BETWEEN FLOOR NAVIGATION COST DEPENDS ON VISUAL INFORMATION

BY

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THESIS

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ABSTRACT

While navigation often occurs seamlessly, some environments prove to be challenging. Previous research has shown that people have difficulty keeping track of target locations across nested environments. Here we examined whether spatial updating is affected by traveling across floors. Participants traversed back and forth along a path connecting two floors, and pointed to target locations on the path. They were more accurate when pointing to targets within a floor than across floors. This increased error was not due to difference in distance, learning exposure, or the amount of movement in the two conditions. Furthermore, when participants were blindfolded, the across floor cost disappeared. These results are consistent with the capacity limitation hypothesis in the spatial updating system, which leads to dropping target vectors across environments. The results also suggest that vision plays an important role in the segmentation of the environmental representations for navigation.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>EXPERIMENT 1</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>EXPERIMENT 2</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>EXPERIMENT 3</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>EXPERIMENT 4</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>GENERAL DISCUSSION</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>REFERENCES</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>APPENDIX A: FIGURES</td>
<td>24</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

People travel a variety of environments in everyday life, such as finding restaurants in a city, locating meeting rooms in an office building, getting to their car in a parking lot, and so on. Most of the time people can find their way around without much difficulty, since multiple mechanisms and strategies can give an individual spatial information about the environment and the ability to use this knowledge to guide navigation. One of the most basic spatial abilities that supports navigation and maintains one’s sense of direction is the spatial updating mechanism, a cognitive process that allows one to keep track of one’s spatial relationship to known places or landmarks based on perceived self-movements.

Humans as well as other animals such as desert ants, honeybees, jumping spiders, and birds use spatial updating to navigate (Kearns, et al., 2002; Philbeck & O'Leary, 2005; Wang & Spelke, 2002; Etienne & Jeffery, 2004; Menzel et al., 1996; Moller & Görner, 1994; Müller & Wehner, 1988). For example, desert ants (Cataglyphis) must search for food quickly due to the harsh climate they inhabit. As the ant exits its nest, its spatial updating system continually updates the location of the nest by adding the animal's current motion vector to its remembered home vector to generate accurate, though not perfect, direction and distance information. An ant's search might take it on a meandering path but once it discovers food, the ant can 'shortcut' directly home using its home vector (Müller & Wehner, 1988).

Humans have also shown the ability to return directly to their “home” after an outbound trip. For example, Loomis et al (1993) guided blindfolded human participants along an outbound trip with several segments and turns, and then they were asked to return directly to the origin by blindfolded walking. They showed that people generally can perform the task well, although systematic errors can occur. Similar ability has also been shown in virtual reality environments,
where people traveled in virtual mazes with different types of visual cues and attempted to return to the origin (e.g., Kearns, et al., 2002; Klatzky, et al., 1997; Riecke, van Veen, & Buelthoff, 2002; Wan, et al., 2010). These studies showed that the human spatial updating system can use different sources of perceptual information about self-movements to keep track of one’s relationship with an unseen target (e.g., the origin) in the environment, although some information may be more reliable and preferable than others.

Regardless of the source of information the spatial updating system uses, errors can accumulate during the process (e.g., Wehner & Srinivasan, 2003). For example, the errors in a path completion task (i.e., returning directly to the origin of a trip) increase as the number of legs of the outbound path increases (Loomis et al., 1993). These errors are generally considered to be a result of the inaccuracy in the estimation of one’s self-movements, and therefore should depend on the amount and type of perceptual information available during the outbound trip.

In addition to these perceptual errors, which primarily depends on the length and structure of the outbound path and self-motion perception, spatial updating may be affected by other cognitive factors. For example, spatial judgments after locomotion depend on whether people paid attention to the targets or to the trajectory of one’s movements (Amorim, & Stucchi, 1997). Furthermore, when people had to keep track of multiple target locations simultaneously, performance decreases as the number of targets increases, suggesting that the spatial updating system has capacity limitations (Wang et al., 2006). Moreover, people do not update their relation to multiple environments simultaneously, either for nested environments such as objects in a building and buildings on campus (Wang & Brockmole, 2003a), or superimposed environments such as objects in a room and furniture in a virtual or imagined kitchen (Wang, 2004; Wan, et al., 2009). These findings suggest that the spatial updating process may be
affected by the structure of the environments, such as the nested environments (Wang & Brockmole, 2003a).

Another important example of environmental structure that can potentially affect people’s spatial learning and spatial updating is multiple floors of a building. In a study on human navigation in complex buildings (Montello & Pick, 1993), participants learned two distinct routes in a university building located on different floors that never crossed. After walking the paths and learning object locations, participants were told how these two routes connected and some even walked up a stairwell to physically link them. When pointing to various locations at test, they were more accurate at pointing to targets within the route they were presently on than targets from the other route. Despite having physically traversed between the two routes twice without any disorientation procedure in between, most of the participants did not even realize that the two routes were roughly aligned with one on top of the other. These results provide some evidence that it is difficult to keep track of the location of a target when one navigates to a different floor. However the trip between the two routes passed through a tunnel, and the traveled distance from the test location to the targets within the same floor/route is shorter than that to targets across floor/route, therefore the difference in performance is difficult to interpret.

Montello & Pick (1993) also showed some evidence that target localization performance is comparable for within- and across-floor objects. The top route used in their study contained two sections, one section was inside the building and the other was outside. The outside half of the path was one floor above the inside half. They found that pointing accuracy to landmarks from the inside (lower floor) section was comparable to landmarks from the outside (upper floor) section. However the target locations differ in many aspects, such as distance from the testing
location, path structure, environment type (outside vs inside a building), in addition to the within vs across floor factor, therefore the relative performance is again difficult to interpret.

Another study compared spatial learning in a two-floor building by map learning, navigating through virtual reality, or navigation through the space directly (Richardson et al., 1999). Participants showed no significant error increases when pointing to locations on another floor when they learned the space by walking or by reading a map. However, they did show worse performance pointing between floors when they learned the environment through virtual reality. These results suggest that spatial learning of multiple-floor environments through direct navigation does not impose a cost compared to single-floor environments. However, the layout of the two floors in their test environments was identical and precisely aligned with each other. This spatial arrangement may have made it difficult to interpret the performance comparison. For example, if participants remembered target locations within the scene on one floor, when they saw a very similar scene (in terms of hallways) on the other floor, they may just assume by default that the two floors are aligned in space and use a scene matching strategy to locate objects across floors, even if they did not actually discover the alignment between the two floors through their navigation. The failure of such a strategy in the virtual reality group may be due to the limited field of view in a virtual reality display, which would make it more difficult to learn the similarity in the scene layout across floors. Thus, it remains unclear whether spatial updating can operate across floors as well as within a floor, especially when the layout of the two floors is not matched or not aligned.

To examine whether people can keep track of a target’s location when they navigate across floors, there are many potential confounding variables that need to be accounted for. For example, distances are often closer for targets within a floor than those across floors.
Furthermore, people often traverse between locations within a floor more often than across floors. Finally, visual cues in the environment, such as floor geometry, boundaries such as doors and hallways might influence the accuracy of spatial updating. The present experiments tested whether spatial updating is more difficult across floors than within a floor while taking into account the effects of experience, learning, and distance differences as well as testing how visual information influences spatial updating.
CHAPTER 2: EXPERIMENT 1

In this experiment participants traversed back and forth between two floors that had different hallway structures so that a scene matching strategy is not useful. At a mid-point response location they pointed to targets either on the same floor or on a different floor. Performance of the within-floor trials and the across-floor trials was compared to test whether there is a cost in spatial updating of target locations across floors.

Participants

Sixteen participants (10 women and 6 men, age 18 to 22 years old) were tested individually. All participants were University of Illinois undergraduate psychology students who participated for course credit. Two additional subjects were tested but not analyzed because both provided at least one pointing response as directly above or below their current location and therefore did not provide an error measure on these responses. No participant had prior knowledge of the space before the experiment. Most (7/16) of the participants had never had a class in the psychology building and most (11/16) were freshman in their first semester of college.

Experimental Setup

Participants navigated through the bottom two floors of the University of Illinois psychology building. The first floor portion of the route passes by lab spaces that most undergraduates would only encounter if they participated in previous psychology experiments (see right map on Figure 1). The basement portion of the route passes the departmental shop and other building resources where undergraduates would likely never explore (see left map on Figure 1). Both portions of the route are closed off by fire doors and therefore form a separate 'space' within the building.
The straight line Euclidean distance from the midpoint to the shop was 18.6 meters (37.2 meters walking distance) while the classroom was 28.3 meters away (39.6 meters walking distance). Therefore, participants always pointed to a physically closer target when pointing across floors compared to within floor pointing.

**Experimental Design**

Participants walked back and forth along the route led by an experimenter. Two rooms at the endpoints of the route were used as targets (Shop and Classroom, see Figure 1). Four other objects were used as fillers to make the task more difficult but were not analyzed further.

**Procedure**

The experimenter and participant began at one of two starting locations (locations 1 and 2 on Figure 1), which were located at the route's endpoints. The first traversal taught the participant the route, the two target locations, and the filler object's locations. For further traversals, the participant and experimenter walked back and forth along the route. For every traversal the participants stopped at the midpoint and pointed to the destination for that trip, either the shop or the classroom. They also stopped at two other locations and pointed to the filler objects.

Participants were requested to point directly to the targets from their present location even if the direct point went through walls, floors, or ceilings. A compass was used to measure the azimuth of the pointing direction disregarding any vertical dimension of the response. Each participant traversed the route seven times, leading to three pointing responses to each target, once during each roundtrip after the initial learning traversal. After the experiment, participants also completed a short questionnaire about their previous experience in the space.
Participants always responded at point A in the first floor stairwell and took the stairs as they traversed the route. The classroom was always within floor, while the shop was always across floors in relation to the midpoint response location. Thus, if there is a cost associated with spatial updating across floors, then pointing errors should be larger for the shop than the classroom.

**Results and Discussion**

Absolute angular pointing error was submitted to a repeated measures ANOVA with roundtrip number (first, second, or third) and target (shop, classroom) as within subject factors. An ANOVA analysis with starting position as a between subject factor showed no significant effect of starting position ($F_{1,14} = 3.15$, $p = .1$) so this factor was removed for the following analysis.

When participants pointed to a location within their floor, they were significantly more accurate ($M = 21.5^\circ$, SE = 5.8) than when they pointed across floors ($M = 57.1^\circ$, SE = 8.1), ($F_{1,15} = 51.39$, $p < .001$), as shown in figure 2. This $35^\circ$ worse performance when pointing across floors suggests that it is more difficult to keep track of a target’s location when traveling across floors then when traveling within a floor. Participants showed no learning across the three roundtrips ($F_{2,30} = .833$, $p = .45$) and showed no interaction of target floor by roundtrip interaction ($F_{2,30} = .044$, $p = .96$).

Difficulty in pointing across floors cannot be due to longer distances across floors. The midpoint response location was actually closer to the across floor location (the shop) than to the within floor location (the classroom), both in terms of the direct Euclidean distance and the navigation distance. This effect also cannot be explained by familiarity with the two routes from the response location to the two target locations, because participants walked the same route
seven times and therefore traversed within and across floors with equal frequency. Nonetheless, even though distance and familiarity cannot explain why people are worse at pointing across a floor vs. within one, because participants traversed the floors through the stairs, they stepped and turned more across the floors than within a floor. This extra movement might have disrupted the spatial updating system which relies on self motion estimations, so that the across floor pointing might have involved either too much accumulated error or more calculations that were error prone. We addressed this possibility with experiment 2 by removing the movement between floors by using an elevator.
CHAPTER 3: EXPERIMENT 2

Participants

Sixteen University of Illinois undergraduate psychology students (5 women and 11 men) who ranged in age from 18 to 23 years old participated in this experiment for course credit. One participant was excluded from further analysis because of an interruption in the elevator operation. None had participated in the previous study. One participant had previously completed a psychology study on the first floor portion of the route a month prior to this experiment. Most (11/16) of the participants had had no classes in the psychology building and most (9/16) were freshman in their first or second semester of college.

Procedure

Participants followed the same procedure from Experiment 1 except they now responded in the hallway of the first floor (at point B, see Figure 1) and used the elevator to traverse the floors (location E, see Figure 1). Participants entered the elevator, turned to face the door and exited once the elevator reached its destination. Most of the movement when crossing floors was eliminated; All the movement that remained matched the types of movement required for within floor movement. Thus if the across-floor cost was due to the extra movements in the stairs, then the cost should be eliminated when participants used the elevator. However, if the across-floor cost was intrinsic to the spatial updating process between environments, then the cost should remain.

Results and Discussion

Absolute pointing error was analyzed using a repeated measures ANOVA as in experiment 1. Again, the between subject factor of starting location was not significant ($F_{1,14} = .32, p = .58$) and was removed from the analysis. Pointing to a location within a floor ($M = 10.4^\circ, SE = 1.7$) was again more accurate than pointing across floors ($M = 25.6^\circ, SE = 4$), ($F_{1,15} = 15.3,$
p = .001). Participants did show improvement over repeated trips (F_{2,30} = 3.657, p = .04).

However, there was no roundtrip by target floor interaction (F_{2,30} = .18, p = .84). These results largely replicated those of Experiment 1, and suggested that the cost in spatial updating across floors was not due to traveling by the stairs per se.

To further compare people’s performance in the two experiments, a mixed ANOVA on the absolute pointing errors was performed with the experiment, roundtrip number and target as factors. There was a main effect of experiment (F_{1,30} = 67, p < .001) and target (F_{1,30} = 64, p < .001), no significant effect of roundtrip number (F_{2,60} = 1.95, p = .15) and a significant interaction of target by experiment (F_{1,30} = 10.5, p = .003). The main effect of experiment suggested that navigation was easier with the elevators than with the stairs. However, even with this overall accuracy increase, across-floor target localization was still more difficult than within-floor target localization. Furthermore, the interaction of target by experiment showed that the across-floor cost was larger when people used the stairs, suggesting that the extra movements in the stairs might have contributed to a portion of the across-floor cost observed in Experiment 1 but was not sufficient to account for the across-floor effect by itself.

Nonetheless, there was still a potential confound in this experiment. Participants always pointed to the shop across floors and the classroom within. It is possible that pointing to the classroom is easier than pointing to the shop, due to the spatial configuration of the route. Experiment 3 had participants always point across floors to test the possibility that something inherent to the space caused our results instead of a true across vs. within floor effect.
CHAPTER 4: EXPERIMENT 3

Participants

Sixteen University of Illinois undergraduate psychology students (9 women and 7 men) who ranged in age from 18 to 21 years old participated in this experiment for course credit. They had not participated in either of the previous studies. Two additional participants were tested but not analyzed because they reported that they did not remember one of the two locations (the classroom or the shop). One participant had previously completed a psychology study on the first floor portion of the route a month prior to this experiment. Most (9/16) of the participants had no classes in the psychology building and most (10/16) were freshman in their first or second semester of college.

Procedure

Participants followed the same procedure as Experiment 2 and used the elevator to traverse the floors. Here though, participants always pointed across floors. This meant that pointing responses to the shop took place outside the elevator on the first floor (at point B, see Figure 1) and participants pointed on the ground floor just outside the elevator to the classroom (at point C, see Figure 1). Thus if the performance difference in Experiments 1 & 2 was due to the difference in the targets themselves or the corresponding path structure, then the pointing errors should be higher for the shop than the classroom. However, if the performance difference was due to the spatial updating cost across environments, then the cost should be eliminated when both targets were across-floors.

Results and Discussion

Absolute pointing error was submitted to a repeated measures ANOVA with roundtrip number, and target as within subject factors. Starting location as a between subject factor did not
reach significance and was removed from the analysis ($F_{1,14} = 1.92, p = .19$). The main effect of roundtrip number was not significant ($F_{2,30} = 2.23, p = .125$). Furthermore, there was no significant roundtrip by target interaction ($F_{2,30} = .06, p = .94$).

Participants were no better at pointing to the classroom ($M = 31.3^\circ$, $SE = 6.2$) than the shop ($M = 35.4^\circ$, $SE = 7.1$) across floors ($F_{1,15} = .57, p = .46$), suggesting that there was no structural reason that one of the target locations was easier to point to than the other. Thus the difficulty in pointing to targets across floors compared to within the same floor in Experiments 1 & 2 was not due to the targets themselves or the path structure associated with them. Instead the across-floor cost was due to the spatial updating process which seems to have difficulty keeping track of targets across different environments such as multiple floors in a building.

To understand the mechanism of spatial updating across floors, it is important to know what allows the spatial updating system to differentiate a target as across-floor or within-floor. There are different perceptual cues that can indicate to a navigator that she is leaving one floor and entering another one. First, visual information allows one to directly perceive the boundaries of each environment and monitor the spatial updating process as one changes environments during navigation. Second, non-visual information such as the vestibular and proprioceptive information allows one to detect vertical acceleration, which may be used as an indication of changing floors. Experiment 4 further examined the perceptual cues that lead to the across-floor cost in target localization by removing the visual input from participants as they traversed the route.
CHAPTER 5: EXPERIMENT 4

Participants

Sixteen University of Illinois undergraduate students (10 women and 6 men) who ranged in age from 18 to 20 years old participated in this experiment for course credit. They had not participated in any of the previous studies. Two participants had previously completed a study on the first floor portion of the route. Most (9/16) of the participants had had no classes in the psychology building and most (11/16) were freshman in their first or second semester of college.

Procedure

Participants followed the same procedure as Experiment 2 and used the elevator to traverse the floors. Before entering the space, participants put on a blindfold. They were asked to adjust the blindfold as necessary so that they couldn't see anything. Most chose to close their eyes as well. The experimenter guided the participant through the space by a short rope while walking slowly. Verbal instructions were given as needed.

During the learning traversal, participants reached out and touched the door to the classroom and shop as well as other filler objects while the experimenter named them. Subsequent test traversals also ended with participants touching the door, either the shop or the classroom, at the end of the path. While this explicit reminder of the target locations differed from previous experiments, sight of the route gave this feedback automatically to participants in the previous experiments. If the across-floor effect was triggered by internal cues such as vestibular information when riding the elevator, or conceptual knowledge that one is entering a different floor, then the across-floor cost should remain. The elimination of the across-floor cost would suggest that visual cues are important in defining the change of environments for the spatial updating system.
Results and Discussion

A repeated measures ANOVA with roundtrip and target as within subject factors was computed with absolute pointing error as the dependent measure. Starting location again did not reach significance as a between subject factor and was removed from the analysis (F_{1,14} = .08, p = .78).

Participants did not improve as they traversed the route multiple times (F_{2,30} = 2.07, p = .14). Again, even with a learning traversal and three roundtrip walks through the space, participants showed no significant improvement in their pointing errors. Even though being blindfolded reduces the participant's experience of the space, they received more instruction than previous participants at the end of each traversal as to the location of the targets of interest (the shop and classroom) and even this explicit information did not boost learning of the space. No interaction of roundtrip by floor was found (F_{2,30} = .28, p = .76).

More importantly, participants were no better at pointing to within floor targets (M = 50.4°, SE = 9.5) than across floor targets (M = 67.5°, SE = 11.9), (F_{1,15} = 2.5, p = .14). Out of the 16 participants, 9 (56%) showed more errors pointing to the shop than to the classroom providing no evidence of across-floor cost (t_{15} = .49, p = .63). These results showed that when visual information was removed, target localization across floors was no longer harder than within the same floor, providing evidence that visual information is important in determining the across-floor cost in spatial updating.

Note that the overall performance (M = 59°, SE = 9.3) decreased comparing to Experiment 2 (M = 33.3°, SE = 6), (t_{15} = 2.5, p = .02). To test whether the non-significant result was due to a ceiling/floor effect, participants were divided into two groups based on their overall pointing accuracy, and the data in the top 50% of participants were examined separately. This
sub group showed significantly better performance (M = 25°, SE = 3.2), which was comparable to those in Experiment 2 (M = 26.9°, SE = 4.6), (t7 = .45, p = .66). Importantly, there was no significant difference in their pointing accuracy to across- (M = 27.9°, SE = 4.9) vs within-floor targets (M = 21.2°, SE = 3.6), (t7 = 1.2, p = .28) in this sub-group. Moreover, 4 out of 8 participants in this sub-group (50%) showed higher pointing errors across floor than within floor, again showing no evidence of across-floor cost.

These data suggest that the comparable performance for the across- vs within-floor targets was unlikely due to the ceiling/floor effect. When participants lost their vision and had to solely rely on internal senses such as proprioception, vestibular and motor information to understand their location within the space, they suddenly lose this distinction of within floor vs. across floor pointing. These results suggest that the vestibular/proprioception cues within the elevator were not sufficient to delineate the space on their own. Furthermore, the participants knew they were entering an elevator and going up or down a single floor. Therefore, conceptual information on its own is not enough to segment the floors within the navigational system. Instead, the across-floor cost in spatial updating was largely dependent on the visual information of the structure of the environment.
CHAPTER 6: GENERAL DISCUSSION

Four experiments examined spatial updating in multi-floor environments. When participants were asked to navigate across two floors of a building, they were less accurate when pointing to targets on a different floor than when pointing to targets within their present floor. These errors could not have been due to the number of turns (amount of movement) required to cross the floors, since the across-floor cost occurred even when all extra turns were eliminated using an elevator ride. Increased errors also could not come from distance differences since the across floor location was closer in both direct line and walking distance to the pointing location. Familiarity was also not a factor here, because all participants traveled between the response location and the two target locations the same number of times. Finally, neither of the locations was more difficult than the other to point to since pointing across floors to both locations resulted in similar errors. These results suggested that spatial updating is more difficult across floors than within the same floor.

To further examine which perceptual cues caused the spatial updating system to differentiate between within- and across-floor targets, the experiment was repeated while participants were blindfolded to remove the visual information. When participants navigated without sight, their overall performance decreased comparing to navigation with full visual information. This result is expected because vision is critical for accurate estimation of self-movement, and the removal of visual information will cause general impairment in spatial updating performance. Note that this overall impairment does not mean that participants were not completing the task. All errors were well above chance. Importantly, the across-floor cost was eliminated when people navigated without vision. The errors did not differ when people
pointed to locations on either of the two floors, suggesting that vision is playing an important role in the mechanism of spatial updating across environments.

Participant's performance suffered when they had to point across floors, but their performance did not drop to chance. One possibility is that spatial updating of a target continues across environments, but with less efficiency and accuracy than that of a target within the environment. Thus performance deteriorates but does not reduce to chance. On the other hand, Wang (2006) showed that across-environment target localization was reduced to chance, suggesting spatial updating of targets may stop entirely when the navigator leaves a given environment. Thus the above-chance performance in our experiments may be due to other factors. For example, there are many features of a building that can constrain the possible response directions and therefore reduce the errors, such as hallways and building geometry. Current heading and knowledge of the space (for example, the shape and size of the building seen from outside) could also lead to non-random guessing. Complete random performance could only be expected if the participants had no cues or knowledge of the space at all. Our experiments cannot differentiate between these possibilities.

Our findings are consistent with the limited capacity hypothesis for spatial updating of multiple targets and multiple environments (Wang et al., 2006; Wang & Brockmole, 2003a, 2003b; Wang, 2004, 2006). For example, Wang & Brockmole (2003b) showed that when participants entered a building and learned a spatial layout inside, they were unable to point to well known buildings on campus outside. Only when the participants went outside could they report these locations, at which point they again lost track of the inside locations. Wang (2006) showed that people could not keep track of a target location from an environment when they navigate to another environment, unless they were forced to continuously report the target
location along the way. Our findings suggest that spatial updating across floors may be similar to spatial updating in nested environments, where spatial updating drops current vectors when leaving one environment and resumes updating remembered locations when re-entering an environment.

A related issue concerns spatial updating in three-dimensional space. While we only recorded azimuth measurements, there is at least some evidence that spatial updating can work when 3D information is useful. Animals are able to spatially update in natural environments that include height as well as longitude and latitude. In one study with Desert ants, individual ants were directed on a hilly path to a food source (Wohlgemuth et al., 2001). On the way home, the hills were replaced with a flat path. If ants only updated the number of steps they walked they would overestimate their walk home on the flat path. However, the ants actually walked the correct distance home showing that they had spatially updated the horizontal projection of their path. This behavior is adaptive because the ant does not know what terrain it will encounter on its way home. Therefore, it is more useful to compute a home vector representing how far the ant should walk on an abstract horizontal plane and spatial updating is capable of this calculation.

Further evidence for three-dimensional spatial updating comes from rats learning to find food sources in a three-dimensional maze (Grobéty & Schenk, 1992). Rats learned how to find a food source in a wire cage where they had to move horizontally and vertically to find their reward. Not only did the rats use spatial updating to track locations with a vertical component, they learned the vertical location of the food faster than the horizontal one. The vertical component in spatial navigation may be easy to recover or adaptive to learn quickly because vertical moves require more energy than horizontal moves.
In both of these animal cases, spatial updating is capable of coding and updating 3-D locations. Humans also might be capable of updating 3D locations. However, man-made structures such as buildings include more environmental segmentations than natural ones, and further research is needed to assess the 3-D spatial updating capability in humans.
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Figure 1: Participants walked between points (1) and (2). In all experiments, participant walked a first traversal of the path as they learned target and filler locations. Experiment 1 had participants using the stairs (double pointed arrows) and the midpoint pointing location (A). Experiment 2 used the elevator (E) and midpoint pointing location (B). Experiment 3 again used the elevator (E) with midpoint pointing location (B) for pointing to the shop while (C) was used for pointing to the classroom. Finally, Experiment 4 followed Experiment 2 using the elevator (E) and the midpoint pointing location (B) while participants were blindfolded.
Figure 2: Absolute angular error for each experiment. Participants took the stairs in experiment 1 and always pointed across floor to the shop and within floor to the classroom. For experiment 2, participants again pointed within floor to the classroom and across floor to the shop but now took the elevator while traversing the floors. In experiment 3, both pointing to the shop and the classroom was across floors. Experiment 4 followed experiment 2’s procedure, except that participants were blindfolded throughout the experiment.