey-Route. It may be possible that subjects associated the phrase *sense of direction* with only cardinal directions. That being said, three of the five questions used in this factor specifically relate to one's orientation ability. Perhaps, though, a greater proportion of questions assessing one's ability to navigate or point to environmental locations may bolster the validity of the construct. Nevertheless, sense of direction showed relationships with each of the FRS components as well as the survey composite factor and approached significance in Survey-LM (p=0.11), indicating that increased sample size may tend the latter to significance and that propensity for mental map formation and manipulation seems to predict sense of direction.

4.2. Decision Preferences under Ambiguous Trials

A frequency distribution of the average turn choices by participants on ambiguous trials (on any trial, -1 was used to indicate a landmark-congruent decision, while 1 was used for turn-congruent decision) shows the greatest proportion (35%) only choosing the turn by the congruent landmark. Indeed, since one's bare-bone spatial representation consists of landmarks (Siegel &

White, 1975), it seems a reasonable measure to fall back on in times of uncertainty. The second largest group (20%) selected turns by the referred[1] and non-referred landmark on an equal basis. Only 10% of participants showed an increased preference for turn-congruent decisions. Thus, landmarks were more salient to subjects than turns, which can be seen by the restricted range of reported attention to landmarks and preference to landmarks under ambiguous conditions (range in both cases was 3; minimum was 4 and maximum was 7). In contrast, responses concerning self-reported attention to turn information exhibited the entire spectrum of possible values. The restriction of range effect may have contributed to the weak positive correlation found with overall attention to landmarks. When average turn choices was plotted against the difference in self-reported attention to landmarks as compared to turns (obtained by subtraction of the two concerned retrospective questions), a reasonably strong negative correlation was found (R^2=0.413, p<0.01), suggesting that people's preferences may be related to their differential attention to landmarks as compared to turns (see Figure 2 in Appendix A). Furthermore, contrary to the expectations of a negative correlation between average turn choice and tendency to mix up left and right, no correlation was observed. Thus, people likely do not base their turn choice on, for instance, an assumption of an error in the turn directions given, due to their own fallibility in this matter (availability heuristic). This lack of relationship may however be due to the inclusion of people with the entire spectrum of spatial representations, rather than a select one, such as a survey perspective.

Indeed, another contribution towards the patterns of decision preferences may be based on the strength of one's survey representation, as a high survey composite score were found to be associated with more landmark-based turns for long distance ambiguous trials. This finding even trended in comparison between survey-centered and landmark-centered individuals (Survey-LM scores), the latter of whom one would expect to have the highest affinity towards landmarks. Since significant differences were found in Survey-Route scores in comparing between the low and high Survey-Landmark groups, formed by a median split, individuals that are more landmark-oriented may also have a dominant route representation, allowing them to perhaps incorporate the egocentric designations of left and right into their decisions more so than survey-centered individuals. Through comparing the two Survey-Route groups, the survey-centered group had a greater tendency to report mixing up left and right, an egocentric concern not normally designated in an allocentric representation and which may account for their behavioral differences. That being said, the FRS survey and survey composite factors showed no relationship to left-right proficiency (p=0.13 and p=0.72, respectively). As a result, an 8-8 median split was conducted on self-reported tendency to mix left and right (all participants who scored the median were removed from analysis) in order to determine if the pattern of relationships concerning survey representations, as predicted by Survey-Route, will occur. People strong in distinguishing between left and right had significantly higher FRS survey scores, sense of direction, and knowledge of cardinal directions; no significance was found in Survey-Route scores. All observations were in a contrary direction to the Survey-Route finding, which thus may be attributed to a false positive, a constant concern in median split measures.

Another rationale for the perceived decision differences among different survey affinities of people may be that survey-centric people are more likely to assume that the instructions refer to someone coming from a different direction, which would result in a congruency between the environment and directions. Spatial perspective-taking may indeed play a role into people's decisions under ambiguous conditions, but no question was enquired as part of the explicit protocol. Nevertheless, the open response question provided enough information to sufficiently categorize people into forming four classes of behavior:

(A) Participants concluded that the instructions were wrong and would turn according to either the instructed landmark or turn, irrespective of the distance between intersections.
(B) Participants concluded that the instructions were wrong and would turn according to the landmark for long intersection distances but would choose the correct turn for short intersection distances.
(C) Participants interpreted directions to be referring to someone coming from another direction[4], irrespective of distance between intersections.
(D) Participants interpreted directions to be referring to someone coming from another direction based on distance between intersections.

Thus, participants whose self-report coincided with either (1) or (2) fell into the category of non spatial perspective-taking, while those who were associated with (3) or (4) were categorized as spatial perspective-takers. It was an 11-9 split, between the former and latter, which may affect the statistical power of the conclusions. Nonetheless, there was a trend towards significance for order on the need for closure scale (p=0.069), where people that thought the instructions were wrong had a higher score (M=4.21) compared to those that assumed it referred to someone coming from another direction (M=3.44). Furthermore, the former group had higher FRS survey scores (M=4.57) as opposed to the latter group (M=3.59), a difference that approaches significance ($t(18)$=1.95, p=0.066) (see Figure 16 of Appendix A). Thus, survey-centered people may have a lesser tendency to employ egocentric transformations, casting the likelihood of spatial perspective-taking accounting for landmark preference in doubt.

4.3. Problematic Findings Related to Need for Closure

The above results suggest a possible association between spatial perspective-taking and order on the NFC scale, although the individual facets of the abridged scale are not amenable to separate analyses (Roets & Van Hiel, 2011). Although the relationship between spatial perspective-taking and average need for closure score was not significant (p=0.24), a similar mean trend was observed. As was expected, the tendency to employ egocentric transformations may be inversely related to need for closure. Among multiple survey measures, survey-centered people tended to have a higher need for closure. A possible association between survey representation and order (median split for Survey-LM resulted in survey-centric individuals having higher order scores, p=0.0558) is particularly interesting as a survey representation has a definitive, “grid-like” configuration, compared to landmark and route-based representations that are perhaps less well-defined. Nevertheless, this conclusion will have to await more substantive evidence that can be given by administration of the complete NFC questionnaire.

It was proposed that high need for closure individuals would tend to choose one type of turn, whereas those who had low need for closure would be more amenable to alternate between turn preferences. Indeed, stronger survey preferences were associated with a greater bias for selecting landmark-based turns on long distance ambiguous trials and a greater individual need for closure. Thus, it may seem contradictory that individuals who had selected only the landmark-congruent turn on ambiguous trials had a lower need for closure compared to another group that frequently chose opposing-based turns. However, a 7-7 split done in the latter finding is more subjective to random noise than a 10-10 split, due to the increased sample size between groups. Indeed, when an 8-9 split is conducted, the need for closure significance disappears. Furthermore, the decision preferences by survey-minded individuals were only observed in long distance trials as opposed to only short distance trials or ambiguous trials overall. Since a survey representation incorporates landmarks and their relative orientations, such individuals may have viewed the egocentric directions as having little bearing when the landmarks are far from each other, to a greater extent than for route and landmark-centered people. Indeed, route and landmark representations are less external-oriented, with the former comprised of localized sequences from one point to another and the latter of non-spatial landmark information.

Additionally, low need for closure individuals tended to use one strategy, either to go off of the instructed landmark or turn, for short ambiguous trials as compared to high need for closure individuals, contrary to predictions. Furthermore, the lack of interaction in tendency to select a singular type of turn based on need for closure score and intersection distance showed that the low need for closure group did not change its behaviors based on distance more so than the high need for closure group, which again is a violation of expectations. The increased proportion of low need for closure participants that exhibited spatial perspective-taking (0.6) as compared to the high need for closure (0.3) trended towards significance ($\chi^2(1,1)=1.82$, $0.10<p<0.20$). Even though spatial perspective-taking may be involved for the low need for closure group, one would still expect the high need for closure group to exhibit one strategy. Thus, one might predict no differences in strategy between the two closure groups, a result which clearly is not seen here. One possibility may be that high need for closure individuals simply chose the first intersection more often, irrespective of it being turn or landmark-congruent. Yet, no significant relationship was found between average tendency to select the first turn and need for closure. Another major issue is that the need for closure construct had very restricted range (range-2.33), making it unclear whether or not one can draw conclusions from differences. Furthermore, the construct has primarily been studied within the social psychology literature, so its application to spatial cognition may not be so straightforward.

4.4. Effects of Distances between Turns on Behavioral Decisions

Beyond the manipulation of ambiguity, another variation in the environments lay in the distances between turns. In support with our hypothesis, people differed in their decision preferences at short distances between intersections as compared to long distances, with the former tending to be less landmark-oriented. However, this difference was found not to be significantly due to variations in the nature of the turns as was expected. That being said, the means did trend so that people tended to use the same strategy on long distance ambiguous trials more so than short distance trials. Thus, the absence of need for closure relations in strategy tendencies for long distance trials may be due to the fact that people generally tended to stick to one strategy for these environments, which may be predominantly landmark-based.

Beyond the small sample size, the lack of significance may be reconciled by suggesting that subjects may have decided on the turn in the same direction as was mentioned in the directions more often than not for short distance trials, whereas on long distance trials, they may have been more inclined to choose the landmark-congruent turn. Indeed, for short distance trials, the referred landmark lay close to both turns, so even though subjects may have taken the turn-congruent path by the non-referred landmark, they may have rationalized that the path was still reasonably in proximity to the referred landmark. Thus, short distance trials may not have been as ambiguous as the long distance trials. They may have represented conditions of intermediate ambiguity, which according to Van Hiel and Mervielde (2002), are most greatly associated with need for closure. In this case, it is unsurprising that need for closure is related to decision preferences only under short trials.

4.5. Unexpected Significance in Between- and Within-Subject Manipulations

The other two manipulations, position of landmark and order of directionality of turns, were not expected to significantly differ within participants. The latter held true to predictions, but the former trended towards significance, with trials where the referred landmark was at the farther turn producing more landmark-congruent decisions than trials consisting of the noted landmark at the first turn. Furthermore, the second-turn landmark trials resulted in significantly greater consistent decisions (either turn-congruent or landmark-congruent only) by participants than the first- turn landmark trials. Note that the contrary result would be expected if participants simply chose the first turn due to task dullness for long distance trials. A tentative explanation of these results is elucidated within the context of comparison between the two experimentally assigned groups.

The counter-balanced experimental groups had differences in their average decision preference, with Group 2 exhibiting a stronger tendency to select landmark-congruent turns than Group 1. Furthermore, participants in Group 2 had a significantly higher tendency to select one strategy on short distance trials than Group 1, with a trend towards significance observed for long distance trials. Thus, ordering of conditions may have contributed towards the decisions made. In particular, Group 1 began with an ambiguous trial, while Group 2 started with a clear, unambiguous trial. Participants were not explicitly told that the labeled landmarks would always consist of the referred landmark and a non-referred building. Nevertheless, since the first trial of Group 1 was ambiguous and contained the referred landmark at the first turn, participants may have travelled towards the second turn with the expectation that the same labeled landmark would be present at that turn. However, once they realized this was not the case, some subjects may have determined that turning around was too much trouble and that they should just proceed with the turn-congruent decision. If this was true, then Group 1 participants would have been less likely to choose the landmark-congruent decision. In contrast, Group 2 had an ambiguous condition at the second trial, whereupon the referred landmark was at the second turn. Thus, regardless of whether or not they had discovered the general environmental pattern, most would have still chosen the landmark-congruent turn at the second trial, using a similar rationale as in Group 1. Thus, it may be that the landmark position of the first ambiguous trial contributed to the between-group differences, which may also explain the decision preference variations based on landmark position, which was previously described. Indeed, a significant interaction between experimental groups and landmark position was observed, where Group 2 seemed to select one strategy regardless of the position of the landmark referred in the directions, while Group 1 was more variable at the first-turn landmark trials compared to the second-turn landmark trials. This then might be due to the first ambiguous trials for Group 1 being first-turn landmark trials. To substantiate this evidence, groups were compared by performance on the first ambiguous trials. 70% of Group 1 participants chose the landmark-congruent, first turn, although the proportion was still less than the 100% of Group 2, a difference that approaches significance (χ^2 (1,1) = 3.53, $0.10<p<0.05$). That being said, there is a ceiling effect in terms of the preference towards landmark-based turns between groups that may impact the statistical conclusions. Nevertheless, this explanation concerning landmark position cannot fully explain the variability between groups observed with short distances between turns. Even though the first ambiguous short trial of Group 1 is a first-landmark turn trial, whereas that of Group 2 is a second-landmark turn trial, the landmark names from both turns are clearly visible from the start, allowing the participant to make a decision prior to navigation. It would have been helpful to ask participants post-experiment when they realized that the environments never consisted of two landmarks that were the same, the knowledge of which would have been useful for the long distance trials.

Furthermore, it is unclear whether or not the two groups are indeed similar in spatial abilities, among other factors, for Group 2 was observed with higher FRS survey scores. Yet, no relationship was seen with the other measures of survey centricity, such as the survey factor of the Pazzaglia questionnaire. A false positive may be at work, brought again by the small sample size.

4.6. Response Time of Navigation as a Function of Ambiguity and Intersection Distance

The time required for navigation between clear and ambiguous trials overall agreed with our expectations, with significantly longer times required for ambiguous trials, even when considering short and long distance trials separately. The relative RT increases between short and long distance ambiguous trials was found to be significantly different, with people requiring less additional time, relative to matched control trials, to navigate short ambiguous trials rather than long trials. Furthermore, people split into groups based on their relative RT increase for ambiguous trials overall did not differ in their RT for short distance trials, which was further elucidated in a significant interaction of intersection distance and overall ambiguous RT increase. The lack of difference between the two groups for short, but not long distance, trials indicate that short distance trials may be less ambiguous. That is, there might be greater environmental correspondence of the landmarks and turns to that which was outlined in the directions, which was previously mentioned regarding the different decision preferences between the different types of trials.

However, an alternative explanation may be that individuals may turn back at the first ambiguous long trial after, for instance, realizing that the landmark at the second turn is not the same as the first labeled landmark (which may be group-dependent of course), incurring far more additional time than turning back for a short distance trial. Thus, the relative RT increase was compared between long and short distance trials without the first ambiguous trial in either condition. Here, the shorter additional time for navigation of short distance trials only trended towards significance (p=0.09), suggesting that the inherent navigational costs of long distance trials may play some role in the reaction time results shown. When a median split is conducted with ambiguous-clear RT scores without the first ambiguous short and long trials and matched controls, no interaction is seen between the short and long distance RTs, suggesting that some of the perceived effects of intersection distance are indeed due to navigation, rather than only strategy or environmental layout. Another possibility for the reaction time differences may simply be due to the fact that the first ambiguous trial always contained long inter-turn distances, an explanation that can only be ascertained through testing a group with a first ambiguous trial that contains a short distance between turns. One might be entitled to claim that, after the first ambiguous trial in either condition, people developed a consistent strategy that prevented further hesitation or other navigational costs from occurring. However, the average overall ambiguous RT was still significantly greater than the clear overall ambiguous RT, indicating that people's mental strategies were still incomplete, even after initial exposure to an ambiguous trial.

As was predicted, low reaction time for ambiguous trials was associated with a greater tendency to select either landmark or turn-congruent decisions only, a one-strategy approach that involves little cognitive load once developed. The reduced information processing may be attributed to the low reaction time group reporting a lesser capability of imagining themselves walking through the environment. Reaction time effects also provided validation for previously observed phenomena, such as the greater bias towards landmark-based turns when the referred landmark is at the second turn or for Group 2. Strangely, the inverse relationship between reaction time and tendency for one strategy is seen when comparing groups on overall ambiguous trials and long distance trials, but not short distance trials, a result that persists even when the first ambiguous trial is removed. Thus, the differences in RT for short distance trials are likely due to considerations beyond simply alterations in strategy. Perhaps a singular strategy can be realized in multiple ways, depending on whether one views the environmental layout as consistent or inconsistent with the instructions; indeed, the split between the groups for short trial RT (with the presence of the first ambiguous short trial) creates one group that does not differ significantly in reaction time under clear and ambiguous trials (p=0.54).

4.7. Minimizing the Negative Repercussions of the Virtual Environment Setting

Besides the novelty of the experimental paradigm, the medium with which it was accomplished in involved an immersive virtual environment (VE) experience. While oculomotor and disorientation symptoms significantly changed due to exposure, differences in symptom severity were found to have no effect on behavioral or self-report data, suggesting the lack of malaise as a confound. While it was thought that the incorporation of rotational movement might afford some interesting within-subject differences, no increase of yaw was seen with ambiguous trials, which may be due to the wide field of view already afforded to the participants, where turning of the head was really only required in order to take a given turn. Furthermore, the environment was simple so that orientation checking was not necessary.

4.8. Comparison of the Map-Based and Virtual-Environment Landmark/Turn Incongruity Studies

One major difference in the map-based study was that, overall, participant's decision choices did not change due to the distances between intersections, likely because distance played no overt role in destination selection (compare clicking a mouse at a particular point to actual navigation down a path). It is for this very reason that the virtual environment analogue of this paradigm was proposed. Furthermore, the ambiguity was immediately inherent in both types of trials for the map study, while in the present study, at least initially for the long distance trial, the second landmark label could only be seen by traversing at least halfway between the two labeled landmarks. Furthermore, far more participants selected turn-congruent decisions in the map-based study. While landmarks may appear more salient in first-person navigation, one may also imagine additional strategies that bias preferences, such as imagining that the referred landmark may be at the end of the instructed turn. In this manner, the virtual environment was much clearer in its absence of alternative turns, although additional complexity may cause a skew of decision preferences to more resemble that of the map study. Finally, more gender differences were elucidated within the map study, particularly in the context of lack of alteration of behavioral strategies, where females matched this property more so than males. It is important to note that the instructions were given through a route perspective, even though the environment was seen through an overhead, extrinsic frame of reference. Perhaps, men's preferential use of a configurational representation allowed for attention to orientation of landmarks to the path more so than women's reliance on route strategies (Miller & Santoni, 1986). Thus, men may have incorporated distance between turns or even the location of the labeled landmark relative to the intersection (which was not manipulated in this current study) into their decision preference as compared to females. Naturally, it may be that the first-person navigation by this study allowed both sexes to appreciate distance. Furthermore, gender did not predict performance on the FRS global-egocentric, sense of direction subscales, or survey factors, in contrast to the map study, although this may be due to the small sample size and unequal split of the gender groups.

4.9. Conclusions and Future Directions

In summary, the main findings of the study can be outlined as:

(1) Overall, there seemed to be a greater tendency to choose landmarks as opposed to turns on ambiguous trials, attributed to the former's more pronounced salience.
(2) Some measures showed that survey-centricity predicted increased taking of turns that corresponded to the referred landmark only under ambiguous long distance trials. Others showed an association between enhanced survey representations and increased tendency to mix up left and right, although this may be a false positive, casting the proposed relation between left-right proficiency and landmark-based preference into doubt.
(3) Contrary to predictions, participants with low need for closure tended to choose one type of turn more often than those with a high need for closure for short ambiguous trials. This construct had a restricted range, which may impact the conclusions that can be drawn.
(4) High need for closure was associated with a high FRS survey score and a high sense of direction. Indeed, survey-minded people were more likely to consider the instructions as wrong as opposed to entertaining additional possibilities that they may have referred to someone coming from the other direction. The relationship between survey-centricity and order as well as structure represents an intriguing possibility due to the factor's correspondence to the allocentric representation.

(5) People's decision choices were more landmark-centered for long distance trials as compared to short distance trials. However, long-distance trials only trended in being associated with a singular behavioral strategy in comparison to short-distance trials. Besides the small sample size, the lack of significance could be contributed by people differing in the type of turn they most prominently select between the two inter-turn distance conditions.

(6) Both the within-subjects manipulation of position of the referred landmark and the between-subjects manipulation of counter-balanced experimental groups produced significant differences in decision choices. The group whose first trial was not ambiguous and the trial where the instructed landmark was at the second turn were associated with decisions that were more landmark-centered. Order effects are purported for the between-group differences, which may have carried over to differences in responses based on the landmark position.

(7) People took longer on ambiguous trials than for clear trials overall, with a greater differential observed for trials that contained long distances between turns as compared to those that had short distances between turns. This effect may have been partly due to navigational cost in turning around for the long distance trials.

(8) A lower reaction time under ambiguous trials was associated with a tendency to select one strategy, which however, did not occur when only trials with short distances between turns were considered. Differences in reaction time for short trials may have been due to the extent to which people saw the environmental layout as actually unambiguous.

Future directions would include comparing participants across the four described classes of rationale for behavior, which could not be done in the current study due to the small sample size and unequal distributions of people in each group. It is clear that no singular rationale for choosing a decision is incorporated by people, which makes it difficult to ascertain conclusions through comparisons of different measures based on average decision choice and extent to which consistency is observed. For instance, it has been shown that participants made more landmark-congruent turns in long distance as opposed to short distance trials. Yet, the specific rationale for this decision pattern may differ among participants. Some may have viewed the directions as completely wrong for the long distance trials, choosing the more salient feature of the environment for them, the landmark, as the guiding point for their decision. For short distance trials, however, they may have viewed the instructions as not completely incongruent to the environment, for the landmark was reasonably close to the specified turn, so the turn-congruent decision may have been made. Others may have viewed the directions as correct in both trials, but employed a different egocentric orientation only in the long distance trial, producing the same sets of behaviors as the previously mentioned group. Separation of participants into these separate groups based on the rationale for their decisions affords more sensitive differences to be noted than simply overt behavioral choices.

The between-group effects suggest that order is somewhat important for shaping turn preferences, so additional counterbalanced groups that begin with a clear and ambiguous short distance trial should be formed. Administering the entire battery of the need for closure scale to some group of participants to determine if any specific individual facets correlate well with decisions or spatial abilities (e.g., survey representation and order) should also be done. Finally, the general salience of the landmark to the participants may be due to the wording of the instructions: *To get to X, turn right at Y*. Perhaps conditions where the directions were reworded as: *At Y, turn right to get to X,* should be implemented to ensure that participants did not prefer the landmark just because it occurred after the turn in the instructions.

Need for closure did not provide the expected relationships in variation of decision preferences, possibly due to the restriction of range of the individual-differences construct. Perhaps it could be situationally-induced by time pressure (Kruglanski & Webster, 1996), which also helps afford causation, rather than correlation. One might imagine a loud environmental noise that increases in frequency as time elapses, which induces more pronounced need for closure in order to prevent the undesirable noise from persisting. It is important to remember that way-finding usually occurs under external constraints (imagine a car honking as you are spending a little more time than is desirable deciding where to turn), so the results would be have more real-world applicability. In the current study, the directions were placed on a wall and removed from any human source. If the instructions were shown to be given via a person to participants, they might be, for instance, less likely to view the instructions as correct from a different perspective, for the introduction of a human mediator introduces fallacy. One might expect spatial perspective-taking to fall, which may depend also on the person's specific age or other qualifications, for instance. Further experimentation within the virtual environment paradigm may include this additional variable.

Additionally, it would be interesting to compare people's behavioral decisions by navigating through a desktop versus a more immersive VE in order to determine if the additional realism impacts one's choices. One would not expect such differences to manifest within a simple environment, so perhaps instead of having multiple environments of different conditions, a complex spatial environment similar to the one recently described by Brunyé, Gardony, Mahoney, and Taylor (2012) should be incorporated. A general set of directions are given to reach a destination, with crucial decision turns being spatially ambiguous. The current study had an environment that was bare apart from the two turns and four landmarks (two of which were designated by a question mark). An environment where not all the landmarks are immediately visible affords completely novel strategies, such as choosing the correctly instructed turn, but by a different landmark, in the hopes that one may find the referred landmark somewhere down that path. Yaw will likely play a more prominent role in such a setting. While the setup and controls will be challenging, this proposed study will likely offer the closest laboratory analogue to the real-world scenario as one is likely to get.

In conclusion, the present study offers a detailed characterization of people's decisions under landmark-turn inconsistencies, a paradigm that has not been fully elaborated to this extent in the literature. While a relatively small sample size and correlational experimentation are certainly limiting factors, it is hoped that, just as the ambiguous trials necessitate no "right" decision, one can see that the results demonstrate no "common" decision, with preferences and reaction times being mediated by distance between turns; positioning of the referred landmark; order of exposure to ambiguous trials; and individual differences, both spatial and non-spatial.

Notes

[1]The “referred” landmark is simply the one mentioned in the instructions that serves as a guiding point for the eventual destination (i.e., in the directions *To get to X, turn left/right at Y*, Y is the “referred” landmark).

[2]Please note that the term “strategy” does not necessarily refer to the rationales of the participants in making their decision choices during navigation; rather, it is used here in describing their behavioral tendencies.

[3]The actual trials varied between experimental groups. For Group 1, the first ambiguous trial was L (left)_R (followed by right)_F (long distance)_1 (referred landmark at first turn)_A (ambiguous trial). Thus, the matched control would be L_R_F_1_C. For Group 2, the first ambiguous trial was L_R_F_2_A, so the matched control was L_R_F_2_C.

[4]One participant thought the instructions were meant for someone coming from one of the buildings at the end of each turn, rather than the more common viewpoint of the other end of the straight path.

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Appendix A

Graphs of Major Findings from the Present Study

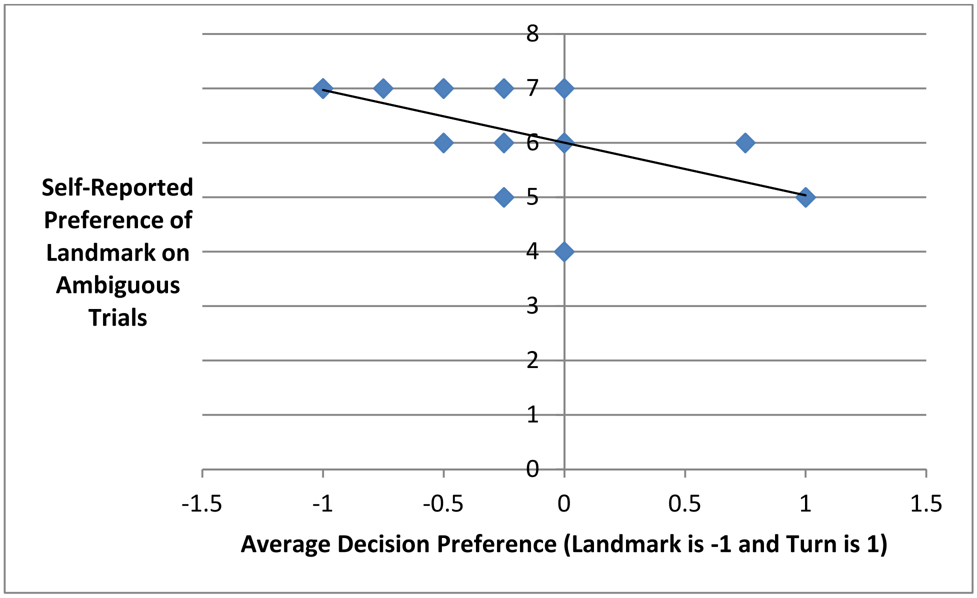


Figure 1. Average decision preference is negatively correlated with self-reported preference of landmark on ambiguous trials ($R^2 = 0.4221$, $p<0.01$).

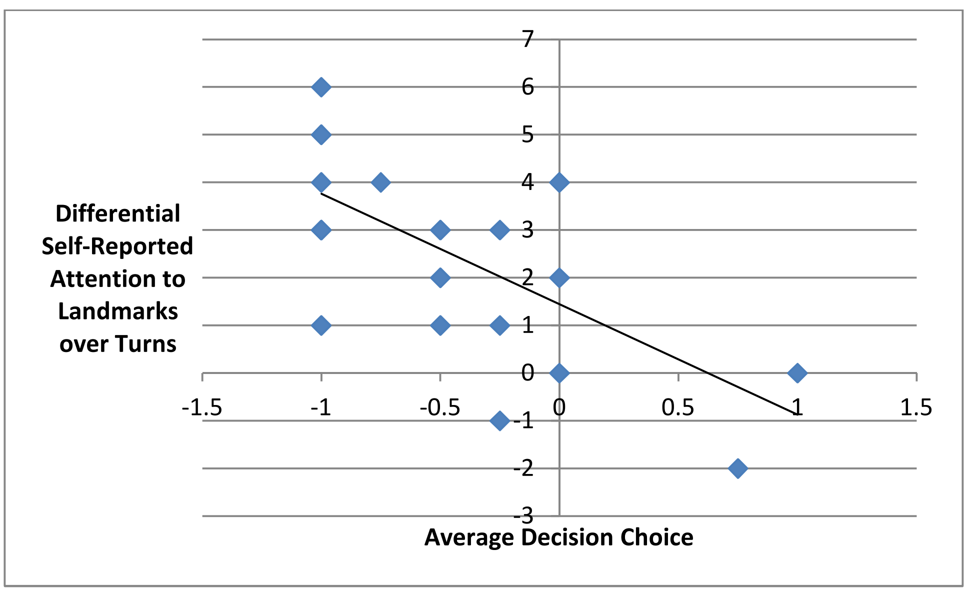


Figure 2. A negative correlation is seen with average decision choice (ranging from -1, all landmark-based, to 1, all turn-based decisions) and differential self-reported attention to landmarks (obtained by subtracting self-reported attention to turns from self-reported attention to landmarks) ($R^2=0.413$, $p<0.01$).

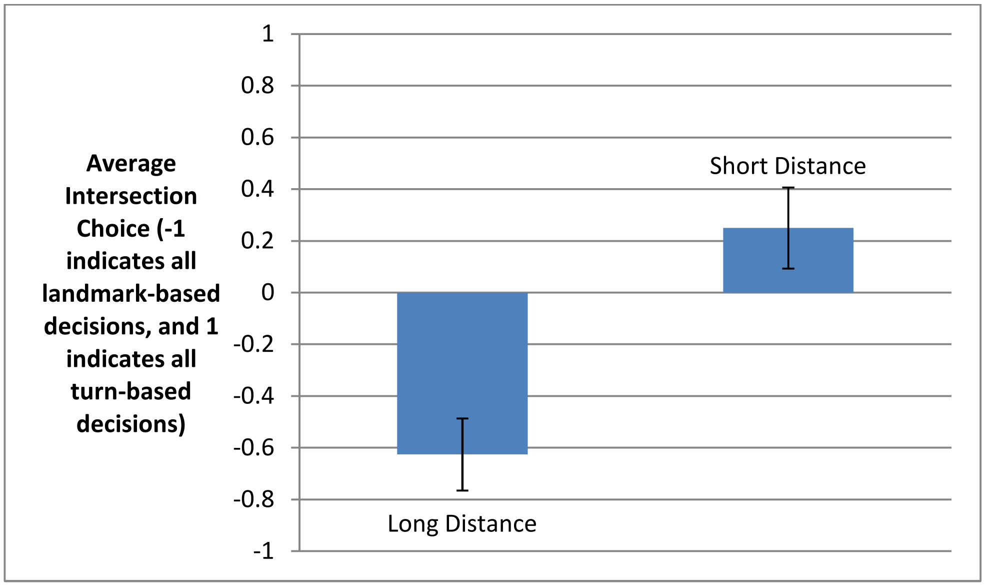


Figure 3. Average decision choice changes based on distance between turns, with long distances between turns causing an increased preference for the landmark-congruent turn ($t(11)=-4.47$, $p<0.01$). Note that this analysis was conducted with only those participants that had changed the type of turn taken at least once (i.e., did not have average decision choices of -1 or 1 across all ambiguous trials) (n=12).

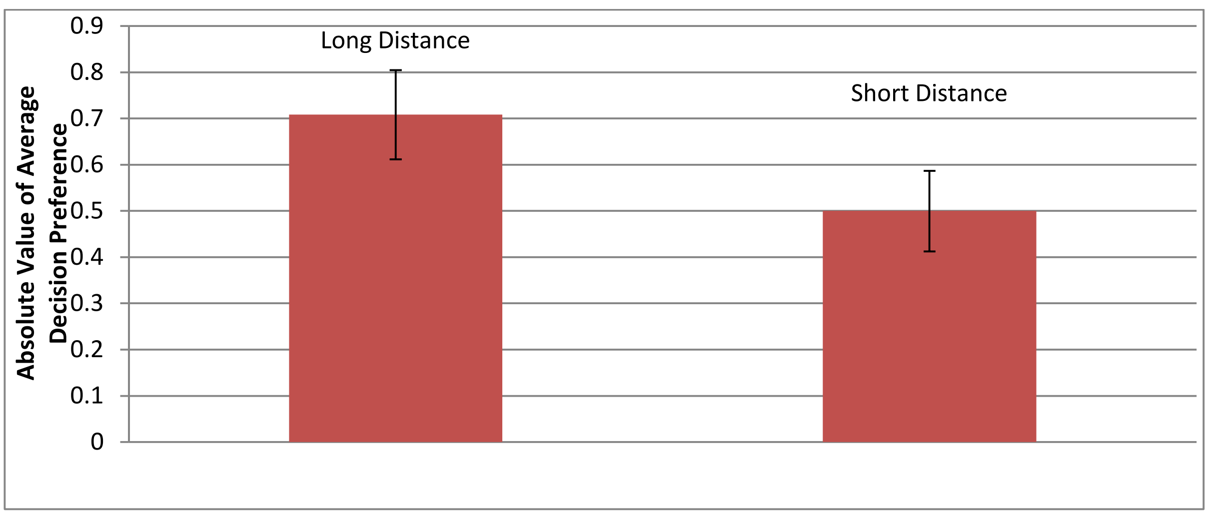


Figure 4. The absolute value of the average decision choice for each participant was taken in order to get a measure of the extent to which each participant chose the same type of turn (either landmark or turn-congruent). This measure was conducted separately for both long and short distance trials only for those participants that had changed their type of turn taken at least once (n=12). Thus, there is a trend towards significance for participants in the long distance trial to be more likely to select the same type of turn than for short distance trials ($t(11)=1.45$, $p=0.175$).

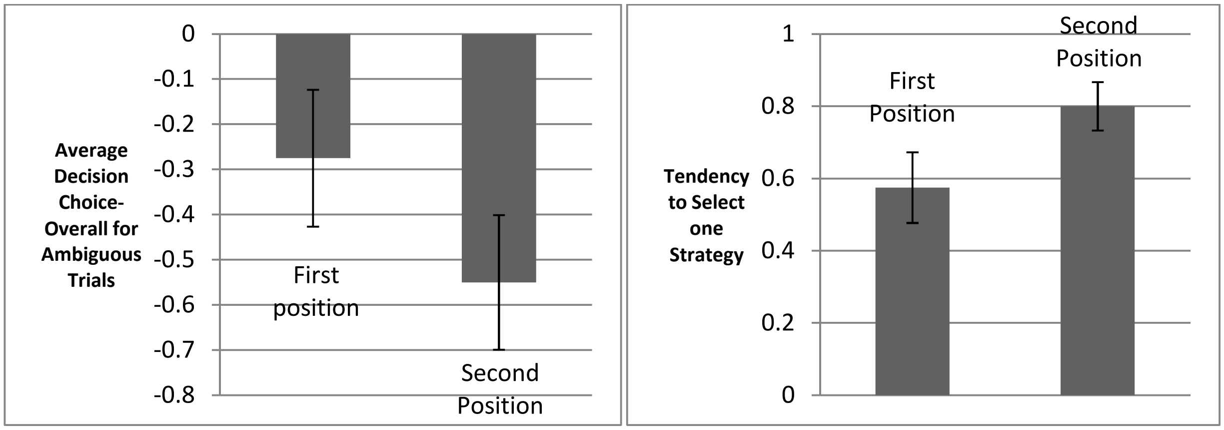


Figure 5. Within-subject comparison was done to compare average decision choices in cases where the referred landmark was at the first turn and where the landmark was at the second turn. There is a trend towards participants selecting more landmark-congruent decisions when the landmark is at the second position ($t(19) = -1.93$, $p=0.069$). Furthermore, trials in which the landmark is at the second position induce more consistent behaviors than when the landmark is at the first position, $t(19)= 2.44$, $p=0.025$.

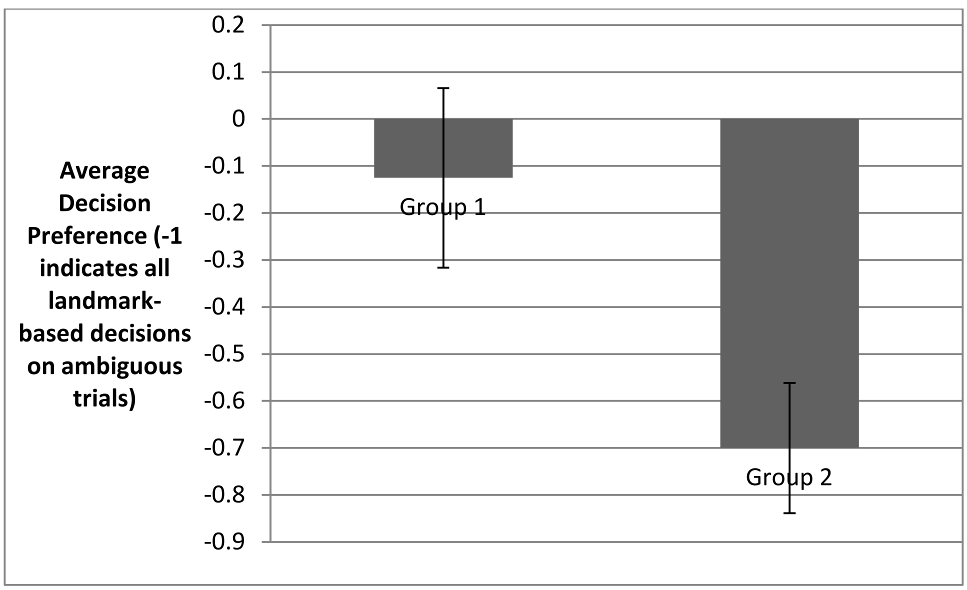


Figure 6. Average decision preference differs among experimentally assigned groups, such that Group 2 exhibits far more decisions based on landmark congruency than Group 1 ($t(18) = 2.44$, $p=0.0253$).

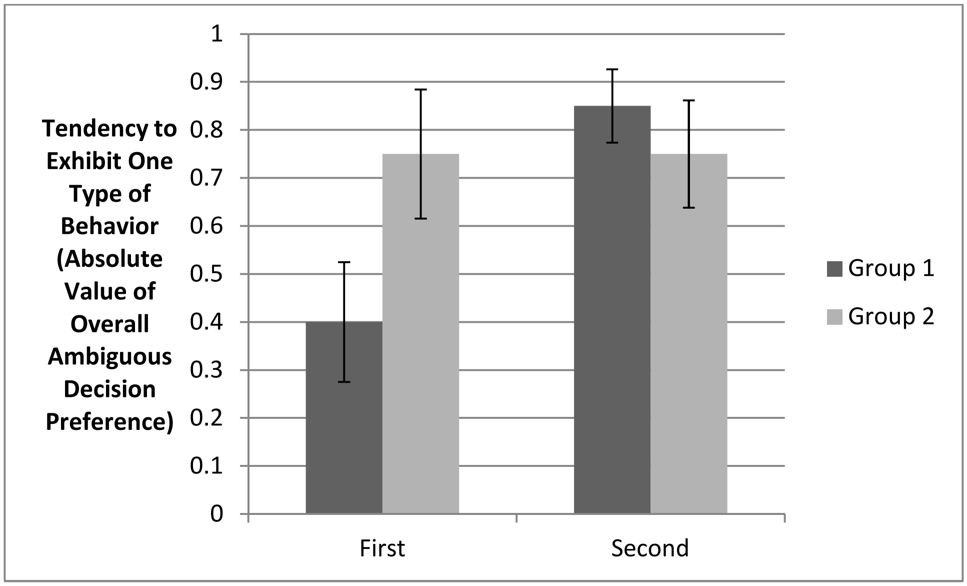


Figure 7. The tendency to select one strategy (consistent turn or landmark-based decision) as a function of position of the referred landmark and experimental group. An interaction can be seen between the experimental group and position of the referred landmark ($F(1,1)=10.565$, $p=0.004$). Group 1 is more variable in types of decisions made when the landmark mentioned in the directions is on the first turn compared to when the landmark is on the second turn. However, Group 2 exhibits similar consistencies in decision preferences regardless of position of landmark.

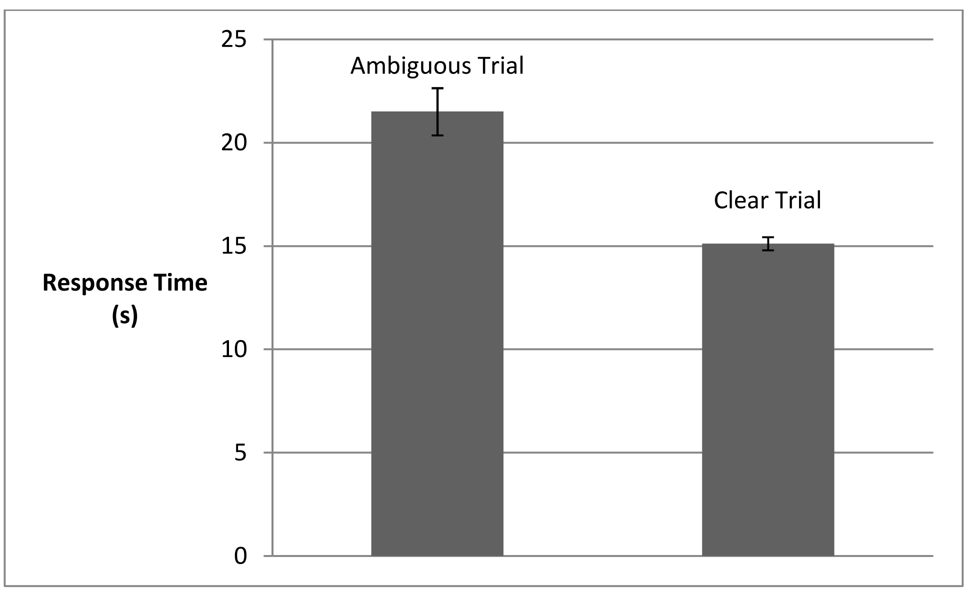


Figure 8. Average reaction time of an ambiguous trial is significantly greater than that of a control trial ($t(19)=6.16$, $p<0.01$). Here, the control/clear trial is one in which the instructions are unambiguous.

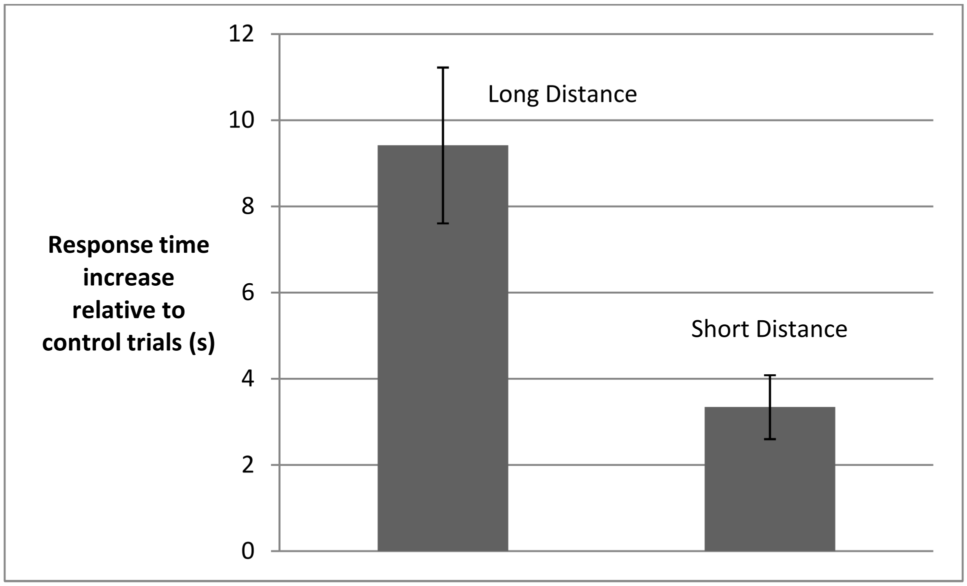


Figure 9. In order to control for differences between individuals as well as distances between turns, an Ambiguous-Clear RT (Response time) score was created, for overall ambiguous trials; those with long distances only; and those with only short distances. Trials with long distance between intersections have a significantly greater relative reaction time increase than those with short distances between intersections ($t(19)=3.32$, $p<0.01$).

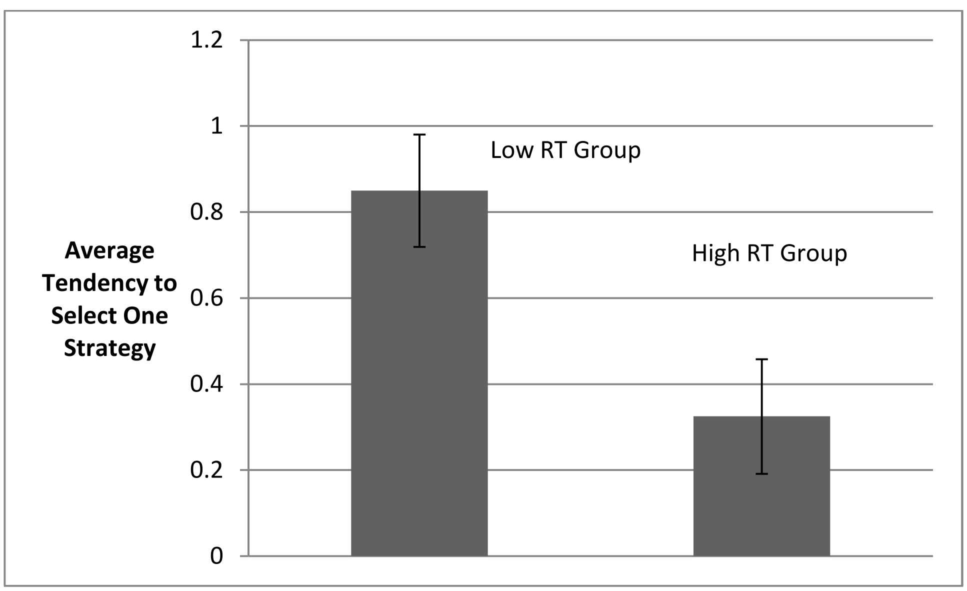


Figure 10. Relative RT increase on ambiguous trial is inversely related to tendency to select one strategy (or type of turn) ($t(18)=3.73$, $p<0.01$). Participants were split into two groups based on the relation of their individual Ambiguous-Clear response time to the median. Thus, the groups differed in the extent of their response time increase on ambiguous trials relative to unambiguous trials.

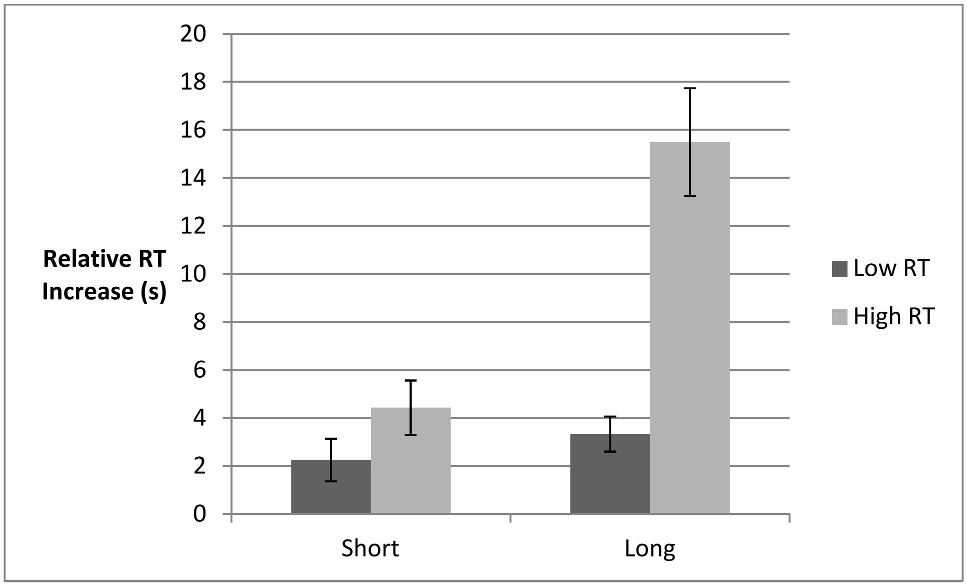
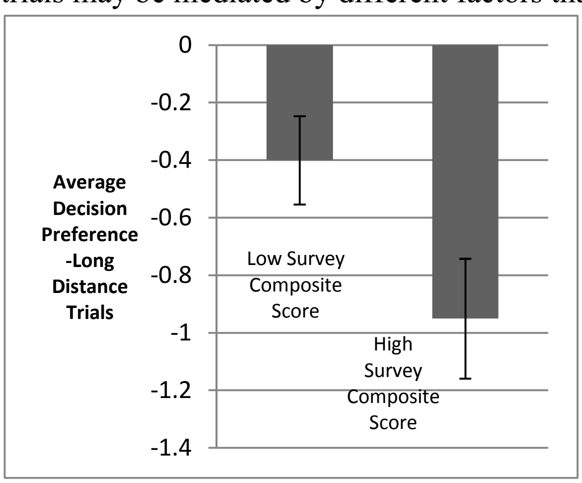


Figure 11. The relative increase in response time for an ambiguous trial as a function of distance between turns and response time groups. The average increase in RT (response time) for an ambiguous trial relative to an unambiguous trial was computed for each participant. A median split was conducted on this construct, Ambiguous-Clear overall RT, to create two groups, Low RT and High RT. A main effect of intersection distance is seen in that participants take more time to complete an ambiguous long distance trial relative to a matched long distance unambiguous trial than they do for an ambiguous short distance trial in comparison to its matched control. More significantly, an interaction is noted between intersection distance and response time groups ($F(1,1) = 11.597$, $p=0.003$). The difference between the relative response times of the low RT and high RT groups is much more pronounced for the long distance trials than the short distance trials. It suggests then that differences in response time for short distance trials may be mediated by different factors than for long distance trials.



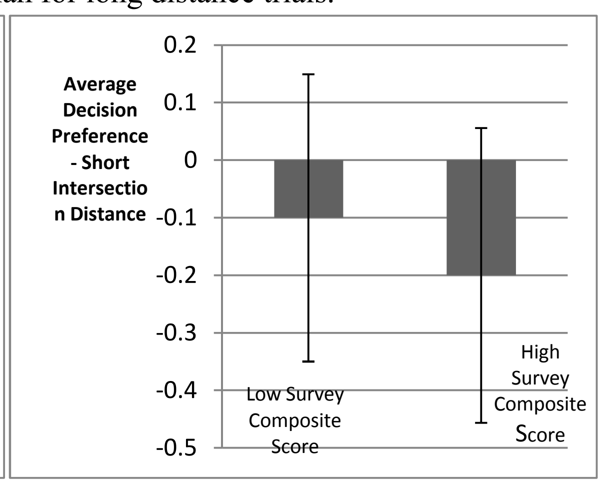


Figure 12. Composite survey score produced from the averages of FRS survey and survey representation subscale of Pazzaglia et al. (2000) questionnaire predicts average decision

preference on long distance trials ($t(10)= 2.43$, $p=0.036$). In contrast, no such difference was found between the two survey groups on choices for short distance trials ($p=0.78$).

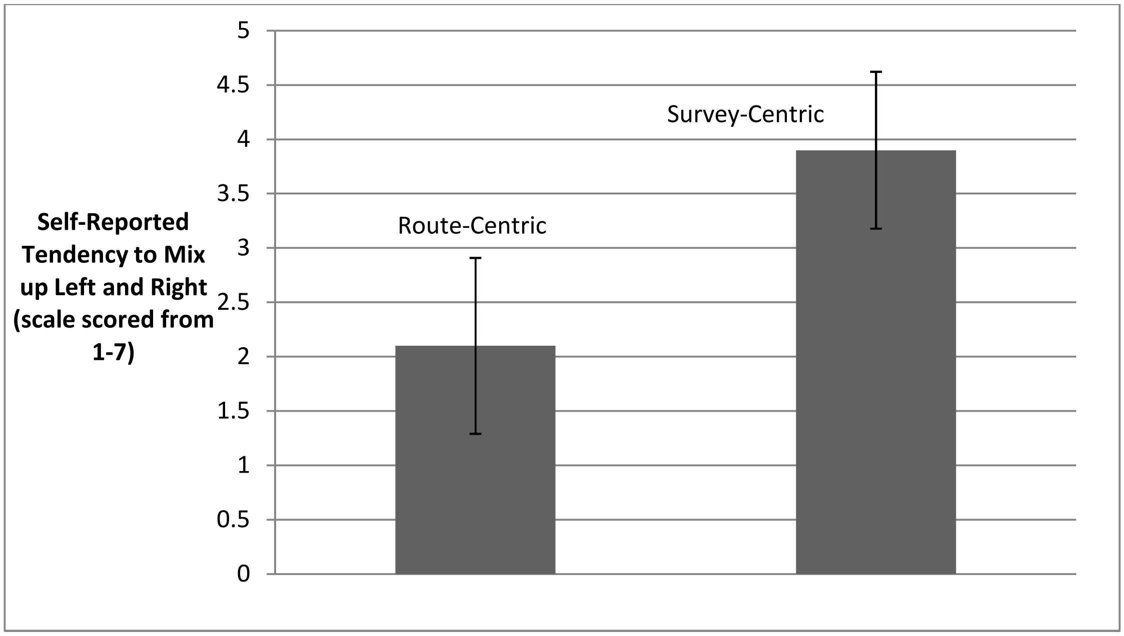


Figure 13. Survey-Route score trends towards predicting tendency to mix up left and right ($t(18)=1.80$, $p=0.088$). Those participants with a Survey-Route score below the median were placed into the route-centric group, while the other participants were allotted to the survey-centric group.

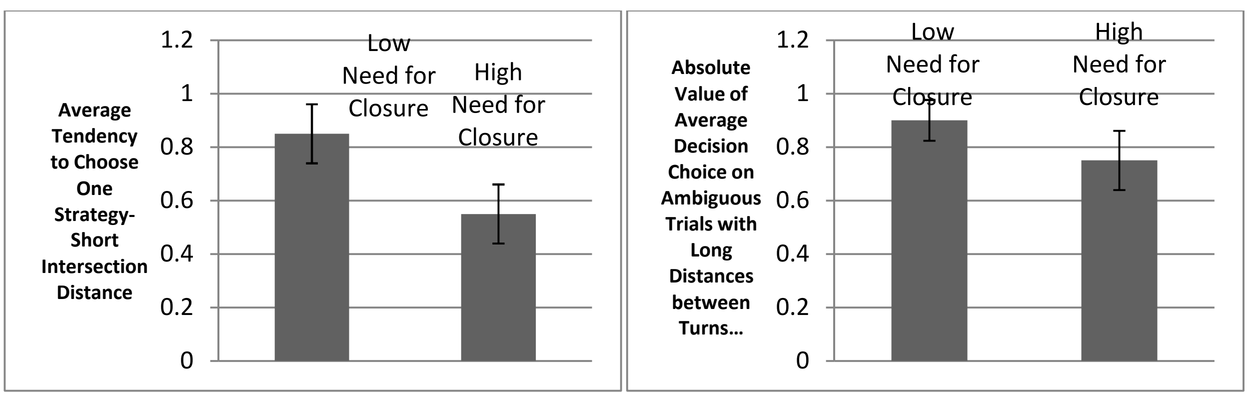


Figure 14. Need for closure is inversely related to tendency to choose one strategy over short distance trials ($t(18)=2.15$, $p=0.045$). However, no such relation is seen with long distance trials ($t(18)=1.15$, $p=0.27$).

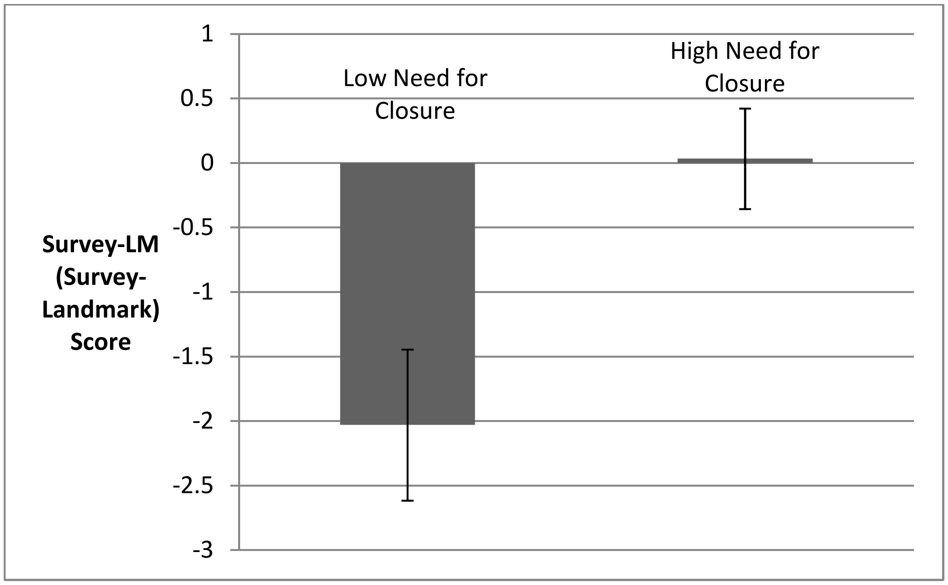


Figure 15. Need for closure is positively related to landmark-centricity ($t(18)= -3.72$, $p<0.01$). The more negative Survey-LM scores (Pazzaglia et al., 2000) indicate landmark-centricity (more dominant landmark representations as compared to survey representations). A split on Survey-LM scores was also found to produce significant differences in need for closure between the two groups in a similar direction.

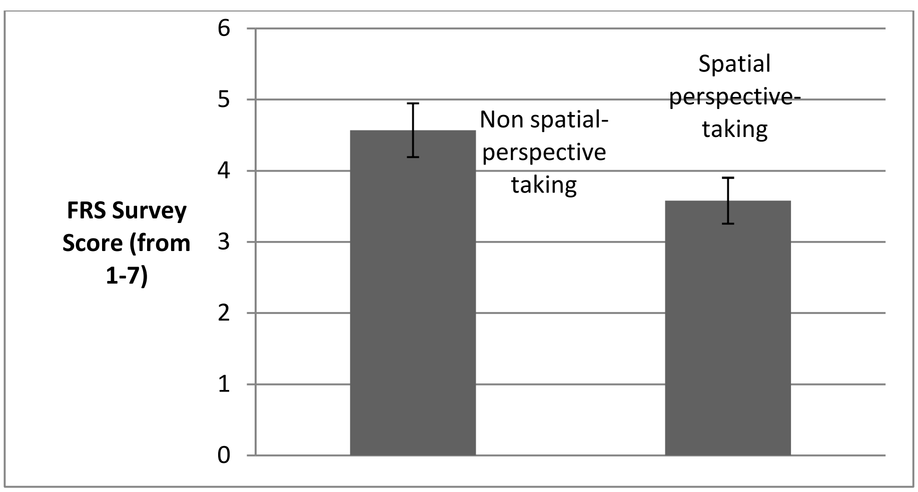


Figure 16. FRS survey score average of groups split based on whether they reported the instructions as meant for people coming from a side different from their starting position. People that exhibited such strategies were classified as spatial perspective-takers, while those that deemed that the directions were wrong were seen as non spatial perspective-takers. There is a trend towards those that thought the instructions were wrong to have a higher FRS survey score ($t(18)=1.95$, $p=0.066$).

Appendix B

Retrospective Questionnaire

Please describe how you solved this task in general terms. What was important to you when you made your decisions? Which things did you pay attention to? Please report everything that comes to your mind when thinking back about how you did this task.

For the following questions, please indicate your response using the scale provided. (Each question shown individually, with the scale at the bottom of the screen)

1. To what extent did you attend to the turn information (left/right)?

1= not at all ... 7= very much

2. To what extent did you attend to the landmark information (such as buildings)?

1= not at all ... 7= very much

3. If the instruction was inconsistent or ambiguous, to what extent did you prefer the turn or the landmark information?

1= turn ... 4= no preference ... 7= landmark

4. To what extent did you attend to the distance between the starting position and the turn options?

1=not at all ... 7= very much

5. To what extent did you prefer the first or the second intersection (relative to the starting point)?

1= prefer first ... 4= no preference ... 7= prefer last

6. To what extent did you prefer a left or right turn?

1= prefer left ... 4= no preference ... 7= prefer right

7. To what extent did you imagine yourself walking through the environment?

1= not at all ... 7= very much

8. Were there any landmarks that stand out clearly in your mind? If so, please list them.

9. Did you have difficulty identifying any of the landmarks? If so, please list them.

Appendix C

Questionnaire of Spatial Representations

The bolded question is the one added for the present study. The question was not entered into consideration of any of the factors of this questionnaire, which were split as done by Pazzaglia and deBeni (2001).

1. Do you think you have a good sense of direction?
   1= not at all ... 7= very much

2. Are you considered, by your family or friends, to have a good sense of direction?
   1= not at all ... 7= very much

3. **To what extent do you tend to mix up left and right?**
   1=not at all…7=very much

4. Think about the way you orient yourself in different environments around you. Would you describe yourself as a person:

   a. Who orients him/herself by remembering routes connecting one place to another?
      1= not at all ... 7= very much

   b. Who orients him/herself by looking for well-known landmarks?
      1= not at all ... 7= very much

   c. Who tries to create a map of the environment in your head?
      1= not at all ... 7= very much

5. Think of an unfamiliar city. Write the name of that city here: _________
   Now, try to classify your representation of that city:

   a. Is your memory map-like (like a bird's-eye view of the city):
      1= not at all ... 7= very much

   b. Is your memory route-based (like a first-person view of the city):
      1= not at all ... 7= very much

   c. Is your memory landmark-centered; that is, memorization of single salient landmarks, such as monuments, buildings, or crossroads:
      1= not at all ... 7= very much

6. When you are in a natural open environment (mountains, seaside, countryside), do you naturally know cardinal points? That is, do you know where North, South, East, and West are?
   1= not at all ... 7= very much

7. When you are in your home-town or city, do you naturally know cardinal points? That is, do you know where North, South, East, and West are?
   1= not at all ... 7= very much

8. If someone is describing the route for you to reach, do you prefer:
   a. To make a mental image of the route (imagine it)?
   1= not at all ... 7= very much

   b. To remember the description verbally (remember the distances, landmarks, and turns)?
   1= not at all ... 7= very much

9. In a complex building (store, museum) do you think spontaneously and easily about your direction in relation to the general structure of the building and the external environment?
   1= not at all ... 7= very much

10. When you are inside a building can you easily visualize what there is outside of the building in the direction you are looking?
    1= not at all ... 7= very much

11. When you are in an open space and you are required to indicate a compass direction (North, South, East, West), do you:
    a. Point immediately?
    b. Need to think before pointing?
    c. Have difficulty?

12. When you are in a complex building (with many floors, stairs, corridors) and you have to indicate where the entrance is, do you:
    a. Point immediately?
    b. Need to think before pointing?
    c. Have difficulty?

Appendix D

Simulator Sickness Questionnaire administered both pre- and post-virtual navigation.

No______________ Date___________________

POST-EXPOSURE SYMPTOM CHECKLIST

Kennedy, Lane, Berbaum, & Lilienthal (1993)

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

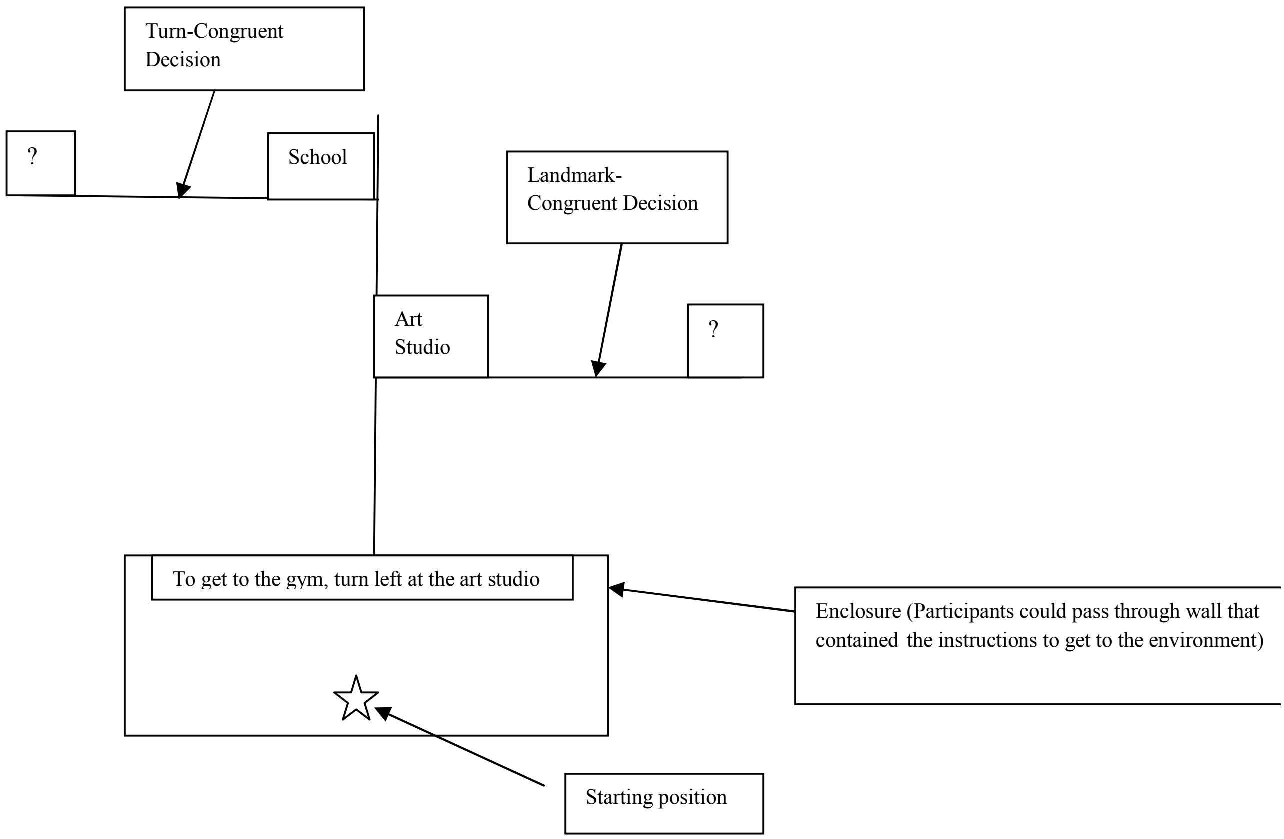
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Appendix E

Distracter Task 1 (used during the first break): Participants were told to find as many items in the picture as they could within one minute. They had to circle the items, but nothing was scored.

Appendix F

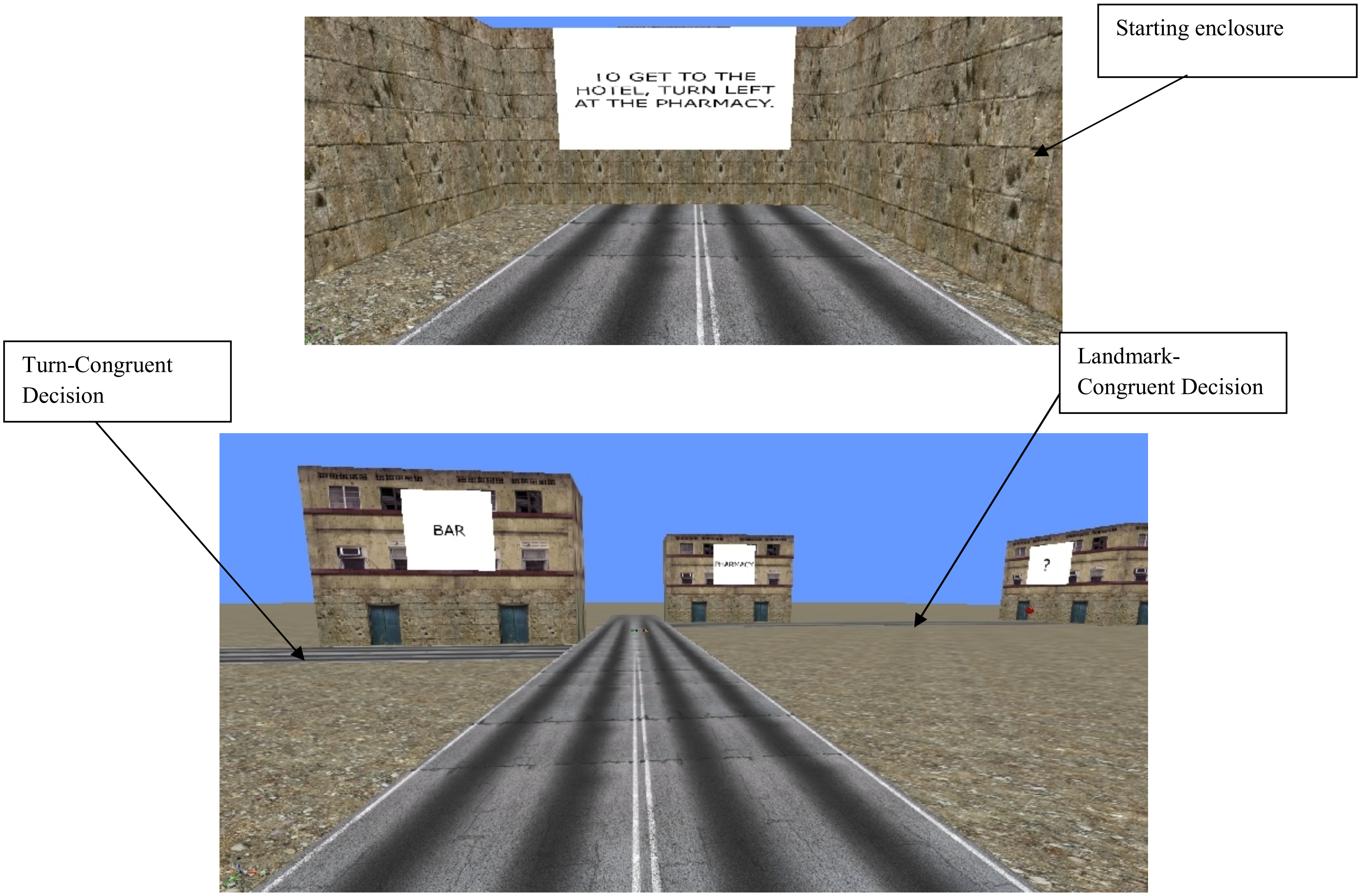
A. Two-Dimensional Overhead Schematic of Experimental Paradigm under Ambiguous Circumstances



Please note that all buildings in the actual environment were of the same size and that the intersections were of an equivalent length with each other. Flags were directly in front of the buildings marked by a question mark, one of which participants touched based on their judgment of the particular building as the destination (in this case, the art studio).

B. Screenshots of a Virtual Environment Trial

Note: The referred landmark in this ambiguous trial is on the second turn, as opposed to the first turn in the overhead schematic shown previously


Starting enclosure
TO GET TO THE
HOTEL, TURN LEFT
AT THE PHARMACY.
Turn-Congruent Decision
Landmark-Congruent Decision
BAR
?