ROUTE CHOICE IN VIRTUAL ENVIRONMENTS: THE EFFECT OF ENVIRONMENT SIZE, DESTINATION VISIBILITY, AND REGIONAL BOUNDARIES

by

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ABSTRACT

Choosing one route among multiple route options represents a navigation task that is influenced by many environmental factors. Several rules have been found that guide how navigators choose a route among several route alternatives. Those rules are called route choice principles. The current project investigates the effect of three environmental factors on people's route choice in a new task paradigm: choose one route among two route options to reach an initial destination when locations of later destinations are indicated. The three environment factors investigated are: size of the environment, visibility of later destinations, and regionalization in the environment. The current project tested, using virtual environments, the influence of these three factors on the recently-found "later-destination-attractor" (LDA) effect.

Existing literature suggests that navigators' route choices adhere to different route choice principles in small-size versus large-size environments. We hypothesized that it is the memory load instead of environment size that makes a difference regarding which route choice principle navigators follow. Existing literature also suggests that the influence of regionalization in the environment, defined as how the environment is perceived as divided into different regions, differ between individuals who are and who are not sensitive to regions in the environment. The current project pits the regionalization effect against the LDA effect. We hypothesized that the general population could be categorized into two groups: region-sensitive and region-insensitive. Finally, we hypothesized that left-handers and right-handers would differ in their route preferences regardless of environmental factors

LIST OF ABBREVIATIONS AND SYMBOLS

LDA	later-destination attractor
PAO	percentage above optimal
TSP	traveling salesman problem
M	Mean: the sum of a set of measurements divided by the number of measurements in the set; arithmetic average
N	Sample size
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
r	Pearson product-moment correlation
SD	Standard deviation: value of variation from the mean
F	The number of standard deviation in an F-distribution that the sample means from three or more groups differ from each other
t	The number of standard deviations in a t-distribution that the sample mean deviates from the mean stated in the null hypothesis
X	multiplication
<	Less than
>	Greater than
=	Equal to

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INTRODUCTION

Imagine moving to a new house. One of the tasks that people do is find local places such as a grocery store, a gas station, a post office, and a shopping mall. Next, people typically plan their route to reach all these destinations in a meaningful order based on factors such as travel time, distance, scenery and congestion (Ben-Akiva et al., 1984). Sometimes they need to look at a map to plan the route because the destinations are not readily visible from the home. Finally, people navigate to the places using their pre-planned order, run their errands, and return home. This scenario describes tasks that involve several cognitive processes to navigate successfully: knowing where things are in the environment, where the destination is relative to the starting point, making decisions about which place to go first, and making decisions about which route to take (i.e. route choice). The current project focuses on the factors that may influence route choice.

Previous research investigating the factors related to spatial cognitive processes run the gamut, from the mental representations of maps (e.g., Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998), to individual and group differences in virtual wayfinding (e.g., Prestopnik & Roskos–Ewoldsen, 2000), to navigation biases in a small-size environment (e.g., a conference room: Fu, Bravo, & Roskos, 2015), and to creating signage that may increase walking behavior (e.g., Birdsall, 2015; see also https://walkyourcity.org/). Most relevant to the current project is research on navigation biases. Fu et al. (2015), for example, found that the locations of later destinations (i.e., destinations that you want to go after reaching the first destination) affected route choice to the first destination. That is, if a later destination is located to the right, people are more likely to take an initial route to the right, and vice versa for locations on the left, even though the initial right/left routes are identical in length, distance, and angle from the origin. The effect that Fu et al. (2015) found was named *later-destination-attractor* (LDA) bias.

Questions to be addressed in the current project

The current project extends the general question, what are the factors that influence one's navigational route to the first destination? More specifically, the current study addresses three questions. First, how does memory load – the extent to which short-term memory is necessary – impact one's route choice? Second, how do environmental features, such as the size of the environment and any regional boundaries, affect the choice of one's route to the first destination? Finally, how do individual differences - such as which hand the person use to perform daily tasks - influence route choice in the LDA task paradigm?

Knowing the answers to these questions is important for two primary reasons. First, they will provide insights into the internal sources (e.g., memory, prior experience, and individual goal) as well as the external sources (e.g., the environment) of the decisions that lead to observable behaviors. Thus, it could help us better understand our spatial decision-making processes. A second reason is that the answers would increase our knowledge about how the various factors (e.g., size of the environment, visibility of later destinations; LDA bias and regionalization) interact to influence navigator's decisions. Having a better understanding of this knowledge could guide design of the physical as well as social environment to help navigators find their way around and help urban designers to ease difficulties such as traffic.

Previous research

In existing literature there is lack of consensus on how route choice behavior should be modeled or conceptualized (Manley, Addison, & Cheng, 2015). Conventional aspect of route choice modeling includes travel time, distance, scenery and congestion (Ben-Akiva et al., 1984). More recently, individual-centric transportation studies incorporate route perception (Cascetta, Russo, Viola, & Vitetta, 2002).

Cognitive biases in differently-sized environments.

Regarding the impact of the size of an environmental of the space on navigation, there are four basic environmental sizes that humans encounter (Montello, 1993). One is called figural space, which most often involves maps of an environment. A second is called Vista space, which is the space around a person where everything in the environment can at least potentially be seen. The third is environmental space, which includes neighborhoods and cities; and the fourth is geographical space, including cities within states or states within countries. According to Montello, the strategies people use to navigate or plan to navigate might differ as a function of the size of the environment.

Single-destination studies in small-size environments. One typical task paradigm used in small-size, single-destination navigation studies is choosing one route from several route options on a map. Bailenson and colleagues, for example, asked participants to choose one of two routes to connect an origin and a destination (Bailenson, Shum, & Uttal, 1998; Bailenson, Shum, & Uttal, 2000; Christenfeld, 1995: study 6; Brunyé et al., 2015). Bailenson and colleagues (2000) found that participants tend to choose a path that has a *long initial segment* or with *fewest turns*. Fu and colleagues asked participants to walk, in a conference room where all destinations are visible, and stop by a first destination for more than one second before walking to the second destination (Experiment 1; Fu et al., 2015; Figure 1). Although the participants' task was to walk to multiple destinations, the focus of our interest is the route they took to go to the first destination. Therefore, we consider this task as comparable to the other single-destination navigation task. In that study, the destinations were several pieces of paper. One survey question was printed on each piece of paper and the participants were told that their task was to walk to the papers and fill the survey questions. Results showed that among the two routes of equivalent length that connected the start location to the first destination, participants preferred the route that formed the least geometrical angle between the starting direction and the direction of second destinations. This effect represents the *later-destination-attractor* (LDA) bias.

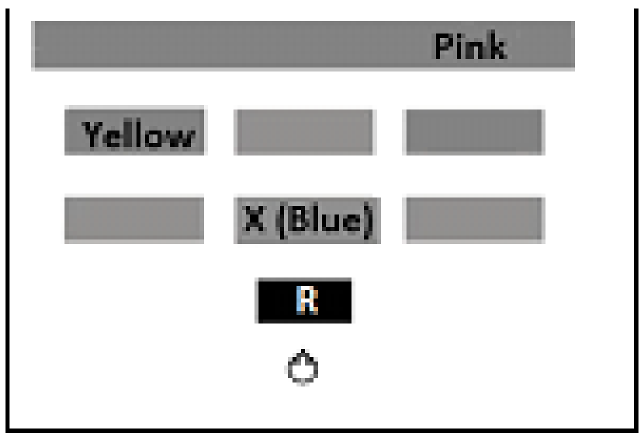


Figure 1. Diagram for a three-destination trial in Fu et al. (2015).

Another route choice principle that participants have consistently adhered to is the so-called *north-up* bias (Brunyé, Mahoney, Gardony, & Taylor, 2010; Brunyé et al., 2015). This principle applies to the task paradigm in which participants have to plan a trip on a map to go from a start location in the east to a destination location in the west (or vice versa). In this task paradigm, there are two route options of equivalent length by visual inspection: neither of the two routes represents a direct route from the start location to the destination location; instead, one route “leans” towards the north and one route “leans” towards the south. The north-up bias describes navigator’s preference to choose the south route over the north route. Further investigation on the north-up bias indicated that the southern bias was due to a misperceived elevation of the northern part of the map (i.e. thus named north-up bias).

In another study that was conducted in book stacks of an actual library in the United Kingdom, participants from both the United States and United Kingdom were told that there was a target at the other end of the aisle on either the left or the right side (Scharine & McBeath, 2002). U.S. participants consistently preferred to turn right upon reaching the end of the aisle, presumably because most people are right-handed and because driving is on the right side of the road in the U.S. This finding was termed the right-turn bias. In this study, the destination was not visible until after participants made a route choice. This study shows that, at least when the destination is not visible from start place, past experiences influence navigators’ route preference.

In the studies mentioned above, all destinations were visible except that in the “British library study” (Scharine & McBeath, 2002). In sum, the following route choice principles were found in small-size, single-destination navigation studies in which the destinations were visible: later-destination-attractor, long initial segment, fewest turn, north-up. And the right-turn bias was found in a study in which the destinations were not visible. The current study adds to the literature of navigation by testing single-destination navigation behaviors in conditions when the later destinations are visible and when the later destinations are not visible. The invisible conditions will provide participants with a diagram indicating locations of later destinations.

Multiple-destination studies in small-size environments. Multiple-destination studies in small-size environments usually adopt the traveling salesman problem (TSP), in which a salesman (the participant) has to stop at a number of locations, and the general goal is to form the shortest route that reaches each destination once. On a map or computer screen in which all destinations are visible, participants were asked to indicate the route they would take. In some cases, the routes that participants indicated represent a convex arch because the participants prefered to reach the outer locations first before going to the inner locations (*convex hull* bias: MacGregor, Chronicle, & Ormerod, 2004; MacGregor & Ormerod, 1996). In tasks that have fewer outer destinations than inner destinations, participants chose to visit the closest location first, then the next closest location, and so on (*nearest neighbor* bias: Vickers, Bovet, Lee, & Hughes, 2003). In other cases, participants chose to visit the nearest cluster of locations first, then the next nearest cluster, and so forth (*hierarchical clustering*: Graham, Joshi, & Pizlo, 2000). In still other cases when there are marked regions (i.e. regionalization) in the environment and the starting location and destination location are in different regions, participants preferred the route that leaves the start region or reaches the goal region the fastest (J. M. Wiener, Ehbauer, & Mallot, 2009). This represents the *regionalization* bias in route choice. The reason underlying regionalization bias is said to be a hierarchical decision-making process in wayfinding through which navigators reach the destination region first before reaching the destination place (Wiener & Mallot, 2003).

After discovering the region-based planning strategy in TSP, Wiener and colleagues (Wiener et al., 2009, Experiment 1) speculated that employing the region-based strategy would prevent participants from finding the shortest route in RS (i.e. region-strategy)-inadequate tasks. RS-inadequate tasks are tasks that were designed following the region-based planning strategy will systematically lead to a sub-optimal path. Following this speculation, Wiener et al. (2009) manipulated the task type so that in some of the trials the tasks were RS-adequate and in other trials the tasks were RS-inadequate. They also manipulated the memory condition so that each trial could fall into one of three conditions. In condition A (no memory required) all destinations were visible. In condition B (spatial working memory required) the participants were required to maintain a temporary representation of the spatial arrangement of the target locations. In condition C (spatial working memory and long-term memory required) the symbols of all 25 possible destinations were hidden under cover and participants learned the position of all possible destinations during a training phase prior to the test phase. Results showed that, when using the percentage of trials in which the participants found the shortest route as the dependent variable, ANOVA test results revealed a significant "task type X memory condition" interaction effect. Specifically, performance of finding the shortest route did not differ between the RS-adequate tasks and RS-inadequate tasks when no memory was required (i.e. memory condition A). In either condition B or condition C, performance was worse in RS-inadequate tasks than in RS-adequate tasks. That is, when the destinations were not readily visible, participants would follow the region-based planning strategy even if that led them to longer route.

In the studies mentioned above, all destinations were visible except for the condition B and C in Wiener et al. (2009; experiment 2) study. In sum, the following route choice principles were found in small-size, multiple-destination navigation studies in which the destinations were visible: convex hull, nearest neighbor, hierarchical clustering, and regionalization. The regionalization bias was found in a study in which the destinations were not visible.

Single-destination studies in large-size environments. Single-destination studies in large-size environments found the same regionalization bias as revealed in multiple-destination, small-size environment experiments when the destination was visible the whole time (Hochmair, Büchner, & Hölscher, 2008) and when the destination was not visible but the navigator had good knowledge of the environments (Spiers & Maguire, 2008). In the Hochmair et al. (2008) study, participants sat in front of a desktop computer and indicated which path they would choose when trying to reach a distant tower as fast as possible (see Figure 2: left figure). Two path options were presented in each trial. The manipulated variables were: whether there were regions in the virtual environment or not, and length of the path segment in the start region and length of the path segment in the destination region for trials that had regions. Moreover, the path options were designed so that sometimes the path that "leaves" the start region the fastest or "reach" the goal region the fastest was the longer path. Results show that more than half of the participants indicated some preference among the path pairs. Participants' path preferences in each pair were sorted using a constraint satisfaction problem technique (Freuder & Wallace, 1992) that generates a path preference profile for each participant. The resulting path preference profiles revealed a varying inclination of participants to trade-off the overall path length and the length of the path segment in the start region or goal region. Then Hochmair et al. categorized all participants into two groups using a hierarchical cluster analysis technique (Ward method with Squared Euclidean distance measure): those who did not always prefer the shortest path and those who would mostly choose the shortest path independent of regionalization. Having tested the same path preference profiles using different clustering methods and distance measurements, Hochmair et al. found a distinction between two clusters that validated the conclusion that some participants were more "region-sensitive" than others.

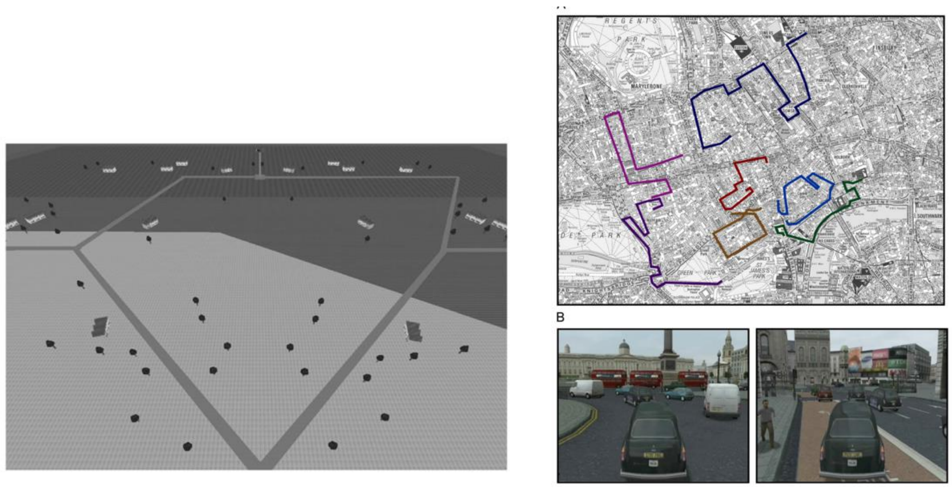


Figure 2. The virtual environment in Hochmair et al. (2008) (left figure) and the virtual environment in Spiers and Maguire (2008) (right figure).

In an observation study, Spiers and Maguire (2008) asked 20 taxi drivers to deliver passengers to places in a virtual environment and examined their self-report navigation strategies (see Figure 2: right figure). The study involved a single-destination navigation task, but at some point during navigation the "customer" requests a change of destination. The virtual environment mimicked the real city of London, and there were no manipulated variables in the design of the roads or destinations. For three of the seven routes, the "customer" made an additional request to avoid a location or take a route via a particular location. After the experiment, participants watched the video recording of their performance in the virtual environment and reported what they remembered thinking during the navigation. Each statement in the participants' verbal report was transcribed and classified into a set of categories. An example of one category is "route planning: spontaneous – re-planning". One example extracts from the verbal report that falls into this category is: "And then I think hold on, there's another way. It's like I said before, there always seems to be an option comes in your way. Um, so I thought well, okay then, if I can turn right, then I'm going to go up through the back of there and across the church". Spiers and Maguire found that the verbal report was consistent across the 20 participants. Specifically, when interviewed, participants said that they constructed a cognitive map that divided the city into different regions. If a destination was two regions away, for example, they tended to drive to the edge of the original region, pause to plan a route to the edge of the next region, and so on. The participants' expectation of the next junction or a landmark demonstrated good knowledge of the environment. Participants reported that they checked with those expected junctions or landmarks to confirm that they are on the right track. This result is consistent with the regionalization bias theory of route planning and route choice. In summary, participants planned a route to reach the destination and adjusted it because of adjustment in the task or because they planned to reach an intermediate point first before filling in the rest of the route plan.

Large-size, single-destination navigation tasks also revealed the usage of *least-angle* principle and initial segment principle. In a virtual environment, participants viewed a series of street intersections in egocentric route-view (i.e. from the participants' perspective) (Hochmair & Karlsson, 2005). At each intersection, participants stated their preference for one of two roads that they would follow to reach a distant goal as fast as possible. Route preference patterns revealed a preference towards routes that form the least angle between starting direction and the direction of the destination.

In the studies mentioned above, all destinations were visible except for the London taxi driver study (Spiers & Macquire, 2008). Therefore, the following route choice principles were found in large-size, single-destination navigation studies in which the destinations were visible: least-angle bias, initial segment strategy, and regionalization. And the regionalization bias, specifically hierarchically planning each segment of one route, was found in a study in which the destinations were not visible.

Multiple-destination studies in large-size environments. In large-size, multiple-destination studies, the destinations were usually not visible at the starting point (Jan M. Wiener, Schnee, & Mallot, 2004; Hölscher, Meilinger, Vrachliotis, Brösamle, & Knauff, 2006). In Wiener et al. (2004), participants were seated on a bicycle trainer (similar to the bicycle trainer in gyms) and could freely “move through” the virtual environments by pedaling and tilting the bicycle. Their task was to search in the virtual environment for specific objects. Participants were randomly assigned to one of two groups: participants in the “regionalized” group completed the experiment in the regionalized environment and participants in the “unregionalized” group completed the experiment in the unregionalized environment. An overshoot value was obtained by dividing the length of participants’ trajectory by the length of the shortest possible route. Results showed that, in the single-destination trials (i.e. experiment 1) as well as multiple-destination trials (i.e. experiment 2), subjects from the unregionalized group showed much higher rate of overshoot than those who navigated in environments that were regionalized. The nearest neighbor strategy was not found in this experiment, in which there were multiple destinations and none of them were visible from the starting point.

Wayfinding studies in buildings that have more than one floor revealed a unique variation of the regionalization strategy. Hölscher and colleagues (2006) asked participants to find six locations in a conference center that they were not familiar with. The conference center is a complex, multi-level and multi-functional building. The dependent variables included time to complete the task, the number of pauses, and total distance covered. While searching for the six targets, participants were filmed with a camera and verbalized their thoughts afterwards. The verbal report shows that participants used a so-called “floor strategy”. That is, they navigated to the correct floor first and then find the target (an example of an alternative strategy would be go to the east side of the building and then go to the third floor). Hölscher and colleagues concluded that this "floor strategy" could be interpreted as a 3D variation of the regionalization bias. The other two common strategies they found were: central point strategy (i.e. found one's way by sticking as much as possible to well-known parts of the building) and direction strategy (i.e. chose routes that head towards the lead to the horizontal position of the target location). Hölscher et al. (2006) also found that the floor strategy was preferred by experienced participants and was related to overall better wayfinding performance.

In the studies mentioned above, all destinations were not visible. That is, the following route choice principles were found in large-size, multiple-destination navigation studies in which the destinations were not visible: central point, direction, floor, and regionalization.

Uncoupling environment size and memory load

Despite the different cognition mechanisms involved during navigation in small- and large-size spaces, size of the spaces are often confounded with memory load. In small-size spaces, there is often no need to remember the locations of the destinations because the destinations can all be seen simultaneously. In large-size spaces, this is not the case; one cannot see the destinations and thus must remember where they are. This situation begs the question: do strategies differ because of the size of the environment, or because of the memory load?

Fu et al. (2015) partially answered this question across three experiments. In a small conference room that was about 18 feet width, 26 feet long, and 9 feet high, participants walked to two or three pieces of papers placed on rows of tables in the room. Crucially, the first destination was always placed on a table right in front of participants, and there was an obstacle between the starting point and the first destination. The dependent variable was the route that participants took to walk around an obstacle to go from the starting point to the first destination.

There were two route options in each trial: participants could either walk around the left side of the obstacle to reach the first destination or walk around the right side of the obstacle to reach the first destination. From Experiment 1 to Experiment 2 to Experiment 3, Fu et al. varied the memory load while keeping the size of the environment the same (i.e., Vista- or room- sized). In Experiment 1, all destinations were visible the whole time (i.e., there was low memory load). In Experiment 2 and Experiment 3, the second and third destinations were not visible from the start place and a simple diagram that indicates the location of all destinations was shown to the participants before they left the starting point in each trial. In Experiment 2, the second and third destinations were not visible until participants reached the first destination (i.e., medium memory load). In Experiment 3 of that study, the second and third destinations were not visible until participants reach them, and the diagram that showed the location of the second and third destinations were upside-down when participants view them at the starting point (i.e., high memory load).

When all destinations were readily visible, which required low memory load, as was the case in Experiment 1, participants' route choice to the first destination was influenced by the second and third destinations. If the second (or third) destination was on the left, participants tended to go around the left side of the obstacle to reach the first destination. If the second (or third) destination was on the right, participants tended to go around the right side of the obstacle to reach the first destination. And if the second (or third) destination was in the center, their route choices were split between the left and right sides of the obstacle. These three behavioral patterns together represent a later-destination attractor bias (Figure 2, Experiment 1).

In Experiment 2 and Experiment 3, the second and third destinations were not visible directly. Instead, participants viewed a simple diagram of the locations of the destinations and had to remember them. In Experiment 2, the diagram was the same orientation as the room, but in Experiment 3 the diagram was rotated 180 degrees when participants view it at the starting point, representing moderate and high memory loads, respectively. As memory load increased, the bias decreased; that is, the location of later destination had less of an effect on one's navigational choice around the first obstacle (Figure 3, Expt2 and Expt3).

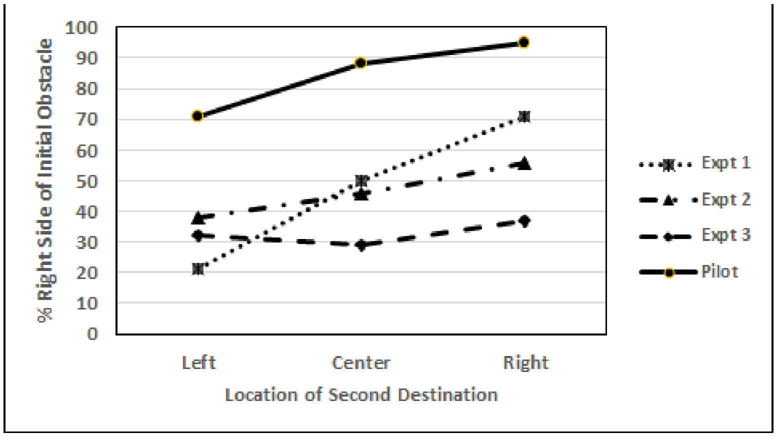


Figure 3. Second destination location and route choice in Fu et al. (2015) and in the pilot study.

The Fu et al. (2015) study partially answered the "size/cognitive-load" question by manipulating the memory load and keeping the environment size constant. However, to fully uncouple the environment size and memory load, further studies are needed. So far, we still do not know the full answer to the question - is it the size of the environment or the memory load (or both) that drives the differences in biases that people have when choosing their routes?

Regionalization bias

Regionalization in the environment has been found influence participants' route choice through two primary means. The first way through which regionalization influences route choice is that navigators prefer the route that leaves the start region fastest or reaches the destination region the fastest (Hochmair et al., 2008; see Hölscher et al., 2006 and Wiener et al., 2004 for variations of region-based planning strategies). The second way through which regionalization influence route choice is that navigators prefer routes that transpass regions that display certain characteristics (e.g. prefer flat over mountainous regions in Brunyé et al., 2015).

In a study that used large-size virtual environments, Wiener and Mallot (2003) showed that adhering to the regionalization principle for route choice requires recognition of the regions in the environment. Through the training phase participants could learn that, for example, some landmarks are animals and some landmarks are buildings. In the "regionalization" trials, landmarks of the same type were close to each other, thus forming a "region". Target places were not visible until participants reached them. The participants' task was to navigate using the shortest route possible to connect their current position with three target places. After the navigation task, all participants were asked whether they had recognized the regions in the environment or not. The researchers found that participants who recognized the regions in the environments significantly preferred routes that crossed fewer region boundaries. Participants who did not recognize the regions in the environment did not show a preference towards the routes that minimize the number of region boundaries. Collapsed across all individuals, however, there was not a significant "region effect" among the participants.

In fact, Hochmair et al. 2008 warranted the influence of region-sensitivity, as an individual trait, on the influence of regionalization on path choices. Participants were seated in front of a screen and were asked to indicate which one of two paths they would follow to reach a distant tower (visible) as fast as possible (Hochmair et al. 2008). The key manipulation in that study was the length of route segments in the start region and the goal region. To examine the trade-off between choosing the shortest route and choosing the route that leaves the start region the fastest, 20 path options were designed by combining the four detour attributes (0%, 10%, 35%, 50%) and five regionalization attributes (10%, 20%, 30%, 40%, 60%). For example, one pair of routes might compare a longer route that reaches the goal region faster and a shorter route that reaches the goal region slower. A preference value was calculated for each route, and that preference value was used as the dependent variable for ANOVA tests. Results show that about half participants were indifferent between these two route alternatives: one that leaves the start region the fastest and one that reaches the goal region the fastest. They also found that there were two groups of participants: the region-sensitive group did not always prefer the shortest path (i.e. took the route that leave the start region fastest or reach the goal region the fastest but longer in terms of overall route length), whereas the region-insensitive group mostly chose the shortest path independent of regionalization. Therefore, it is better practice to use region-sensitive participants only when studying spatial behaviors using the regionalization paradigm.

Another study further investigated the relative impact of the regionalization principle and two other route choice principles on the ultimate route choice behavior in navigators. Brunyé et al. (2015) examined the relative importance of three route choice principles. The *initial segment* principle encourages navigators to select the straight rather than windy routes when leaving the origin. The *north-up* principle encourages navigators to select generally south- rather than north-going routes. The *regionalization* principle encourages navigators to select routes that avoid traversal of complex topography such as mountainous areas. Participants chose one of two route options on satellite maps presented on a computer screen. Factorial repeated-measures design was used to manipulate the routes' cardinal direction (north, south, east, west), the initial straightness (straight, winding), and relative topography of regions traversed (flat, mountainous, mixed). Selection frequency was calculated for each route and used as dependent variable in the ANOVA tests. Results showed no clear interaction regarding the influences of these three route-choice-principles, meaning the influence of one principle on route choice was not dependent on the condition of another principle. Moreover, Brunyé et al. found that participants initially focus attention on the initial segment of each route option; when no initial straight segment was available, participants tended to consider the characteristics of the entire route. Based on the rationale behind least-angle strategy (Hochmair & Karlsson, 2005), whether the initial segment of a route is straight or winding is important because it determines whether or not the starting direction of a route would form a least-angle with the goal direction. Therefore, the implication of Bruenyé et al.'s observation is that navigators would pay attention to the goal direction first before attending to the overall features of the route.

In the current study, regionalization in Experiment 3 was manipulated so that the behavioral results of the LDA effect (i.e. prefer the route that starts off in a direction that forms a smallest angle with the later destination direction) and the behavioral results of the regionalization effect (i.e. prefer the route that leave the start region and reach the goal region the fastest) will be congruent in some condition and incongruent in some other conditions. The goal of the current manipulation is to test the relative impact of the regionalization principle and the LDA principle on people's route choice. Based on the results in Hochmair et al. (2008), it is expected that participants will pay attention to the location of later destination first. When the location of later destination is neutral, then participants' route choice will be influenced by the regionalization condition.

Handedness effect

Another individual characteristic that has been found to be related to route preferences is handedness. Scharine and McBeath tested participants' turning preference in a simple "T-maze" task (2002, as described above). They found that handedness was the best predictor of which side (i.e. left or right) the participant would turn at the intersection of the "T-maze". U.S. participants were more likely to turn right than the U.K. participants. Eye dominance and reading direction were not related to the directional preference.

Handedness was also found to be related to memory capacity in a wayfinding task (Devlin & Bernstein, 1997). In their experiment, there were four major steps. First, participants in a Visiter Center were asked to locate an “entrance” of the Visiter Center by touching on a computer screen the visitor center on a map near the “entrance.” Feedback was provided on the computer screen that showed the map to inform participants whether they located the “entrance” successfully. The participants then were asked to touch Schaefer Building using the same touch procedure. In step three, participants were shown a “correct path” from the Visitor’s Center to the Schaefer Building and they were asked to remember that path. In step four, the participants were asked to select from several alternatives the correct path to go from the Visitor’s Center to the Schaefer Building. The results showed that left-handers, measured by a self-report survey, made significantly fewer errors than right-handers.

Another study in which handedness may have been a factor was a study in which participants walked to two or three destinations in a pre-determined order (Fu et al., 2015). Fu et al. reported an overall left-route bias among participants. That is, most participants went around the left side of the obstacle to reach the first destination. The reason for this left route bias was unclear. One speculation could be related to the right-handedness in the general American population through the following mechanisms: at both the start location and the first destination, participants had to write (i.e. sign the consent form at the start location and respond to the survey question at the first destination) before proceeding to the next destination. The preference to walk around the left side of the obstacle to reach the first destination might have been related to this writing task: by passing the table on the left, they prevented their body from getting in the way of their right hand. However, as stated earlier, the actual reason for the left route bias was not clear, especially that we did not collect handedness information of the participants. Therefore, one of the goals of the current study is to collect handedness data and further investigate the impact of handedness on participants' route choice.

Summary of previous research

The results of existing studies indicate that any difference in cognitive biases reflected in route choice between small- and large- size environments may be due to the difference in memory load and not due to the size of the environment. Also, the impact of various cognitive biases might have an additive effect of route choice. That is, routes that are preferred by all cognitive biases (i.e. route choice principles) will be the most popular routes demonstrated by navigators' actual route choice behavior. Moreover, individual characteristics such as region-sensitivity and handedness might influence people's route choice. The Fu et al. (2015) study partially explored the issue revealed in the fact that memory load and size of the environment might be confounded in most of the large-size environments. However, they provide only half of the picture: only a Vista-sized space was used. To further investigate the robustness of the later-destination attractor bias, one must also use an environment-sized space and manipulate the memory load. Finally, there are two individual characteristics (i.e. region-sensitivity and handedness) that may be related to route choice.

Shape of objects in the environment

Shape of objects in the environment, such as shape of landmarks or shape of the obstacle table in Fu et al.(2015), influence route choice through influencing navigator's heading orientation at decision points. Vandenberg et al. (2016) summarized three cognitive and sensorimotor components that are involved in wayfinding: orientation, decision making, and path integration. Topography in the environment has been shown influence wayfinding performance through influencing orientation of the navigators during the wayfinding task. In a large-size virtual city, young adults and old adults performed wayfinding tasks in a city with either block-topography (straight corridors and 90 degree turns at decision points) or variable-topography (winding corridors and variable degrees of turning at decision points). Results show that navigational learning was easier in a city-block than a variety topography for young but not old men. Aguirre and D'Esposito (1999) suggest that navigators incorporated landmarks in a body-reference fashion. Therefore, landmarks that are aligned with the boundary frame of the environment would help navigators orient their headings. For example, "turn right at the bank" would be more helpful if the destination is on the right side in the environment and the bank is facing the backside of the environment.

In the current study, objects in each environment (not targets) were arranged to form a symmetric setting and the contour of the rectangle objects were aligned with the contour of the rectangle environments. The purpose of this environmental design was to minimize memory load induced by misalignment between contour of reference object and contour of global reference frame.

Overview of Current Project

The current project aimed to investigate several factors that may influence navigators' route choice to a first destination in multi-destination navigation task. There was a pilot study and three experiments in the current project. In all experiments, the participants' task was to walk to two or three destinations in a pre-determined order. In all experiments, the first destination was located directly on the other side of an obstacle so that the participant needed to walk around the obstacle to reach it. The second destination (and third destination in the first two experiments) varied in location (left, center, and right side of the environment). The main dependent variable was whether the participants walked around the left or right side of the obstacle to get to the first destination. The LDA effect would be displayed if participants walk around the left side when the second (or third) destination is on the left, and the right side when the destination(s) are on the right. The pilot study was designed to test whether the LDA effect would be seen in a virtual environment. In the first two experiments, both the size of the environment and the memory load (i.e., the visibility of the destinations) were manipulated. The third experiment introduced regionalized spaces that are hypothesized to affect the LDA effect.

Experiments 1A and 1B replicated Fu et al.'s (2015) study in virtual environments. Experiment 1A replicated Experiment 1 in Fu et al. in which participants walked to two or three destinations in pre-determined sequences and all destinations were visible the whole time. Experiment 1B replicated Experiment 2 in Fu et al. in which participants walked to two or three destinations in a pre-determined order just like those in Experiment 1A. In experiment 1B, however, the second and third destinations were not visible until participants reach the first destination. Instead, a diagram was provided to the participants at the beginning of each trial to show them where the destinations were. Experiments 2A and 2B are similar to Experiments 1A and 1B respectively, except that the environments in 2A and 2B represented larger environments than those in 1A and 1B. In Experiment 2A, participants walked in large-size virtual environments to reach the destinations in pre-determined sequences and all destinations were visible the whole time. In Experiment 2B, the second and third destinations were not visible until after participants reached the first destination. Experiment 3 tested the effect of regionalization on participants' route choice. The virtual environments in Experiment 3 were divided into regions by manipulating the texture of the floor in different areas while varying the location of the second destination. Each participant completed one of the five experiments: 1A, 1B, 2A, 2B, 3. There were 12 conditions with 4 repeated trials of each condition in Experiments 1A, 1B, 2A, and 2B. There were 9 conditions with 8 repeated trials of each condition in Experiment 3. In each trial, participant's route choice to the first destination was coded as either "0" (i.e. chose the left route) or "1" (chose the right route). Average value from the repeated trials were calculated for each condition to generate a probability for each participant to choose the right route in that condition.

Hypotheses and Research Questions

Hypothesis 1. If the LDA effect can be generalized from real environments to its counterpart virtual environments, then the probability that participants will walk the right route around the obstacle will be different when the second destination is on the right than when the second destination is on the left (i.e., the LDA bias will present). If the LDA effect was strongly influenced by factors that differentiate real environments from virtual environments, then the probability that participants walk the right route around the obstacle will not be different when the second destination is on the right than when the second destination is on the left (i.e., the LDA bias will not present)

Hypothesis 2. If the LDA bias is positively influenced by visibility factor, then the LDA bias will be more salient when all destinations are visible than when the visibility of some destinations are restrained. If the LDA bias is not strongly influenced by visibility factor, then the LDA bias will be comparable when all destinations are visible and when the visibility of some destinations is restrained. If the LDA bias is negatively influenced by visibility of destinations, then the LDA bias will be less salient when all destinations are visible than when the visibility of some destinations are restrained. Saliency of the LDA bias was evaluated by inspecting the effect size of the influence of later destination location on participants' route choice to the first destination.

Hypothesis 3. If the LDA effect is not influenced by the size of the environment, then the LDA effect would be no different in Experiment 2 than that in Experiment 1 for comparable conditions. If the LDA effect is influenced by the size of the environment, then a different pattern of results would be seen in Experiment 1 and Experiment 2. The LDA effect in each condition would be compared through inspecting the effect size of later destination locations on the proportion of walking the right-route paths.

Hypothesis 4. (a) If the nature of LDA effect is a principle that guides navigators' route choice, then it should have similar influence on route choice as other principles such as regionalization effect. That is, when both LDA factor and regionalization factors were manipulated in an environment, both factors should influence route choices; (b) If the LDA effect and regionalization effect have independent influences on navigators' route choice, then there should be additive effect when the route encouraged by the LDA condition is consistent with the route encouraged by the regionalization condition and there should be no interaction between these two factors when both factors are manipulated in a task paradigm. (c) If later destination location influence participants' route choice prior to regionalization does, then participants' route choice should be in the same direction as is encouraged by the LDA condition. That is, if the LDA condition encourages a preference towards the right-route paths and, in the same trial, the regionalization condition encourages the left-route paths, then participants should take the right-route paths.

Hypothesis 5. If handedness influences route choice, then the route choice in right-handers would be different from the route choice in left-handers. If handedness does not influence route choice, then the route choice in right-handers would not be different from the route choice in left-handers. Moreover, if the left-route bias observed in Fu et al. (2015) was related to the benefit of walking the left-route paths in the writing task, then right-handers should prefer the left-route paths more than left-handers do when a writing task is involved in the navigation.

PILOT STUDY

The current project used 3D virtual environments in which participants can show their route choice by "walking" to the destinations. Navigation study using virtual environments enjoy the convenience of manipulating the size of the environment and memory load in each experimental condition while controlling for other variables. Creating identifiable regions is also much easier in virtual environments than in real outdoor environments.

Existing studies reveal inconsistent results regarding whether human performance in virtual environments are comparable to those in real environments. Most studies, using spatial tasks, did not find major differences in their results using virtual environments or real environments (wayfinding task: Farran, Courbois, Van Herwegen, Cruickshank, & Blades, 2012; water maze task: Horne, León, & Pearce, 2013; Redhead & Hamilton, 2007; Buckley, Smith, & Haselgrove, 2014; spatial learning: Rand & Thompson, 2016; Chrastil & Warren, 2013; Wiener et al., 2004; line bisection task: Gamberini, Seraglia, & Priftis, 2008). There are, however, some navigation tasks that did not generate comparable human performance in real versus virtual environments. Wiener and Mallot (2003), for example, tested in virtual environments the *Initial Straight Segment* strategy, based on which the navigators should always choose the route with the longest initial segment among alternative routes. They found that the initial straight segment strategy did not influence the route that participants took.

The purpose of the pilot study was to test the computer programs and study procedures before recruiting participants for the main experiments. Therefore, the pilot study included only the “two-destination” trials and “all destination visible” conditions from Fu et al. (2015). If the LDA bias can be replicated in the pilot study, then one could manipulate both the size of the environment and visibility of destinations independently. The pilot study was conducted in a virtual room to replicate Experiment 1 in Fu et al. (2015), where the environment was a vista-sized conference room. In this pilot study, we placed two objects in a virtual room that mimicked the two-destination trials in Fu et al., in which the participants walked to two pieces of papers in pre-determined order.

Participants

Twenty-four students (13 females, aged 18-22) from the University of Alabama participated in the pilot study. They received credits towards a course requirement for their participation.

Environment, Tasks, and Materials

The virtual environment in the pilot study mimicked the real environment in Fu et al. (2015), which was a conference room of the following measures: width 18 feet, length 26 feet and 3 inches, height 9 feet. At the beginning of the experiment, each participant was given the following oral instruction: “This is a virtual classroom with tables. In each trial, your task is to walk to a hat and then a hotdog and then a burger. You can use these four keys (point to the keys on the keyboard) to move in the virtual environment and use the mouse to look around. The targets will disappear once you walk to them. After you reach the last target, just walk to the wall on the back to connect to the next trial. There are 12 testing trials in total. In some trials there is no burger, in which case just walk to the hat and then to the hotdog. You will complete three practice trials before starting the testing trials.”

The pilot study adopted a within-subject design. The independent variable – second destination location - has three levels of values: second destination on the left, second destination in the center, and second destination on the right. Each participant completed four repeated trials of each condition, generating 12 trials in total. The sequence of the 12 trials was randomly generated for each participant. The dependent variable was the percentage of times the participants walked around the right side of the obstacle to reach the first destination. In each trial, the participant could either walk around the left side or the right side of the obstacle to reach the first destination. If the participant walked around the left side of the obstacle to reach the first destination, it was coded as "0" for the dependent variable. If the participant walked around the right side of the obstacle to reach the first destination, it was coded as "1" for the dependent variable. Each participant came for one experiment session, and all sessions were recorded by a free screen-capture software named OBS (https://obsproject.com/). Each participant completed a questionnaire after the navigation task. The questionnaire asked about demographic information as well as a one-item measure of handedness (see Attachment A)

Procedures

There was one participant in each study session. In one study session, the participant signed a consent form upon arrival at the lab. Next, the participant completed the navigation task. Finally, the participant completed a paper-and-pencil questionnaire, was told about the study, and received an informational handout for educational purposes. The experiment generated 12 route choice responses (either "0" or "1") from each participant. Each study session lasted about 20 minutes.

Results and Discussion

The basic LDA effect was found (Figure 2, Pilot), such that participants were more likely to go around the right side of the obstacle when the later (second) destination was on the right, and vice versa for destinations on the left, $F(2, 88) = 25.57$, $p < .001$. These findings indicate that a virtual environment can be used to investigate LDA bias. But, overall, there was a much higher incidence of navigating around the right side of the obstacle in the virtual environment (95%) compared to the original experiment (75%). This right route bias was likely due to participants' using their right hand to press the keys necessary for moving around in the virtual space. This methodological issue was rectified in the current study by having the participants move around in the virtual space using their left hand on half of the trials and using right hand on the other half of the trials. Also, room and table measurements in the current study were adjusted to better reflect the respective room and table measurements in the original study (Experiment 1, Fu et al., 2015).

The pilot study tested, for the first time, the basic LDA task paradigm in a virtual room. The strong influence of the second destination location on participants' route choice to the first destination suggests that the basic LDA effect could be replicated in a desktop virtual environment. Results from the pilot study, however, revealed a stronger preference towards the right route than that in Fu et al. (2015: 2-destination trials in Experiment 1). Overall, the pilot study suggests a possibility to use the LDA paradigm to test spatial behavior in virtual environments and generalize the results to comparable real environments. A comparison between the pilot study results and results from Fu et al. cautions functionality differences between navigation in virtual environments and navigation in real environments

EXPERIMENTS 1A AND 1B: VISTA-SIZED SPACE

The purpose of the first set of experiments (1A and 1B) was to replicate the *later-destination attractor* (LDA) bias in a vista-sized virtual room. Specifically, in Experiment 1A, the room-sized virtual environment was constructed so that each destination was visible to the navigator throughout the whole trial if the navigator "look" to the direction of that destination. In Experiment 1B, the environment is also vista-sized, but the second and third destinations were not visible to the navigator from the starting point until the navigator reached the first destination. Instead, a diagram was used to indicate the locations of the second and third destinations. In both experiments, the locations of the second and third destinations were manipulated within-subjects to create a 3 (second destination location: Left, Center, Right) X 4 (third destination: Left, Center, Right, nonexistent) factorial design. The "nonexistence" condition for the third destination means that there were only two destinations. The critical dependent variable was the proportion of times participants navigated around the right side of the table between the starting point and the first destination.

Method and Data Analyses

Participants

A power analysis based on the linear trend analyzes from the original study indicated that there should be 44 participants in each experiment (eta squared = .16, alpha = .05, beta = .80) for a total of 88 participants. The final sample included only participants who provided valid experiment data, resulting in a total of 161 participants (47 males, 108 females, 2 self-identified as other gender, and 4 with missing gender information) aged 18 to 25 with 4 missing age information. Participants were recruited from a pool of students taking an introduction to psychology course. They received credit towards a course requirement.

Materials and Tasks

Surveys. Survey1 was administered through Qualtrics before each navigation experiment and Survey2 was administered after the experiment. There were two types of questions in Survey1: demographic questions (Appendix B) and the Edinburgh Handedness Inventory (Oldfield, 1971) (Appendix C). The Handedness Inventory indicates to what extent they are left-handed or right-handed. Each item is rated on a size ranging from 1 (not at all) to 5 (always). Research shows that this size has satisfying reliability and validity (Raczkowski, Kalat, & Nebes, 1974; Bryden, 1977). One question reads "to what extent are you right-handed?" Handedness were analyzed separately from the main hypotheses. In Survey2, there were three questions regarding sense of immersion in the environment. The demographic questions ask participants their gender identity, age, race, and ethnicity. Answers to these questions were used primarily to describe the participants.

Navigation Task. The task comprises a brief practice phase and a testing phase. During the practice phase, participants completed more than one practice trials. The practice trials were randomly sampled from regular testing trials. During the testing phase, two blocks of testing trials were presented to the participant. In each block, there were two repetitions of the 12 experiment conditions: 3 location of the second destination (left, center, right) X 4 location of the third destination (left, center, right, non-existent). The 24 testing trials in each of the 2 blocks were presented in counterbalancing sequence. Each participant was given the following oral instruction: “This is a virtual classroom with tables. In each trial, your task is to walk to two or three targets. For example, in this trial, you will walk to a hat and then a suitcase and then a crate (point to the hat and then the suitcase and then the crate on computer screen). You can use these four keys (point to the keys on the keyboard) to move around in the virtual environments and use the mouse to look around. The targets will disappear once you walk to them. After you reach the last target, just walk to the backwall to connect to the next trial. There are 48 testing trials in total. In some trials, there are no crate so just walk to the hat and then to the suitcase. You will complete a couple of practice trials first. I will get you started with the testing trials once you demonstrate sufficient understanding of my instruction during practice trials.” During the experiment, participants had the freedom to either use mouse or the keyboard to move to the left and right.

Virtual environment. The current experiment used the “Hammer” editor to build the virtual environment and used Garry’s Mod (Copyright Valve Corporation, 2004) to execute the experiment. The layout and a screenshot of a three-destination trial are shown in Figure 4. The environment mimicked the original conference room environment in Fu et al. (2015). There was a table right in front of the start location mimicking the “reception table” in the original study. Six rectangular tables, three tables in a row, were placed behind the reception table in grid setting. The only difference between the room in the original study and the current study is that there were five tables in the last row in the original study and three tables in the last row in the current study. The purpose for this change is to allow participants to proceed to the next trial by walking to the back wall whereas in the original study the participants proceeded to the next trial by walking back to the reception table. In Experiment 1A, all tables were visible from the starting point. In Experiment 1B, there were barriers between the first destination and the later destinations.

(a) (b) (c)

Figure 4: Diagram and screenshots of a three-destination trial in Experiment 1: (a) Environment layout (b) screenshots of Experiment 1A and in (C) screenshot of Experiment 1B.

Screen recording and coding. The computer screen (not the face of the participant) during each experiment was recorded using Open Broadcaster Software, which is an open-source software for recording and live-streaming. The recordings were coded at a later time for the path the participants took around the obstacle, which was converted to the proportion of times a participant walked around the right side of the obstacle table for each condition. Experiment data from each participant was coded by one of the 18 coders. Coders were recruited from volunteer research assistants who were unaware of the study hypotheses. On each trial, the route that participants walked around the obstacle to reach the first destination was coded as the dependent variable.

Procedure

Participants were tested individually. When participants arrived at the lab, they first read and signed a consent form. Then they completed Survey1 on the computer before starting the navigation task. After the navigation task, participants completed Survey2 also on the computer and were debriefed. This was a one-session experiment, and each session lasted around 45 minutes.

Data Analysis

The data from Experiment 1A and Experiment 1B were analyzed separately. The data from two-destination trials and three-destination trials were analyzed separately. For each condition, the dependent variable is the proportion of trials in which the participant walked around the right side of the obstacle to reach the first destination. The independent variables were the locations of the second and third destinations. During the experiment, participants had the freedom to either use mouse or the keyboard to move to the left and right. While observing the video recording, we found that participants who used the mouse to "orient" their body in the virtual environments displayed different route choice behavior from those who only used keyboard thus never rotated their body in the virtual environments. Therefore, the results will be presented for these two groups of participants separately.

1A Results. Out of the 92 participants in Experiment 1A, 48 used mouse to navigate in the virtual environments and 44 did not use mouse to navigate in the virtual environments.

Two-destination Trials. For two-destination trials, according to Hypothesis 1, the proportion of right-route paths would differ when the second destination is on the left side, centered, or on the right side if the LDA effect can be generalized from real environments to its counterpart virtual environments. Similarly, the proportion of right-route paths would not differ when the second destination is on the left side, centered, or on the right side if the LDA effect cannot be generalized from real environments to its counterpart virtual environments. A one-way repeated-measures ANOVA was conducted to test whether the proportion of "right route preference" differed when the second destination was on the left side, in the center, or on the right side.

Participants who used the mouse to navigate in the environment. Location of second destination influenced participants' route choice to the first destination, $F(2, 94) = 31.54$, $MSE = .10$, $p < .001$, $\eta^2 = .40$ (Table 1). There was a linear trend of preferring the right route as the second destination was relocated from the right to the center to the left, $F(1, 47) = 43.86$, $MSE = .15$, $p < .001$, $\eta^2 = .48$. Table 1 and Figure 5 present the descriptive statistics for this analysis.

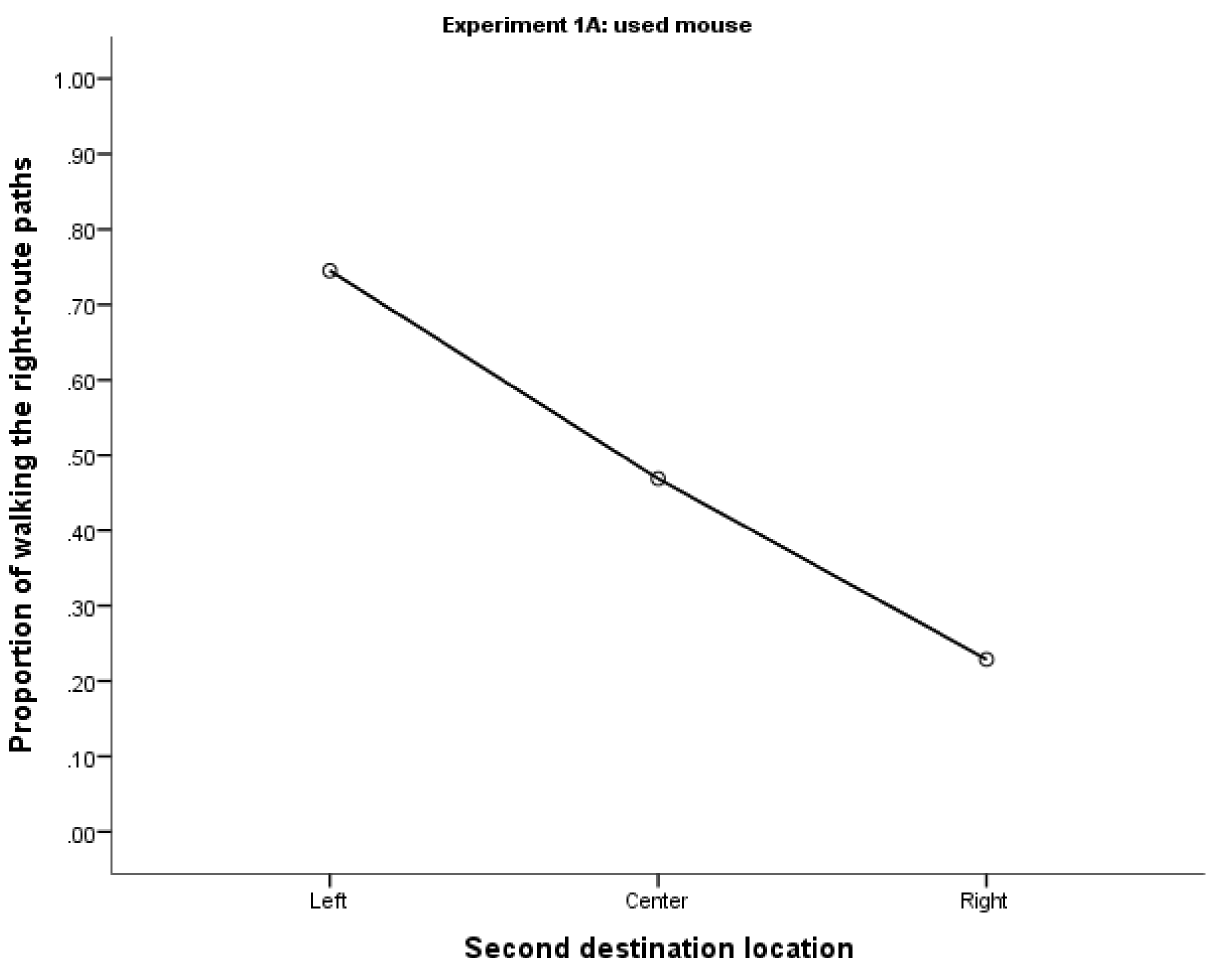


Figure 5. Proportion of choosing the right-route paths in Experiment 1A with mouse in two-destination trials.

Participants who did not use the mouse to navigate in the environment. Location of later destinations did not present a significant influence on their route choice to the first destination, $F(2, 86) = 1.05$, $MSE = .10$, $p = .35$, $\eta^2 = .02$. There was no significant linear trend of preferring the left-route paths or right-route paths as the second destination was relocated from the right to the center to the left, $F(1, 43) = 1.00$, $MSE = .14$, $p = .32$, $\eta^2 = .02$. Table 1 and Figure 6 present the descriptive statistic for this analysis.

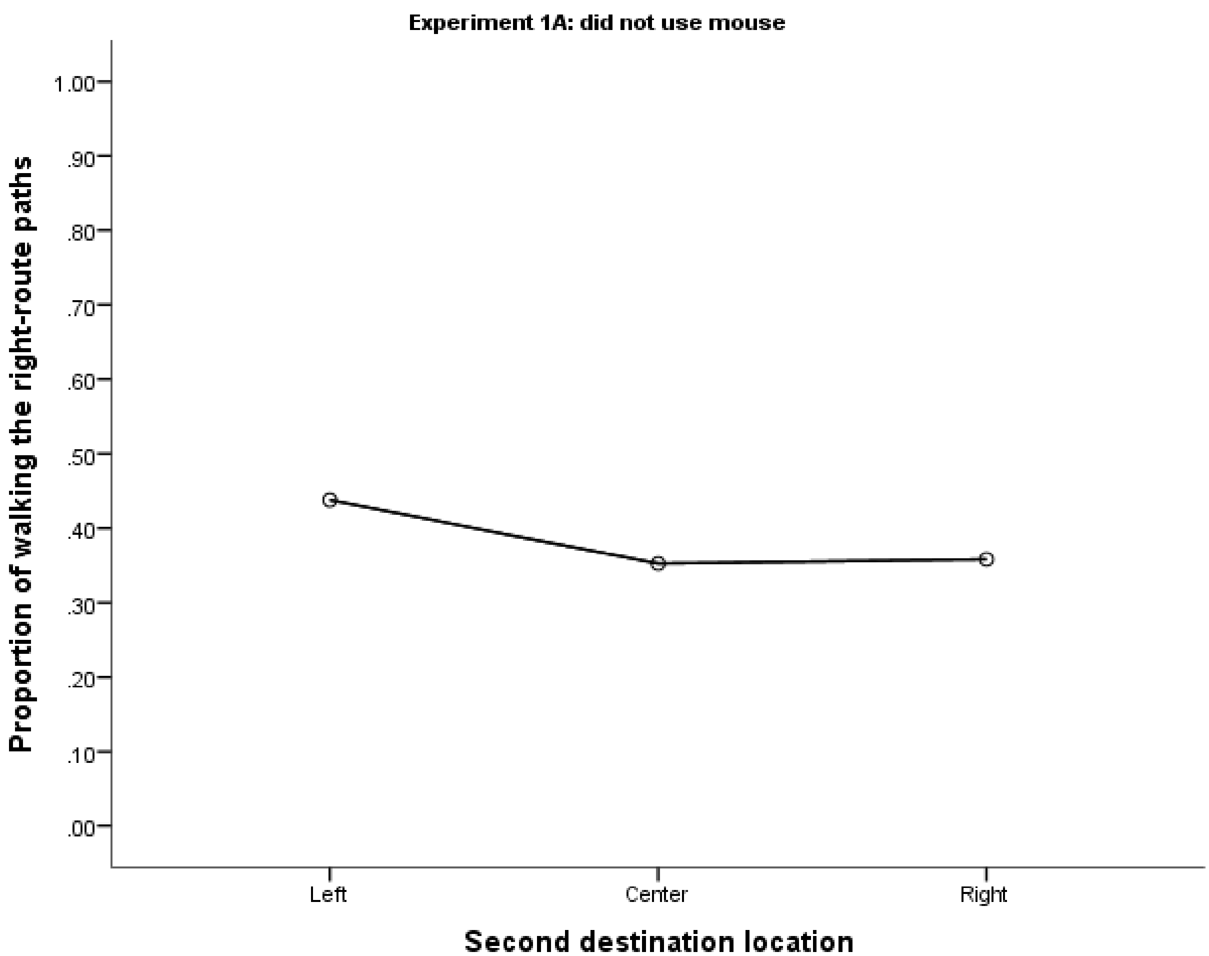


Figure 6. Proportion of choosing the right-route paths in Experiment 1A without mouse in two-destination trials.

Three-destination Trials. For three-destination trials, it was hypothesized that the proportion of right-route paths would be influenced by the location of the second and third destinations. A 3 (second destination location: left, center, right) X 3 (third destination location: left, center, right) repeated measures ANOVA was conducted to test the influence of the second and third destinations on participants' route choice as well as possible interactions between these two factors.

Participants who used the mouse to navigate in the environment. Location of second destination had an effect on their route choice to the first destination, $F(2, 94) = 44.29$, $MSE = .15$, $p < .001$, $\eta^2 = .49$ (Table 3). There was a linear trend of preferring the right route as the second destination relocated from the right to the center to the left, $F(1, 47) = 57.53$, $MSE = .22$, $p < .001$, $\eta^2 = .55$. There was no main effect of the third destination on participants' route choice to the first destination, $F(2, 94) = 1.02$, $MSE = .10$, $p = .36$, $\eta^2 = .02$. There was no linear trend in the proportion of choosing the right-route paths as the third destination relocated from the right to center to left, $F(1, 47) = .82$, $MSE = .14$, p .37, $\eta^2 = .02$. There was no significant interaction effect of the second and third destination location on the proportion of choosing the right-route paths, $F(4, 188) = 1.16$, $MSE = .05$, $p = .33$, $\eta^2 = .02$. Descriptive statistics are present in Table 2 and Figure 7.

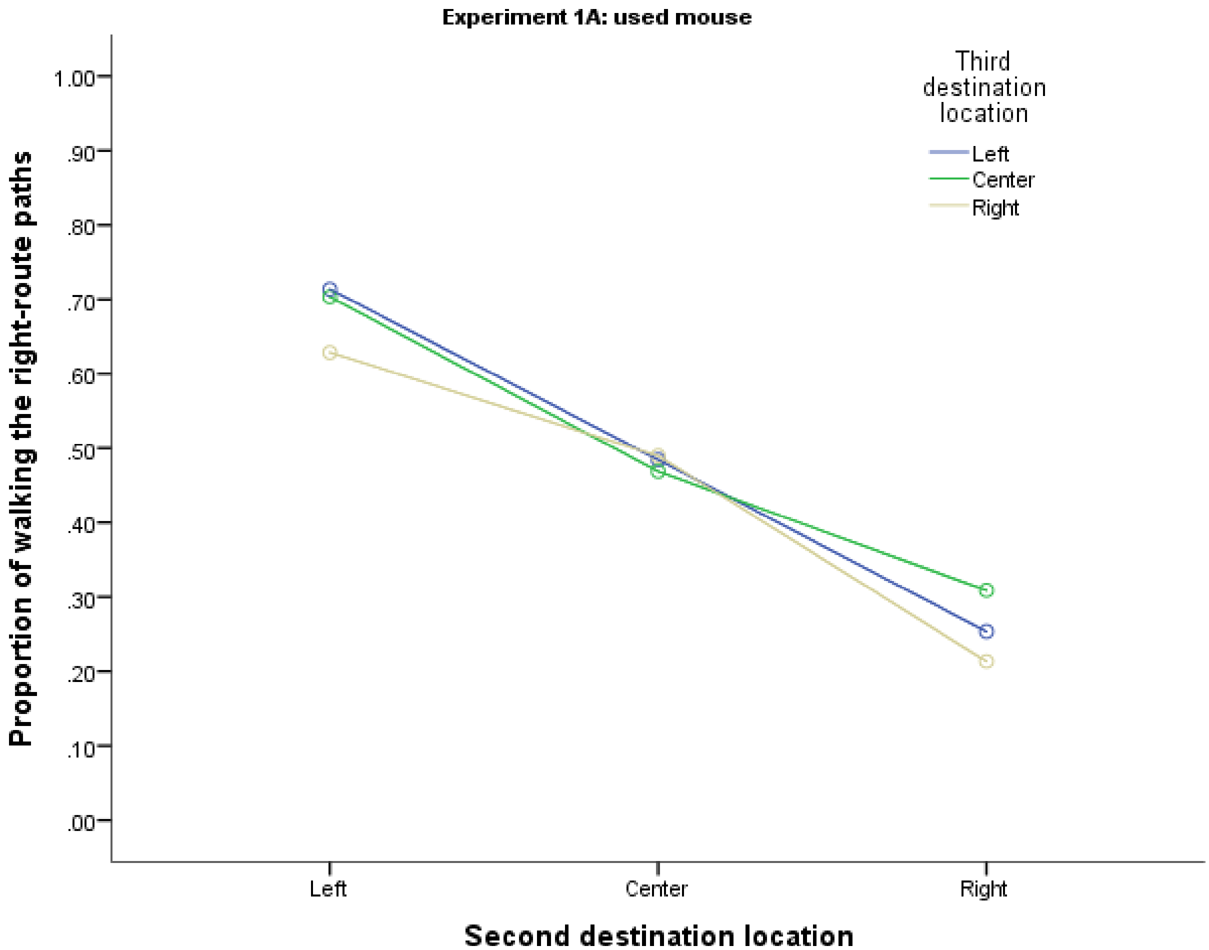


Figure 7. Proportion of choosing the right-route paths in Experiment 1A with mouse in three-destination trials

Participants who did not use the mouse to navigate in the environment. There was no main effect of the second destination location on the proportion of right-route paths, $F(2, 86) = .67$, $MSE = .12$, $p = .52$, $\eta^2 = .02$. There was no main effect of the third destination location on the proportion of right-route paths, $F(2, 86) = .05$, $MSE = .10$, $p = .95$, $\eta^2 = .00$. There was no significant linear trend of preferring the right route as the second destination relocated from the right to the center to the left side of the room, $F(1, 43) = .74$, $MSE = .20$, $p = .39$, $\eta^2 = .02$. There was no significant linear trend of preferring the right route as the third destination relocated from the right to the center to the left, $F(1, 43) = .01$, $MSE = .14$, $p = .92$, $\eta^2 = .00$. There was an interaction effect of the second destination location and third destination location, $F(4, 172) = 3.52$, $MSE = .06$, $p < .01$, $\eta^2 = .08$. When the third destination was on the left side, participants were more likely to walk the right-route paths as the second destination relocated from right to center to left, $F(2, 86) = 6.41$, $MSE = .06$, $p < .01$, $\eta^2 = .13$.

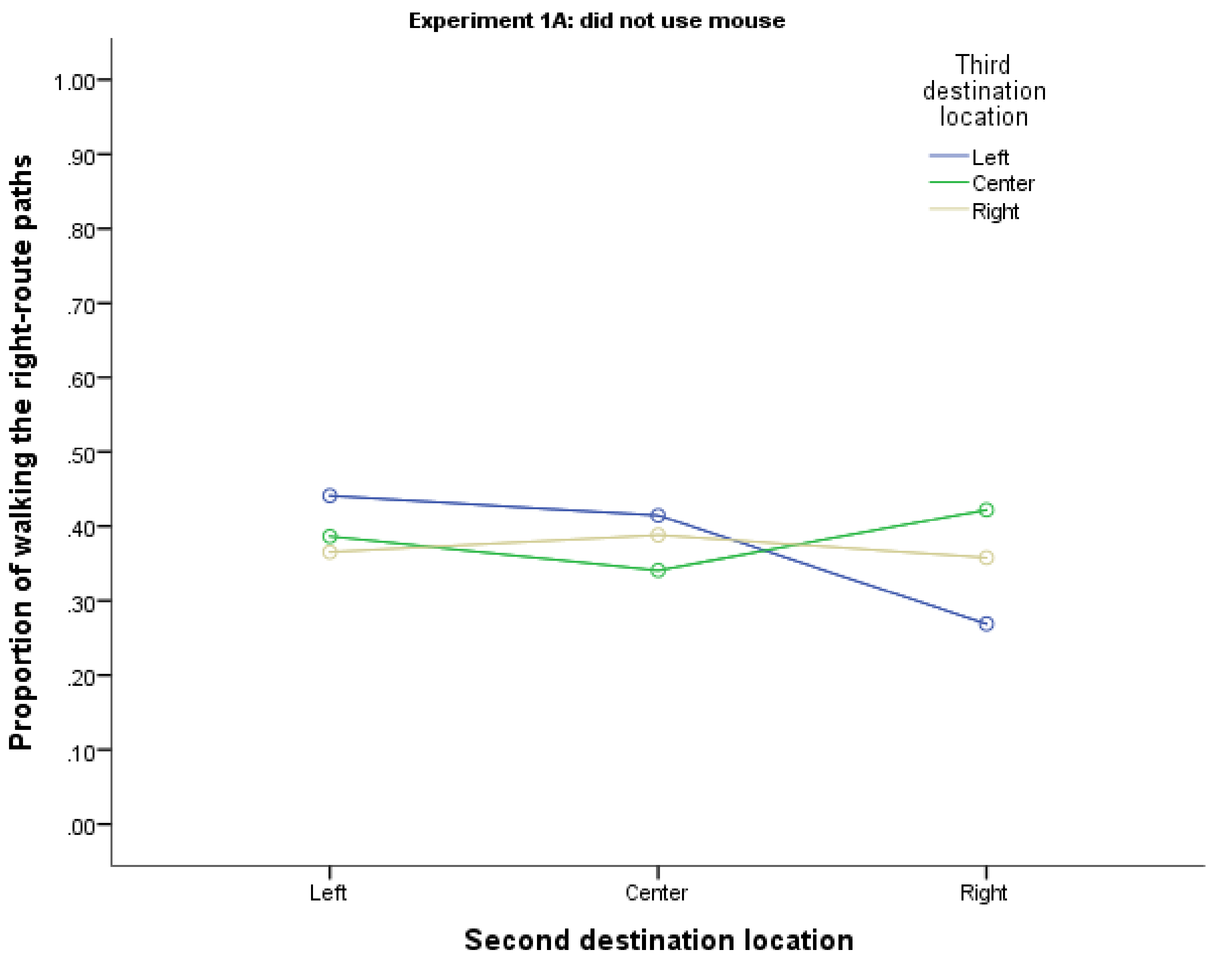


Figure 8. Proportion of choosing the right-route paths in Experiment 1A without mouse in three-destination trials

1B Results. Out of the 69 participants in Experiment 1B, 34 used the mouse to navigate in the virtual environments and 35 did not.

Two-destination Trials. For two-destination trials, according to Hypothesis 2, the influence of second destination locations on proportion of right-route paths would be smaller in 1B than that in 1A if the LDA bias is positively influenced by visibility of destinations. Similarly, the influence of second destination locations on proportion of right-route paths would not differ in 1B compared to that in 1A if the LDA bias is not influenced by visibility of destinations. Finally, the influence of second destination locations on proportion of right-route paths would be larger in 1B than that in 1A if the LDA bias is negatively influenced by visibility of destinations. A repeated-measures ANOVA was conducted to test whether the proportion of right-route paths differed when the second destination was on the left side, in the center, or on the right side.

Participants who used the mouse to navigate in the environment. The proportion of choosing the right route differed when the second destination was on the left, center, and right, $F(2, 66) = 9.11$, $MSE = .08$, $p < .01$, $\eta^2 = .22$. There was a linear trend of preferring the right-route paths as the second destination relocated from the right to the center to the left, $F(1, 33) = 11.58$, $MSE = .13$, $p < .01$, $\eta^2 = .26$. Table 1 and Figure 9 present the descriptive statistics for this analysis.

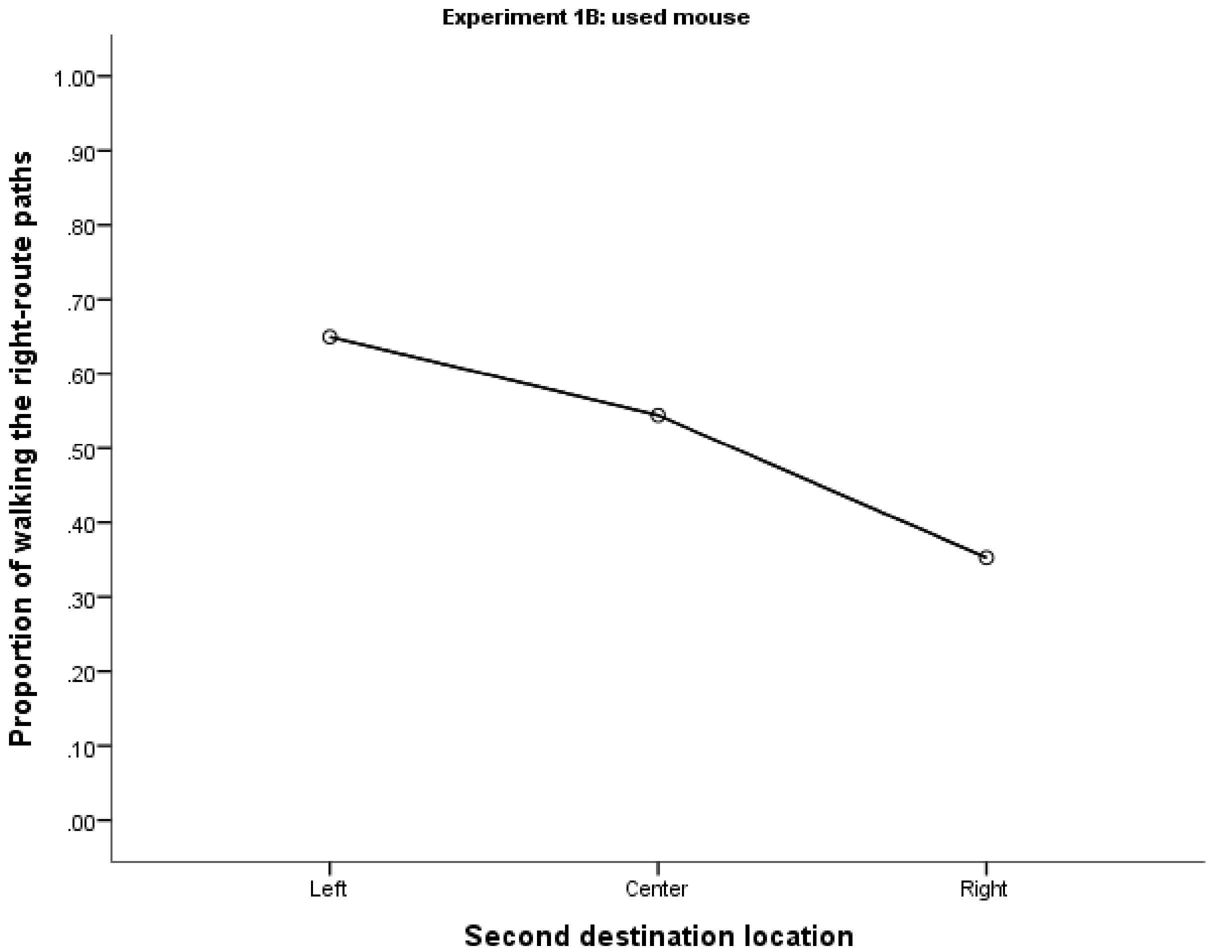


Figure 9. Proportion of navigating the right-route paths in Experiment 1B with mouse in two-destination trials

Participants who did not use the mouse to navigate in the environment The proportion of trials in which participants walked the right-route paths differed when the second destination was on the left, center, and right side in the environment, $F(2, 68) = 3.70$, $MSE = .09$, $p < .05$, $\eta^2 = .10$. Moreover, there was a linear trend of preferring the right route as the second destination relocated from the left to the center to the right, $F(1, 34) = 4.73$, $MSE = .12$, $p < .05$, $\eta^2 = .12$. Table 1 and Figure 10 present the descriptive statistics for this analysis.

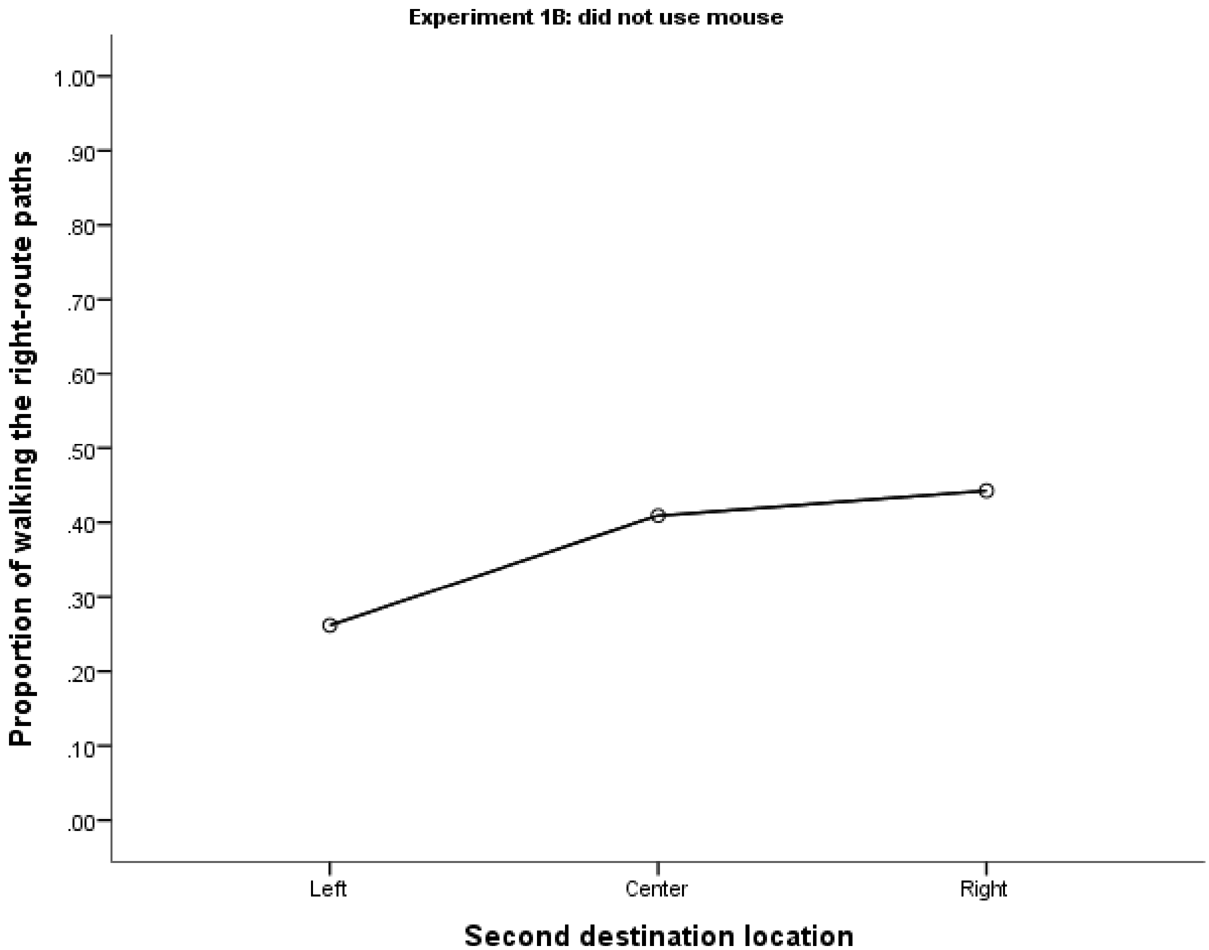


Figure 10. Proportion of navigating the right-route paths in Experiment 1B without mouse in two-destination trials

Three-destination Trials. For three-destination trials, according to Hypothesis 1 and 2, the second destination location and third destination location would have smaller influence on proportion of right-route paths in 1B than that in 1A if the LDA bias is positively influenced by visibility factor. Similarly, the second destination location and third destination location would have comparable influence on proportion of right-route paths in 1B and in 1A if the LDA bias is not influenced by visibility factor. Finally, the second destination location and third destination location would have larger influence on proportion of right-route paths in 1B and in 1A if the

LDA bias is negatively influenced by visibility factor. A 3 (second destination location: left, center, right) X 3 (third destination location: left, center, right) repeated measures ANOVA was conducted to test the influence of the second and third destinations on participants' route choice as well as possible interactions between these two factors.

Participants who used the mouse to navigate in the environment. Both second and third destination locations influenced navigation to the first destination (Figure 9). The proportion of choosing the right route differed when the second destination was on the left, center, and right, $F(2, 66) = 17.49$, $MSE = .13$, $p < .01$, $\eta^2 = .35$. There was also a main effect of the location of third destinations on the proportion of trials in which participants walked the right-route paths, $F(2, 66) = 5.33$, $MSE = .08$, $p < .05$, $\eta^2 = .14$. There was a linear trend of preferring the right route as the second destination relocated from the right to the center to the left, $F(1, 33) = 23.36$, $p < .01$, $\eta^2 = .41$. There was no significant linear trend of preferring the right-route or left-route paths as the third destination relocated from the right to the center to the left, $F(1, 33) = 3.72$, $MSE = .08$, $p = .06$, $\eta^2 = .10$. There was a significant interaction effect of the second destination locations and third destination locations on the proportion in which participants walked the right-route paths, $F(4, 132) = 5.47$, $MSE = .06$, $p < .01$, $\eta^2 = .14$. When second destination was on the left, there was no significant difference regarding the proportion of walking the right-route paths among the three third-destination-location conditions, $F(2, 66) = 2.76$, $MSE = .05$, $p = .07$, $\eta^2 = .08$. When second destination was centered, there was a small effect of the third destination locations on the proportion of walking the right-route paths, $F(2, 66) = 4.44$, $MSE = .07$, $p < .05$, $\eta^2 = .12$. When second destination was on the right, there was a medium effect of the third destination locations on the proportion of walking the right-route paths, $F(2, 66) = 8.33$, $MSE = .07$, $p < .01$, $\eta^2 = .20$. Table 2 and Figure 9 present the descriptive statistics.

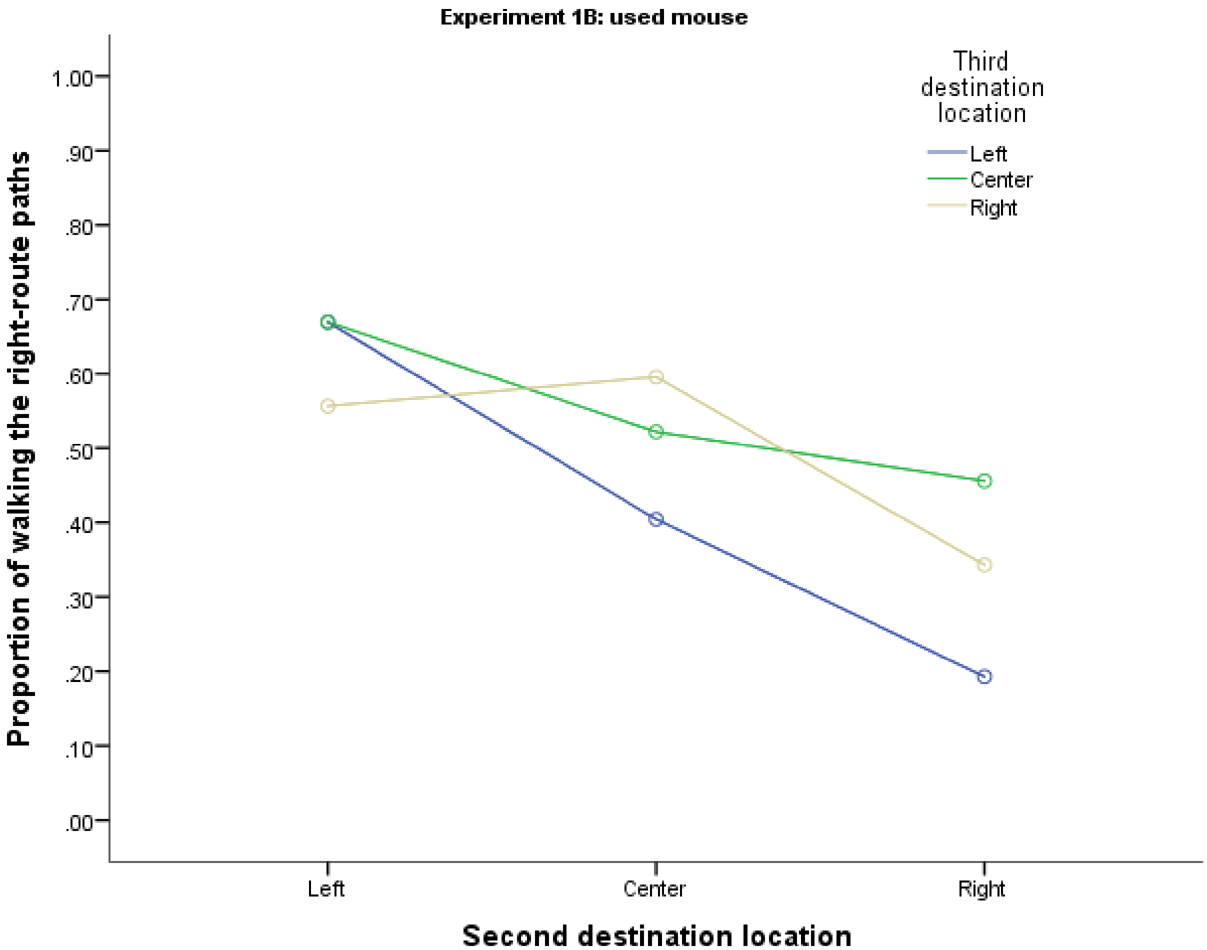


Figure 11. Proportion of navigating the right-route paths in Experiment 1B with mouse in three-destination trials

Participants who did not use the mouse to navigate in the environment. There was no main effect of the second destination locations on the proportion of trials in which participants walked the right-route paths, $F(2, 68) = .83$, $MSE = .10$, $p = .44$, $\eta^2 = .02$. Third destination locations influenced route choice to the first destination, $F(2, 68) = 9.29$, $MSE = .05$, $p < .01$, $\eta^2 = .22$. There were significant linear trends in proportion of walking the right-route paths as the third destinations relocated from left side to the center to the right side of the room, $F(1, 34) = 10.76$, $MSE = .07$, $p < .005$, $\eta^2 = .24$. There was no linear trend in the proportion of walking the right-route paths as the second destination relocated from the right to the center to the left, $F(1, 34) = .28$, $MSE = .12$, $p = .60$, $\eta^2 = .01$. There was also an interaction effect of the second and third destination on proportion of navigating the right-route paths, $F(4, 136) = 5.61$, $MSE = .06$, $p < .01$, $\eta^2 = .14$. When second destination was on the left, there was no significant difference in the proportion of walking the right-route paths among the three third-destination-location conditions, $F(2, 68) = .36$, $MSE = .04$, $p = .70$, $\eta^2 = .01$. When second destination was centered, there was no difference in the proportion of walking the right-route paths among the three third-destination-location conditions, $F(2, 68) = 1.90$, $MSE = .05$, $p = .16$, $\eta^2 = .05$. When second destination was on the right, there was a medium effect of the third destination locations on the proportion of walking the right-route paths, $F(2, 68) = 14.01$, $MSE = .07$, $p < .01$, $\eta^2 = .29$.

Table 2 and Figure 9 present the descriptive statistics.

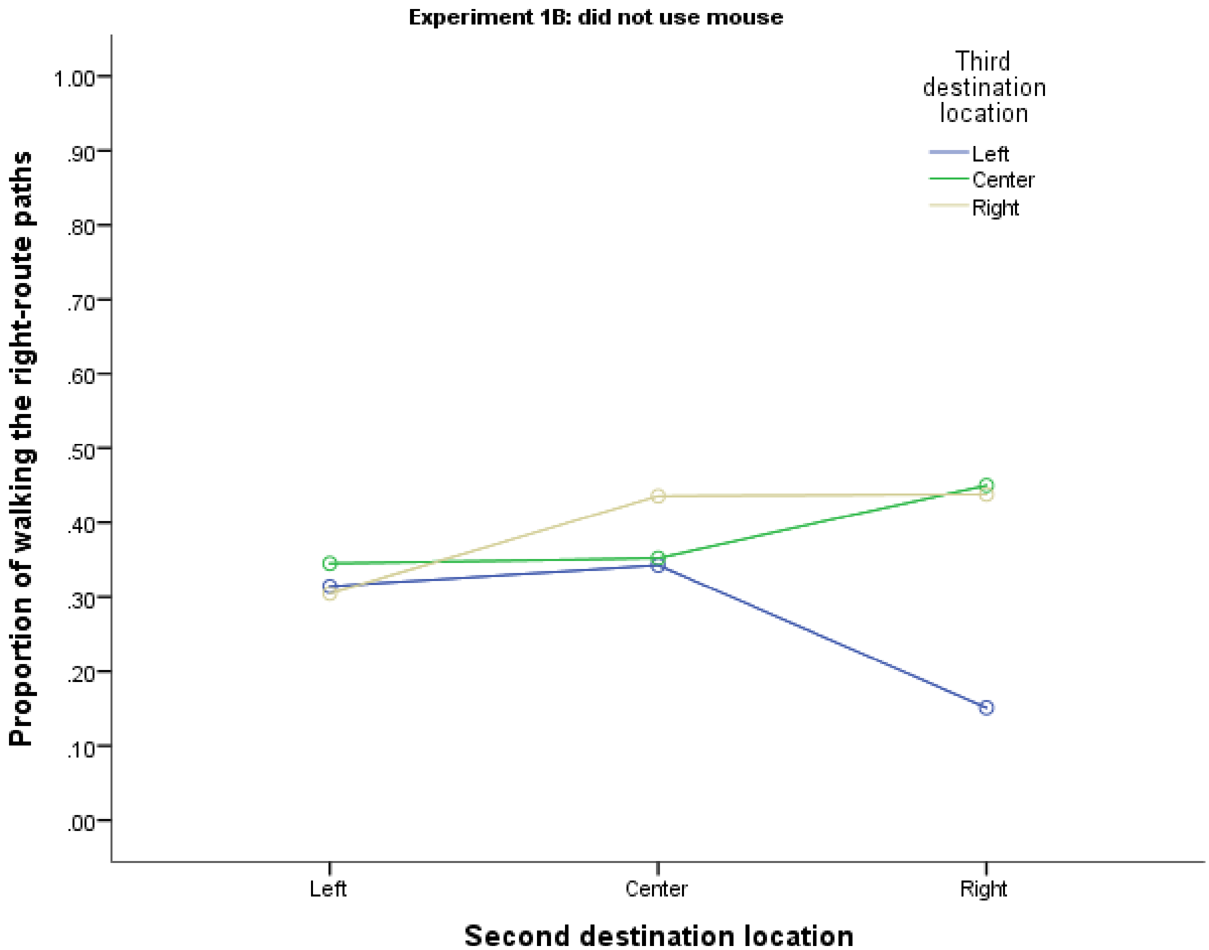


Figure 12. Proportion of navigating the right-route paths in Experiment 1B without mouse in three-destination trials.

Comparison Between 1A and 1B for Two-Destination Trials. For participants who used the mouse to navigate in Experiment 1, there was a stronger influence of second destination locations on the proportion of walking the right-route paths in 1A (ANOVA η^2 = .40; Linear trend η^2 = .48) than that in 1B (ANOVA η^2 = .22; Linear trend η^2 = .26). For participants who did not use mouse to navigate in Experiment 1, there was an influence of second destination locations on the proportion of walking the right-route paths in 1B (ANOVA η^2 = .10; Linear trend η^2 = .12) but not in 1A (see Table 1).

Discussion

In Experiment 1A and 1B, the proportion of participants' walking the right-route paths was influenced by the locations of second and third destinations and whether participants used mouse to navigate. This result is generally consistent with the principle behind LDA effect in that the location of later destinations influence route choice to the immediate destination. In all but one condition (i.e. 1B participants who did not use mouse to navigate in the two-destination trials), the influence of later destination on participants' navigation behavior was revealed as a linear trend of lower proportion of walking the right-route paths as the later destination relocated from left to center to right. This result is opposite to the results in Fu et al. (2015), in which the proportion of walking the right route increased as the later destinations relocated from left to center to right. One possible explanation for the opposite effect in the current study and those in Fu et al. is the differences in functionalities involved in the two studies. In the current study, participants faced the left side of the virtual room when they reached the first destination if they walked the right-route paths. Therefore, walking the right-route paths instead of the left-route paths resulted in a better view of the second or third destinations that was on the left. In Fu et al., walking the right-route paths, compared to walking the left-route paths, resulted in a longer distance between first and second destination if the second destination was located on the left. Interestingly, in 1B when participants did not use mouse to navigate, there was an increase in the proportion of walking the right-route paths as the second destination relocated from left to center to right. Although this result is consistent with the LDA effect found in Fu et al, the underlying mechanism is not clear.

Whether participants used the mouse or not to navigate in the virtual environment influenced the relationship between later destination locations and the proportion of walking the right-route paths in Experiment 1A and 1B. This result is surprising nevertheless reasonable when considering the influence of the functionality of movement on spatial behavior. When walking the right-route paths without using the mouse, navigators ended up facing the back side of the room thus resulted in equivalent view of the left and right side of the virtual room. Therefore, if the LDA effect is based on visual perception of the environment, then the location of later destinations should have no effect on which paths participants walked to reach the first destination when not using the mouse. This hypothesis is supported by the small or non-significant influence of later destination locations on route proportions in 1A and 1B when participants did not use mouse to navigate.

In the Experiment 1B two-destination trials, the proportion of walking the right-route paths increased as the second destination located from the left to center to right. A closer inspection revealed that the variance of the proportion of choosing the right-route paths increased as the second destination relocated from the left to center to right (see Table 1: M_L = .26, SD_L = .28; M_M = .41, SD_M = .37; M_R = .44, SD_R = .45). Therefore, it is possible that the influence of second destination location on the participants' navigation behavior in this condition resulted from the inappropriate usage of "sphericity assumed" method in conducting one-way ANOVA. In fact, when using the "lower-bound" method of one-way ANOVA, the effect of second destination locations on the proportion of walking the right-route paths was not significant, $F(1, 34) = 3.697$, $MSE = .175$, $p = .06$, $\eta^2 = .10$.

When participants used the mouse to navigate, there was a stronger influence of later destination locations on the proportion of walking the right-route paths in Experiment 1A than that in Experiment 1B. According to Hypothesis 2, the results support the assumption that LDA effect is positively influenced by visibility factor. That is, better visibility of destinations is associated with stronger LDA effect.

EXPERIMENTS 2A AND 2B: ENVIRONMENT-SIZED SPACE

Experiments 2A and 2B used environment-sized virtual environments that appeared as an apartment neighborhood area in a city. The size of the area approximated the size of a football field. To mimic the scenes in real life, there were buildings and trees far from the participants and short bushes close to the participants. The basic configuration of Experiment 2 was the same as that in Experiment 1 except that it was ten times as large as the environments in Experiment 1.

According to Hypothesis 3, if the *later-destination-attractor* (LDA) bias is not influenced by size of the environment then the results of Experiments 2A and 2B should be generally consistent with the results of Experiments 1A and 1B for comparable conditions. If this is true, then LDA effect in the two-destination trials would be stronger in 2A than that in 2B based on Experiment 1 results.

Method and Data Analysis

Participants

A power analysis based on the linear trend analysis from the original study indicated that there should be 44 participants in each experiment (eta squared = .16, alpha = .05, beta = .80) for a total of 88 participants. Data from participants who did not understand the instruction or did not complete the experiment were excluded from data analysis (see Discussion of Experiment 2). The final sample included a total of 127 participants (47 males, 75 females, 5 missing gender information) aged 17 to 21. Participants were recruited for Experiment 2 in the same way as those in Experiment 1.

Materials, Tasks, and Procedures

The virtual environment was built using the same tools as in Experiment 1, but the environment appeared larger by having city blocks with buildings of various sizes in the distance. Figure 13 shows the screenshots of (a) one trial in Experiment 2A, (b) one trial in Experiment 2B, and (c) one diagrams that was provided to participants in Experiment 2B. For each participant, an experimenter gave oral instruction as following: "this virtual environment mimicked a neighborhood with trees and buildings. Your task is to walk to two or three targets located on the bottom of a building. After you reach the last target, walk to the backside of the environment to connect to next trial. The targets will disappear when you reach them." In Experiment 1A, participants were given this further instruction "If you see a blinking light on the top of one building, it means there is a target in front of that building on the ground." In Experiment 1B, participants were given this further instruction "when you reach the last target in a trial, a diagram will pop up on the computer screen to indicate to you locations of targets in the next trial." A printed diagram was shown to participants in Experiment 1B at the beginning of each of the two blocks of trials.

The procedure and number of trials were the same as in Experiments 1A and 1B, but because of the longer distances. Experiment 2 lasted about 50 minutes.

(a)

(b)

(c)

Figure 13: screenshots of (a) one trial in Experiment 2A, (b) one trial in Experiment 2B, and (c) the diagram that was provided to participants in one trial in Experiment 2B.

Data Analysis

As is Experiments 1A and 1B, the analyses for Experiments 2A and 2B involved a 3 (location of the second destination) X 4 (location of the third destination) repeated measures ANOVA, with follow-up linear trend comparisons. If the LDA bias depends only on memory load, then the pattern of results should produce an LDA bias that is stronger in Experiment 2A than in 2B. If the LDA bias depends only on the size of the environment, then the LDA bias should be stronger in Experiment 1 than that in Experiment 2 and do not differ between 2A and 2B. If the LDA bias depends on both visibility and environment size, then the LDA bias will differ in Experiment 2 and Experiment 1, and between 2A and 2B. Video recording of each experiment session was coded in terms of the path walked and whether the participant looked for the flashing lights on the top of the buildings. The flashing lights were not visible at the beginning of each trial unless using the mouse to "look up" to the top of the buildings.

2A Results. Out of 59 participants in Experiment 2A, 51 used mouse to navigate in the virtual environments and 8 did not use mouse to navigate. First, data from 5 participants who did not look up to acknowledge the location of later destinations were excluded from the data analysis. Second, data analysis in 2A included only participants who used the mouse to navigate because there were too few non-mouse users to have enough power to generate any meaningful conclusions. The final data consists of 46 participants (24 males, 20 females, 2 missing gender information; aged 18 to 20).

Two-destination trials. A one-way ANOVA was conducted to test the influence of second destination locations on the proportion of walking the right-route paths, $F(2, 90) = 11.03$, $MSE = .07$, $p < .01$, $\eta^2 = .20$. There was a linear trend of decreasing proportion of the right-route paths as the second destination relocated from left to center to right, $F(1, 45) = 15.36$, MSE = .10, $p < .01$, $\eta^2 = .25$. Table 1 and Figure 14 present the descriptive statistics for this analysis.

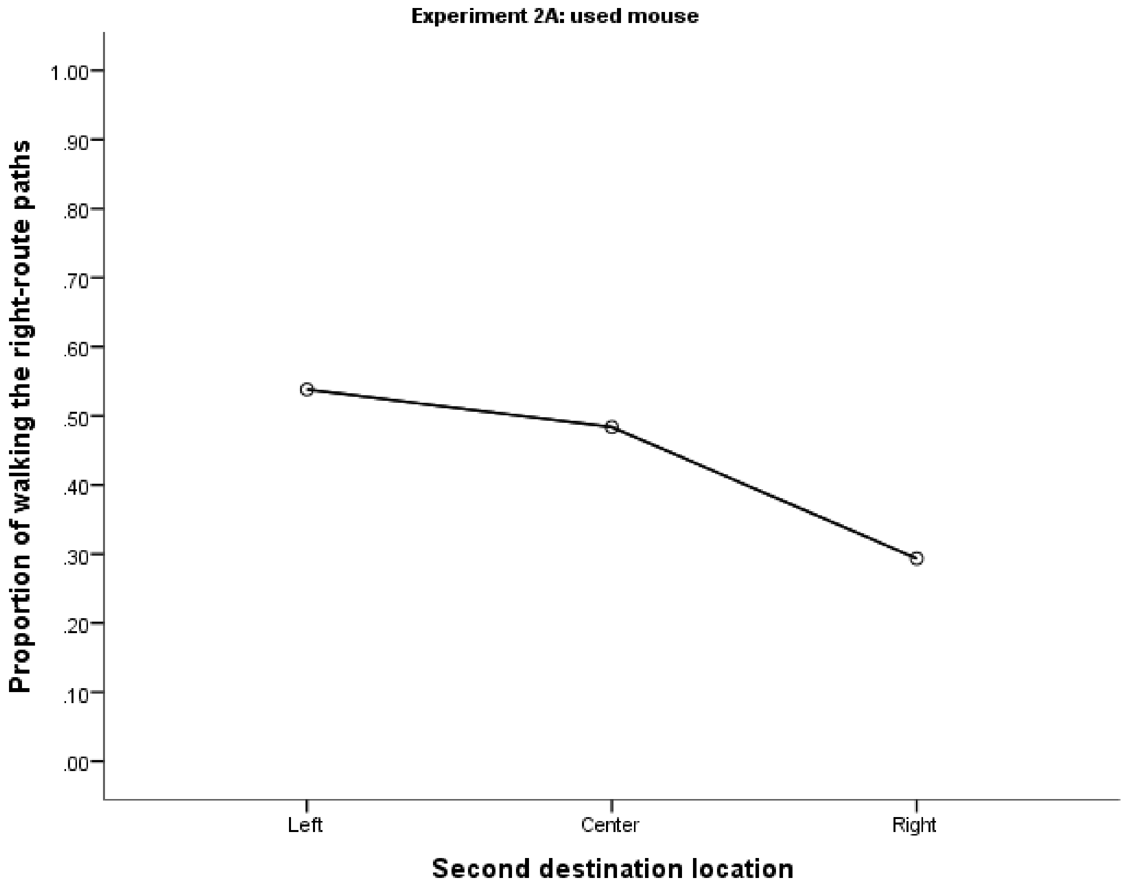


Figure 14. Second destination locations influenced the proportion of walking the right-route paths in two-destination trials in Experiment 2A.

Three-destination trials. A 3 (location of the second destination) X 3 (location of the third destination) repeated measures ANOVA was conducted to test the influence of second and third destinations on the proportion of walking the right-route paths in Experiment 1A.

There was a main effect of the second destination locations on the proportion of walking the right-route paths, $F(2, 90) = 25.23$, $MSE = .16$, $p < .01$, $\eta^2 = .36$. There was no significant main effect of the third destination on participants' route choice to the first destination, $F(2, 90) = 2.76$, $MSE = .05$, $p = .07$, $\eta^2 = .06$. Moreover, there were significant linear trends that participants were more likely to walk the right-route paths as the second destinations moved from right side to the center to the left side of the environment, $F(1, 45) = 29.90$, $MSE = .26$, $p < .01$, $\eta^2 = .40$. There was no significant linear trend of preferring the right-route or left-route paths or left-route paths as the third destinations moved from right side to the center to the left side of the room, $F(1, 45) = 3.70$, $MSE = .06$, $p = .06$, $\eta^2 = .08$. There was no interaction effect of the second destination locations and third destination locations on the proportion of walking the right-route paths, $F(4, 180) = .51$, $MSE = .05$, $p = .73$, $\eta 2 = .01$. Table 2 and Figure 15 present the descriptive statistics for this analysis.

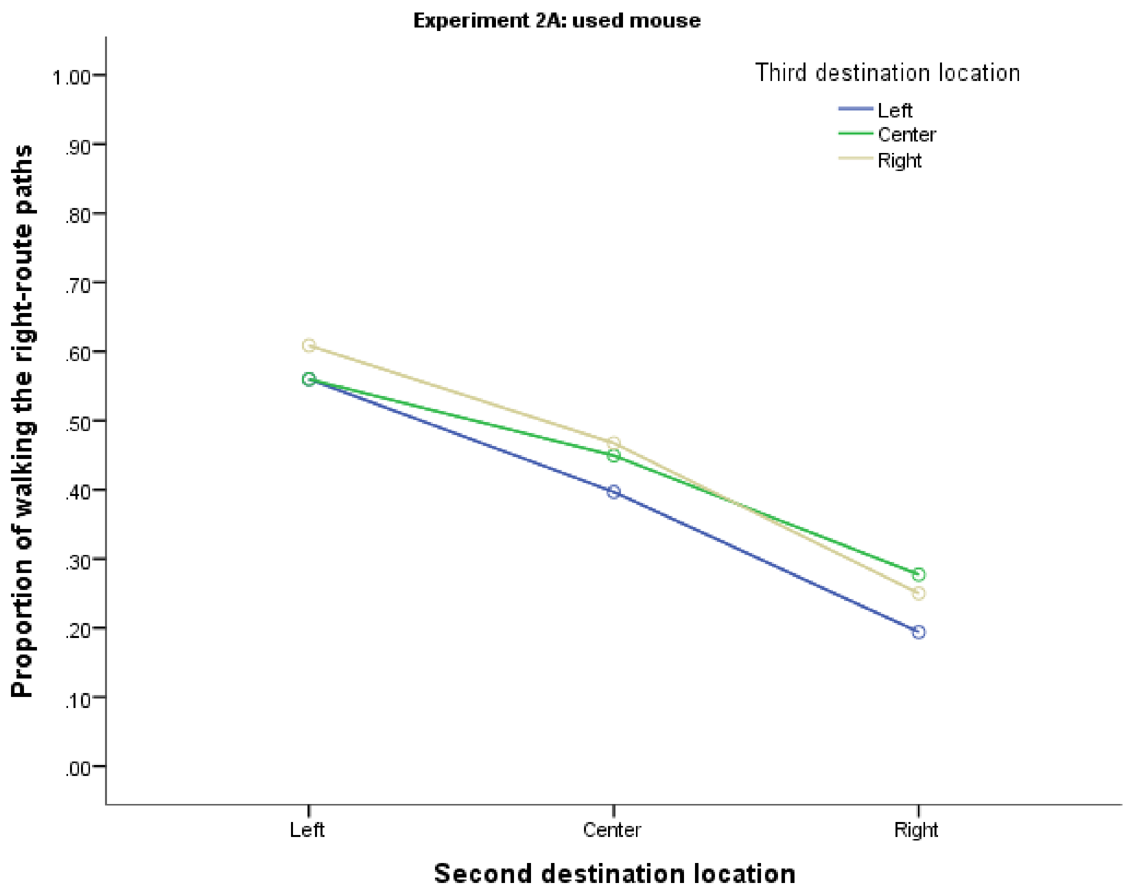


Figure 15. Location of second destination influenced the proportion of walking the right-route paths among participants who used mouse to navigate in three-destination trials in Experiment 2A.

2B Results. The final data consists of 68 participants (21 males, 45 females, 2 missing gender information, aged 17 to 21), of which 48 used mouse to navigate in the environments and 20 did not use mouse to navigate. Data analysis was conducted separately for these two groups of participants.

Two-destination Trials. One-way ANOVA was conducted to test the influence of second destination location (left, center, right) on the proportion of trials in which participants walked the right-route paths to the first destination.

Participants who used the mouse to navigate in the environment. Second destination location did not influence the proportion of walking the right-route paths, $F(2, 94) = 1.13$, $MSE = .07$, $p = .33$, $\eta^2 = .02$. There is no significant linear trend of the location of second destination on participants' route choice to the first destination, $F(1, 47) = 1.06$, $MSE = .10$, $p = .31$, $\eta^2 = .02$.

Table 2 and Figure 16 present the descriptive statistics for this analysis.

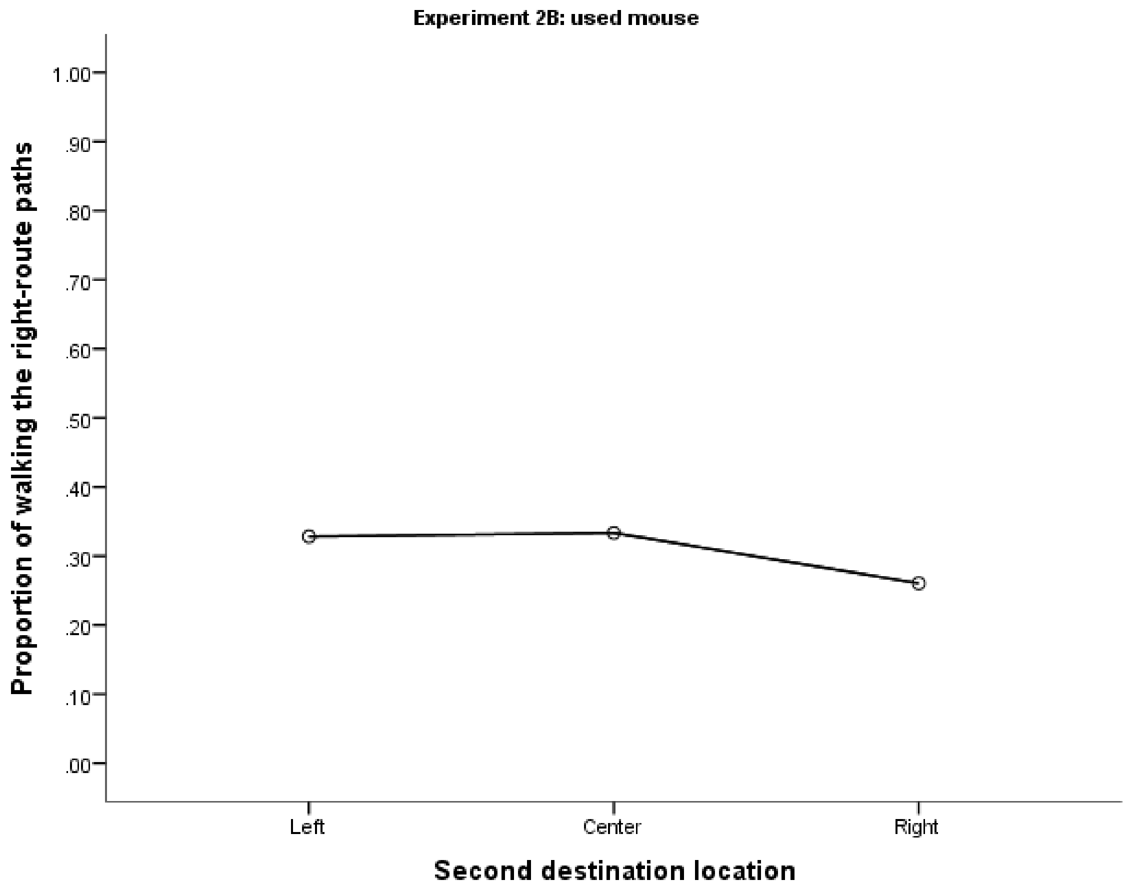


Figure 16. Second destination location did not influence the proportion of walking the right-route paths in two-destination trials for participants who used the mouse in Experiment 2B

Participants who did not use the mouse to navigate in the environment. location of second destinations influenced participants' route choice to the first destinations, $F(2, 38) = 3.71$, *MSE* = .05, $p < .05$, $\eta^2 = .16$. Post-hoc tests showed that the proportion of walking the right-route paths did not differ when the second destination located on the left side versus center of the environment, $t(19) = .22$, $p = .83$. The proportion of walking the right-route paths, however, differed when the second destination relocated from the center to the right side of the environment, $t(19) = 2.26$, $p < .05$, cohen's $d = .51$. There was no significant linear trend of walking the left-route or right-route paths as the second destination moved from left to center to right side of the room, $F(1, 19) = 4.19$, *MSE* = .08, $p = .06$, $\eta^2 = .18$. Table 1 and Figure 17 present the descriptive statistics for this analysis.

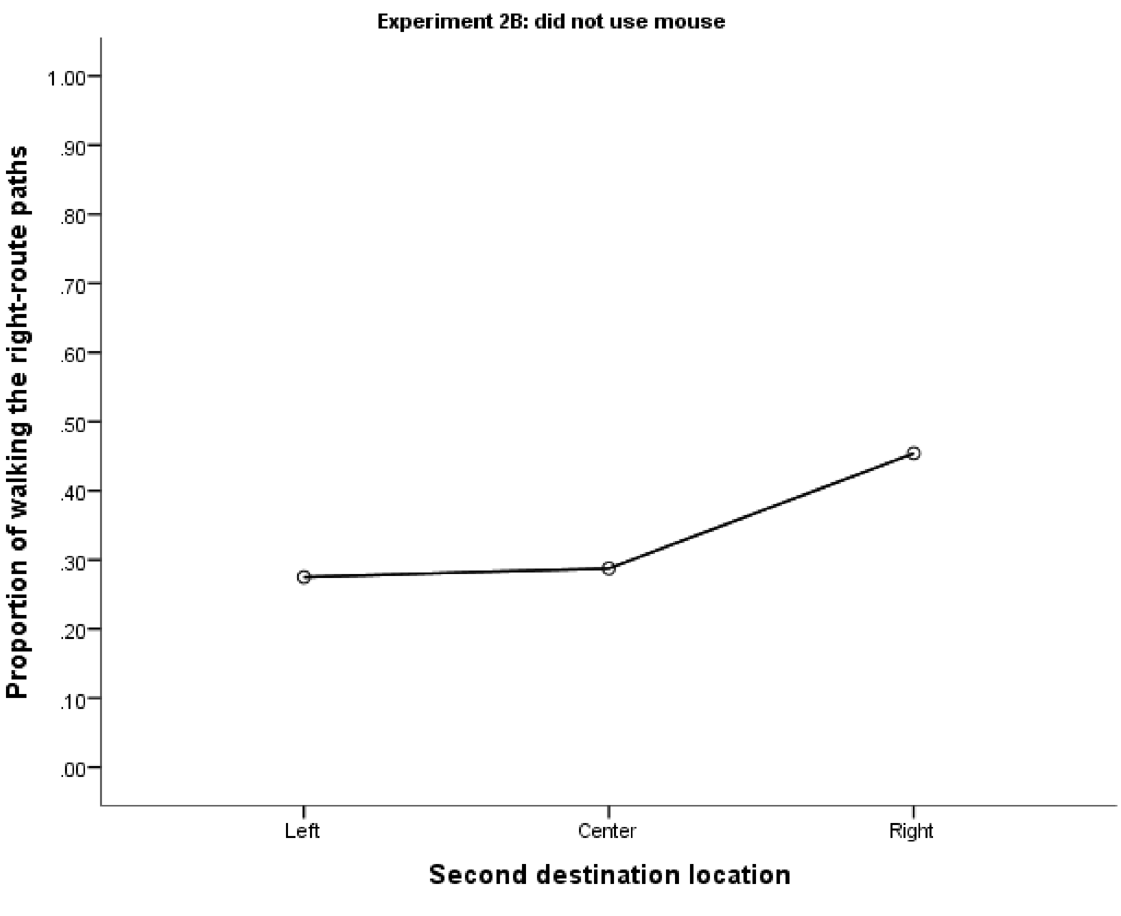


Figure 17. Second destination location influenced the proportion of walking the right-route paths among participants who did not use mouse to navigate in two-destination trials in Experiment 2B

Three-destination Trials. A 3 (location of the second destination) X 3 (location of the third destination) repeated measures ANOVA was conducted to test the influence of second and third destination locations on the proportion of walking the right-route paths.

Participants who used the mouse to navigate in the environment. both second and third destination locations influenced route choice to the first destination. Specifically, there was a main effect of the second destination on participants' route choice to the first destination, $F(2, 94) = 9.29$, $MSE = .12$, $p < .01$, $\eta^2 = .17$. There was a main effect of the third destination on participants' route choice to the first destination, $F(2, 94) = 21.06$, $MSE = .04$, $p < .01$, $\eta^2 = .31$. There was also an interaction effect of the second and third destination on participants' route choice to the first destination, $F(4, 188) = 4.84$, $MSE = .05$, $p < .01$, $\eta^2 = .09$. Moreover, there were significant linear trends that participants were more likely to choose the right route as the second destinations moved from right side to the center to the left side of the room, $F(1, 47) = 11.18$, $MSE = .20$, $p < .01$, $\eta^2 = .19$. Participants were also more likely to choose the right route as the third destinations moved from left to center to right side of the environment, $F(1, 47) = 32.68$, $MSE = .04$, $p < .01$, $\eta^2 = .41$.

There was also a significant interaction of the second destination location and third destination location on the proportion of walking the right-route paths in the environment, $F(4, 188) = 4.84$, $MSE = .05$, $p < .01$, $\eta^2 = .09$. When the third destination was on the left, the proportion of walking the right-route paths decreased as the second destination relocated from left to center to right, $F(2, 94) = 14.70$, $MSE = .07$, $p < .01$, $\eta^2 = .24$. When the third destination was centered, the proportion of walking the right-route paths was not influenced by the second destination location, $F(2, 94) = 1.14$, $MSE = .06$, $p = .32$, $\eta^2 = .02$. When the third destination was on the right, the proportion of walking the right-route paths decreased as the second destination relocated from left to center to right, $F(2, 94) = 5.82$, $MSE = .08$, $p < .01$, $\eta^2 = .11$.

Table 2 and Figure 18 present the descriptive statistics in this analysis.

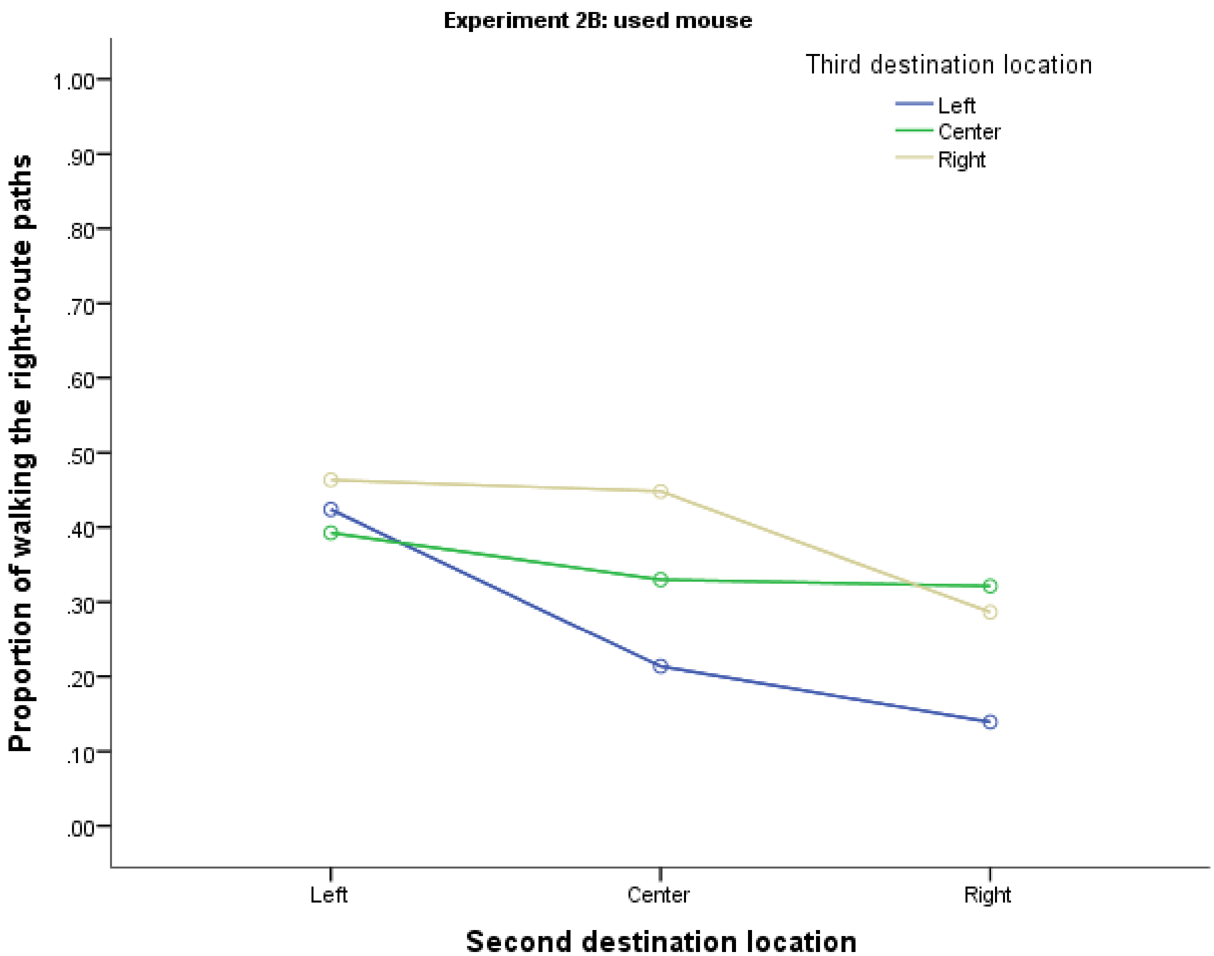


Figure 18. Both the second destination location and third destination location influenced the proportion of walking the right-route paths among participants who used the mouse to navigate in three-destination trials in Experiment 2B.

Participants who did not use the mouse to navigate in the environment. There was no main effect of the second destination location on the proportion of walking the right-route paths, $F(2, 38) = 2.70$, $MSE = .13$, $p = .08$, $\eta^2 = .12$. Location of the third destination influenced route choice to the first destinations, $F(2, 38) = 7.07$, $MSE = .06$, $p < .01$, $\eta^2 = .27$. There was no significant linear trend in the proportion of walking the right-route paths as the second destination relocated from left to center to right, $F(1, 19) = 3.22$, $MSE = .19$, $p = .09$, $\eta^2 = .14$. There was a significant linear trend that the proportion of walking the right-route paths increased as the third destination moved from the left to center to the right side of the environment, $F(1, 19) = 8.92$, $MSE = .08$, $p < .01$, $\eta^2 = .32$.

There was also a significant interaction of the second and third destination location on the proportion of walking the right-route paths, $F(4, 76) = 6.66$, $MSE = .04$, $p < .01$, $\eta^2 = .26$. When the third destination was on the left, the proportion of walking the right-route paths did not change significantly as the second destination relocated from left to center to right, $F(2, 38) = 1.81$, $MSE = .07$, $p = .18$, $\eta^2 = .09$. When the third destination was centered, the proportion of walking the right-route paths increased and the second destination location relocated from the left to center to right, $F(2, 38) = 1.18.64$, $MSE = .06$, $p < .01$, $\eta^2 = .31$. When the third destination was on the right, there was a marginally significant linear trend that the proportion of walking the right-route paths increased as the second destination relocated from left to center to right, $F(2, 38) = 3.18$, $MSE = .08$, $p = .05$, $\eta^2 = .14$.

Table 2 and Figure 19 present the descriptive statistics for this analysis.

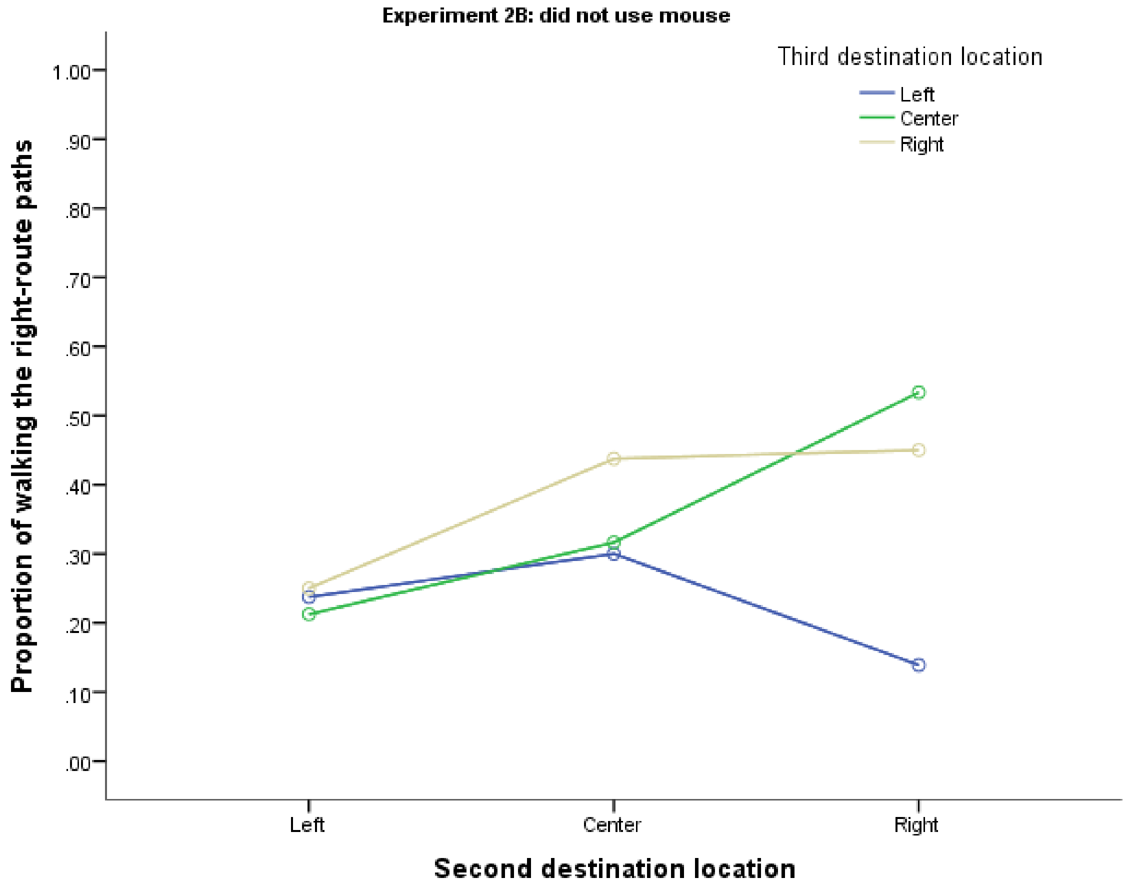


Figure 19. Later destination locations influenced the proportion of walking the right-route paths among participants who did not use mouse to navigate in three-destination trials in Experiment 2B.

Comparison Between 2A and 2B for Two-Destination Trials. The current comparison only concerned participants who used mouse to navigate since there were only 8 participants in Experiment 2A who did not use mouse to navigate. For participants who used the mouse to navigate in Experiment 2, there was a stronger influence of second destination locations on the proportion of walking the right-route paths in 2A (ANOVA η^2 = .20; Linear trend η^2 = .25) than that in 2B (ANOVA η^2 = .02; Linear trend η^2 = .02).

Discussion

In experiment 2A, the proportion of walking the right-route paths was influenced by locations of later destinations. This result is consistent with the general definition of LDA effect. However, the LDA effect in the current study was largely in the opposite direction from that in Fu et al. (2015). Among participants who did not use the mouse to navigate in Experiment 2B, the influence of later destination locations on the proportion of walking the right-route paths was in the same direction as the original LDA effect. It is possible that the same functionality as discussed in Experiment 1 led to the results in Experiment 2. It was not clear why, for participants who did not use the mouse to navigate in Experiment 2B, the influence of later destination locations on route revealed an effect that was in the same direction as that in the original study.

Table 5 shows similar results in Experiment 1 and Experiment 2 under comparable conditions. For example, the proportion of walking the right-route paths among participants who used the mouse to navigate in two-destination trials was significantly influenced by the location of second destination in both Experiment 1A and Experiment 2A. Moreover, in the two experiments described in the previous sentence, there was a significant linear trend that the proportion of walking the right-route paths decreased as the second destination relocated from left to center to right. According to Hypothesis 3, Experiment 1 and Experiment 2 would generate similar results if the LDA effect is not influenced by the size of the environment. Therefore, results from Experiment 1 and Experiment 2 are consistent with the assertion that the size of the environment does not influence LDA effect.

A comparison between the results of Experiment 2A and 2B revealed similar patterns under comparable conditions. Comparisons of other pairs of conditions (i.e. in one condition the destinations were visible and in another condition the destinations were hidden) revealed patterns that are consistent with the assertion that the LDA effect is influenced by visibility factor. Specifically, the LDA effect is stronger when destinations were visible rather than hidden.

Experiment 2 required participants to navigate in a virtual environment that mimicked a neighborhood with 10 buildings. It required participants to maintain larger memory load to complete the navigation task in Experiment 2 than that in Experiment 1. In fact, the percentage of participants who failed to complete the navigation task was higher in Experiment 2 (14/136) than that in Experiment 1 (1/162). Moreover, experimenters in Experiment 2 reported more cases of the participant getting lost than that in Experiment 1. It is possible that the participants in Experiment 1 who provided valid data did not have the same memory capacity as participants who provided valid data in Experiment 2. Future studies should carry out careful procedures to control the memory capacity required to complete Experiment 1 and Experiment 2.

EXPERIMENT 3: REGION VERSUS LOCATION

Experiment 1 and Experiment 2 attempted to uncouple the effect of the environment size and the effect of memory load on people's route choice. The size of the environment was manipulated by testing Experiment 1 in vista-sized space and Experiment 2 in environment-sized space. The memory load factor was manipulated by having some "visible" trials (i.e. Experiment 1A and Experiment 2A) in which all destinations are visible and some "non-visible" trials (i.e. Experiment 1B and Experiment 2B) in which the second and third destinations are not visible until participants reach the first destination. Experiment 3 addressed a different question. In Experiment 3 there were obvious regions within the virtual environment, in addition to varying the locations of the later destinations. The goal of this experiment is to explore the influence of LDA factor relative to regionalization factor, which is another environmental factor that has been shown influence route planning behavior (e.g. Hochmair et al., 2008). Experiment 3 aimed to investigate the interactivity or relative influence of the *later-destination-attractor* (LDA) bias and regionalization factor.

There were five main types of trials (Figure 20). In each trial, there was an obstacle between the starting point and the first destination; the first destination was always in the center behind the obstacle; all destinations were visible. Further, only two-destination trials were used in this experiment because this study aims to investigate the conflict between LDA and regionalization than on the effects of second and third destination location. In one type of trials

(Region Only condition) the location of the second destinations were neutral (i.e., in the center, behind the first destination), and the boundaries of a region varied to encourage either the left path around the obstacle (Figure 20A, left) or the right path around the obstacle (Figure 20A, right). In the second type of trials (LDA Only condition), the boundary of the regions was neutral and the location of the second destination varied (Figure 20B). In the third type of trials (Congruent condition) both the region and the location of the second destination encouraged the same path around the obstacle (Figure 20C). In the fourth type of trials (Incongruent condition), the region and location encouraged opposite paths (Figure 20D). The final type of trials served as the control (Neutral condition): both the region boundary and the location of the second destination were neutral (Figure 20E). As in the other experiments, the dependent variable in this experiment is the percentage of trials in which the participants took the right route to walk around the obstacle to reach the first destination.

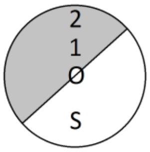
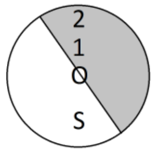
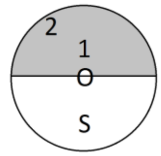
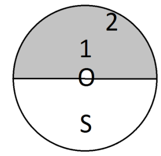
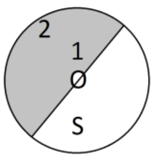
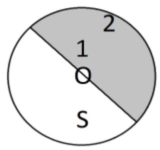
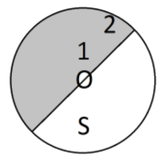
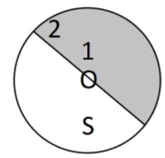
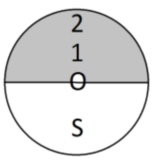
S = start place, O = obstacle, 1 = first destination, 2 = second destination, Neut = neutral					
A	Region bias – left LDA bias - Neut	Region bias – right LDA bias - Neut	B	Region bias – Neut LDA bias - Left	Region bias – Neut LDA bias - Right
					
C	Region bias – Left LDA bias - Left	Region bias – Right LDA bias - Right	D	Region bias – Left LDA bias - Right	Region bias – Right LDA bias – Left
					
E	Region bias – Neut LDA bias - Neut				
					

Figure 20: Diagram of the nine conditions in Experiment 3

The hypotheses were as follows: (1) In the control condition (represented by Figure #20E), both region boundary and second destination location were neutral. If there was no dominant individual factors (e.g. handedness) that could influence route preference, then the proportion of walking the right-route paths in the control condition should be 0.5. Differences between the proportion of walking the right-route paths in the control condition and another condition will reflect the influence of environmental factors. (2) For the Region Only trials, if the regionalization factor influence route choice in the current task paradigm, the percentage of choosing the right route will be higher when the region boundary is on the right (Figure #20A, right) than when the region boundary is on the left (Figure #20A, left). (3) For the LDA Only trials, if the LDA effect is present in the current task paradigm, the percentage of choosing the right route would be higher when the second destination is on the right (Figure #20B, right) than when the second destination is on the left (Figure #20B, left). (4) For the Congruent trials, if the influence of regionalization on route choice and the influence of LDA factor on route choice did not counterbalance each other, then the percentage of taking the right route will be higher when both the region boundary and the second destination are on the right (Figure #20C, right) than when they are both on the left (Figure #20C, left).

(5) Both Hochmair et al. and Brunyé et al. (2015) warranted the influence of individual difference on the application of route selection strategies. According to Hochmair et al. (2008), regionalization in the environment influences route selection behavior in individuals that are region-sensitive but not in individuals that are region-insensitive. For the incongruent trials, therefore, the results are expected to differ between two types of participants: region-sensitive and region-insensitive. A cluster analysis, described in the data analysis section, was used to differentiate these two groups. The comparison of the influence of LDA effect and the influence of regionalization on route choice was analyzed among region-sensitive participants only. If the LDA effect is stronger than the regionalization effect, then the proportion of walking the right-route paths would be significantly larger in condition "Figure #20D-left" than that in condition "Figure #20D-right". If the LDA effect is weaker than the regionalization effect, then the proportion of walking the right-route paths would be significantly smaller in condition "Figure #20D-left" than that in condition "Figure #20D-right". If the LDA effect is comparable to the regionalization effect, then the proportion of walking the right-route paths would not be

significantly different in condition “Figure #20D-left” than that in condition “Figure #20D-right”.

Method and Data Analyses

Participants, Materials, and Procedures

Eighty-one participants participated in this experiment (22 males, 58 females, 1 unknown, age 18 – 24). The same tools were used to construct the environments, which looked like simple outdoor environments (e.g., a back yard) with a stone patio and grassy lawn creating the boundaries (see Figure 6). Each participant completed one study session that lasted about 50 minutes. Each study session started with Survey1, an experiment session, and Survey2. Participants provided informed consent at the beginning of the study session and were debriefed at the end. Each experiment session consisted of 2 blocks of trials. Left and right hands were balanced across participants for the two blocks of trials. That is, if a participant used left hand to move the mouse and right hand to press the keyboard in block1, then that participant would use the right hand to move the mouse and left hand to press the keyboard in block 2. Each block consisted of 36 trials: 4 repetitions of the 9 conditions (3 region boundary conditions X 3 second destination location condition) as shown in Figure 20.

Participants were given the following instruction: “This virtual environment mimics someone’s backyard patio. Your task in each trial is to walk to the bench and then walk to the beach chair. The targets will light up in purple when you ‘reach’ them. After you reach the beach chair, walk to the back wall to connect to the next trial. You can use the keyboard and mouse to move in the environment.”

Figure 21: (a) Screenshot and (b) diagram of a “second destination on the right” trial in Experiment 3.

Data Analyses

In the current study, whether use the mouse or not would not influence visibility of the destinations because of the arrangement of destinations locations in the environment. Therefore, in this experiment, data analysis did not differentiate between participants who used the mouse and those who did not use the mouse to navigate. Data analyses included for the control condition, region-only trials, LDA-only trials, congruent trials and all trials included all participants. Data analyses for incongruent trials included only participants who were categorized as region-sensitive.

Control condition. The proportion of walking the right-route paths in the control condition (Figure #20E) was tested against 0.5. Results show that the proportion of walking the right-route paths was not significant different from 0.5, $t(80) = -.201$, $p = .84$ (Table 4). This means that, when both LDA condition and regionalization condition were neutral, the proportion of walking the right-route paths was not different from 0.5.

Region-only Trials. For the Region Only trials, a paired-sample t-test was conducted to test if there is any difference in terms of the percentage of choosing the right route between when the region boundary is on the right (Figure20A, right), and when the region boundary is on the left (Figure 20A, left). Results showed that participants walked the right route more often when the region boundary was on the right than when the region boundary was on the left, $t(80) = 2.13$, $p < .05$ (Table 4). Specifically, participants walked the right-route paths in around 46% of the trials in "20A left" condition and around 55% of the trials in "20A right" condition. This result supports Hypothesis 5(a) (see Introduction section) in that participants were more likely to walk the right-route paths when the nearest region boundary was on the right side than when the nearest region boundary was on the left side.

LDA-only Trials. For the LDA Only trials, a paired-sample t-test was conducted to test if there was any difference in terms of the percentage of choosing the right route when the second destination was on the right (Figure #20B, right), compared to when the second destination was on the left (Figure #20B, left). Results showed that participants walked the right route more often when the second destination was on the right than when the second destination was on the left, $t(80) = 8.16$, $p < .01$ (Table 4). Specifically, participants chose the right route in around 27% of the trials in "20B left" condition and around 68% of the trials in "20B right" condition. This result supports Hypothesis 4(a) (see Introduction section) in that participants were more likely to walk the right-route paths when the second destination was on the right side than when the second destination was on the left side.

Congruent Trials. For the Congruent trials, a paired-sample t-test was conducted to test if there was any difference in terms of the percentage of choosing the right route when both the region boundary and the second destination were on the right (Figure20C, right) compared to when both the region boundary and the second destination were on the left (Figure 20C, left). Results show that participants walked the right route more often when both the region boundary and the second destination were on the right than when both the region boundary and the second destination were on the left, $t(80) = 8.43$, $p < .01$ (Table 4). Specifically, participants chose the right route in around 25% of the trials in “20C left” condition and around 69% of the trials in “20C right” condition. This result supports Hypothesis 4(b) (see Introduction section) in that the LDA factor and regionalization factor had additive effect on participants’ route choice.

Incongruent Trials. To create the region-sensitive and region-insensitive grouping, the proportion of walking the right-route paths in condition Figure #20D (right), Figure #20D (left) and Figure #20E were used to classify participants. The Ward method with Squared Euclidean distance measure (Hochmair et al., 2008) was used to cluster participants into a region-sensitive group and a region-insensitive group. Based on the 2-cluster solution, each participant was classified as either “1 = region-insensitive” or “2 = region-sensitive” (see Figure 22 for the Dendrogram). The following data analysis were conducted using data from group 2 participants only.

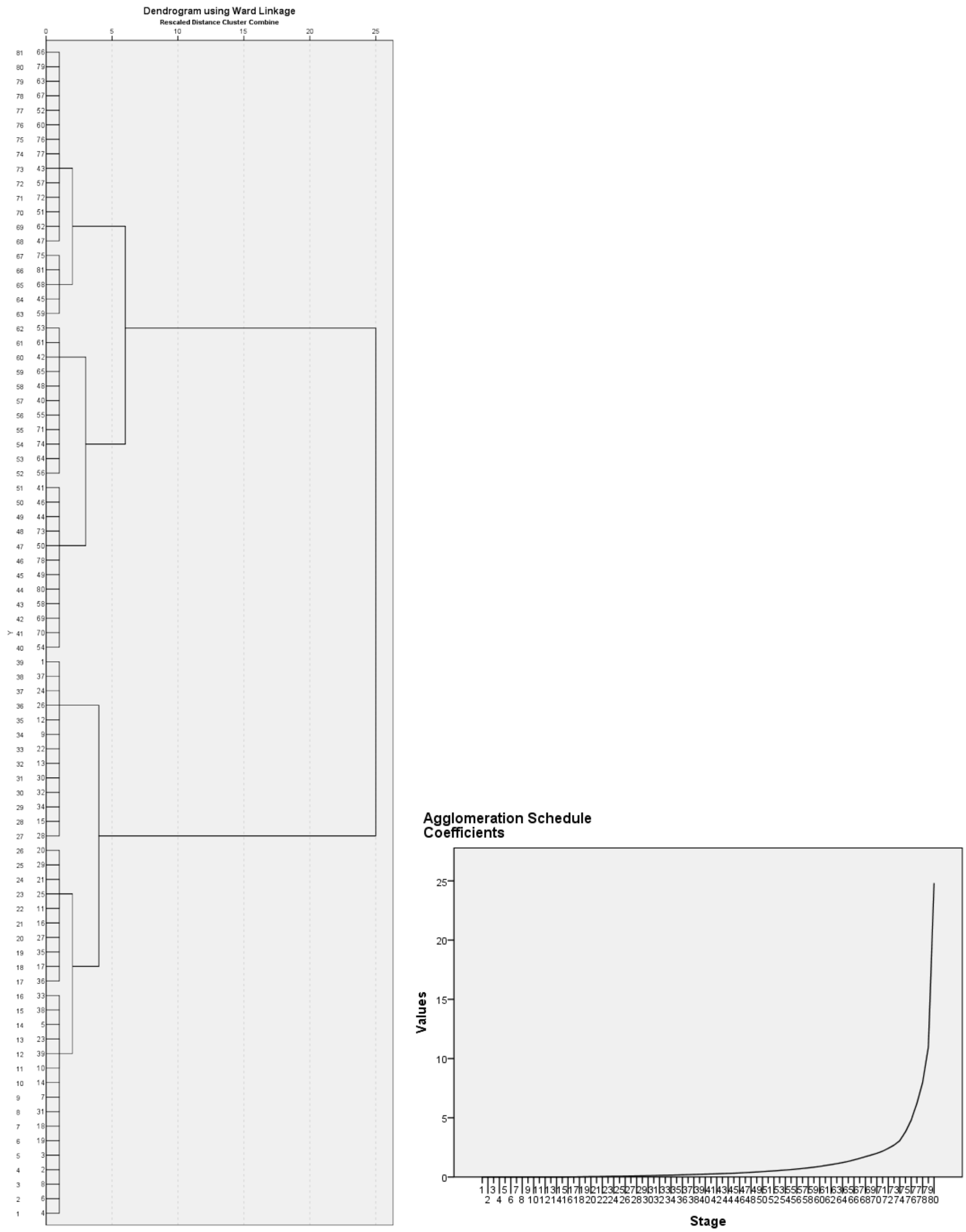


Figure 22. Participants in Experiment 3 can be roughly categorized into two groups: region-insensitive and region-sensitive: (left) Dandrogram and (right) Allomeration Schedule Coefficients.

According to Hypothesis 4 and Brunyé et al. (2015), participants would pay attention to the initial direction of a route option before attending to the features of the overall route. Therefore, it is expected that participants would follow the route encouraged by the LDA condition and not the route encouraged by the regionalization condition for the incongruent trials. Paired-sample t-test was conducted to compare the proportion of walking the right-route paths in condition "Figure 20#D-left" and that in condition "Figure #20D-right". Results showed that the proportion in condition "Figure #20D-left" was significantly larger than that in condition "Figure #20D-right", $t(41) = 2.197$, $p < .05$ (Table 4). Specifically, when the regionalization condition encouraged walking the left-route paths and LDA condition encouraged walking the right-route paths, the proportion of trials in which participants walked the right-route paths was 0.46 (SD = .35). When the regionalization condition encouraged walking the right-route paths and LDA condition encouraged walking the left-route paths, the proportion of trials in which participants walked the right-route paths was 0.29 (SD = .25). This result supports Hypothesis 4(c) (see Introduction section) in that quick route choice decision conformed to the LDA principle over the regionalization principle. This result is especially significant considering that only region-sensitive participants were included in this analysis.

All Trials. The final analysis aimed to test Hypothesis 4(c) as stated towards the end of the Introduction section. A 3(nearest region boundary on the left, nearest region boundary in the middle, nearest region boundary on the right) X 3(second destination on the left, second destination centered, second destination on the right) repeated-measure ANOVA was conducted. Results showed that both the regionalization factor and LDA factor influenced the proportion of trials in which participants walked the right-route paths. Specifically, there was a main effect of the regionalization factor, $F(2, 160) = 11.56$, $MSE = .02$, $p < .01$, $\eta^2 = .13$. There was a main effect of the LDA factor, $F(2, 160) = 48.42$, $MSE = .19$, $p < .01$, $\eta^2 = .38$. These was also a linear trend of increasing proportion of walking the right-route paths as the nearest region boundary relocated from left to center to right, $F(1, 80) = 18.31$, $MSE = .03$, $p < .01$, $\eta^2 = .19$. There was a significant linear trend of increasing proportion of walking the right-route paths as the second destination relocated from left to center to right, $F(1, 80) = 60.81$, $MSE = .30$, $p < .01$, $\eta^2 = .43$. There is no interaction between these two factors, $F(4, 320) = .94$, $MSE = .02$, $p = .44$, $\eta^2 = .01$. This result supports Hypothesis 4(b) (see Introduction section) in that the LDA factor and regionalization factor did not show interaction effect on participants' route choice. Table 2 and Figure 23 present the descriptive statistics of this analysis and Table 3 summarizes the inferential statistics of this analysis.

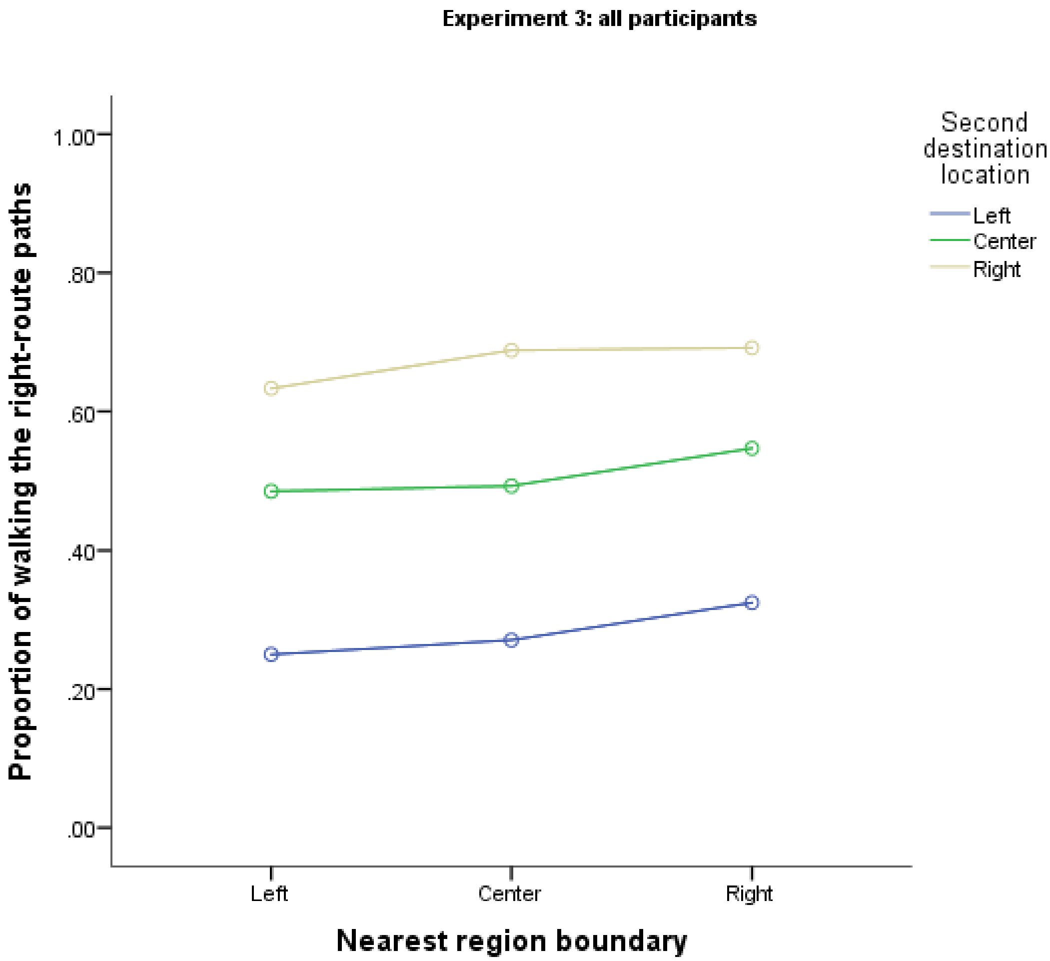


Figure 23. In Experiment 3, proportion of walking the right-route paths was influenced by both the regionalization factor and LDA factor

Discussion

Experiment 3 demonstrated LDA effect in small-size environments in which the navigators could see all destinations without rotating their body in the virtual environments. The influence of second destination location on the proportion of right-route paths was consistent with that reported in Fu et al. (2015). The current study also supported the existence of individual differences regarding sensitivity to regions in an environment (Hochmair et al., 2008). Moreover, results from the current study are consistent with the hypothesis that later destination location influences route selection by directing navigators' initial attention to the starting direction of the route options. If the initial direction of all route options was equivalent in terms of the angle they would form with the goal direction, then navigators would attend to the overall feature of the routes.

There was no interaction of regionalization factor and LDA factor on the proportion of walking the right-route paths among both region-insensitive participants and region-sensitive participants. This result showed that regionalization and LDA effect belong to two groups of route-choice principles that are independent from each other in terms of their role in deterring navigators' route choice. Another example of two route selection strategies had independent influence on route selection behavior can be found in Brunyé et al. (2015), in which the initial segment strategy (choose routes that have straight initial segment versus winding initial segment) and the topography strategy (choose routes that across flat surface versus mountainous surface) had no interaction effect on route choice.

An inspection into the Agglomeration schedule coefficients (Figure 22, right) revealed that the cluster analysis does not model the data well until there are more than 60 clusters. That is, the 2-cluster division of region-sensitive and region-insensitive participants is a very rough grouping method. In fact, many individual differences other than region-sensitivity have been found to influence route planning behavior. Participants' aversion towards uncertainty, for example, has been found related to more usage of heuristics and quicker decision making (Roets & Hiel, 2008). Nevertheless, the region-sensitive versus region-insensitive classification is sufficient for the purpose for testing the influence of regionalization on route in the current study.

ACROSS ALL EXPERIMENTS

Participants

A total of 437 participants participated the current study (132 males, 293 females, 10 unknown), of which 369 participants provided valid experiment data (116 males, 241 females, 2 self-identified as “other gender”, 10 unknown). It is shown in Figure 24 that there were less participants who did not use mouse than the sample size required for most statistical analysis. Therefore, the following analysis included only participants who used the mouse to navigate.

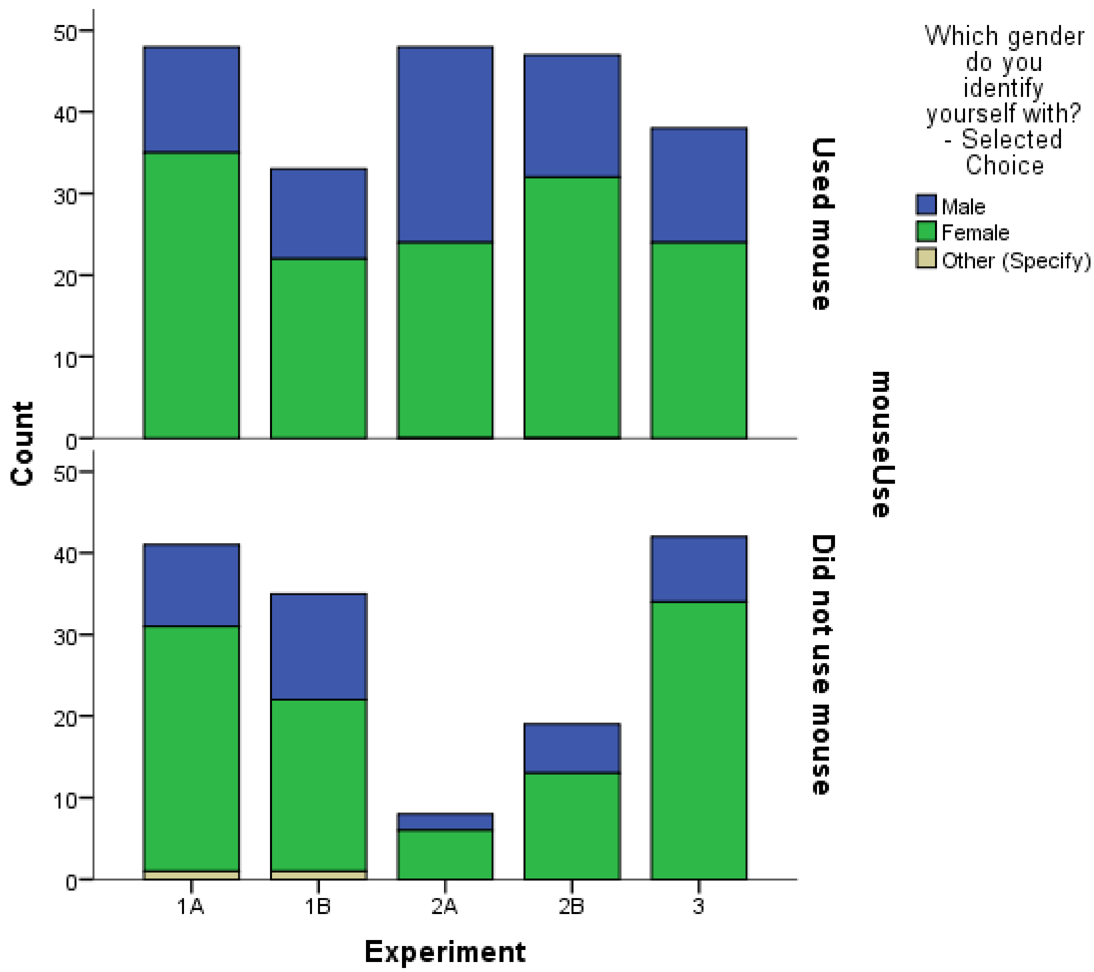


Figure 24. Gender distribution in the current study

Influence of visibility and Environment Size on LDA effect

Two-destination Trials. To test whether LDA effect is influenced by visibility and environment size, a 2(destinations visible vs. destinations hidden) X 2(small size vs. large size) X 3(second destination on left, second destination centered, second destination on right) repeated-measure ANOVA was conducted for all two-destination trials in Experiment 1 and Experiment 2 for participants who used the mouse to navigate. Results showed the “second destination location” factor and “environment size” factor had main effects on route choice.

Specifically, within-subject factor “second destination location” influenced the proportion of walking the right-route paths among participants, $F(2, 354) = 40.87$, $MSE = ..08$, $p < .01$, $\eta^2 = .19$. Between-subject factor “memory-load” did not influence the proportion of walking the right-route paths among participants, $F(1, 177) = 1.82$, $MSE = .25$, $p = .18$, $\eta^2 = .01$. Between-subject factor “environment size” influenced the proportion of walking the right-route paths among participants, $F(1, 177) = 6.98$, $MSE = .25$, $p < .01$, $\eta^2 = .04$.

There was also significant interaction between the “memory-load” factor and “environment-size” factor on participants’ route choice, $F(1, 177) = 4.59$, $MSE = .25$, $p < .05$, $\eta^2 = .03$.

Moreover, both the “memory-load” factor and “environment size” factor influenced the LDA effect. Specifically, the “visibility” factor interacted with “second destination location” factor in their influence on route choice, $F(2, 354) = 4.46$, $MSE = .08$, $p < .05$, $\eta^2 = .03$. The “environment size” factor interacted with “second destination location” factor in their influence on route choice, $F(2, 354) = 10.11$, $MSE = .08$, $p < .01$, $\eta^2 = .05$. Simple effect of the second destination location on routes in each condition can be found in Table 6.

Based on Hypothesis 2 and Hypothesis 3 (see Introduction section for the hypotheses), results from the current study support the assumption that LDA effect is influenced by the visibility factor and the assumption that the LDA effect is influenced by the size of the environment. This result is expected when considering the significant interaction effect between “visibility” factor and “environment size” factor on route choice.

Three-destination Trials. To test whether the LDA effect is influenced by visibility and environment size, a 2(visibility: destination visible vs. destination hidden) X 2(environment size: small vs. large) X 3(second destination location: left, center, right) X 3(third destination location:

left, center, right) was conducted. Results showed that the “second destination location”, “third destination location”, and “environment size” factors had main effects on the routes participants took. The “visibility” factor did not show main effect on routes but it interacted with other factors to influence routes. The following report of the results emphasizes comparison across experiments, details about comparisons within each experiment can be found in previous sections.

Influence of Second Destination Location on Routes. Across all conditions in Experiment 1 and Experiment 2, the “second destination location” factor showed main effect on the proportion of walking the right-route paths, $F(2, 354) = 91.84$, $MSE = .14$, $p < .01$, $\eta^2 = .34$. There was a linear trend of decreasing proportion of walking the right-route paths as the second destination relocated from left to center to right, $F(1, 177) = 114.97$, $MSE = .22$, $p < .01$, $\eta^2 = .39$. Influence of second destination location on routes depended on other factors such as third destination location and visibility (Table 7).

Influence of Third Destination Location on Routes. Across all conditions in Experiment 1 and Experiment 2, the “third destination location” factor showed main effect on the proportion of walking the right-route paths, $F(2, 354) = 12.95$, $MSE = .07$, $p < .01$, $\eta^2 = .07$. There was a significant linear trend of decreasing proportion of walking the right-route paths as the third destination relocated from left to center to right, $F(1, 177) = 13.22$, $MSE = .09$, $p < .01$, $\eta^2 = .07$. Moreover, the influence of “second destination location” on the routes that participants walked depends on other factors such as second destination location, visibility, and environment size.

Influence of third destination location on routes depended on second destination location (Table 8). When the second destination was on the left, third destination did not influence routes, $F(2, 360) = .30$, $MSE = .03$, $p = .74$, $\eta^2 = .00$. There was no linear trend for this effect, $F(1, 180)$

= .50, *MSE* = .04, *p* = .48, η^2 = .00. When the second destination was centered, third destination location influenced routes, *F*(2, 360) = 9.02, *MSE* = .07, *p* < .01, η^2 = .05. There was a significant linear trend of increasing proportion of walking the right-route paths as the third destination relocated from left to center to right, *F*(1, 180) = 13.89, *MSE* = .10, *p* < .01, η^2 = .07. When the second destination was on the right, third destination location influenced routes, *F*(2, 360) = 15.86, *MSE* = .06, *p* < .01, η^2 = .08. In this condition, there was a significant linear trend of increasing proportion of walking the right-route paths as the third destination relocated from left to center to right, *F*(1, 180) = 9.08, *MSE* = .10, *p* < .01, η^2 = .05.

Influence of third destination location on the proportion of walking the right-route paths among participants depended on whether later destinations were seen or hidden from participants at the starting point (Table 8). When the later destinations were visible from the starting point, third destination did not influence routes, *F*(2, 196) = 1.35, *MSE* = .08, *p* = 26, η^2 = .01. There was no linear trend for this effect, *F*(1, 98) = .80, *MSE* = .11, *p* = .37, η^2 = .01. When the later destinations were not visible, third destination influenced routes, *F*(2, 162) = 18.31, *MSE* = .05, *p* < .01, η^2 = .18. There was a significant linear trend of increasing proportion of walking the right-route paths as the third destination location relocated from left to center to right when later destinations were visible to participants at the starting point, *F*(1, 81) = 26.92, *MSE* = .06, *p* < .01, η^2 = .25.

Influence of third destination location on the proportion of trials in which participants walked the right-route paths depended on the size of the environment (Table 8). In small-size environments, third destination location did not influence routes, *F*(2, 162) = 2.66, *MSE* = .09, *p* = .07, η^2 = .03. There is no significant linear trend for this effect, *F*(1, 81) = .07, *MSE* = .12, *p* = .79, η^2 = .00. In large-size environments, third destination location influenced routes, *F*(2, 196) =

21.83, *MSE* = .05, $p < .01$, $\eta^2 = .18$. In large-size environments, there was a significant linear trend of increasing proportion of walking the right-route paths as the third destination relocated from left to center to right, $F(1, 98) = 30.02$, *MSE* = .06, $p < .01$, $\eta^2 = .23$.

Finally, the influence of third destination location on routes depended on visibility in small-size environment but not in large-size environment. Table 8 present the influence of third destination location on the proportion of trials in which participants walked the right-route paths in this four conditions: small-seen, small-hidden, large-seen, large-hidden.

Visibility. Across all conditions in Experiment 1 and Experiment 2, the "visibility" factor did not show significant influence on the proportion of walking the right-route paths, $F(1, 177) = 1.46$, *MSE* = .53, $p = .23$, $\eta^2 = .01$. The influence of visibility on route choice was seen in the interaction effects of visibility with second and third destination locations on route choice, as detailed in Table 4, 5, and 6.

Environment Size. Across all conditions in Experiment 1 and Experiment 2, the "environment size" factor showed a significant influence on the proportion of walking the right-route paths, $F(1, 177) = 6.78$, *MSE* = .53, $p < .05$, $\eta^2 = .04$. The influence of environment size on route choice was seen in the interaction effects of environment size with second and third destination locations on route choice, as detailed in Table 4, 5, and 6.

The visibility factor did not interact with the environment size factor to influence the proportion of trials in which participants walked the right-route paths, $F(1, 177) = 2.72$, *MSE* = .53, $p = .10$, $\eta^2 = .02$.

Left-route Bias

Data from all experiments were used to test the overall route preference among all participants. Results showed that the proportion of wakling the right-route paths was significantly different from 0.5, $t(368) = 6.157$, $p < .01$, cohen's $d = .32$. That is, participants walked the left-route paths more frequently than the right-route paths, regardless of experimental manipulations. This is consistent with the overall left-route bias reported in Fu et al. (2015).

Handedness Effect

Route choice data from the Experiment 1, 2, 3 were collapsed to test the relationship between handedness and participants' route choice. Survey1 results showed that majority of the participants were right-handed (Figure 25).

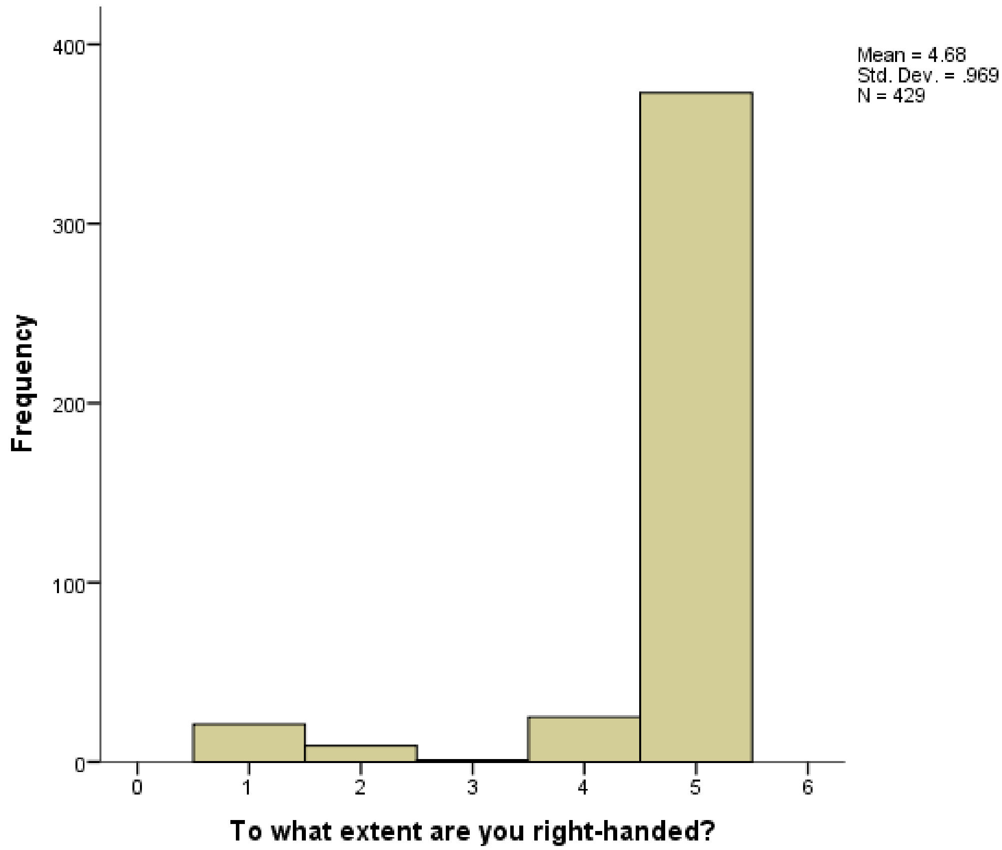


Figure 25. Frequency of self-report handedness in all participants
1 = mostly left-handed
2 = a little more left-handed than right-handed
3 = esentially ambidextrous
4 = a little more right-handed than left-handed
5 = mostly right-handed.

Participants who self-reported as 1 or 2 or 3 or 4 were categorized as “left-handed” and participants who self-reported as 5 were categorized as “right-handed” for the convenience of data analysis. Overall, there were 44 left-handed and 315 right-handed participants. An independent-samples t-test showed that right-handed participants were more likely to choose the right route than left-handed participants, $t(357) = 2.52$, $p < .05$. Specifically, left-handers walked the right-route paths in 33% of the trials (SD = .27) and right-handers walked the right-route paths in 43% of the trials (SD = .25). That is, right-handers were more likely to walk the right-route paths than left-handers. This result supports Hypothesis 5 (see Introduction section) in that route choice differed between left-handers and right-handers if handedness influences route choice, which was the hypothesis consistent with the literature conclusion (e.g. Scharine & McBeath, 2002). Based on Scharine and McBeath's results, the current study achieved a power of .66, which might warrant the validity of the conclusion that participants who were right-handed walked the right-route more often than participants who were left-handed.

Discussion

The current study revealed a left-route bias that was consistent with the left-route bias reported in the original study (Fu et al., 2015). The handedness effect revealed in the current study – right-handers preferring the right-route paths more than left-handers did - was consistent with the handedness effect reported in the literature (e.g. Scharine & McBeath, 2002). The relationship between the left-route bias effect and handedness effect observed in the current study, however, does not support the relationship between left-route bias and handedness stated in Hypothesis 5 by the end of Introduction section. While the power of the test that implicates the relationship between handedness and route preference was not big enough to warrant valid conclusions, the left-route preference is worth further investigations in future studies. It is not clear, therefore, why participants would prefer the left-route paths over the right-route paths in an environment in which all objects were symmetric, including the two route options. The left-route bias in Experiment 1 and 2 is intriguing when considering the result from Experiment 3 that showed chance level of walking the right-route path. The current study did not further investigate the left-route bias because it was not of the interest to the current study. However, future studies that explore the causes of this left-route bias would have implications to practices that involve route planning, such as urban design and transportation.

Another line of future study could investigate the learning curve. That is, whether the LDA effect increases as the participants become more experienced with the environments. It is possible that the more experience a participant has with the environment, the better he or she will be at using mental representation of the environment in navigation and route planning. If the influence of third destination location on route depended on the usage of mental representation of the environment, then the influence of third destination location on route would increase as participants gain more experience with the environments. This hypothesis can be tested by dividing the experiment into four blocks in time sequence, and then comparing the proportion of right route across the four blocks.

GENERAL DISCUSSION

The current study investigated which one of two routes navigators would walk to reach a first destination when intending to walk to later destinations in virtual environments. The results revealed an influence of later destination locations on the route navigators walked to reach the first destination, which demonstrated the essence of the later-destination-attractor effect (Fu et al., 2015). Moreover, the extent of this effect is influenced by factors that could potentially influence memory load involved in the spatial navigation task, such as the size of the environment and visibility of destinations.

Influence of the third destination location on route that participants walked, however, differed from the influence of second destination location on route. In the current study, the second destination location had larger influence on route when the later destinations were seen at the starting point and when the environment size was small (Table 6, Table 7). The third destination location, however, had a larger influence on route when the later destinations were hidden at the starting point and when the environment size was large (Table 8). Also, the second destination location and third destination location influenced route in opposite directions. The reason for these different influences of second destination location and third destination location on route revealed in the current study is not clear and subject to future studies.

One possible reason for the observed differences between second destination location and third destination location in terms of their influence on route could be the functionality of each movement during navigation. According to a series of studies, for example, people tend to grab the top of a water bottle if the next step was to serve themselves, but they grab the bottom of a water bottle if the next step was to hand the bottle to another person (Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001). According to Rosenbaum et al., the visual information of the environment at decision points determines specific movement trajectory. Therefore, if the second destination locate is on the right side of the environment, participants would prefer to face the right side when they reach the first destination, which necessarily requires choosing the left route at the starting point. The functionality of walking the right-route paths would be different for reaching a second destination that was on the right side of the environment compared to the functionality of walking the same paths for reaching a third destination that was on the right side of the environment. Therefore, the differences in functionality of walking the right-route paths for second and third destination could possibly explain the different influence of second destination location and third destination location on routes that participants walked.

The visibility factor played different roles in the current study and in Fu et al. (2015). In fact, for the third destination to have an influence on route choice to the first destination, it is more important to see a diagram of the whole environment than to see the destinations directly. In both the small- and large- environments, location of third destination had larger influence on route choice to the first destination when the third destination was shown on a diagram than when the third destination was readily visible from the starting point. This effect might root in the function of mental representation of space in navigation. When the later destinations were visible at the starting point, participants could form an allocentric mental representation of the environment and plan a route to reach the immediate destination. When participants reached the first destination, they could not see the third destination in the current study unless they turned to the direction of the third destination. In Fu et al. (2015), however, participants could see all destinations in the “visible” condition without rotating their torso or navigation direction. In the current study, the diagram could have helped formation and maintaining of the mental representation of the environment because participants in the “hidden” condition viewed the diagram for more than one second. Further study is needed to fully understand the role that visibility plays In the LDA effect.

The orientation of the map can provide cues to the spatial relationships among destinations. Mora (2011) proposed that this topological relationship shapes people’s understanding of a map and this understanding shapes the way the map is mentally represented. According to Roskos-Ewoldsen et al. (1998), factors that increase memory load such as contra-aligned retrieval and learned views would necessarily influence spatial performance through influencing mental representation of the space. Participants watched navigation films and were told to pay attention to landmarks during the viewing. fMRI evidence shows persistent mental representation of spatial information that is relevant to the task, which is stable after only one exposure to the environment (Spiers, 2008). This suggests that mental representation of the destinations is registered in the brain once they find the destination and this information would stay relatively stable once the mental representation is formed. When diagrams, but not direct visual cues of the third destinations, were available (i.e. Experiment 1B and 2B) the proportion of walking the right-route paths was influenced more by the third destination location and less by the second destination. Therefore, the results from current study might indicate that participants’ route choice to the second destination was guided by direct view of the destination and their route to the third destination was guided by mental representation of the third destination location in the environment.

In Fu et al (2015), the LDA effect was strongest when all the destinations were visible during the task. The LDA effect was smaller when later destinations were non-visible. The LDA effect was even smaller when the diagram was rotated 180 degrees than when the diagram was aligned with the view of the environment.

Also, In Fu et al., participants stopped at each destination to answer a survey question using pencil and paper. In the current study, participants did not stop at each destination before preceding to the second and third destinations. It is possible that the time delay between first and second route segments makes the navigation task more like a discrete movement rather than continuous movement. In a hand movement experiment, van der Wel and Fu (2015) found that the influence of a partner's hand movement on the participants' hand movement differed when the task involved continuous hand movements versus when the task involved discrete hand movements. For continuous movements, the influence of a partner's hand movement depended on whether the participant could see the partner's hand movements. In contrast, the partner's hand movement modulated the height of discrete movements, regardless of the availability of visual information. This distinction between entrainment and co-representation might have played a role in the differences between results of the current study and results from Fu et al. (2015). That is, it is possible that the original study (Fu et al., 2015) involved discrete movements and the current study involved continuous movements thus visual cue had different influences on the LDA effect in the current study compared to that in the original study.

The influence of visibility on LDA effect and the influence of environment size on LDA effect can be compared by inspecting their interaction with the influence of second destination location and third destination location on route (Table 4, 5, 6). Overall, the environment size had larger influence on the LDA effect than visibility did. However, there was also significant interaction between these two factors in several conditions. Therefore, it is possible that the visibility factor and environment size factor were not entirely teased apart in all conditions in the current study. Further study is needed to test the hypothesis that the LDA effect is influenced by visibility factor but not influenced by environment size factor.

The current study also demonstrated the influence of regionalization on route. In Experiment 3, region boundaries indicated by the ground texture influenced participants' route choice to the first destination. Specifically, when the nearest boundary of the destination region was on the right side, participants were more likely to choose the right route than the left route. This result is consistent with the hierarchical theories of spatial representation. According to Wiener and Mallot (2003), environments that are divided into regions lead to hierarchical encoding of space such that navigators would use fine-space information for close locations and coarse-space information for distant locations simultaneously. That is, navigators would likely want to reach the destination region first before finding the actual destination place.

In the current study, participants' route was influenced by an unexpected factor – mouse use. Existing studies using desktop computer to execute virtual environments did not report the influence of mouse usage on participants' behavior. By observing participants' navigation behavior in the virtual environments, it is easy to notice that participants who did not use mouse to navigate did not "rotate" their "head" in the virtual environments thus did not change the orientation they were facing. Therefore, it is possible that it was the re-orientation factor rather than mouse use factor that influenced the route.

Limitations

One limitation of the current study is that in Experiment 1B participants could see the second destination once they have reached the first destination. This design might have led to stronger LDA effect than that in comparable conditions in Fu et al. because the object placed at the second destination in the current study (i.e. a suit case) has larger visual impact than the object placed at the second destination in Fu et al (i.e. a piece of paper). Future studies could replicate the current study design with subtler objects placed at the second destination. In fact, a stricter control over the visibility factor could be implemented through making the later destinations completely invisible until close approximation.

The current study also involved experiments that required slightly different cognitive capabilities to provide valid data. For example, participants in Experiment 2 got lost more frequently than that in Experiment 1. There were also more cases of participants failing to provide valid experiment data due to misunderstanding of instructions in Experiment 2 than that in Experiment 1. There were also far more female participants than male participants. Gender of the participants was not screened prior to the study thus was not controlled by the researcher. Students voluntarily registered in the study and the demographic characteristics of the participants represent the demographic characteristics of the student population at The University of Alabama. Existing research has demonstrated many gender differences in spatial behavior. For example, female navigators performed better in navigation tasks when using egocentric navigational aids versus allocentric navigational aids (Chen, Chang, & Chang, 2009). In the current study, the female/male ratio was not equivalent across all experimental conditions (Figure 24). One example of invalid experiment data could be that participants completed the experiment without following instructions. It is possible that the participants who contributed valid experiment data had different spatial capabilities across Experiment 1A, 1B, 2A, 2B, and 3.

Yet another limitation of the current study is that participants' perception of the size of the virtual environment was not measured. Therefore, it is possible that the environment size manipulation was not successful due to participants' perceiving the small- and large-environments as the same size on the computer screen.

There were also a few cases (less than 20) in which participants got dizzy in the middle of the study. The researcher attended to this ethical concern and modified some parameters in the experiment program to try to reduce the frequency of dizziness. For example, the "walking speed" in Experiment 1A and 1B was reduced to avoid rapid scene change due to "head rotation" in the virtual environments. For participants who reported minor discomfort but insisted on completing the study, "walking speed" was modified to be slower than that for other participants and a fan was provided to the participant to help increase air flow in the experiment area.

The current study categorized participants into region-sensitive and region-insensitive groups based on their route choice behavior. This methodology might be improved by categorizing region-sensitivity based on other intrinsic characteristics such as the way one perceives spatial environment. Also, region boundary could be manipulated in multiple ways including re-arranging buildings in the environment or changing the sidewalks in the environment. Yet a third way of manipulating the region boundary variable is to manipulate the continuity of boundary: from continuous boundaries to discrete boundaries. In the current study, the region boundary might not be strong enough to have a larger influence on route than second destination location did. By manipulating the strength of region boundary, it is possible to see a changing balance between the influence of second destination location and regionalization on routes. Because of this limitation in the current study, the results about regionalization might not be generalized to other regionalization situation such as sidewalk or mountainous areas.

Future Studies

The current study showed influence of environment size on LDA effect. According to Hypothesis 2, Hypothesis 3, and existing studies (e.g. Roskos-Ewoldsen et al., 1998), it was expected that the environment size would not influence the LDA effect. There were many methodology flaws that could be avoided in future studies. The large-size environment in the current study, for example, was related to more cases of participants' getting lost than that in the small-size environment. This should not be the case if the navigation tasks in the small-size environment and large-size environment provided equal visibility. Future studies could reduce the discrepancy between visibility provided in small- and large- size environments through modification of the virtual environments. For example, the buildings in the large-size environment could be made of transparent materials, thus enabling direct visibility of the destinations. Another method of controlling memory load involved in different experiments is to measure individual differences such as short-term memory capacity.

Another line of future study could focus on the influence of gender on route. One question, for example, could examine whether the LDA effect differ in males and females. Since males displayed overall better performance on re-orientation tasks than females, it is possible that the proportion of mouse-users will be higher in males than in females. Future study could further investigate the essence of LDA effect by studying the different wayfinding behaviors in males and females.

CONCLUSION

The current study demonstrated LDA effect in virtual environments: location of later destinations influenced which route navigators would walk from the starting point to the first destination. The current study also demonstrated the influence of memory load and environment size on the LDA effect and compared the LDA effect with regionalization effect. Furthermore, the current study showed the influence of functionality in movement planning, including route planning.

The current study helps theoretical modeling of wayfinding behavior. Specifically, understanding navigators' route choices has practical implications, such as helping to locate isolated personnel and prevent traffic congestion in public spaces. The fact that LDA effect was present in both the small-size environments and the large-size environments can potentially help with modeling efforts for both sizes of environments in the future. In sum, the current study demonstrated LDA effect in virtual environments and showed that which route navigators would walk depends on many factors such as: location of later destinations, visibility of the destinations, size of the environment, and individual differences such as handedness.

Results from the current study have implications on areas such as urban design. For example, route preference to a first destination could be predicted based on locations of popular later destinations and sidewalks can be located accordingly. Also, direction signs at major decision making points should indicate both direction of immediate destinations and, with smaller font sizes, directions of later destinations.

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Appendix A – Demographic questionnaire used in the Pilot Study

Please check the box for appropriate answer and, where appropriate, answer the question in the space provided.

1. What is your sex?

□ *Male* □ *Female* □ *Other (Specify ___________)*

2. How old are you now? __________ *years*

3. How would you describe your <u>primary</u> racial or ethnic group?

□ *White, Caucasian*

□ *Black, African-American*

□ *Native American*

□ *Hispanic, Latino*

□ *Asian/Pacific Islander*

□ *No primary group*

Specify: ____

□ *Other*

Specify: ____

4. To what extent are you right-handed? (circle the number)

Mostly left-handed	A little more left-handed than right-handed	Essentially ambidextrous	A little more right-handed than left-handed	Mostly right-handed
1	**2**	**3**	**4**	**5**

Appendix B – Survey1 questions in the current study

Enter the participant ID as indicated on the participant sign-in sheet. ________

Which gender do you identify yourself with?

□ *Male* □ *Female* □ *Other (Specify __________)*

What is your date of birth?

Month ______ Date ______ ……. Year ______

How old are you now? _________

How would you describe your primary racial or ethnic group?

□ *White, Caucasian*

□ *Black, African-American*

□ *Native American*

□ *Hispanic, Latino*

□ *Asian/Pacific Islander*

□ *No primary group*

□ *Other*

Specify: ____

How often do you play video games?

A. I don't play video games
B. Sometimes
C. Quite often

To what extent are you right-handed?

Mostly left-handed	A little more left-handed than right-handed	Essentially ambidextous	A little more right-handed than left-handed	Mostly right-handed

Please indicate your preference in the use of hands in the following activities. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, select for strong preference.

	Strong Preference for Left	Slight Preference for Left	Indifference	Slight Preference for Right	Strong Preference for Right
Writing					
Drawing					
Throwing					
Scissors					
Toothbrush					
Knife (without fork)					
Spoon					
Broom (upper hand)					
Striking Match (match)					
Opening box (lid)					
Which foot do you prefer to kick with?					
Which eye do you use when using only one?					

How often do you do each of the following activities?

	never	Once a month	Several times a month	Once a week	Several times a week	Once a day	Several times a day	Once an hour	Several times an hour	All the time
Play games on a computer, video game console or smartphone BY YOURSELF										
Play games on a computer, video game console or smartphone WITH OTHER PEOPLE IN THE SAME ROOM										
Play games on a computer, video game console or smartphone WITH OTHER PEOPLE ONLINE										

Which country are you from? ___________

Appendix C – Survey2 questions in the current study

Enter the participant ID as indicated on the participant sign-in sheet. __________

Think about the experience you just had in terms of navigating in the virtual environment. How immersed did you feel?

10 = very immersed
9
8
7
6
5
4
3
2
1
0 = not at all immersed

While moving in the environment, how much did you feel like you were really "there" in the environment?

1 = there
2
3
4
5
6
7 = not there

While moving in the environment, how much did you feel like the environment was a real place?

1 = real
2
3
4
5
6
7 = not real

Appendix D – Tables

Table 1

Influence of second destination locations on the proportion of trials participants navigated the right-route paths in two-destination trials

Experiment	Second destination locations						Repeated-measure ANOVA					Linear Trend				
	Left		Center		Right		df	*F*	*MSE*	*p*	η^2	*df*	*F*	*MSE*	*p*	η^2
	M	SD	M	SD	M	SD										
1A (small, seen) – used mouse	.74	.32	.47	.35	.23	.30	2, 94	31.54	.10	< .01	.40	1, 47	43.86	.15	< .01	.48
1B (small, hidden) - used mouse	.65	.37	.54	.37	.35	.43	2, 66	9.11	.08	< .01	.22	1, 33	11.58	.13	< .01	.26
1A (small, seen) – did not use mouse	.44	.37	.35	.36	.36	.39	2, 86	1.05	.10	.35	.02	1, 43	1.00	.14	.32	.02
1B (small, hidden) – did not use mouse	.26	.28	.41	.37	.44	.45	2, 68	3.70	.09	.03	.10	1, 34	4.73	.12	.04	.12
2A (large, seen)	.54	.39	.48	.41	.29	.32	2, 90	11.03	.07	< .01	.20	1, 45	15.36	.09	< .01	.25
2B (large, hidden) - used mouse	.33	.38	.33	.39	.26	.38	2, 94	1.13	.07	.33	.02	1, 47	1.06	.10	.31	.02
2B (large, hidden) – did not use mouse	.28	.36	.29	.42	.45	.42	2, 38	3.71	.05	.03	.16	1, 19	4.19	.08	.06	.18

Table 2
Descriptive statistics of the proportion of trials participants navigated the right-route paths in the environment in three-destination trials

	Experiment 1 & 2																	
Third destination location	Left						Center						Right					
Second destination location	Left		Center		Right		Left		Center		Right		Left		Center		Right	
Experiment	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1A (small, seen) – used mouse	.71	.33	.70	.36	.63	.33	.48	.34	.47	.37	.49	.36	.25	.20	.31	.33	.21	.31
1B (small, hidden) – used mouse	.67	.35	.67	.37	.56	.37	.40	.38	.52	.39	.60	.35	.19	.21	.46	.41	.34	.36
1A (small, seen) – did not use mouse	.44	.32	.39	.37	.37	.33	.41	.35	.34	.34	.39	.41	.27	.21	.42	.42	.36	.43
1B (small, hidden) - did not use mouse	.31	.32	.35	.34	.30	.35	.34	.39	.35	.37	.44	.43	.15	.20	.45	.36	.44	.42
2A (large, seen) - used mouse	.56	.37	.56	.42	.61	.39	.40	.39	.45	.39	.47	.39	.19	.23	.28	.33	.25	.30
2B (large, hidden) - used mouse	.42	.39	.39	.39	.46	.42	.21	.33	.33	.37	.45	.39	.14	.20	.32	.35	.29	.37
2B (large, hidden) – did not use mouse	.24	.35	.21	.37	.25	.35	.30	.38	.31	.40	.44	.40	.14	.20	.53	.40	.45	.46
	Experiment 3																	
Second destination location	Left						Center						Right					
Nearest region boundary	Left		Center		Right		Left		Center		Right		Left		Center		Right	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Experiment 3 – all participants	.25	.30	.49	.32	.63	.34	.27	.29	.49	.33	.69	.31	.32	.28	.55	.31	.69	.32

Table 3

Influence of factor 1 (second destination location in Experiment 1 and 2; region boundary in Experiment 3) and factor 2 (third destination location in Experiment 1 and 2; second destination location in Experiment 3) on the proportion of trials participants navigated the right-route paths in three-destination trials

		Repeated-measure ANOVA					Linear trend				
Experiment	Factor	df	*F*	*MSE*	*p*	η^2	df	*F*	*MSE*	*p*	η^2
1A (small, seen) – mouse user	Second destination location	2, 94	44.29	.15	< .01	.49	1, 47	57.53	.22	< .01	.55
	Third destination location	2, 94	1.02	.10	.36	.02	1, 47	.82	.14	.37	.02
	Second destination location X Third destination location	4, 188	1.16	.05	.33	.02					
1B (small, hidden) – mouse user	Second destination location	2, 66	17.49	.13	< .01	.35	1, 33	23.36	.20	< .01	.41
	Third destination location	2, 66	5.33	.08	.01	.14	1, 33	3.72	.08	.06	.10
	Second destination location X Third destination location	4, 132	5.47	.06	< .01	.14					
1A (small, seen) – non mouse user	Second destination location	2, 86	.67	.12	.52	.02	1, 43	.74	.20	.39	.02
	Third destination location	2, 86	.05	.10	.95	.00	1, 43	.01	.14	.92	.00
	Second destination location X Third destination location	4, 172	3.52	.06	.01	.08					
1B (small, hidden) – non mouse user	Second destination location	2, 68	.83	.10	.44	.02	1, 34	.28	.12	.60	.01
	Third destination location	2, 68	9.29	.05	< .01	.22	1, 34	10.76	.07	< .01	.24
	Second destination location X Third destination location	4, 136	5.61	.06	< .01	.14					
2A (large, seen) – used mouse	Second destination location	2, 90	25.23	.16	< .01	.36	1, 45	29.90	.26	< .01	.40
	Third destination location	2, 90	2.76	.05	.07	.06	1, 45	3.70	.06	.06	.08
	Second destination location X Third destination location	4, 180	.51	.05	.73	.01					
2B (large, hidden) – used mouse	Second destination location	2, 94	9.29	.12	< .01	.17	1, 47	11.18	.20	< .01	.19
	Third destination location	2, 94	21.06	.04	< .01	.31	1, 47	32.68	.04	< .01	.41
	Second destination location X Third destination location	4, 188	4.84	.05	< .01	.09					
2B (large, hidden) – did not use mouse	Second destination location	2, 38	2.70	.13	.08	.12	1, 19	3.22	.19	.09	.14
	Third destination location	2, 38	7.07	.06	< .01	.27	1, 19	8.92	.08	< .01	.32
	Second destination location X Third destination location	4, 76	6.66	.04	< .01	.26					
3 (small, seen) – all participants	Nearest region boundary	2, 160	11.56	.02	< .01	.13	1, 80	18.31	.03	< .01	.19
	Second destination location	2, 160	48.42	.19	< .01	.38	1, 80	60.81	.30	< .01	.43
	Nearest region boundary X Second destination location	4, 320	.94	.02	.44	.01					

Table 4

Proportion of trials participants navigated the right-route paths in Experiment 3

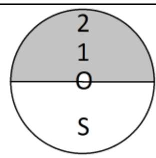
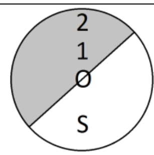
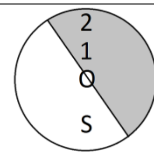
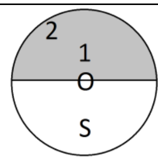
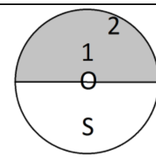
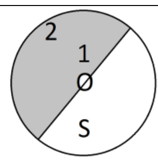
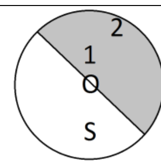
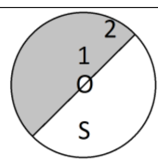
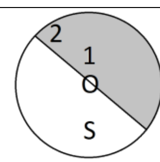
	Diagram	M	SD		Diagram	M	SD		*df*	*t*	*p*	Cohen's d
Control Condition		.49	.33		One-sample t-test to compare proportion of choosing the right-route paths against chance level in control condition	0.5			80	-.201	.84	.02
Region-only Trials		.49	.32			.55	.31		80	-2.13	.04	.24
LDA-only Trials		.27	.29			.69	.31		80	-8.16	.00	.91
Congruent Trials		.25	.30			.69	.32		80	-8.43	.00	.94
Incongruent Trials		.46	.35			.29	.25		41	2.20	< .05	.34

Table 5

Line graphs summary of results for Experiment 1 and 2

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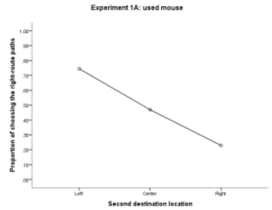
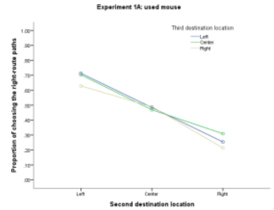
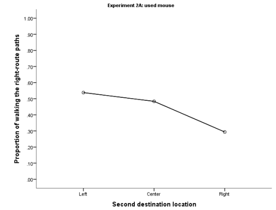
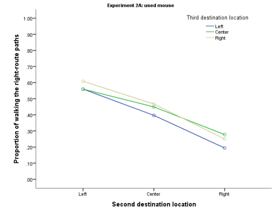
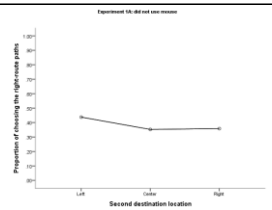
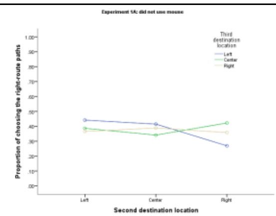
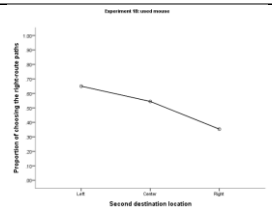
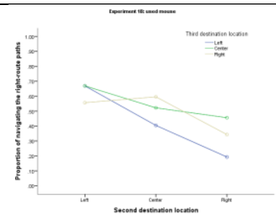
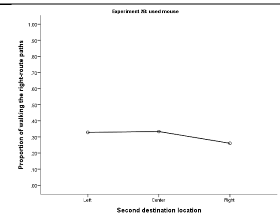
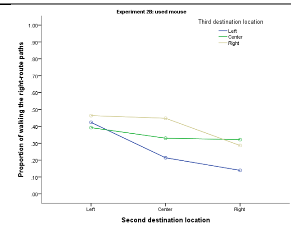
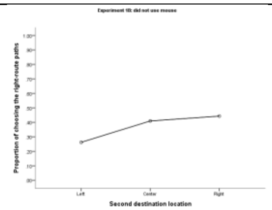
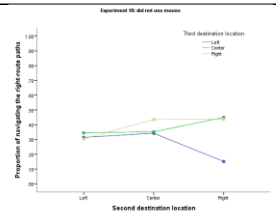
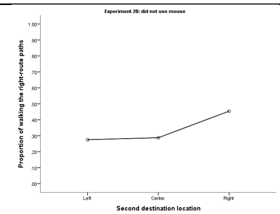
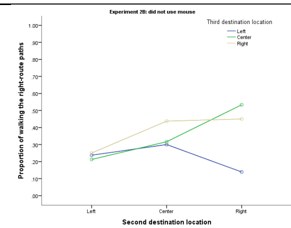
<td>1A
-
Used
mouse</td>
<td></td>
<td></td>
<td>2A
-
Used
mouse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A
- did
not
use
mouse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1B
- used
mouse</td>
<td></td>
<td></td>
<td>2B
- used
mouse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1B
- did
not
use
mouse</td>
<td></td>
<td></td>
<td>2B
- did
not
use
mouse</td>
<td></td>
<td></td>
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Table 6
The influence of second destination locations on routes in two-destination trials

		ANOVA						Linear trend				
Factor		df	*F*	*MSE*	*p*	η^2		df	*F*	*MSE*	*p*	η^2
Destination visibility	Later destinations seen	2, 196	34.96	.09	< .01	.26		1, 98	49.18	.13	< .01	.33
	Later destinations hidden	2, 162	7.48	.08	< .01	.08		1, 81	9.11	.12	< .01	.10
	Second destination location X Destination visibility	2, 354	4.46	.08	.01	.03						
Environment size	Small-size environment	2, 162	38.38	.10	< .01	.32		1, 81	51.77	.14	< .01	.39
	Large-size environment	2, 196	7.84	.07	< .01	.07		1, 98	9.77	.10	< .01	.09
	Second destination location X Environment size	2, 354	10.11	.08	< .01	.05						

Table 7
The influence of second destination location on routes in three-destination trials

		Repeated-measure ANOVA						Linear trend				
Factor	Value of factor	df	*F*	*MSE*	*p*	η^2		df	*F*	*MSE*	*p*	η^2
Third destination location	Third destination on left	2, 360	88.734	.08	< .01	.33		1, 180	166.46	.09	< .01	.48
	Third destination centered	2, 360	32.73	.08	< .01	.15		1, 180	47.61	.11	< .01	.21
	Third destination on right	2, 360	49.59	.08	< .01	.22		1, 180	65.24	.12	< .01	.27
Destination visibility	Later destinations seen	2, 196	72.01	.15	< .01	.42		1, 98	89.48	.23	< .01	.48
	Later destinations hidden	2, 162	25.07	.13	< .01	.24		1, 81	31.54	.20	< .01	.28

Table 8
The influence of third destination location on proportion of walking the right-route paths depended on other factors

		Repeated-measure ANOVA						Linear trend				
Factor	Value of factor	df	*F*	*MSE*	*p*	η^2		df	*F*	*MSE*	*p*	η^2
Second destination location	Second destination on left	2, 360	.30	.03	.74	.00		1, 180	.50	.04	.48	.00
	Second destination centered	2, 360	9.02	.07	< .01	.05		1, 180	13.89	.10	< .01	.07
	Second destination on right	2, 360	15.86	.06	< .01	.08		1, 180	9.08	.08	< .01	.05
Destination visibility	Later destinations were seen	2, 196	1.35	.08	.26	.01		1, 98	.80	.11	.37	.01
	Later destinations were hidden	2, 162	18.31	.05	< .01	.18		1, 81	26.92	.06	< .01	.25
Environment size	Small-size environment	2, 162	2.66	.09	.07	.03		1, 81	.07	.12	.79	.00
	Large-size environment	2, 196	21.83	.05	< .01	.18		1, 98	30.02	.06	< .01	.23
Second destination on left	Later destinations seen	2, 196	.10	.03	.90	.00		1, 98	.09	.04	.77	.00
	Later destinations hidden	2, 162	.33	.04	.72	.00		1, 81	.52	.04	.48	.01
Second destination centered	Later destinations seen	2, 196	.52	.08	.59	.01		1, 98	.78	.11	.38	.01
	Later destinations hidden	2 162	16.81	.06	< .01	.17		1, 81	28.70	.07	< .01	.26
Second destination on right	Later destinations seen	2, 196	3.16	.06	.05	.03		1, 98	1.00	.08	.32	.01
	Later destinations hidden	2, 162	16.67	.06	< .01	.17		1, 81	11.96	.08	< .01	.13
Small-size environment	Later destinations seen	2, 94	1.02	.10	.36	.02		1, 47	.82	.14	.37	.02
	Later destinations hidden	2, 66	5.33	.08	< .01	.14		1, 33	3.72	.08	.06	.10
Large-size environment	Later destinations seen	2, 100	5.59	.05	< .01	.10		1, 50	7.10	.08	.01	.12
	Later destinations hidden	2, 94	21.06	.04	< .01	.31		1, 47	32.68	.04	< .01	.41

Appendix E – IRB approval letters

THE UNIVERSITY OF ALABAMA | Office of the Vice President for Research & Economic Development
Institutional Review Board for the Protection of Human Subjects

May 12, 2016

En Fu
Dept. of Psychology
College of Arts & Sciences
Box 870348

Re: IRB#: 16-OR-190 "Route Choice in Virtual Environments: The Effect of Environment Size, Destination Visibility, and Regional Boundaries"

Dear En Fu:

The University of Alabama Institutional Review Board has granted approval for your proposed research.

Your application has been given expedited approval according to 45 CFR part 46. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies

Your application will expire on May 10, 2017. If your research will continue beyond this date, complete the relevant portions of the IRB Renewal Application. If you wish to modify the application, complete the Modification of an Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, complete the appropriate portions of the IRB Request for Study Closure Form.

Please use reproductions of the IRB approved stamped consent forms to provide to your participants.

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.

Sincerely,

Carpantato T. Myles, MSM, CIM, CIP
Director & Research Compliance Officer

358 Rose Administration Building | Box 870127 | Tuscaloosa, AL 35487-0127
205-348-8461 | Fax 205-348-7189 | Toll Free 1-877-820-3066

THE UNIVERSITY OF
ALABAMA | Office of the Vice President for
Research & Economic Development
Institutional Review Board for the Protection of Human Subjects

June 8, 2016

En Fu
Department of Psychology
College of Arts & Sciences
The University of Alabama
Box 870348

Re: IRB # 16-OR-190 (Revision) "Route Choice in Virtual Environments: The Effect of Environment Size, Destination Visibility, and Regional Boundaries"

Dear En Fu:

The University of Alabama Institutional Review Board has reviewed the revision to your previously approved expedited protocol. The board has approved the change in your protocol.

Please remember that your approval period expires one year from the date of your original approval, May 11, 2016, not the date of this revision approval.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants.

Good luck with your research.

Sincerely,

Stuart Usdan, PhD.
Chair, Non- Medical Institutional Review Board
The University of Alabama

358 Rose Administration Building | Box 870127 | Tuscaloosa, AL 35487-0127
205-348-8461 | Fax 205-348-7189 | Toll Free 1-877-820-3066

THE UNIVERSITY OF ALABAMA® | *Office of the Vice President for* Research & Economic Development **Office for Research Compliance**

October 11, 2016

En Fu
Department of Psychology
College of Arts & Sciences
The University of Alabama
Box 870348

Re: IRB # 16-OR-190 (Revision # 2) “Route Choice in Virtual Environments: The Effect of Environment Size, Destination Visibility, and Regional Boundaries”

Dear En Fu:

The University of Alabama Institutional Review Board has reviewed the revision to your previously approved expedited protocol. The board has approved the change in your protocol.

Please remember that your approval period expires one year from the date of your original approval, May 11, 2016, not the date of this revision approval.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants.

Good luck with your research.

Sincerely,

Carpantato T. Myles, MSM, CIM, CIP
Director & Research Compliance Officer
Office for Research Compliance

358 Rose Administration Building | Box 870127 | Tuscaloosa, AL 35487-0127
205-348-8461 | Fax 205-348-7189 | Toll Free 1-877-820-3066