“HEADING TO THE FINAL GOAL”: A NEW BIAS IN ROUTE PLANNING

by

EN FU

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Written under the direction of

Mary Bravo

and approved by

Benedetto Piccoli

Bill Whitlow

Mary Bravo

Robrecht van der Wel

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ABSTRACT OF THE THESIS

Heading to the final goal: A new bias in route planning

By EN FU

Thesis director:

Mary Bravo

Walking from place to place requires route planning. Past studies have shown that animal and human navigators tend to go directly towards their goal despite environmental constraints such as obvious obstacles. The current study investigated route planning in small indoor spaces that involved stopping at multiple destinations in a pre-determined sequence. In three sets of experiments, participants walked in a small room to reach two to three temporary stopping points. In Experiment 1, we investigated the effect of later destinations on participants' route choices towards the first and second destinations. The results support our hypothesis that, when choosing between symmetric two routes of the same length, participants would show a clear bias towards the route that deviate the least from the direction of their final, or, goal destination. In Experiment 2, we screened participants' view of most of the room and indicated the location of later destinations on a map. Results showed that the effect of subsequent destinations on participants' route choice to immediate destinations was reduced. In Experiment 3, we used a different method to hide subsequent destinations and provided participants with an up-side down map. With up-side down diagrams showing the location of the destinations, the result showed no effect of later destinations on participants' route choice to go the first and the second destinations. The results showed that ultimate destinations affect route choice to intermediate destinations and this effect is greatest when the ultimate destination is visible. Results of this study can be applied to environmental design such as arranging multiple events for a conference. Organizers should consider the location of the events that occur at the same time in order to balance traffic flow through the pathway spaces.

Introduction

The process of wayfinding has been defined as identifying a current location and finding one's way through an environment to get to a desired destination (Brunye, Gardony, Mahoney, & Taylor, 2010; Allen, Kirasic, Rashotte, & Haun, 2004). Sometimes the trip involves visiting multiple destinations. In this case, each destination becomes the "current place" from which to get to the next destination. Obviously, planning a route to visit multiple places involves much cognitive effort (Golledge, 1995; Basso, Bisiacchi, Cotelli, & Farinello, 2001). There are many situations in which planning a route is needed. A suitable example for introducing the topic of route planning for visiting multiple destinations could be my friend Faith driving home for a dinner party and having to stop at several locations. The first two stops were my apartment and Tina's workplace. Tina worked at a mall that was half way from my apartment and Faith's. Therefore Faith decided to come pick me up before she went to Tina's workplace. As Tina got in the car she told Faith that she had invited Liz, a friend of hers, so we would have to pick her up. Faith didn't expect this additional task and wondered which route to take because she had never been to that area before. Finally, she drove onto a main road before slipping into the avenue where Liz's house was located, although this route apparently differed from the shortest route suggested by her GPS.

Over the course of driving home, Faith made a lot of decisions that accommodate several route planning strategies. When planning the sequence of picking up her guests, she tried to minimize the distance of the trip. When choosing the route to Liz's house, Faith first went onto the familiar main road despite the resulting detour. As Faith tried to plan an efficient route for visiting multiple locations, she realized that there are many factors to consider. So what are the processes or strategies through which we plan a route to visit multiple locations? Do we always, if at all, calculate the length of each route alternative and choose the shortest one? In the current study, we will investigate the cognitive process by which people plan their routes to visit multiple destinations in pre-determined order. This is a largely neglected topic but it is related to several lines of research.

1. Single-destination tasks: heading towards the goal

For the purpose of studying route planning strategies, navigation tasks can be categorized as involving single or multiple destinations. We first consider route planning for single-destination tasks. Bailenson (1998), for example, found that people prefer routes that have long and straight segments at the beginning. In one of his studies, for example, participants were asked to choose one from two route alternatives on a map that represented a mountain area. Both the IS (Initially – Straight) route and IC (Initially – Cursive) route were of the same length (Figure 1). Results show that participants preferred the IS route over IC route.

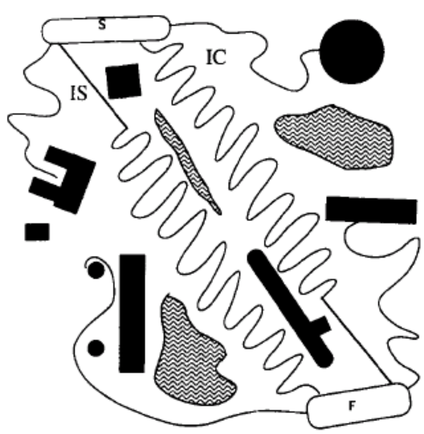

Figure 1. Mountain map in Bailenson (1998).

Golledge (1995) surveyed route selection criteria by which navigators plan their route from an origin to a destination. Grid maps were presented which represented a “town” and participants were asked to imagine traveling from the origin to the destination. The task was to first choose one of the three routes on the maps, then identify what criteria they used in choosing that route. Participants were also asked to indicate what criteria they think are normally used in real-life activities. They found that the criterion of “shortest distance” was the most frequent response to both questions. Apart from minimal distance, minimal time, and minimal effort, participants also suggested criteria such as “fewest turns,” “most aesthetic,” “first noticed,” “longest leg first,” and “many curves”. Similar to the route choosing strategy found by Bailenson (1998), Golledge defined the “longest leg first” strategy as a preference for routes that have their longest straight segment first. For example, Figure 2 shows one of the maps on which the “longest leg first” strategy was tested: participants who used this strategy would prefer route A to B or C when asked to imagine walking from location 1 to location 2.

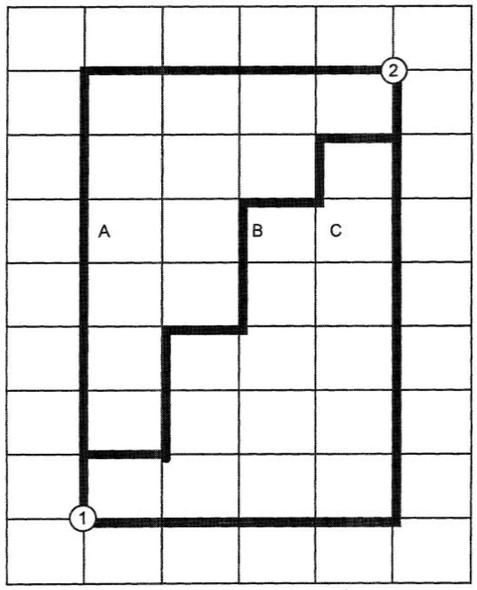

Figure 2. Participants who used the "longest leg first" route selection criterion preferred route A over B or C when traveling from 1 to 2.

A more recent study was carried out in a British library reading room (Conroy-Dalton, 2003, see Figure 3). The task was to walk from one corner of the room, location A, to the inquiry desk at the other corner. Although the diagram looks similar to that in Figure 2, the proposed theory and hypothesis are different. According to this study, the route with longest leg as its first segment is preferable because it is angularly less deviant from the destination direction.

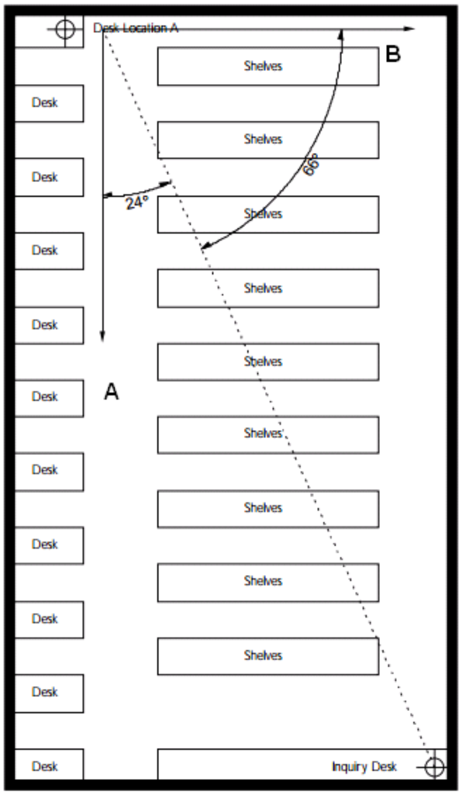

Figure 3. Route A is preferred over route B according to Conroy-Dalton (2003).

In forming this "least deviant route" theory, Conroy-Dalton used a virtual simulation of an urban environment to investigate participants' route choices at each road junction (Figure 4). Starting from the same position, her participants were instructed to the opposite corner by the most direct route possible. Calculation of route choices at all road junctions revealed a significant tendency among participants to minimize the angular difference between the direction of their route and the perceived direction of the wayfinding goal.

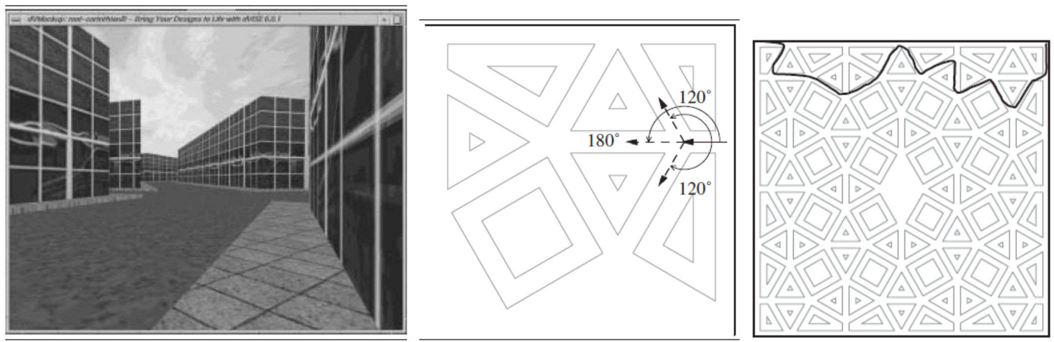

Figure 4. The virtual environment (left), angular options at a road junction (middle) and whole path (right) in Conroy-Dalton's study.

Two ideas presented in these studies are that first people tend to go straight towards their goal and second, route selection processes place more weight on the initial segment than on later ones. In previous studies, there was always one destination so the next destination and the final goal were always the same. We wondered whether the direction of the goal would influence route choice to intermediate destinations.

2. Multi-step planning: an integrated whole

Past studies have found that humans being do plan several steps ahead in consecutive movement tasks and this prospective planning is reflected early in the movement trajectory (Keele, 1968). Haggard (1998) asked his participants to grasp an object and put it into two, three, or five slots that differed in their orientation. The results showed that participants adopted different initial grasps depending on the orientation of slots two or three moves later but not four or five moves later.

In studying multi-destination navigation, one popular paradigm is called the Traveling Salesman Problem (TSP). In one version of this task, participants pick up multiple objects according to a "shopping list" and the goal is to finish this trip with minimal route length. Studies of route planning using the TSP framework often compare the routes drawn by participants with those predicted by route planning strategies. For example, one route planning strategy is to always go to the next nearest destination. Graham et al (2000) suggested that this nearest neighbor strategy fails to predict human performance for tasks involving more than 20 destinations. In fact, the usefulness of the nearest neighbor strategy depends on a fundamental assumption: people look only one step ahead when planning routes. This assumption has been challenged by evidence supporting alternative route planning strategies that emphasize grouping and organizing multiple destinations (e.g. Vickers et al., 2003; Wiener, Ehbauer, & Mallot, 2009). In one of Vickers' experiments, participants were asked to draw paths on computer screens to connect the nodes (Vickers, Bovet, Lee, & Hughes, 2003). Participants could start by clicking on any of the nodes and draw either an "open" route (begin at random node and finish at a different node) or a "closed" route (begin at random node and finish at that node). All participants' solutions adhered to the cyclic order of a convex hull when participants were asked to start and end their path at the same nodes. But their solution rarely reflected this pattern when they did not have to come back to the same nodes (Figure 5). The fact that changing only the location of last destination generated a totally different route indicates that the participant started out planning the whole route.

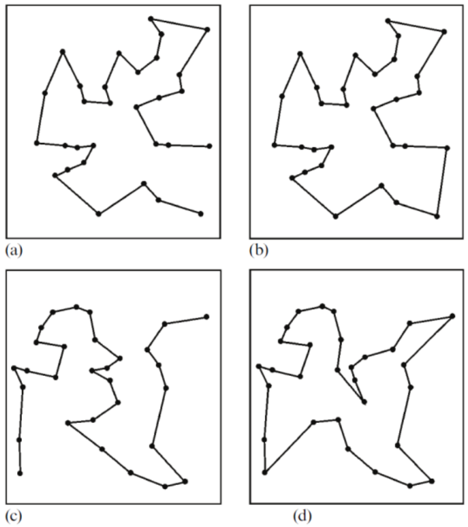

Figure 5. Convex contour always results when participants were asked to draw a closed route (b and d) versus an open route (a and c).

Experiments on vervet monkeys also suggest a prominent effect of the very last destination on route planning (Gallistel & Cramer, 1996). When the monkeys did not intend to return to the start place, a lightning bolt route was the most popular route (dashed line in Figure 6). When they intended to return to the start place (the experimenter placed a grape at the start location after the monkey reached the first destination) the diamond shaped route was the most popular route (solid line).

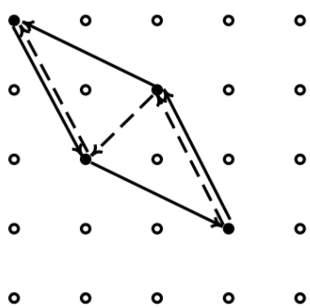

Figure 6. Foraging route of vervet monkeys from Gallistel and Cramer (1996)

It is worth noticing that the travel patterns studied within the TSP paradigm depend on two interrelated components of route planning: the order of locations to visit and the path between locations (Golledge, 1995). The current study focus only on the path selection component of route planning. That is, we focus on navigation tasks that provide a pre-determined visiting sequence but various path alternatives.

3. Target visibility effect

Although the least-deviant-route and longest-leg-first strategies are able to explain the results in the studies mentioned above, they failed to predict the route preference in an experiment by Wiener and Mallot (2003). In one of their trials, participants were asked to navigate from location 9 to location 8 (Figure 7). According to either the least-deviant-route or the long-leg-first strategy, participants would prefer route 9-10-11-8 more than route 9-6-7-8. However, results show that subjects followed the 9-10-11-8 route in only 54.1% of the navigations (not much different from chance level).

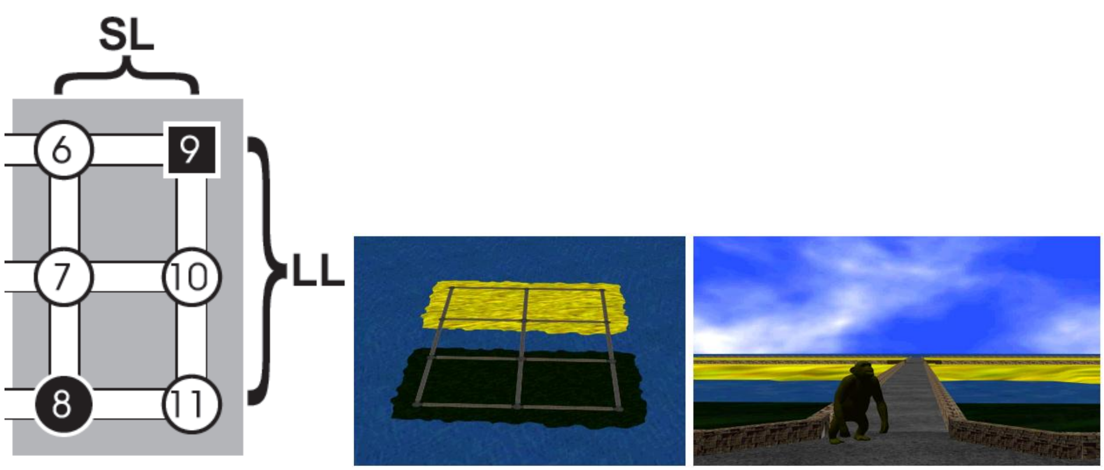

Figure 7. diagram map and virtual environment from Wiener and Mallot (2003)

It is worth noting that in this experiment the target places were not readily visible from the start place. Subjects planned and executed the navigation based on their knowledge of the virtual environment, which was acquired during a "training" phase. Roads were recognized by "pop-up" landmarks that were only visible when subjects were in close proximity. In contrast, experiments that provided evidence for the least-deviant-route and longest-leg-first strategies provided participants clear visual information about the goal direction. For example, the direction of the target in the British Library study was clear because it was a simple target (i.e. one target A) in a small space (i.e. library reading room). Likewise, all the map studies that supported the least-deviant-route or long-leg-first strategy provided readily visible navigation targets. Therefore, it might be that participants use the least-deviant-route or long-leg-first strategy in their route planning only when the navigation targets are directly visible or could be easily visualized.

The first effort to study directly the target visibility effect on route planning was made by Poucet (1983) through experimenting on cats. In one of his settings, cats were presented with two route alternatives: a shorter route (a) and a less divergent route (b) (Figure 8). Although all the cats were familiar with the environment through training trials, they chose the shorter but more divergent path in 85% of the trials when an opaque screen hid the target (the "U"-shaped solid line) and in 51.25% of the trials when the screen was made of transparent materials. This suggests that the principle of "choosing the shortest route" loses its priority over a less divergent route when the goal is readily visible. Research on detour reaching tasks also shows that it is very difficult for apes, sparrows, and human children to learn to reach around barriers to obtain a target (e.g. Vlammings, Hair, & Call, 2009).

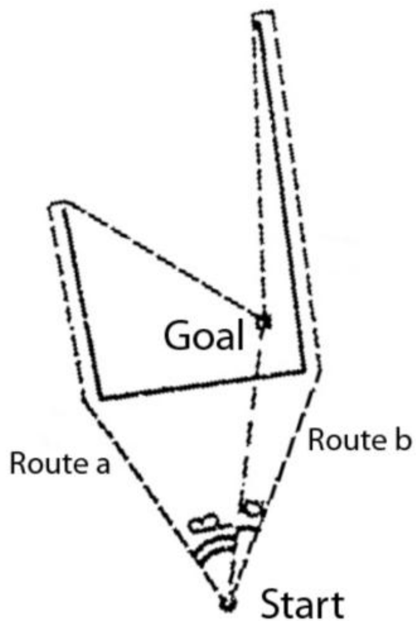

Figure 8. Poucet (1983) investigated the goal visibility effect on cats. The two paths are shown by dashed lines and the screen by solid lines.

4. Current study

The studies summarized above suggest that (1) in simple origin-destination navigation, there is a strong tendency for route planners to minimize the deviation between the heading of the immediate route segment and the direction of the goal destination; (2) in multi-destination navigation, a mere relocation of the final destination influences the whole route plan; (3) the tendency to go directly towards the destination is especially strong when the goal is readily visible. Combining these observations leads to the somewhat counterintuitive prediction that planning to later destinations may influence people's path choices to an immediate destination.

To test this conjecture, we structured a small scale environment by arranging tables in a small conference room (Figure 9). If participants plan the navigation from S (start place) to D1 (first destination) and from D1 to D2 (second destination) as two independent route segments, then route choice to D1 should be independent of location of D2. If, however, participants plan the navigation from S to D2 as an integrated whole route, then the location of D2 may have an influence on route choice towards D1 because of a heuristic to minimize the deviation between heading of the initial route segment (i.e. tangent lines of the initial curve route segment) and the direction of the goal destinations (i.e. direction of D1 and D2). Therefore, it was predicted that the participants would prefer the dashed route over the solid route because angle a is smaller than angle b.

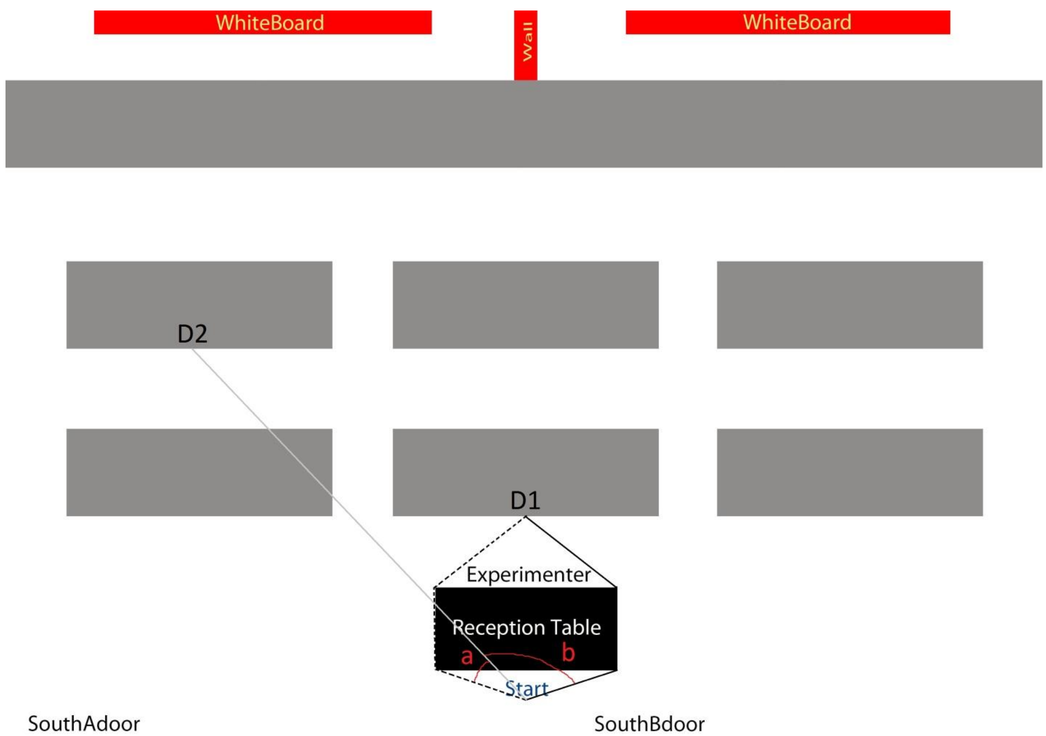

Figure 9. Simplified diagram of current experiment. The red line denotes the direction of the further destinations from the view of the start point.

In Experiment 1, we investigated whether changing the location of later destinations would influence path choices to earlier destinations. In our experimental setting, participants chose between a right route and a left route to reach their first destinations. The two routes were symmetric and of equal length. If participants treat the first route segment independently of future destinations, then the proportion of left routes versus right routes should be independent of the location of later destinations. However, if the participants integrated route planning for later route segments into their route planning for earlier route segments, then the location of later destinations might influence the planning of the first route segment. In this case, the route choice to go from the start place to the first destination would depend on the location of the second and third destinations.

Hypothesis 1: Locations of later destinations will influence participants' route choices to earlier destinations (Heading-to-the-goal effect)

In Experiment 2, we investigated the effect of goal visibility on the heading-to-the-goal effect by inserting opaque screens between the first and second destinations. Thus, the participants could not see the second and third destination from their view at the start place. A diagram was provided to indicate the location of these destinations.

Hypothesis 2: The heading-to-the-goal effect will be reduced when the locations of later destinations are not readily available through visual cues but is instead represented by a diagram.

In Experiment 2, the target direction indicated on the graph was aligned with the target direction in real environment, and so route choice may still have been biased by direct perceptual cue. In Experiment 3, we further investigated the proposed "heading-to-the-goal" strategy by forcing the participants to use an up-side-down map instead of direct visual cue when planning their route. We expected that the heading-to-the-goal effect based on the least-deviant-route strategy would disappear when it is hard for the participant to perceive the destination directions relative to their own location.

> Hypothesis 3: The heading-to-the-goal effect will disappear when the information of later destinations is provided by a graphical representation that is not consistent with the participants' view.

Experiment 1

Participants

Participants were recruited through flyers and from the undergraduate subject pool at Rutgers University-Camden campus. These recruitment procedures were approved by the Rutgers Institutional Review Board. Seventy-one students participated in the current study. Each participant went through one session that lasted about 45 minutes.

The participants for Experiment 1 were twenty-two students from Rutgers University-Camden Campus (13 females, 8 males, 1 missing gender information; 20 right-handed, 2 left-handed; Age ranges from 18 to 56, Average age 21.6). Each participant went through one session consisting of two blocks of 12 trials, one for each experimental condition. The order of conditions in each block was randomly assigned (see Figure 13 and Figure 14). Each session lasted about 45 minutes including necessary time for instruction, assent form signing, and debriefing. Only one student participated at a time. All three experiments involve only one session and each student only participated in one of the three experiments.

Material

Small indoor space The experiments took place in an undecorated and bilaterally symmetrical conference room on the Rutgers Camden campus. Desks were arranged in the room to form the experimental setting. Unnecessary items were either removed from the room or arranged in a way that did not noticeably influence the symmetry of the room. The room setting (Figure 10) was maintained throughout the study period.

Figure 10. Room setting for Experiment 1.

Question items The question items presented at each destination were randomly selected from two psychology measurement scales (Attachment 1). They concerned the research topics described on the recruitment flyer and subject pool website (i.e. self-management, decision making). The question content and responses were irrelevant to the study and were not analyzed.

Procedure

Sequence of trials and questions

Each participant went through two blocks of trials. In each trial, all question items were randomly selected without replacement from the two measurement scales and were sequenced in random order. Each question was printed on a separate piece of paper with a color randomly selected from pink, yellow, blue, and green.

Measurement

Subjects' walking routes were recorded directly on the site by the experimenter from a neutral position along the midline of the room. Route choice was coded dichotomously as "Right" or "Left".

Filler task

To fill the time between trials while the experimenter set up the next trial, participants were asked to copy a printed picture on a piece of white paper. Participants resumed this task every time they completed a trial and went back to the start location. At the end of the session, participants were asked to draw from memory the location of all the tables in the room.

Training phase

Each participant completed two training trials at the beginning of the session. The purpose of these training trials was to make sure that the participants understood the instruction for the tasks. Question items for the training trails were randomly selected from the question pool.

Testing phase

Figure 10 shows the diagram of a two-destination trial. The first destination was always centered on the first row of tables so that the initial route alternatives were of same length and symmetric from the view of the start location. Each participant went twice through the 12 conditions (nine conditions for 3-destination trial and three conditions for 2-destination trial), adding up to a total of 24 trials.

Before leaving the start place, participants were verbally instructed to notice the sequence of papers they were to visit (from the one closest to the start place to the one furthest from the start place). Since the color of each paper was randomly selected on each trail, it was used to identify the sequence of papers to be visited. An example of the oral instruction would be “Now remain seated and take a look at the papers behind me on the tables. You are going to fill the questions on them in order from the first row to the last row. But before you leave this reception desk, tell me the color of the papers in order. ” Only after receiving the correct answer to the color sequence question did the experimenter tell the participants to go ahead and fill in the questions. Very few mistakes were made in Experiment 1 and 2. Trials in which mistakes occurred were noted as missing value.

Two-destination trials

Participants navigated through the room to fill in the questionnaires that consisted of two papers placed on two tables (i.e. two destinations). In order to assess the influence of the independent variable - location of the second destination - on participants' route choice towards the first destination, three conditions were considered: the second piece of paper was located on the left, right, or center of the second row of tables (Figure 11).

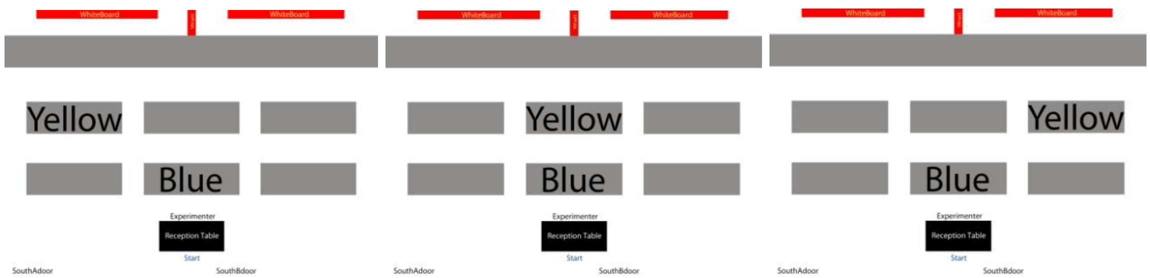

Figure 11. Two-destination trials in Experiment 1 (paper color randomly assigned).

Three-destination trials

All procedures and instructions were the same as in the two-destination trials except that each questionnaire consisted of three, instead of two, sections. In order to assess the influence of the independent variable - location of latter destinations - on pedestrian's route choice toimmediate destinations, nine conditions were considered in which the first destination was always placed at the middle table of the first row and the location of the second and third destinations were manipulated (Figure 12). Participants completed two trials for each condition.

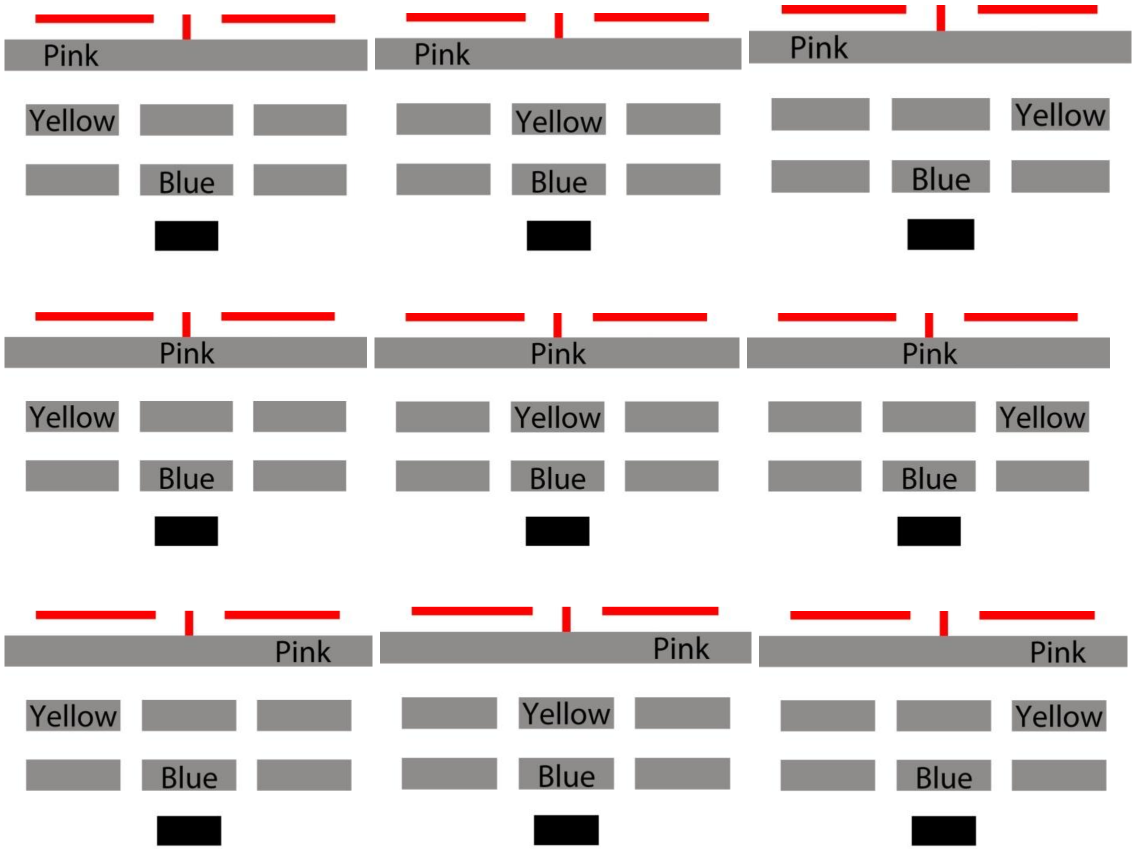

Figure 12. Three-destination trials in Experiment 1 (paper color randomly assigned).

Because each trial generated two possible outcomes –left route or right route – and because there were two trials per condition, there were four possible outcomes for each condition: left left, left right, right left, right right. For the current study, we combined the "left right" and "right left" results and used three values to code the route choice variable: "choosing the left route in both trials" was coded "0," "switching between left and right routes" was coded "0.5," and "choosing the right route in both trials" was coded "1."

Results

Route choice to the first destination

Data from the 22 participants are shown in Figure 13, which displays the percentage of trials when participants chose the right route.

In the two-destination trials ("third destination did not exist" condition in Figure 16), participants' route choice to the first destination was influenced by the location of the second destination, $X^2(2) = 23.724$, $p < .001$(Friedman test). A post-hoc Wilcoxon test shows that participants were more likely to prefer the left route when the second destination was on the left side than when it was on the right side of the second table row, $Z = -3.619$, $p < .001$, $r = 0.772$.

In the three-destination trials, the effect of the second and the third destinations on participants' route choice to the first destination was examined. When one destination was centered, then the other destination influenced participants' route choice. When the third destination was centered, participants' route choice to the first destination was significantly influenced by the location of the second destination, $X^2(2) = 7.320$, $p = 0.026$ (Friedman test). A post-hoc Wilcoxon test shows that participants preferred the route that was most in line with the direction of the second destination, $Z = -2.546$, $p = 0.011$, $r = 0.543$. When the second destination was centered, participants' route choice to the first destination depended on the location of the third destination, X^2 (2) = 9.913, $p = 0.007$ (Friedman test). A post-hoc Wilcoxon test shows that participants preferred the route that was most in line with the direction of the third destination, $Z = -2.972$, $p = 0.003$, $r = 0.634$. When the second and third destinations were located on opposite sides, participants were more likely to choose the right route when the second destination was on the right side, $Z = -3.087$, $p = 0.002$, $r = 0.658$.

Route choice to a centered second destination

The decisions that participants made in going from the start point to the first destination is similar to the decision they made going from the first destination to the second destination in three-destination trials that had their second destination centered.

In these three-destination trials, participants' route choice to a centered second destination was influenced by the location of the third destination (Figure 19), $X^2(2) = 7.236$, $p = 0.027$ (Friedman test). A post-hoc Wilcoxon test shows that, when the second destination was in the middle and the third destination was on the left or right side, participants preferred the route that was least deviant from the direction of the third destination, $Z = -2.830$, $p = 0.005$, $r = 0.603$.

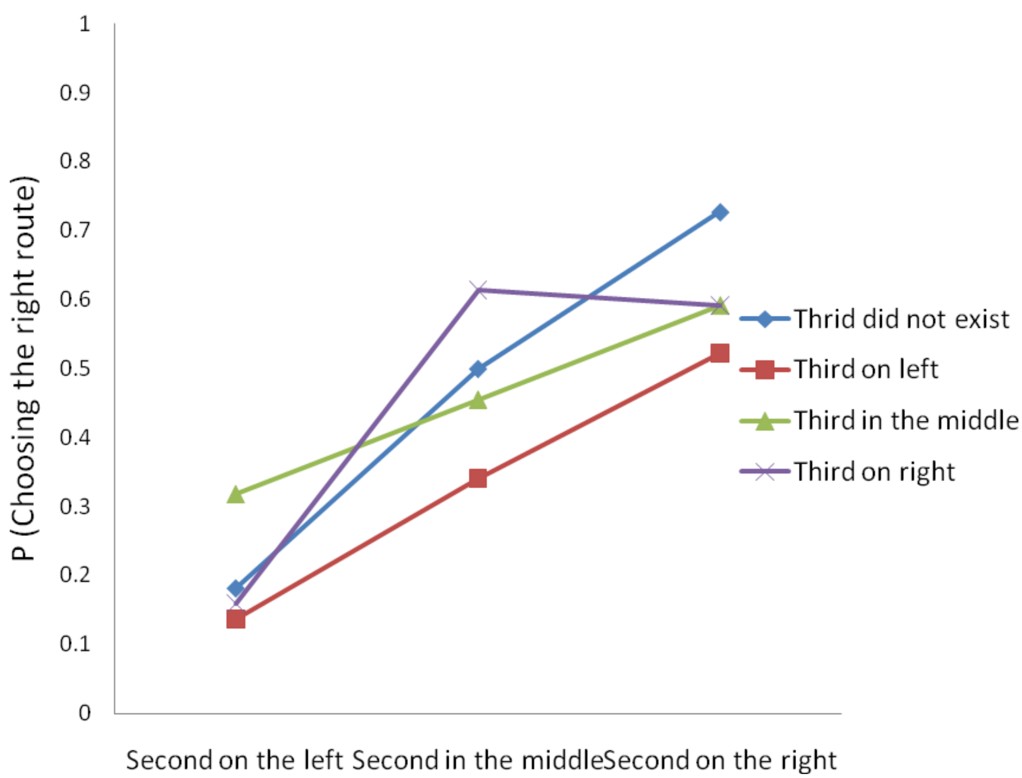

Figure 13. Experiment 1 results: Participants' route choice when going to the first destination.

Discussion

The present experiment demonstrates that later destinations influence people's route choice to intermediate destinations. It is worth noting that a survey question was presented at each destination. This made participants not only reach and stop at the destination but also read and answer the survey question. The purpose of designing this survey task is to prevent participants from completing each trial as a continuous walking movement. Instead, the multiple destinations were designed to "break" the whole route into discrete route segments. This makes it more remarkable that participants showed a bias in their route choices.

Importantly, we have shown that the location of a later destination has a strong effect on participants' route choice as early as when they were at the start place. When both the first and second destinations were centered and the third destination varied its location, participants preferred the same side to the first and second destination and this preference was related to the location of the third destination. This suggests that participants decided which side to go on early in their trip instead of switching to the final destination direction in the middle of the trip. Unlike existing studies in wayfinding and route planning, this experiment required visiting multiple destinations in a pre-determined order. Therefore, the participants were notified of all the "stops" during the trip as well as the final destination before starting.

However, as we described in the introduction section, this effect may rely on a readily visible target. That is, it might be important that participants have a strong perception of the destination direction for the heading-to-the-goal effect to occur. In Experiment 2, we explored this factor by manipulating how participants obtain information about the goal direction relative to their own location.

Since participants' route choice to intermediate destination was biased towards the "perceived direction" of later destinations, it is important to understand the nature and source of this perceived direction. The existing literature proposes two reference systems by which people perceive the direction of objects in their environment: an egocentric reference system or an allocentric/exocentric reference system (e.g. Gallistel & Cramer, 1996). In the egocentric reference system, navigators construct environmental features into a body-centered coordinate system and use this system to guide their spatial navigation. The reference frame in an egocentric system is the perceiver and all environmental features are encoded based on their relative direction to the perceiver. The allocentric system, on the other hand, constructs a spatial frame external to the perceiver. An example of the allocentric reference system would be the coordinate axes system on a world map. If the results we observed in Experiment1 indeed came from the preference for the route that was "least deviant from the destination direction", then the egocentric reference system clearly specifies the "destination direction": the angular deviation refers to the route's or destinations' spatial relationship to the perceiver (Holmes & Sholl, 2005). Therefore, we expect that environmental barriers or experimental instructions that discourage the use of egocentric reference system and encourage the use of allocentric reference system would reduce the route preference effects found in Experiment 1 (see Hypothesis 2 in introduction section).

In Experiment 2, we used opaque screens to block the view from the first destination to later destinations and provided participants with a graphic diagram of their destinations before each trial. Because the diagram provides direction cue of the rectangular shape of the room, we expected the graphic diagram would to be more likely to encourage the use of an allocentric reference system among participants than the actual view of the real environment (Mou, McNamara, Valiquette, & Rump, 2004). Based on this reasoning and the consistent evidence presented in the introduction section (see "goal visibility effect" subsection), we designed a second set of experiments to investigate the heading-to-the-goal effect in situations when later destinations are not readily visible but are instead indicated on a graphic diagram.

Experiment 2

Participants

Participants were recruited from students in the Introduction to Psychology class at Rutgers University – Camden campus. The participants for Experiment 2 were twenty-seven students from Rutgers University Camden Campus (15 females, 12 males; 26 right-handed, 1 left-handed; Age ranges from 17 to 32, Average age 18.8).

Material

Small indoor space The room setting was very similar to that in Experiment 1 except that screens were used to block the view between the first destinations and second and third destinations (Figure 14).

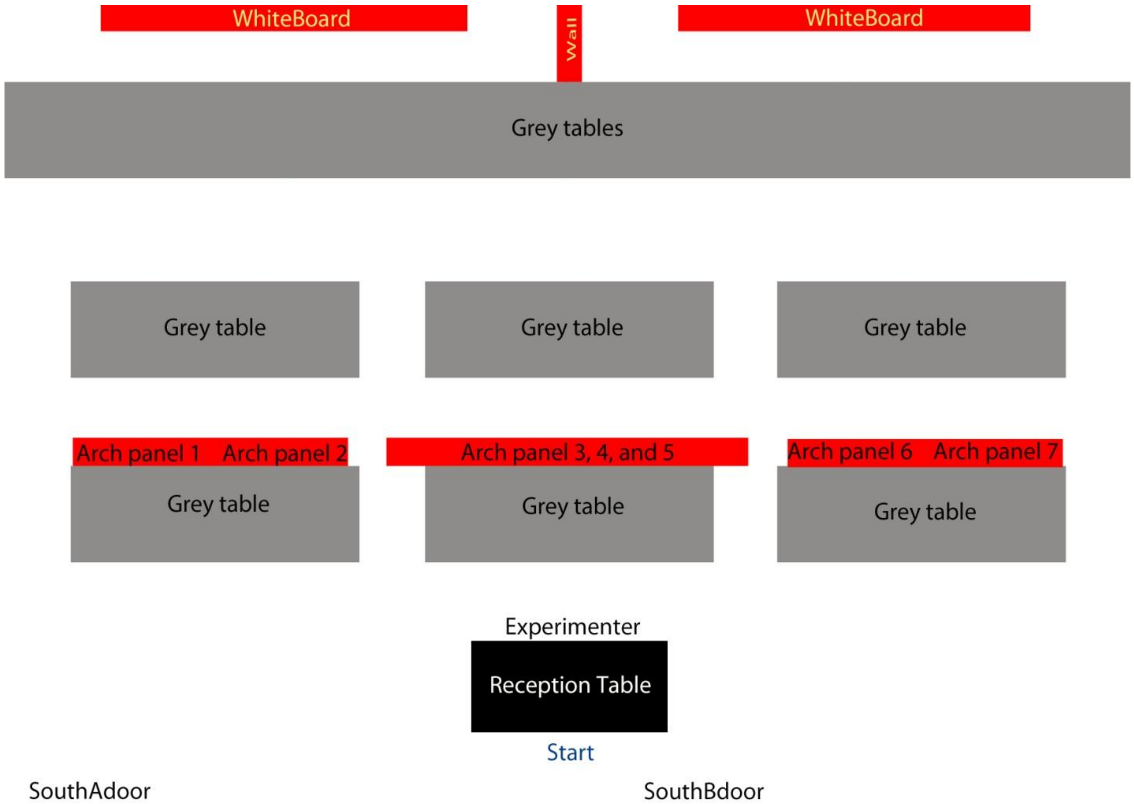

Figure 14. Room setting for Experiment 2.

Diagram booklet A diagram was provided to participants to show the location of destinations in each trial. In the trial shown by Figure 15, for example, the participant was told to fill in three surveys in order, from the first table row to the third table row. The three surveys were identified by the colors of the survey paper. Therefore, the participant would say “blue, yellow, pink” to show that they were aware of the sequence of papers that they were going to visit.

Procedure

Participants were instructed to turn to the corresponding page of the diagram booklet before each trial. The tasks were identical to those in Experiment 1. Before each trial, participants were instructed to look at the diagram (instead of the real destination locations) and report the color of the survey papers in order. Figure 16 shows the diagram page (a) and the corresponding setting (b) for a three-destination trial.

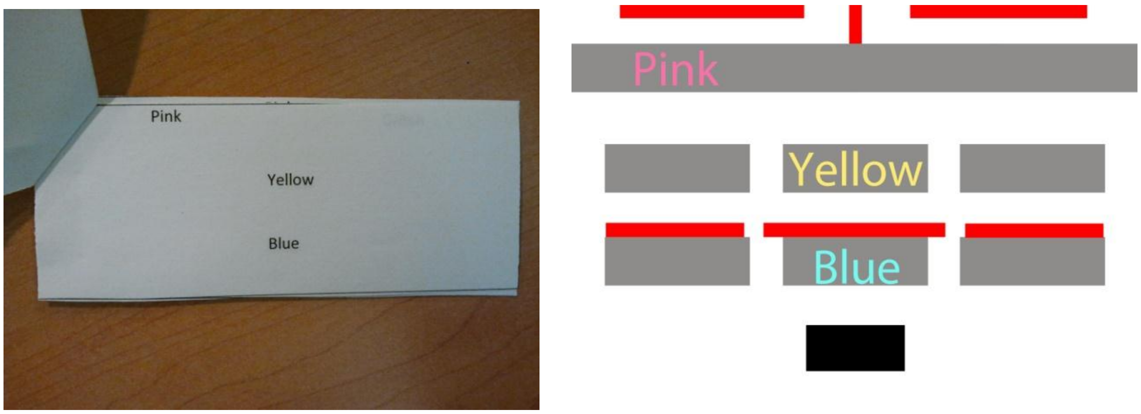

Figure 15. Booklet and room setting diagrams for a three-destination trial in Experiment 2.

Results

Data analysis for Experiment 2 was identical to that for Experiment 1. A Friedman test was used to investigate the effect of the second and third destination on route choice tothe first destination. The results showed that participants' route choice was moderately influenced by the location of the second destination in both the two-destination trials (third destination did not exist), $\chi^2(2,27) = 5.880$, $\rho = .053$, and three destination trials (third destination was centered), $\chi^2(2,27) = 9.033$, $\rho < .05$. A post-hoc Wilcoxon test showed that, when the third destination was centered, participants were more likely to choose the right route to the first destination when the second destination was on the right side than when it was on the left side, $\rho < .05$. When the second destination was centered, the location of the third destination did not have significant influence on route choice towards the first destination, $\chi^2(2,27) = 2.633$, $\rho = .268$.

A Friedman test was used to investigate the effect of the third destination on participants' route choice to the second destination. Results show that participants' route choice was significantly influenced by the location of the third destination, $\chi^2(2,27) = 19.013$, $\rho < .001$. A post-hoc Wilcoxon test shows that participants more inclined to choose the right route than the left route when the second destination was on the right side rather than on the left side, $\rho < .001$.

Overall, the effects of latter destinations on route planning towards the immediate destination in Experiment 2 were similar but less pronounced than those in Experiment 1 (Figure 16).

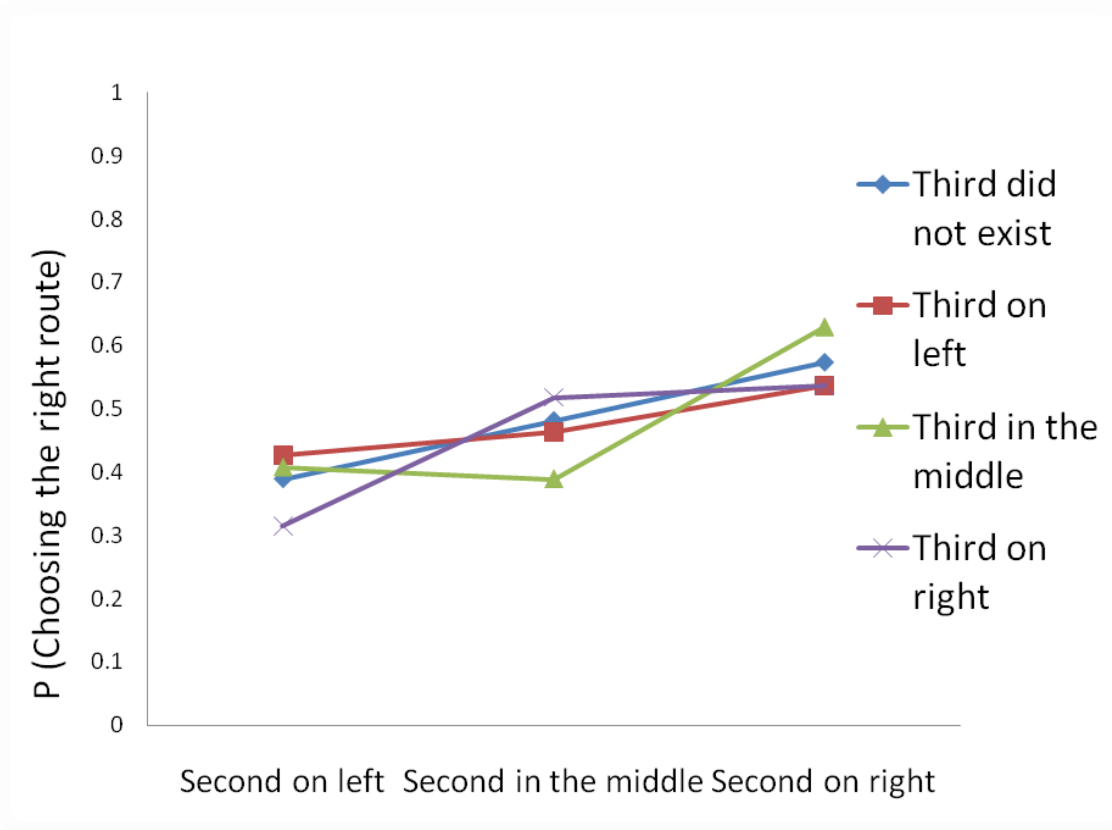

Figure 16. Experiment 2 results: Participants' route choice when going to the first destination.

Discussion

Experiment 2 supports the importance of target visibility for the heading-to-the-goal effect. When the opaque screen blocked participants' view from the first destination to the second and third destinations, it was impossible to perceive directly the direction of those two destinations relative to the participant. According to the "least deviant route" hypothesis (see Conroy-Dalton, 2003), a more direct perception of the deviance angle would facilitate angle comparison and thus enhance the route bias. The results from Experiment 2 confirmed this hypothesis. When real-environment visual information was replaced by its graphical equivalent, particpants' route choice was less influenced by the location of the second and third destinations. To further examine this effect, we designed Experiment 3 to make the perception of destination direction (relative to one's own) even less direct.

In Experiment 2, the location of the second and third destinations still had some effect on participants' route choice to the first destination. However, the effects were smaller compared to those in Experiment 1. One result from Experiment 2 that contradicts our hypothesis is the effect of the third destination on participants' route choice to the second destination. According to hypothesis 2, the effect of the third destination on participants' route choice to the first and second destination would decrease or even disappear when a direct visual cue is not available but replaced with graphical representation. Our data, however, revealed a significant effect of the third destination on participants' route choice to the second destination. This effect could possibly result if the participants could actually see the third destination on their way from the first destination to the second destination and they planned their route in the middle of the "trip" based on the updated visual information. Therefore, In Experiment 3, we removed the opaque screens and replaced them with six small boxes on the second and third row of tables. Therefore, the participants couldn't see where the papers were until they were in close proximity.

Experiment 3

Participants

Participants were recruited from students in the Introduction to Psychology class at Rutgers University – Camden campus. The participants for Experiment 3 were twenty-two students from Rutgers University Camden Campus (11 females, 11 males; 17 right-handed, 4 left-handed, 1 missing handedness data; Age ranges from 18 to 38, Average age 22.2).

Procedure

In Experiment 3, the navigation destinations (i.e. two or three piece of papers) were hidden in a subset of six boxes. Therefore, the participant had to rely on the diagram for information about the destination location. The diagrams were the same as those used in Experiment 2. However, we placed the diagram up-side-down so that the diagram orientation was not in line with the view of the participant at the start place. Because this eliminated direct visual information about the destination direction, we expected that the heading-to-the-goal effect found in Experiment 1 would be eliminated.

Because the destinations were hidden in boxes and therefore not visible from the start place, participants needed to maintain location information in short-term memory. Some participants clearly failed to remember this information becaues they went to the wrong destinations and had to make a detour to look for the survey papers. We noted this situation as an “error trial” and dismissed the route choice data immediately preceding this behavioral sign of “getting lost”. Fortunately, the participants became more reliable in making use of the diagram information over the course of the experiment. Overall, the number of “error trials” in the second block (9 error trials) was half of that in the first block (22 error trials). Therefore, for the three-destination trials, we used only data from the second block for analysis. For the two-destination trials, the numbers of “error trials” for the two blocks differred only slightly (0 error trials in the first block and 1 error trial in the second block). Therefore, for the two-destination trials, we used data from both blocks just as we did for Experiment 1 and Experiment 2.

Results

Although the locations of destinations were indicated by the diagram, many participants made mistakes when approaching the destinations. This is understandable because the navigation task in Experiment 3 requires encoding and maintaining the destination information based on an up-side-down diagram. As Experiment 1 and Experiment 2, in Experiment 3 each participant went through two blocks of 12 trials, with one trial for each of the 12 conditions. The results show that the number of errors participants made in the first block was twice that in the second block. Therefore, in Experiment 3 we analyzed only the result of the second block.

The data analysis for Experiment 3 was identical to that for Experiments 1 and 2. Figure 17 shows the effect of the second and third destinations on participants' route choice to the first destination. A Friedman test was used to investigate the effect of the second and third destinations on route choice to the first destination. The results show that participants' route choice to the centered first destination was not influenced by the location of the second destination in the two-destination trials (third destination did not exist), $\chi^2(2,22) = 0.857$, $\rho = .651$, and three-destination trials (third destination was centered), $\chi^2(2,22) = 1.13$, $\rho = .568$ (Chi-square). When the second destination was centered, the location of the third destination did not have significant influence on route choice towards the first destination, $\chi^2(2,19) = 0.45$, $\rho = .799$ (Chi-square).

A Friedman test was used to investigate the effect of the third destination on participants' route choice to the centered second destination. Results show that participants' route choice to the centered second destination was influenced by the location of the third destination, $\chi^2(2,19) = 6.22$, $\rho < .05$.

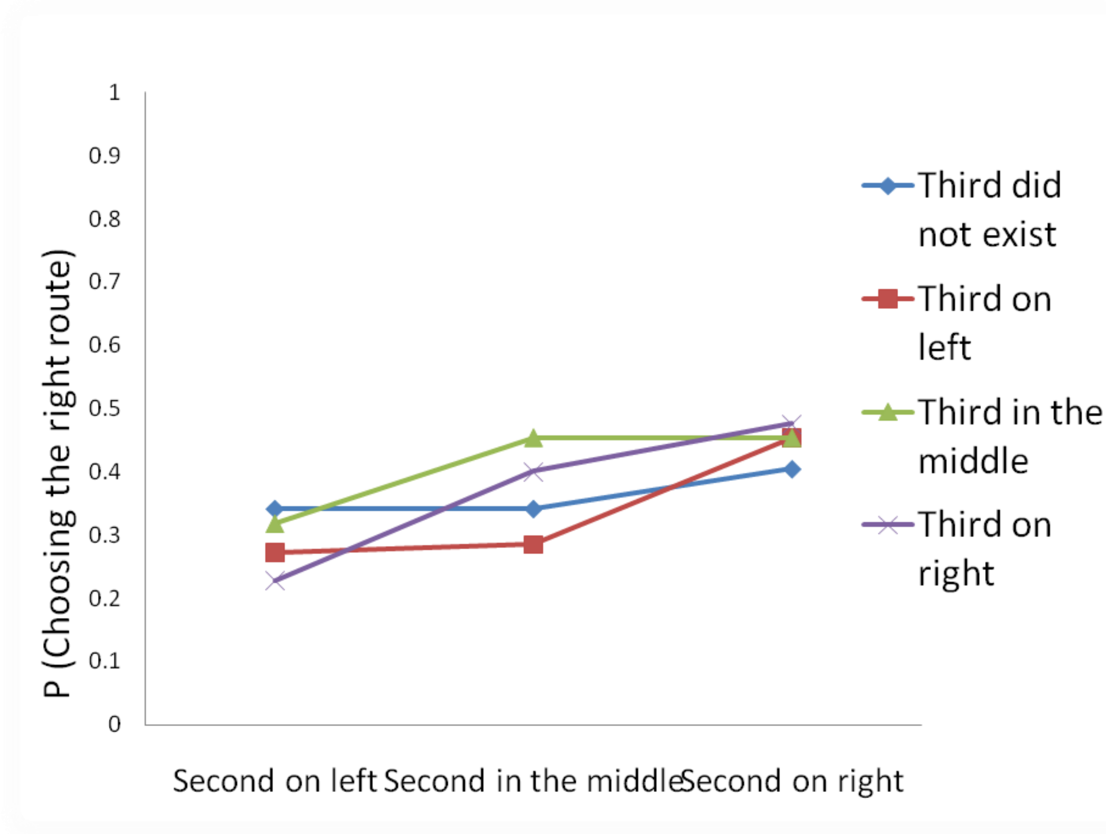

Figure 17. Experiment 3 results: Participants' route choice when going to the first destination.

Discussion

The current experiment confirmed the importance of direct visual information for the heading-to-the-goal effect to occur. Unlike Experiment 2, participants in Experiment 3 relied on an up-side-down diagram to form a mental representation of their destination locations when choosing one of the two route alternatives. To do this, it is necessary to mentally rotate the diagram and keep that representation in short term memory. People who fail to carry out these two functions will get lost. We observed many such error trials in this experiment, especially in the first block of trials. Participants did improve over the course of the experiment and most errors occurred in the three-destination trials. This is understandable because the three-destination trials produced a higher demand on memory than did the two-designation trials, and so would be expected to produce more errors. Nonetheless, we had sufficient data to examine, under different conditions, the probability of participants' route choice against chance level. We did not find any evidence that the second destination influenced participants' route choice to the first destination when the third destination was absent or centered. Nor did we find any evidence that the third destination influenced participants' route choice to the first destination when the second destination was centered. Unexpectedly, the third destination had a persistent effect on participants' route choice to the centered second destination across the three experiments.

General Discussion

The effect of the second destination on participants' route choice to the first destination was compared across the three experiments. As shown in Figure 18, the effect of the second destination on participants' route choice to the first destination was large in Experiment 1, moderate in Experiment 2, and absent in Experiment 3.

A similar situation was examined in which the location of the third destination had an effect on participants' route choice to the centered second destination. Figure 19 compares this effect across the three experiments. Unusually, the three effects appear to be very similar (especially when compared to Figure 18).

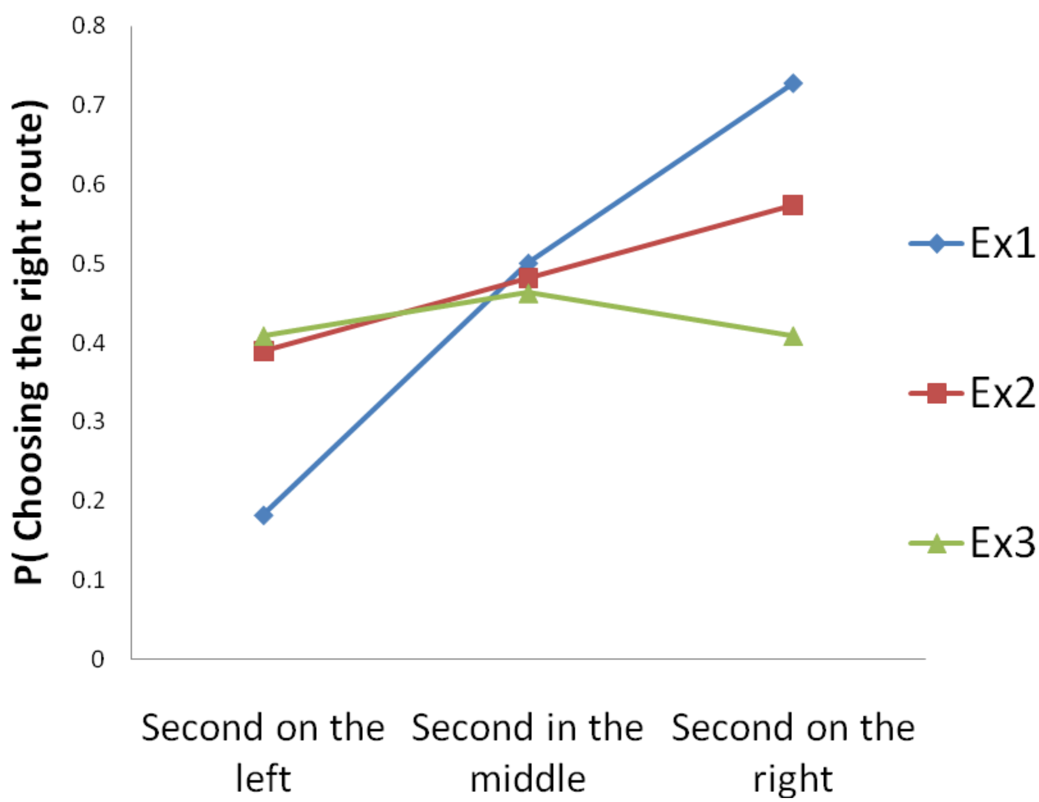

Figure 18. Route choice to the first destination across the three experiments.

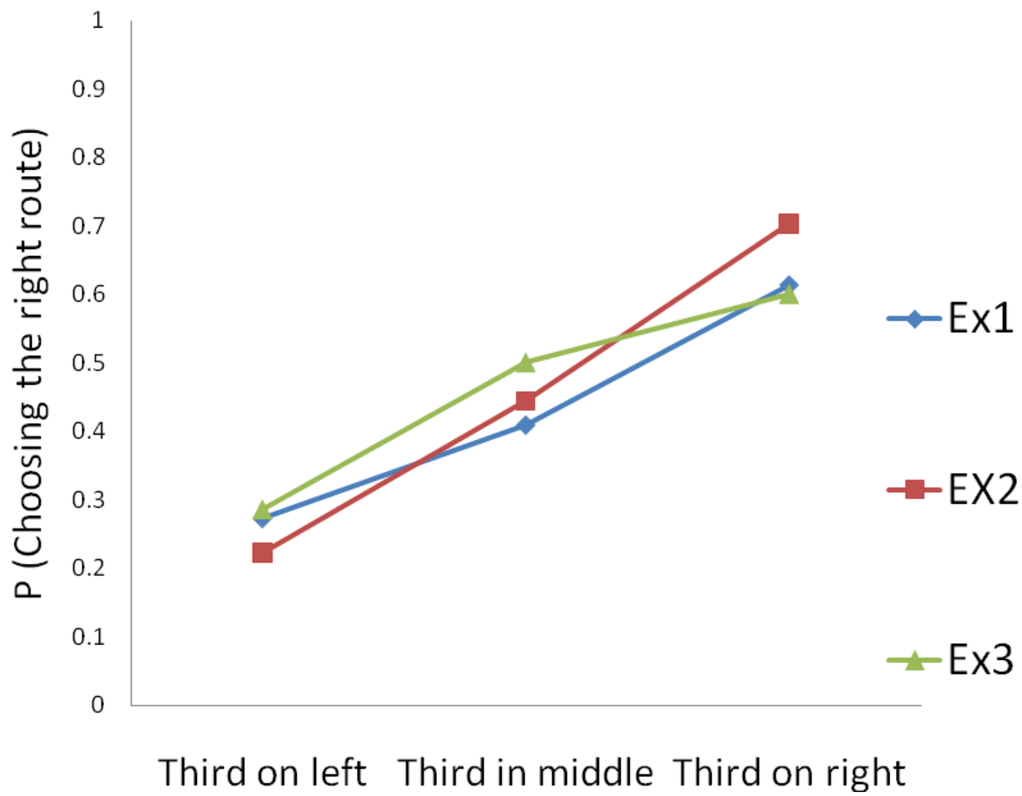

Figure 19. Route choice to the centered second destination across the three experiments.

To sum up, this is the first study demonstrating the effect of later destinations on route choice to intermediate destinations. The task was so designed that participants had to stop at each destination (see Experiment 1 discussion). Despite this, participants' showed a bias to choose the right route to the first destination when the second and third destinations were on the right side. We named this effect "heading-to-the-goal" to highlight the distinction between intermediate destinations and later destinations. The effect was largest when all destinations were readily visible. It was diminished or reduced when direct visual information was replaced by a diagram and the effect was eliminated when the diagram was placed up-side-down. That is, the more easily accessible the spatial direction of the goal, the more salient the heading-to-the-goal effect was.

Conclusion

The current study adds evidence to the literature showing that whether the target is visible or not is influencing in human spatial cognition. For example, participants were more likely to minimize the total distance when the street map was available versus not available (Nasar et al., 1985). Specifically, this effect was larger among male participants than among female participants. Further study could be conducted to explore the relationship among these effects to sort out the mechanisms underlying the influence of visual perception on route planning.

Another line of research the current study has contributed to could be action planning that involves multiple steps. Studies on action planning show that intermediate and final goal can be regarded as the intended outcomes of our actions at different levels in a hierarchically organized system (Sherrington, 1947). This theory is supported by fMRI studies showing that superior frontal gyrus and left inferior parietal cortex was involved in task that required planning for the final goal (Majdandzic et al., 2007). Occipito-parietal and occipito-temporal cortex was activated in task that required planning for immediate goal. Usually, human participants plan movements at least three steps ahead. Studies on object manipulation, for example, found that people grasp objects differently depending on the expected postures later on with that object (Rosenbaum et al., 2012).

The result of the current study has a variety of applications, including environmental design that requires a control over pedestrian flow. In large exhibitions, for example, the arrangement of events should take into consideration not only the visitor flow in the exhibition space but also the surrounding spaces that could potentially lead pedestrians to the exhibition space. For example, if there are two doors (noted A for the left one and B for the right one) leading to a big conference room through which visitors can walk to exhibition C (on the left side of the conference room) or exhibition D (on the right side of the conference room). Although everybody has to go to the registration desk at the center of the conference room, people would, according to the result of the current study, be more likely to go through door A when heading to exhibition C than when heading to exhibition D. Once the route plan bias related to later destinations are understood, the event could be so designed that pedestrian flow at the two doors are appropriately distributed and the probability of traffic is minimized.

Attachment 1

Question item pool

Scale one

The following questions have two different answers. Please choose the alternative (A or B) that applies best to you.

1. When I have lost something valuable and can´t find it anywhere:

   ( ) A. I have a hard time concentrating on anything else.

   B. I don't dwell on it.

2. When I know I must finish something soon:

   ( ) A. I have to push myself to get started.

   B. I find it easy to get it done and over with.

3. When I´ve worked for weeks on one project and then everything goes completely wrong:

   ( ) A. It takes me a long time to get over it.

   B. It bothers me for a while, but then I don´t think about it anymore.

4. When I don´t have anything in particular to do and I am getting bored:

   ( ) A. I have trouble getting up enough energy to do anything at all.

   B. I quickly find something to do.

5. When I´m in a competition and lose every time:

   ( ) A. I can soon put losing out of my mind.

   B. The thought that I lost keeps running through my mind.

6. When I am getting ready to tackle a difficult problem:

   ( ) A. It feels like I am facing a big mountain that I don´t think I can climb.

   B. I look for a way that the problem can be approached in a suitable manner.

7. When I have to solve a difficult problem:

   ( ) A) I usually get on it right away.

   B. Other things go through my mind before I can get down to working on the problem.

8. When I have to talk to someone about something important and, repeatedly, can´t find her/him at home:

   ( ) A. I can´t stop thinking about it, even while I´m doing something else.

   B. I easily forget about it until I can see the person again.

Scale two

For each of the following statements, please indicate the likelihood that you would engage in the described activity or behavior if you were to find yourself in that situation. Provide a rating from *Extremely Unlikely* to *Extremely likely*, using the following scale:

No	Statement	Extremely unlikely	Moderately unlikely	Somewhat unlikely	Not sure	Somewhat likely	Moderately likely	Extremely likely
1	Admitting that your tastes are different from those of a friend.	1	2	3	4	5	6	7
2	Going camping in the wilderness.	1	2	3	4	5	6	7
3	Betting a day’s income at the horse races.	1	2	3	4	5	6	7
4	Investing 10% of your annual income in a moderate growth mutual fund.	1	2	3	4	5	6	7
5	Taking some questionable deductions on your income tax return.	1	2	3	4	5	6	7
6	Disagreeing with an authority figure on a major issue	1	2	3	4	5	6	7
7	Betting a day’s income at a high-stake poker game.	1	2	3	4	5	6	7
8	Passing off somebody else’s work as your own.	1	2	3	4	5	6	7
9	Going down a ski run that is beyond your ability.	1	2	3	4	5	6	7
10	Investing 5% of your annual income in a very speculative stock.	1	2	3	4	5	6	7
11	Going whitewater rafting at a high water in the spring.	1	2	3	4	5	6	7
12	Betting a day’s income on the outcome of a sporting event.	1	2	3	4	5	6	7
13	Revealing a friend’s secret to someone else.	1	2	3	4	5	6	7

14	Driving a car without wearing a seat belt.	1	2	3	4	5	6	7
15	Taking a skydiving class.	1	2	3	4	5	6	7
16	Riding a motorcycle without a helmet.	1	2	3	4	5	6	7

Attachment 2

ASSENT

You are invited to participate in a research study that is being conducted by En Fu, who is a graduate student in the Psychology Department at Rutgers University. The purpose of this research is to explore human decision making behavior in real environments.

This research is anonymous. Anonymous means that I will record no information about you that could identify you. This means that I will not record your name, address, phone number, date of birth, etc. If you agree to take part in the study, you will be assigned a random code number that will be used on each test and the questionnaire. Your name will appear only on a list of subjects, and will not be linked to the code number that is assigned to you. There will be no way to link your responses back to you. Therefore, the data collection is anonymous.

The research team and the Institutional Review Board at Rutgers University are the only parties that will be allowed to see the data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. All study data will be kept for one year.

The risks associated with participation in this study are no different from those associated with a pencil-and-paper exam. . If you are participating to fulfill a class requirement, you will be given 1 credit for each session (Note that participating in this survey is just one of the ways in which you can fulfill your course requirement; contact your instructor to learn of other ways). If you are participating for payment, you will receive $5.

Participation in this study is voluntary. You may choose not to participate, and you may withdraw at any time during the study procedures without any penalty to you. In addition, you may choose not to answer any questions with which you are not comfortable.

If you have any questions about the study or study procedures, you may contact me at 215 3rd Str., Camden NJ 08102 Tel: 856-236-7241, Email: en.limegreen12@rutgers.edu. You can also contact my advisor Dr. Mary Bravo at Psychology Department, Armitage Hall, 311 N. 5th St., Camden NJ 08102.

If you have any questions about your rights as a research subject, you may contact the IRB Administrator at Rutgers University at:

Rutgers University, the State University of New Jersey

Institutional Review Board for the Protection of Human Subjects
Office of Research and Sponsored Programs

APPROVED
Date: 5/24/12

3 Rutgers Plaza
New Brunswick, NJ 08901-8559
Tel: 848-932-0150
Email: humansubjects@orsp.rutgers.edu

You will be given a copy of this assent form for your records.

By participating in this study/these procedures, you agree to be a study subject.

Signature of Participant: Date:

Signature of Principle Investigator: Date:

This assent form was approved by the Rutgers Institutional Review Board for the Protection of Human Subjects on Approval of this form expires on

APPROVED
Date: 5/24/12

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