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School of Behavioural & Social Sciences

Spring 4-16-2018

The validity of inferring real-world cognitive mapping ability based on performance in a virtual environment

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Honours Psychology Thesis
Department of Psychology
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London, Ontario, Canada
April 2018

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Abstract

This study investigated whether virtual environments (VE) have ecological validity in studies of cognitive mapping ability. Forty female undergraduate students completed the spatial orientation test (SOT) and other tasks that assessed their cognitive of real-world locations they visit often and a VE, through direction estimation and map accuracy tasks. Participants had lower error scores on real-world direction estimation than VE direction estimation, suggesting that the accuracy of their cognitive maps was associated with familiarity and exposure to an environment. Real-world direction estimation, VE direction estimation, and VE map building were all correlated with the SOT, suggesting a shared reliance on perspective-taking. The results of this study question the ecological validity of VE studies of cognitive mapping in females.

Inferring Real-World Cognitive Mapping Ability Based on Performance in a Virtual Environment

The ability to successfully navigate an environment and maintain sense of direction is essential for carrying out everyday tasks such as getting to work, finding an item in a supermarket, or locating a car in a parking lot (Wolbers & Hegarty, 2010). Those who are poor at navigation experience emotional upset and frustration when they cannot effectively navigate an environment, so understanding the functions involved in navigation is important (Kozlowski & Bryant, 1977). Individuals develop spatial knowledge of an environment by integrating a variety of information they receive from travelling in an environment (Ikishawa & Montello, 2006). Individuals receive sensory cues from their environment that aid in navigation including visual and auditory information that indicates the locations and distance between objects (Wolbers & Hegarty, 2010). Individuals also use self-motion cues of movement such as muscular activation and vestibular information to track how they move within the environment allowing for distance estimations (Wolbers & Hegarty, 2010). Individuals use sensory and self-motion cues to update their position in the environment and understand where things are relative to one another independent of perspective to have the most comprehensive knowledge of an environment (Wolbers & Hegarty, 2010). The information gathered from sensory and self-motion cues develops into a two-dimensional survey representation of the environment (Siegal & White, 1975). This map-like representation that individuals have of an environment is what researchers call a cognitive map (Tolman, 1948).

Cognitive maps are map-like mental representations of an environment that include knowledge of where landmarks are relative to one another independent of perspective, allowing the mapper to take novel shortcuts (Tolman, 1948; Siegal & White, 1975). Cognitive maps go beyond route knowledge, which is the memory of the sequence of landmarks on a path previously travelled (Siegal & White, 1975). Landmarks are the notable locations that are used to organize the sequence as individuals travel between them (Siegal & White, 1975). Individuals do not develop cognitive maps as an alternative to route memory, rather they incorporate a variety route representation into their cognitive map representaion (Siegal & White, 1975).

Tolman (1948) was the first to define cognitive maps when he observed that hungry rats were able to locate food in a maze by taking paths they had not previously travelled, thus he suggested that cognitive maps were necessary for taking novel routes. O'Keefe and Nadel (1978) later added to his definition, stating that the primary difference between cognitive maps and route representations is that cognitive maps are more flexible to changes than routes. That is, a disruption in a route where landmarks are blocked off or removed completely disintegrates the route representation making it useless to the individual. Disruptions in a route would require individuals to use an alternative and novel sequence of landmarks that would be very difficult to think of if they only have the single route representation (Bennett, 1996). Alternatively a cognitive map is less vulnerable to disruptions in the environment because the rest of the representation remains intact (O'Keefe & Nadel, 1978). Individuals are better able to adapt to changes in their environment as the map becomes more comprehensive, including more elements from the environment (Tolman, 1948). Another task that requires a cognitive map is direction estimation, which is how well one can estimate the direction of an object it relative to a standing position and this can be evaluated by having individuals point to locations that are not visible via perspective taking tasks (Bennett, 1996). Pointing to visible landmarks only requires recognition of the landmark and is possible from landmark or route knowledge, however being able to indicate the direction of a landmark that is not visible requires a cognitive map (Bennett, 1996).

There are two prominent theories that explain spatial cognitive microgenesis, namely how cognitive maps are developed (Siegal & White, 1975, Montello, 1998). Siegal and White (1975) suggested that individuals develop cognitive maps in a hierarchical manner, which is what they called the main framework. The main framework suggests that the first aspects of an environment that are learned are landmarks, which are discrete objects in an environment that offer no spatial information aside from how they look (Siegal & White, 1975). Individuals then go on to develop route knowledge as described above, and finally develop survey knowledge, which is where knowledge on landmarks and routes come together to form a cognitive map (Siegal & White, 1975). The idea here is that individuals need to have the lower level in place before they can get to the next level (Siegal & White, 1975). Montello (1998), however, suggested a new framework to account for the fact that cognitive maps are loosely formed with first exposure and become more accurate with increased exposure. He suggested that landmark, route, and survey information is simultaneously integrated into a cognitive map beginning at first exposure to an environment. This framework supported claims by Tolman (1948) that as individuals are repeatedly exposed to an environment, their cognitive map becomes increasingly complex. Although cognitive maps typically improve with exposure, there is a great deal of individual variation is how they are developed.

Individuals are found to range from developing very strong to very weak cognitive maps (Ikishawa & Montello, 2006). Individual differences could be caused by differences in the information individuals attend to in an environment, how individuals consolidate information, or how they retrieve information (Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). Sophistication of environments maps can vary a great deal depending on the nature and exposure to the environment (Seigal & White, 1975). Ikishawa and Montello (2006) used route integration to investigate individual differences in cognitive mapping ability. Route integration is when two separate routes are learned separately with no overlapping features, and a connector route is later introduced allowing the participant to make connections about where landmarks on one route are relative to landmarks on the other route (Ikishawa & Montello, 2006).

Ikishawa and Montello (2006) drove participants along two distinct routes for a total of ten weeks and at the third week introduced a connecting route. Participants then demonstrated the quality of their cognitive map by sketching a map of the environment and pointing to unseen landmarks. Participants were evaluated over the ten-week period and performed consistently poor or consistently well throughout trials (Ikishawa & Montello, 2006). That is, those with poor performance showed little to no improvement over time. Since each participant was subject to the same exposure to the environment, there must be a difference in how the information is processed that resulted in the difference in performance (Ikishawa &Montello, 2006). Kozlowski and Bryant (1977) did an experiment involving maze running, which involved participants being led through a series of tunnels, they were then asked to sketch a map of the environment and do a direction estimation task after each pass through the maze. They found that those who self reported as being good navigators showed improvement over trial of direction estimation, and those who were poor at the start performed consistently poorly. This lack of improvement is similar to findings in Ikishawa and Montello (2006).

Weisberg et al., (2014) aimed to determine whether similar individual differences found by kishawa and Montello (2006) using real-world environments occur when individuals developed cognitive maps of a virtual environment (VE). Cognitive mapping ability is studied by having participants learn an unfamiliar environment, but finding unfamiliar areas in the real world is time consuming and creating these conditions in a lab is costly (Ikishawa, & Montello, 2006). For this reason the use of a VE is common. VEs are an objective and cost-effective measure of navigational ability (Weisberg et al., 2014). Given the increased use of VE in cognitive mapping research, it is very important to ensure that VE are a valid measure of real world spatial ability. Weisberg et al. (2014) evaluated individual differences in cognitive map development via a VE that was modeled after Temple University's Ambler campus called Silcton. Participants completed a route integration task where the participants followed two individual routes and two connecting routes in Silcton. The evaluations of cognitive map performance were direction estimation tasks and map building tasks similar to that used by Ikishawa and Montello (2006). The direction estimation task was divided into within-route trials (landmark they needed to point to was on the same route) and between-route trials (landmark they needed to point to was on a different route). Weisberg et al. (2014) found that individuals could be good on routes and good at maps, good on routes and poor at maps, or bad on both which supports the main framework by Siegal and White (1975) that routes are necessary for developing cognitive maps, but routes do not require a cognitive map of an environment to be formed.

Weisberg et al. (2014) found that there was a large range in direction estimation accuracy from minimal error, to very high error, and similarly large range of accuracy in the map-drawing task, which suggested that individual differences in cognitive maps occur with VE similar to how they do with real-world locations.

Hegarty, Montello, Richardson, Ishikawa and Lovelace (2006) also investigated navigation in a VE. They did an experiment where participants learned a real environment (two floors of a campus building), a very simple VE (single path, passing items), or watching a video of the inside of a local building. Small scale spatial abilities predicted learning from visual media, not the real environment and sense of direction predicted real environment learning and to a lesser degree visual media. This suggests that there is a difference between creating cognitive maps in a real environment vs. video or simple VE. Self-motion perception also impacts how well individuals develop cognitive maps of VEs over cognitive maps developed via direct experience in a real environment (Hegarty et al., 2006). In a VE, individuals receive less self-motion cues aside from visual input, they miss indicators such as kinesthetics, or vestibular information making it more effortful to update position (Hegarty et al., 2006). VE are also less visually immersive and less complex than a real environment. Individual differences may result from variances in ability to internally maintain environmental info based on sensory input (Hegarty et al., 2006). The findings in Weisberg et al. (2014) and Hegarty et al. (2006) suggest that VEs have a potential to be reflective of real world performance, but this may be mediated by how immersive and complex the VE is.

Developing cognitive maps of real environments that are meaningful to the individual could potentially be better because there is higher motivation to create an efficient cognitive map (Tolman, 1948). In his research on rats, Tolman (1948) found that rats that were hungry had reduced error in maze, which means they either had a better cognitive map of their environment or were better able to effectively use the map they had. This highlights the impact of necessity on performance. The hungrier the rats were the more important it is to be able to successfully navigate the environment and find the most efficient way to get to the food (Tolman, 1948). Similar to how rats were able to make better use of their cognitive maps because of their motivation to find food, real-world environments have more importance to individuals in that it influences their everyday life so individuals will likely put more effort into learning these environments and create or make better use of the cognitive maps they have of these environments. Studies that involve direct learning of a novel real environment (Hegarty et al., 2006; Kozlowski, and Bryant, 1977) do not have the same degree of importance or familiarity to the individual. An individual navigating their every day environment is more important (Kozlowski and Bryant, 1977). On top of necessity, familiarity breeds precision, repeated exposure to the environment improves the accuracy of a mental model in a cumulative fashion (Montello, 1998). These factors would have us believe that real-world cognitive maps should be more extensive than mental models of an environment learned in a lab setting, whether that environment be virtual or real. So ensuring that a VE can reflect real world cognitive mapping ability is important for the practical application of research in this field. Spatial cognition has relatively little information about whether real-world ability (different from learning an environment in a lab) is similar to VE performance.

The current study investigated whether VEs have ecological validity in the study of cognitive mapping, that being whether the quality of cognitive maps created with VE are reflective of the cognitive maps created of real world environments. Participants completed tests of direction estimation and map building ability using both real-world locations and a VE called Silcton, (Weisberg et al., 2014) to assess the quality of the cognitive maps they have of these environments. It was hypothesized that real-world sketch map accuracy would be positively correlated with real-world direction estimation, and Silcton map building would be positively correlated with Silcton onsite direction estimation. It was also hypothesized that the quality of cognitive maps participants have of real-world locations will be positively correlated with the quality of the cognitive map they create of Silcton. Finally, it was hypothesized that individuals would perform better on tasks using real-world locations than Silcton.

Method

Participants

Forty female undergraduate students, with ages ranging from 18 to 46 with a mean age of 20.70 years, they were recruited via the Brescia Sona recruitment system. All participants resided in the City of London at the time of testing. Participants were tested individually and received three research credits towards their psychology 1000 research requirement for participating in the study.

Materials

The Silcton VE and all measures of spatial ability that used Silcton were administered via a 15” Toshiba laptop running Windows 8.1 with a 64-bit Intel Core Processor @ 2.40GHz.

Demographic questionnaire. This questionnaire was a paper-and-pencil task. The survey had five items that gathered information including the participant’s age, sex, year in university, and how long they had resided in London. Finally, participants rated how often they played video games, as this is potentially related to performance in virtual environments (see demographic questionnaire in Appendix A).

Spatial Orientation Test (SOT). The SOT is a paper-and-pencil task that uses an array of objects to test perspective-taking ability (Hegarty & Waller, 2004). On each item of the test there is an array of objects on the top of the page, and a circle on the bottom half. Participants are told to imagine that they were standing at one object in the array (e.g. the cat) facing another object (e.g. flower) and were instructed to draw a line indicating the direction of the third object (e.g. tree) relative to their starting position. The completion of one of the circles is a trial. Participants have five minutes to complete as many of the 12 trials as possible. Responses were scored by comparing the participant's estimated degrees with the actual degrees to calculate their mean average error (MAE). A higher MAE indicated poorer performance and a lower MAE indicated better performance.

Location Gathering. After reading a script on how to complete the task (see script in Appendix B) the researcher asked the participant to think of a minimum of four to a maximum of ten locations that the participant visited often within the City of London and to rate how frequently they were visited them within a typical week (see location gathering sheet in Appendix C). As the participants provided locations, the researcher looked up the addresses on Google Maps to verify and obtain the latitude and longitude of the exact addresses. Of the locations the participant provided, the four most frequently visited formed the basis for the real world pointing and map sketching tasks that followed.

Real-world direction estimation task. This was a paper-and-pencil task modelled after the SOT that measured how well participants could estimate the direction of a location they visit often from a starting orientation (see Appendix D). The first page of the booklet consisted of directions for the task and a legend where the researcher assigned labels of *A, B, C,* and *D* to the four most frequently visited locations in the location gathering booklet. Participants were provided a sheet of paper with a circle on it, which indicates a location at the center and a location on the top. Participants were instructed to imagine they were standing at the center location, facing the location at the top of the circle, then participants were instructed to draw a line in the circle provided, in the direction of a third location. Participants then completed the 24 trials with the locations alternating between the standing position, facing position, and direction estimation. Responses were scored by comparing the participants' estimated degrees with the actual degrees to calculate their MAE. A higher MAE indicated poorer performance and a lower MAE indicated better performance.

Real-world sketch map. Participants drew a map of the four most frequently visited locations they provided in the location gathering booklet (see Appendix E for script). They were given a sheet of paper that included the letter assigned to each of the four locations, a square, and the word "North" written directly above the square for them to sketch their map (see Appendix F for map sketching worksheet). Participants labelled each of the locations on the map as *A, B, C,* and *D*, and were encouraged to add additional landmarks or streets if it helped them improve their accuracy.

Map accuracy was determined using Gardony Map Drawing Analyzer (GDMA) software (Gardony, Taylor, & Brunyé, 2016). This program took the latitude and longitude coordinates of the real world locations provided by the participants and created an actual map of the real world area. GDMA then compared the map that the participant drew to the actual real-world map. The program used distance and the angular accuracy between landmarks to calculate an *r* value, which was then converted to an R^2 value ranging from 0-1.0 with higher numbers indicating higher correspondence of the participant's map with the actual map.

Silcton practice and free exploration. Participants completed the Silcton free exploration task on the laptop computer. This task involved the participant moving freely in the non-immersive virtual environment Silcton (Weisburg et al., 2014)(see Appendix G for script). Participants used the arrow keys on the laptop keyboard to move forward, backwards, left or right and the mouse to look around (up, down, left, or right). First, participants practiced moving in Silcton using the controls by travelling in a circle around a statue and then the researcher directed them to an example of the diamonds and signs they were to look for during free exploration. Once they were comfortable with the controls, the timer started. Participants were given a minimum of 10 minutes and a maximum of 20 minutes to wander freely through Silcton, travelling anywhere in the environment. Participants' objective for the free exploration task was to find and remember the locations of the eight diamonds and signs associated with eight target buildings (Batty House, Golledge Hall, Harris Hall, Harvey House, Lynch Station, Sauer Centre, Snow Church, and Tobler Museum)(see example of a diamond and a sign in Appendix H). When the participant located one of the target buildings they used a pencil to cross the building off a list on a sheet of paper on the desk in front of them. Participants were instructed to stop exploring when they felt confident that they had a sufficient understanding of where the target buildings were located in Silcton or until 20 minutes had elapsed.

Silcton onsite direction estimation. This task was part of the Silcton software suite and was administered on a laptop. The task measures participants' direction estimation ability using the eight target buildings from Silcton (see Appendix I for script). Participants were situated in front of the front door of one of the target buildings in Silcton and a prompt at the top of the screen instructed them to point to another target building (see Appendix J for a screen shot of onsite direction estimation). They used the mouse to move the crosshair in the direction of the target building and clicked the mouse to record their direction estimate. This task included trials where the target building was and was not visible. This task had 56 trials, with each of the eight target buildings serving once as the standing position from where participants need to point to the other seven target buildings.

Responses were processed by averaging the absolute differences between the participant's estimated degrees and the actual degrees for each trial. Higher MAE indicated poorer performance and lower MAE indicated better performance.

Silcton map building task. This task was also part of the Silcton software suite and was administered on the laptop (see Appendix K for script). Participants used a mouse to drag and drop small overhead images of the eight target buildings into a two-dimensional square to create a birds-eye map of the Silcton environment (see Appendix L for image of map building). When participants finished, they selected the "I'm Done" button on the bottom left part of the screen.

The data from the map was analyzed within the Silcton software using bidimensional regression and resulted in an R^2 value that ranged from 0-1.0, with higher numbers indicating higher map accuracy and lower numbers indicating lower map accuracy. Higher accuracy in map building means the participant's map was close to the actual map of the buildings in Silcton.

Procedure

Participants were met in the front foyer of Brescia's Ursuline Hall and led by the researcher to the psychology undergraduate research lab. The participant was given a letter of information describing the experimental procedure and was encouraged to ask questions if she was unsure of any of the procedures. Participants then signed their informed consent form.

The first task was to complete the demographic questionnaire via paper-and-pencil, followed by the SOT. The participant then filled out the location gathering booklet alongside the researcher. Next, participants completed the real-world direction estimation task, followed immediately by the real-world sketch map. After completing the sketch map, there was a five-minute break.

After five minutes or once the participant was ready to continue, the Silcton phase began. First, participants completed the Silcton practice and free exploration tasks. Immediately after the exploration task, they completed the onsite direction estimation task and map building task. Finally, participants were given a debriefing sheet to keep that explained the purpose of the study and provided the researcher's contact information. The study took approximately 1.5 hours.

Results

Data were analyzed using SPSS. Two participants completed only 23 of the 24 trials for the real-world direction estimation task, so their MAE was calculated with 23 total error scores instead of 24. Participants' provided information on age (*M* = 20.70, *SD* = 5.92), year in university (*M* = 1.20, *SD* = .41), and video game activity (*M* = 1.73, *SD* = 1.65). Of the locations provided by participants, 54.38% were campus buildings. A bidimensional regression was used to calculate an R^2 value for the real-world sketch map (*M* = .43, *SD* = .27), and Silcton model building (*M* = .45, *SD* = .29). As mentioned above, MAE was calculated for SOT (*M* = 43.89, *SD* = 28.80), real-world direction estimation task (*M* = 43.89, *SD* = 20.82), and the Silcton onsite direction estimation task (*M* = 68.38, *SD* = 8.01).

Two paired samples *t* tests were conducted to determine whether there were differences in performance on real-world versus Silcton-based measures. The first test showed a significant difference between the mean error scores for the real-world direction estimation task and Silcton onsite direction estimation task, with participants performing significantly better on the real-world direction estimation task, $t(39) = -7.64$, $p = .001$, $d = 1.21$ (see Figure 1). Cohen's d indicated that this was a large effect. The second paired-samples t-test compared the means for accuracy scores on the real-world sketch map and Silcton model building and found no significant difference between tasks, $t(39) = 0.47$, $p = .64$, $d = 0.07$ (see Figure 2).

A Pearson correlation analysis was completed to determine the associations between age, year in university, error scores on the SOT, real-world direction estimation, Silcton onsite direction estimation, accuracy scores on the real-world sketch map, and

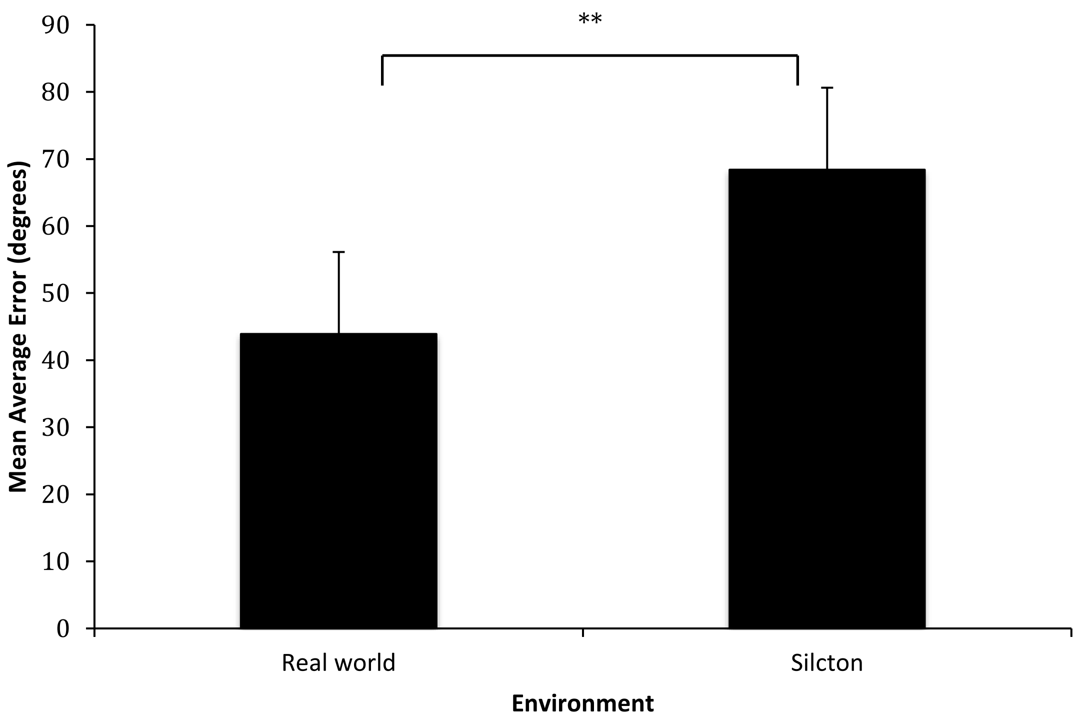

Figure 1. Higher error scores indicate poorer performance. The bars represent the means of all participants' error scores on the real-world direction estimation task and Silcton onsite direction estimation.
** $p < .01$.

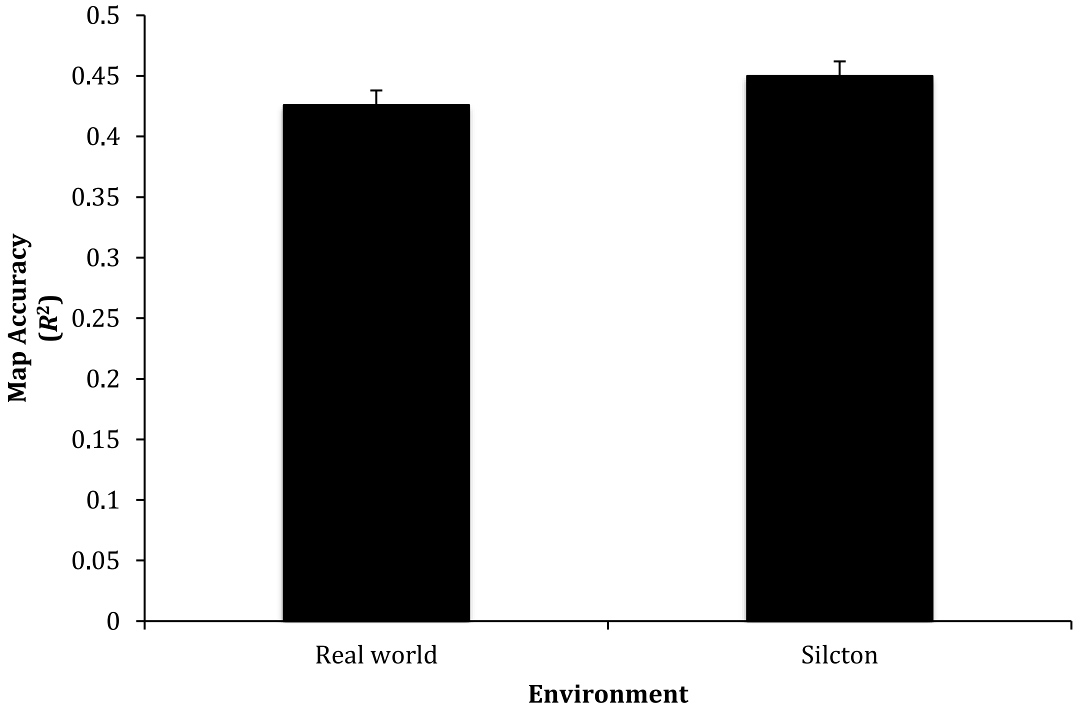

Figure 2. Bar graph of participants' map accuracy (y-axis) in the real-world and Silcton environments (x-axis). Higher scores indicate better performance. The bars represent the means of all participants' scores on the real-world sketch map and Silcton model building.

Silcton model building (see Table 1). There was a significant moderate positive correlation between age and length of time residing in London, indicating that as participants got older, they had resided in London longer. There was also a significant moderate positive correlation between error score on the real-world direction estimation task and year in university, which indicated that as year in university increased, participants showed less error on the real-world direction estimation task. Next, there was a significant moderate positive correlation between error scores on the SOT and the real-world direction estimation task indicating that as participants showed more error on the SOT, they also showed more error on the real-world direction estimation task (see Figure 3). As shown in Figure 4, error scores on the Silcton onsite direction estimation task and SOT had a significant moderate positive correlation, indicating that as error scores on Silcton onsite direction estimation increased, error scores on the SOT also increased. Finally, there was a significant positive correlation between scores on Silcton model building and the SOT, which was moderate in strength (see Figure 5), indicating that as participants maps of Silcton were more accurate they had less error on the SOT. None of the other correlations was significant.

Table 1

Correlation Summary of Demographic Questionnaires and Ability Measures

		1	2	3	4	5	6	7	8
1	Age								
2	Year in University	-.02							
3	Months living in London	.43**	-.17						
4	Video Games	.17	.28	.11					
5	Real-world Direction Est.	.05	.45**	.02	.15				
6	Real-world Sketch Map	.02	-.03	.11	.29	.10			
7	Silcton Onsite Direction	-.13	.10	.20	.26	.26	-.001		
8	Silcton Map Building	-.09	-.15	-.14	-.24	-.24	.08	-.08	
9	SOT	.22	.15	.07	-.14	.34*	.03	.38*	-.37*

Note. Bivariate correlations between demographic questionnaire and dependant variables in the study
*p < .05. **p < .01.

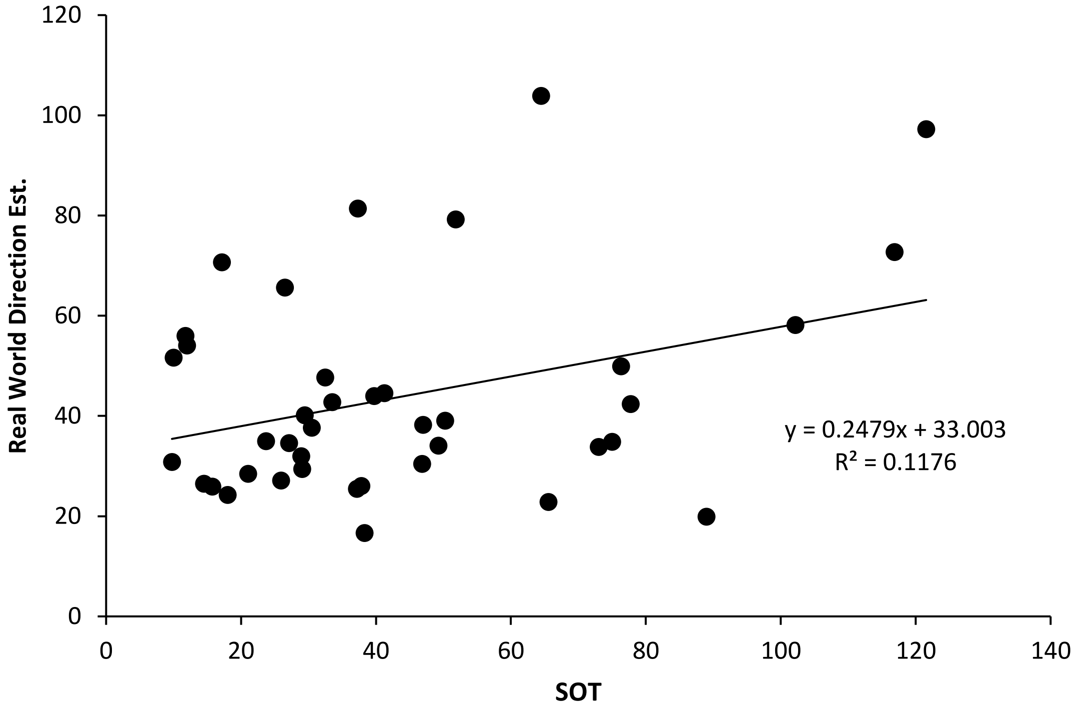

Figure 3. Scatterplot and line of best fit for error scores on real world pointing (y-axis) and the SOT (x-axis). Higher scores on real world pointing and the SOT indicate poorer performance.

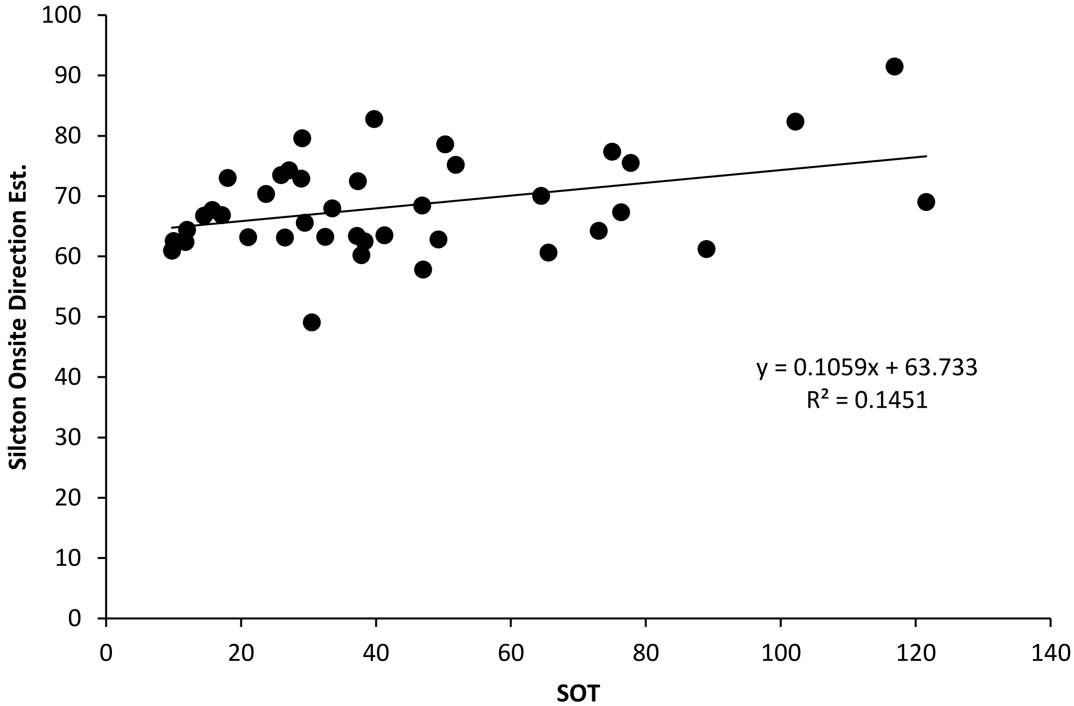

Figure 4. Scatterplot and line of best fit of error scores on Silcton onsite direction estimation (y-axis) and the SOT (x-axis). Higher scores on Silcton onsite direction estimation and SOT indicate worse performance.

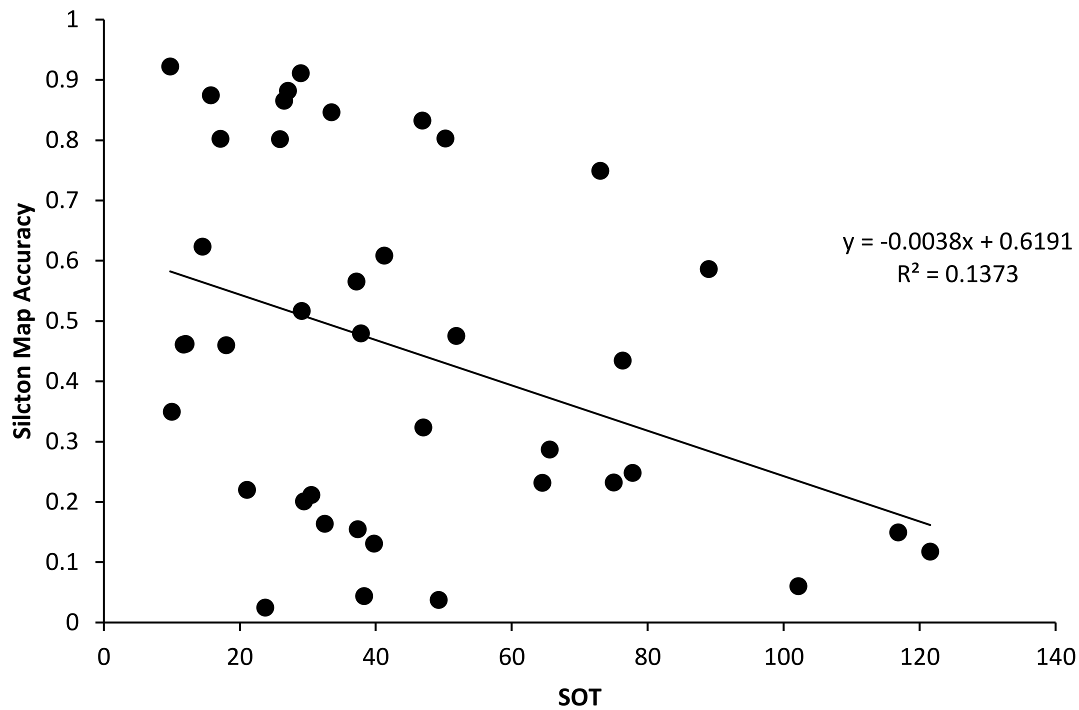

Figure 5. Scatterplot and line of best fit of scores on Silcton map building task (y-axis) and error score on SOT (x-axis). Higher scores on Silcton map building indicate better performance and higher scores on SOT indicate poorer performance.

Discussion

The present study investigated whether cognitive mapping performance in a VE was reflective of real-world cognitive mapping ability. Participants completed direction estimation and map building tasks that evaluated the accuracy of their cognitive maps for the VE Silcton, and of real-world locations within London that they provided. The results did not provide support for two of the three hypotheses. In terms of the associations between measures in the same environment, there was no relationship between real-world direction estimation and real-world sketch maps, or between Silcton onsite pointing and Silcton model building. In terms of associations between measures of the same ability in different environments, there was also no relationship between direction estimation tasks or map building tasks of the different environments. The results do provide support for the third hypothesis that participants would have more accurate cognitive maps for real-world locations than a novel VE as participants had less error on the real-world direction estimation task than on Silcton onsite pointing. This finding suggests an important function of exposure and familiarity for creating an accurate cognitive map. The results of this study also indicated that real-world direction estimation, Silcton onsite direction estimation, and Silcton map building were all associated with the SOT suggesting there may be a common underlying mechanism across measures.

Participants in this study showed better ability to visualize different perspectives and higher accuracy on real-world direction estimation than Silcton onsite direction estimation. This outcome was anticipated because the locations participants provided were ones they visited often. This finding is consistent with the familiarity effect, meaning that the more exposure individuals get with an environment the more accurate their cognitive map is of that environment (Holahan, 1978). The familiarity effect was also supported by evidence that there was a relationship between year in university and accuracy when sketching a map of real-world locations. Of the locations participants chose, 54.38% were campus buildings. Assuming that those in second year have had more exposure to campus buildings, it could be that this familiarity allowed them to produce more accurate cognitive maps of that environment. This finding is consistent with another study conducted by Stephan, Jäschke, Oberzaucher, and Grammer (2014) that assessed the accuracy of sketch maps that residents of Vienna made of the city. They found that map accuracy increased with duration of residency in Vienna for females, but not for males (Stephan et al., 2014). The findings of that study suggest that frequent exposure to an environment is particularly important for women to create an accurate cognitive map, which could be why the all-female participants in the present study performed better on real-world direction estimation than Silcton onsite pointing since they had only been in the VE once.

Participants' lower error scores on real-world direction estimation than Silcton onsite direction estimation is also consistent with a theory proposed by Montello (1998) that increased exposure to an environment and motivation to learn an environment increases the quality of the cognitive map. Montello (1998) suggested that with increased exposure to an environment, individuals develop more accurate representations of the angles and distances between landmarks. Participants in this study had more exposure to the locations they provided in the real-world tasks than Silcton, so it would make sense that they would perform better using these locations than the locations in Silcton since they had only been in the VE once. Ikishawa and Montello (2006) found that participants' performance improved with exposure to the routes and participants performed better on distance and direction estimation on the final exposure to the environment compared to the first. To acquire more complex knowledge of an environment there needs to be a deliberate integration of information (Montello, 1998). It is assumed that the participants more deliberately and thoroughly got to know locations in their everyday life, so on top of increased exposure to an environment, they were motivated to integrate this information because the environment was meaningful. Both exposure and motivation likely resulted in participants' superior performance on real-world direction estimation over Silcton onsite pointing.

A factor that may have influenced the lack of relationship between the real-world direction estimation task and the real-world sketch map participants created is the all-female subject pool. For instance, Stephan et al. (2014) had participants draw maps of their home range or the area they were familiar with between their home and locations they visit often. They found that males were more accurate at sketching their home range than females. They also found that men were more accurate at sketching their home range than women, especially in terms of estimating distances between landmarks. It is possible that the women in our study produced sketch maps that were inconsistent with their performance on real-world direction estimation because direction estimation tasks rely on the individual knowing the angles between landmarks and do not take distance into account. Alternatively, sketch maps were scored via bidimensional regression which takes into account distance estimation to determine accuracy of the maps, thus putting the women in our study at a disadvantage for this task. In addition, Webley (1981) found that female children were less accurate than males for map sketching but equally accurate when alternate tasks, such as model construction, were used instead. Therefore, if females are less accurate at producing sketch-maps that accurately reflect their cognitive mapping ability, that could explain why the real-world sketch map produced results that were inconsistent with the real-world direction estimation task. It will be important to test males under the same conditions as the current study to determine whether the current findings are seen only in females.

Males superior sketch map accuracy may be a result of men having larger home ranges than women (Ecuyer-Dab, & Robert, 2004; Hart, 1979; Stephan et al., 2014). In current hunter-gatherer societies, men travel further for resources than women do, so having a larger home range is more beneficial to men than women, and it is presumed that this also occurs in Western societies because hunter-gatherer societies reflect anscetors of individuals in Western cultures (Ecuyer-Dab, & Robert, 2004; Stephan et al., 2014). From a social perspective, boys in industrialized Western cultures are often offered more opportunities for autonomy and freedom to explore their environment without supervision, which could contribute to sex differences in home range (Matthews, 1987; MacDonald & Hewlett, 1999). Having a larger home range may contribute to having more frequent exposure to the environment thus allowing more opportunity for males to fine-tune their mental representation of the environment (MacDonald & Hewlett, 1999; Webley, 1981). The evolutionary benefit of men having a larger home range than women and the higher of autonomy amongst boys than girls may have made the sketch-maps a less accurate cognitive mapping assessment in the women in the present study, which then contributed to the lack of relationship between sketch maps and the other measures of real-world direction estimation and Silcton map building.

The lack of association between the two dependent measures that assessed memory for Silcton, Silcton onsite direction estimation and Silcton map building, may be a function of the lack of variation in some aspects of the data. First, the subject pool played very low levels of videogames play, having an average play-time of less than once a week. This could have put the participants at a disadvantage in the online tasks which resulted in a floor effect, an indication that the tasks were so hard, even the strong cognitive mappers performed poorly on Silcton onsite pointing and Silcton map building. For instance, 95% of participants' error scores for Silcton onsite direction estimation were between 60 and 80, compared to real-world direction estimation which participants were equally distributed with scores ranging from 16 to 101. This demonstrates the lack of variation with in the Silcton data. This lack of variation makes it less likely there would be a relationship between these variables since all participants performed consistently poorly. It is possible that a sample that had more experience with first-person videogames would have performed better on the Silcton tasks. Next, the Silcton onsite pointing and Silcton map building were both correlated with the SOT, which is an outcome found in prior research using this VE (Weisberg et al., 2014). However, the mean error score for participants in this study was substantially higher for the SOT and Silcton onsite pointing, and accuracy scores for Silcton model building were lower, when compared to prior studies using the same measures (Weisberg et al., 2014; Weisberg & Newcombe, 2015), and this variation between samples needs to be addressed in future research.

This study did not provide evidence that a VE accurately reflects real-world cognitive mapping ability, however their common relationship with the SOT suggests that the perspective-taking process is involved in tasks assessing memory for both of these environments. Specifically, there was a relationship between the SOT, a small-scale task, and real-world direction estimation, Silcton onsite pointing, and Silcton map building, which are measures of large-scale spatial ability. Hegarty et al. (2006) defined small-scale spatial ability tasks as paper-and- pencil tests that involve "perceptually examining, imagining, or mentally transforming representations of small shapes or manipulatable objects"(p. 151). They defined large-scale tasks as those including learning a novel environment and having to navigate or exhibit knowledge about the environmental configuration. The correlations in this study are consistent with other studies, which have found a relationship between small and large-scale spatial tasks (Weisberg et al., 2014; Hegarty & Waller, 2004). In addition, the corelations between SOT and measures of large scale ability provide support for the partial dissociation model, which suggests that small-scale and large-scale abilities rely on a common process, but they also use unique processes depending on the scale of space (small vs. large) and the environment (real-world vs. VE) (Hegarty et al., 2006). The relationship between small-scale cognitive mapping ability in real-world locations and a VE indicates that there may be a shared reliance on perspective-taking among all these measures.

There are a number of limitations in the current study that can be addressed with further research. One of the limitations of the current study is that we did not control for the frequency that participants travelled to the locations they provided. Some participants visited all their locations more than five times a week and other participants visited the locations they provided less than once a week. If there were more consistency in frequency, this study may have provided outcomes that were more related to ability without the influence of an exposure advantage. This study had participants investigate a completely novel VE and future research should have participants explore the VE for an hour several days in a row, or for weekly sessions to determine whether an individual may produce a cognitive map of their everyday environment. Given these findings in females, future research should investigate sex differences between males and females, VE may prove to be more a more accurate assessment for the spatial cognition of males than females. When travelling through a real-world environment people obtain vestibular cues, proprioceptive feedback, and optic, auditory and optic flow (Wolbers & Hegarty, 2010). These cues could be maintained in research by having participants travel real-world environments to maintain these cues, and that these environments be novel to maintain equal exposure and motivation between participants.

In conclusion, participants' performance on the Silcton did not reflect their real-world cognitive mapping ability and performance on VE tasks and real-world tasks were not correlated. They may however, rely on a similar underlying process since the Silcton measures and real-world direction estimation were correlated with perspective taking. Future research is needed to further investigate whether VEs are appropriate in the use of cognitive mapping research, especially with females. If familiarity and exposure are a factor in cognitive map accuracy, experiments should include more exposure to the VE prior to assessment. Overall the results of this study questions the ecological validity of virtual reality studies of cognitive mapping, especially in females.

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Appendix A

Demographic Questionnaire

1. **Age: __________**

2. **Sex**

   ☐ Female ☐ Male ☐ Other

3. **Current Year in University**

   ☐1st year ☐2nd year ☐3rd year ☐4th year ☐5th year

   ☐ Other (please explain):____

4. **How long have you lived in London (Please be specific ex. months/years)?**
   ____

5. **Do you play video games (for example using a phone, computer, iPad or other tablet, console such as Wii, Playstation, Xbox, Kinect, or other)?**

   ☐ Yes ☐No

*If you answered **No**, please skip to End of survey, below.*

If you answered **Yes**:

Overall, how often do you play? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

Which game(s) do you play on a regular basis? (Please list all)

____

____

____

You have completed the first page. Let the Researcher know you are finished.

Appendix B

Script for Location Collection

Instructions delivered by the researcher: For the next couple of tasks we will need locations of places within London that you go to frequently in daily life. Two of these locations may be Brescia and Home (if you live off campus). Other locations may include places such as: your workplace, a mall, a gym, a grocery store, or other places you frequent often. As we complete this questionnaire I will be asking you for the address and the frequency at which you go to each location. You do not need to know the exact address of the location as long as we are able to find it on Google maps. We require a minimum of four locations you frequent in daily life for the next tasks however we encourage you to provide as many locations as you feel you frequent daily with a maximum of 10 locations. Do you have any questions before we began?

Appendix C

Location Collection

List All Locations Regularly Visited in Current Everyday Life

#	Location	Description	Address	X Coordinate	Y Coordinate
1					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
2					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
3					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
4					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
5					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
6					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
7					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
8					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
9					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

#	Location	Description	Address	X Coordinate	Y Coordinate
10					

Overall, how frequently do you go to this location? Please circle one:

Less than once per week	1 – 2 times per week	3 – 4 times per week	5 - 6 times per week	More than 6 times per week

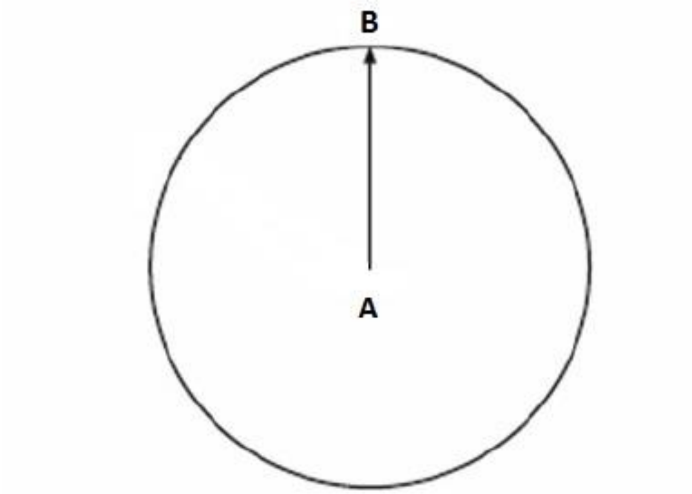
Appendix D

Real-World Direction Estimation Task

Instructions: The next task is another perspective taking task similar to the one you just did with the cat, stop sign and car. In this task you will imagine you are standing at one of the locations you frequently visit in the centre of the circle facing another location you frequently visit at the top of the circle. Then, you will need to draw an arrow from the centre of the circle indicating the direction of a third location you frequently visit from this specific facing direction. As a reference for which locations are a, b, c, and d, you may refer to the legend on the first page throughout the task, however make sure not to turn the booklet or make any other marks on the page other than the arrow inside the circle.

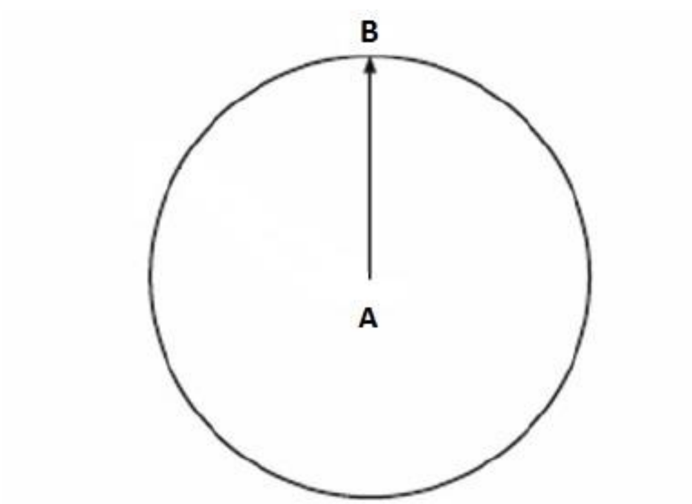
Legend	Location
A	
B	
C	
D	

Trial #1



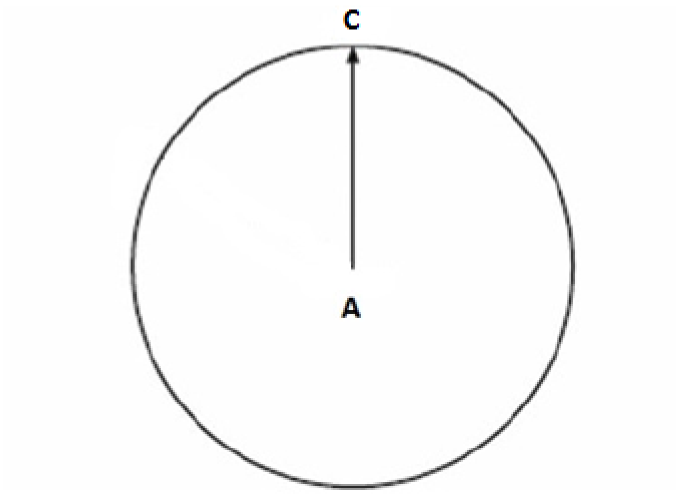
Directions: Imagine you are standing at location A facing location B now point to location C

Trial #2



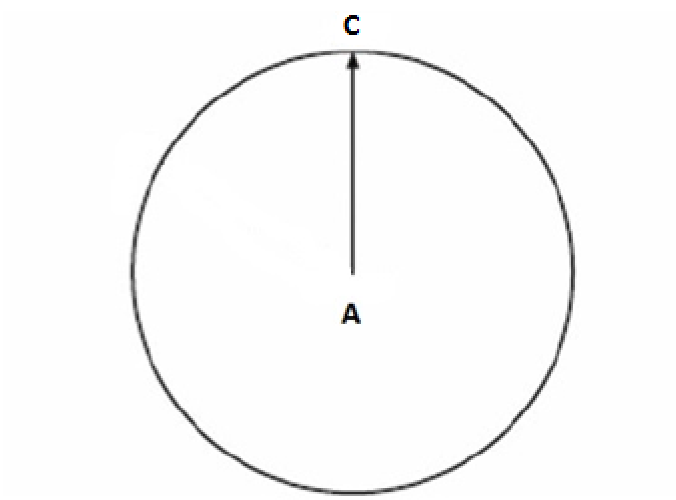
Directions: Imagine you are standing at location A facing location B now point to location D

Trial #3



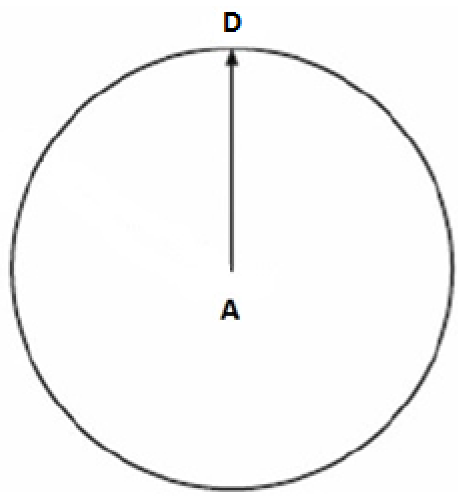
Directions: Imagine you are standing at location A facing location C now point to location B

Trial #4



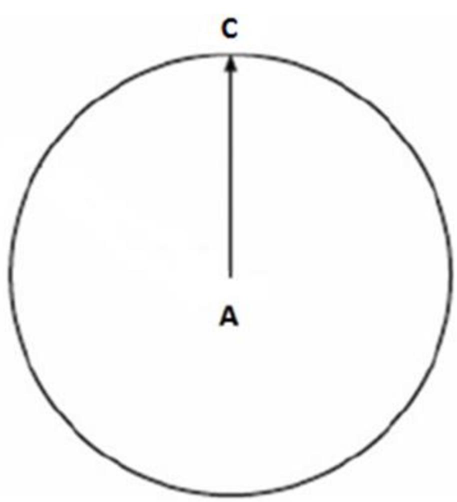
Directions: Imagine you are standing at location A facing location C now point to location D

Trial #5



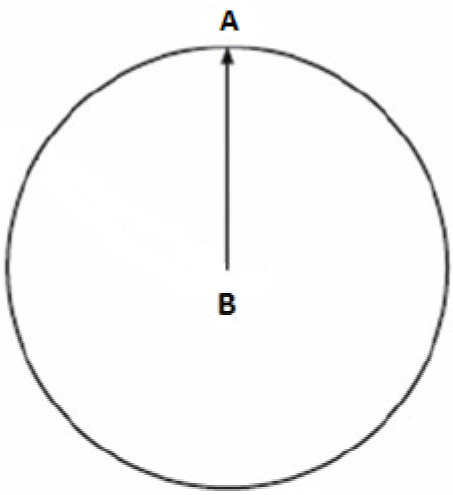
Directions: Imagine you are standing at location A facing location D now point to location B

Trial #6



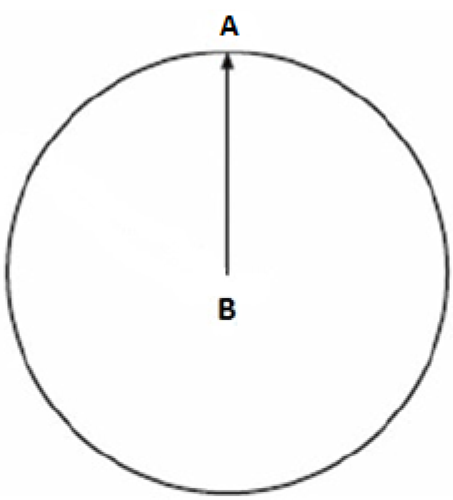
Directions: Imagine you are standing at location A facing location D now point to location C

Trial #7



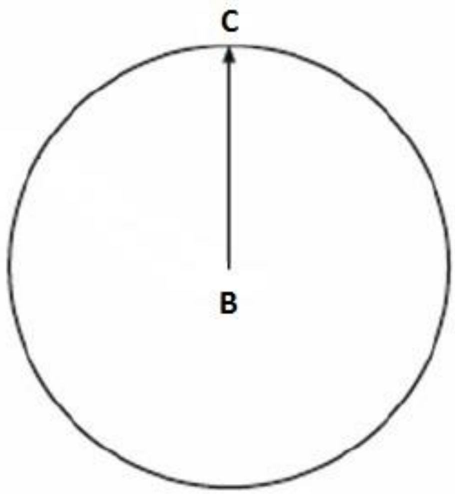
Directions: Imagine you are standing at location B facing location A now point to location C

Trial #8



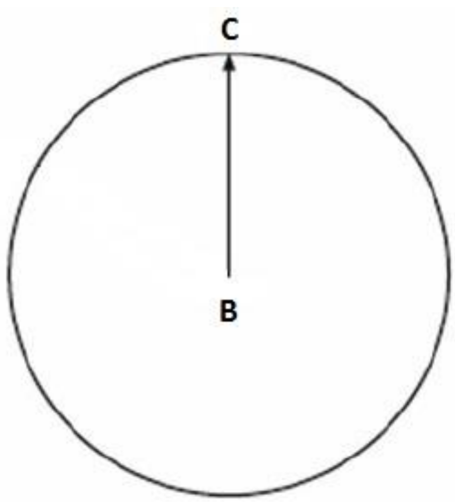
Directions: Imagine you are standing at location B facing location A now point to location D

Trial #9



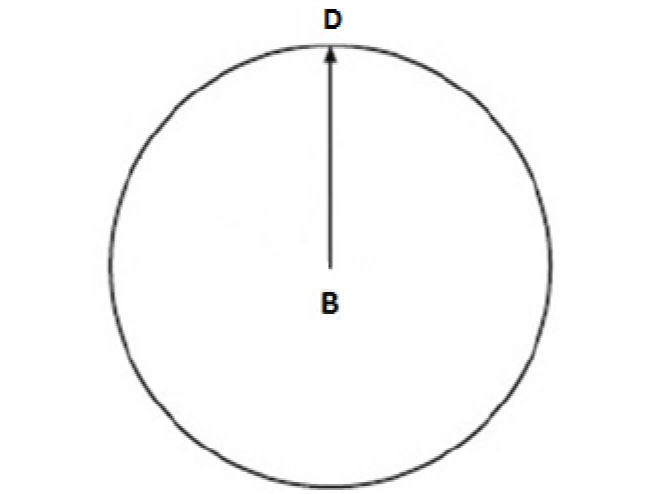
Directions: Imagine you are standing at location B facing location C now point to location A

Trial #10



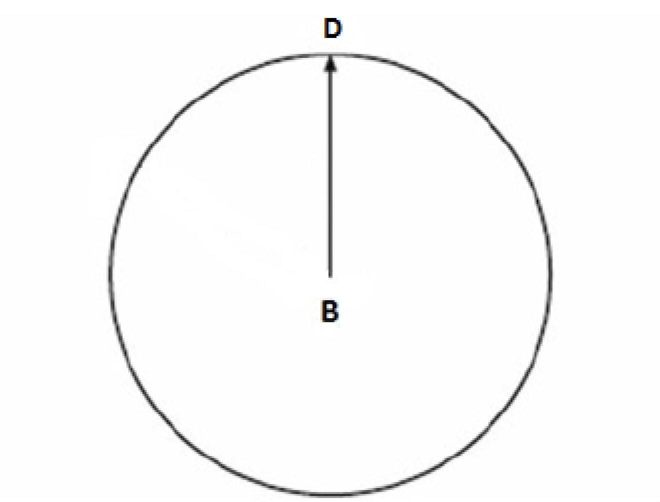
Directions: Imagine you are standing at location B facing location C now point to location D

Trial #11



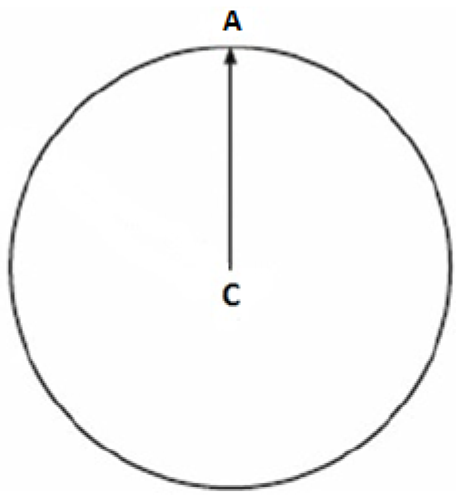
Directions: Imagine you are standing at location B facing location D now point to location A

Trial #12



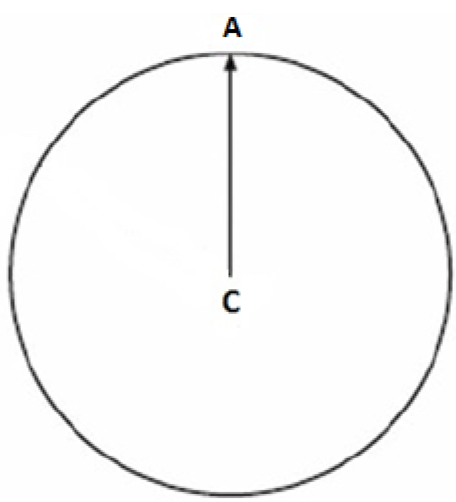
Directions: Imagine you are standing at location B facing location D now point to location C

Trial #13



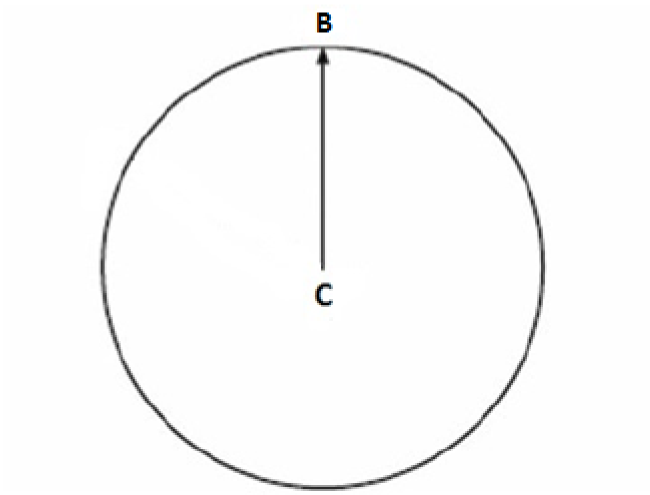
Directions: Imagine you are standing at location C facing location A now point to location B

Trial #14



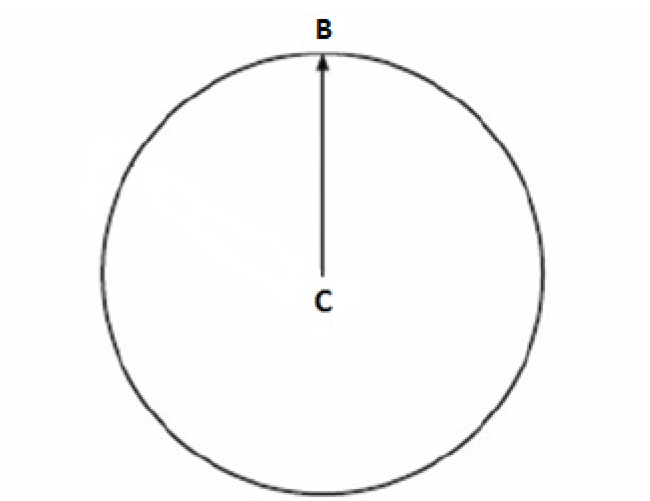
Directions: Imagine you are standing at location C facing location A now point to location D

Trial #15



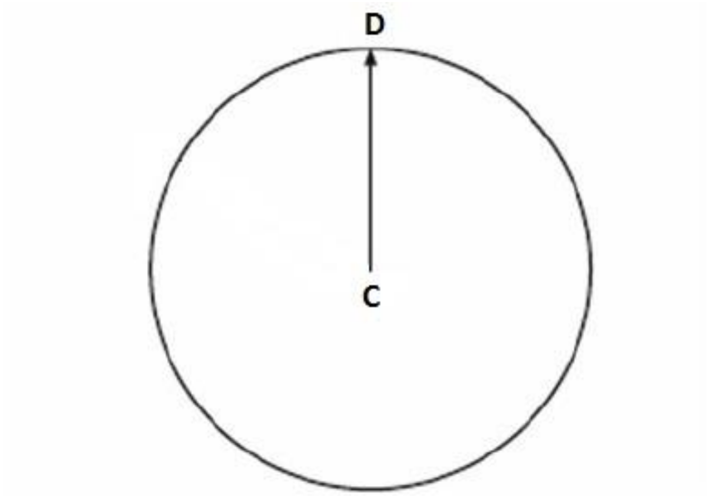
Directions: Imagine you are standing at location C facing location B now point to location A

Trial #16



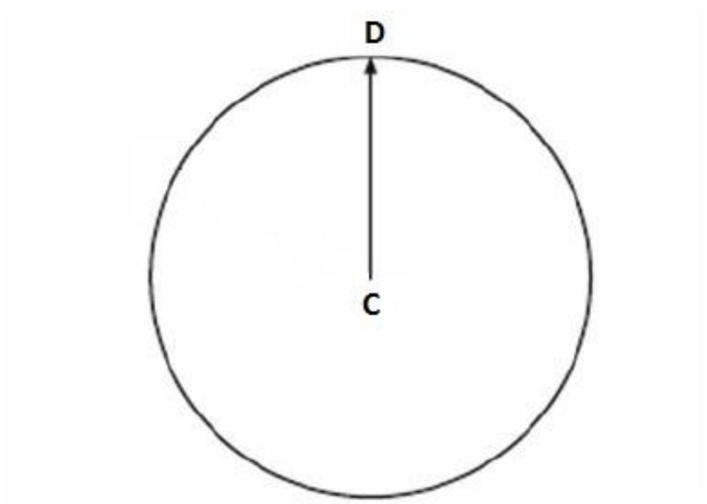
Directions: Imagine you are standing at location C facing location B now point to location D

Trial #17



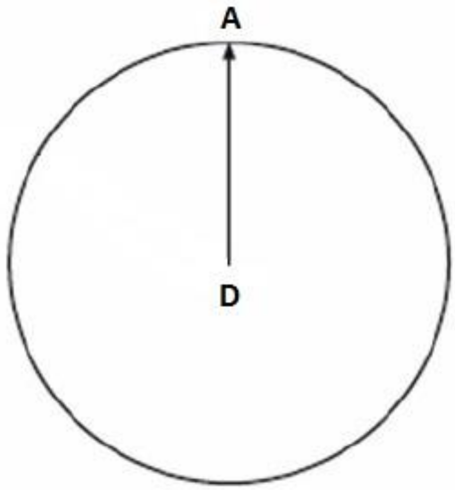
Directions: Imagine you are standing at location C facing location D now point to location A

Trial #18



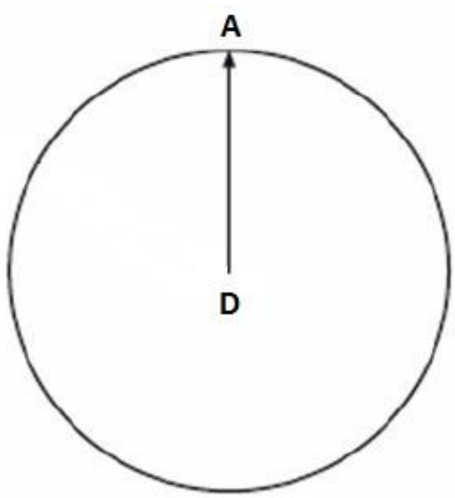
Directions: Imagine you are standing at location C facing location D now point to location B

Trial #19



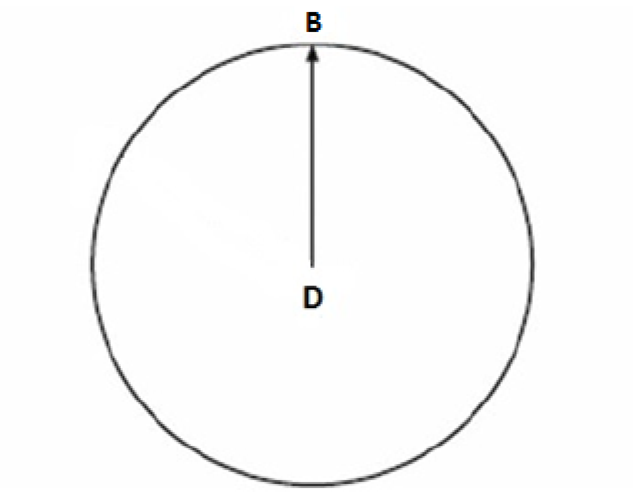
Directions: Imagine you are standing at location D facing location A now point to location B

Trial #20



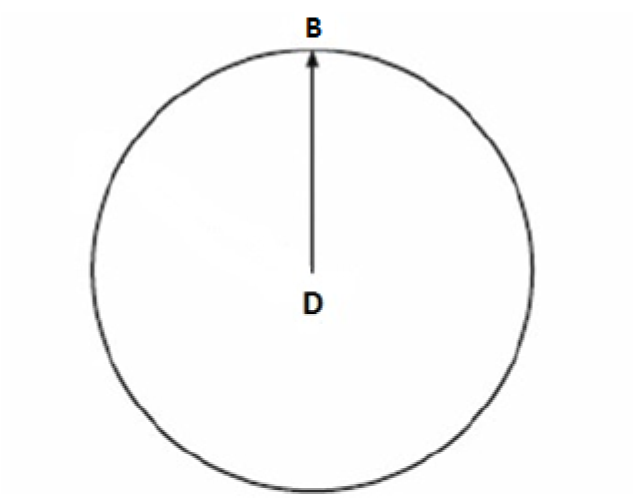
Directions: Imagine you are standing at location D facing location A now point to location C

Trial #21



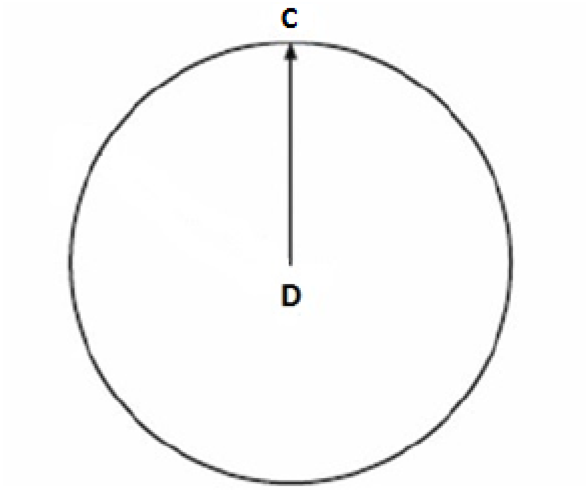
Directions: Imagine you are standing at location D facing location B now point to location A

Trial #22



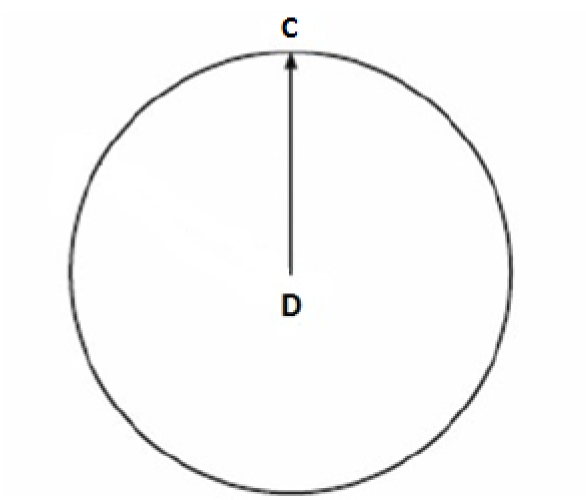
Directions: Imagine you are standing at location D facing location B now point to location C

Trial #23



Directions: Imagine you are standing at location D facing location C now point to location A

Trial #24



Directions: Imagine you are standing at location D facing location C now point to location B

Appendix E

Real-World Sketch Map Script

Instructions delivered by researcher: "In this task, you will create a map of the four locations you have listed previously. This empty box represents a bird's eye view of the city of London. You can draw each of these buildings in any part of the box where you believe they are located in the city. Do not place any buildings outside the box. Please indicate each location by drawing a square or rectangle and labeling it with the correct letter (A, B, C, or D). You may feel free to draw other landmarks such as buildings, trees or roads if that helps you in completing the task however please be sure to mark the four buildings clearly. You will have as much time as you need to complete this task. Do you have any questions?"

Appendix F

Participant # _____

Real World Sketch Map

North

Directions: Please fill in the legend box below according to the four London locations you provided the Researcher previously. Draw an aerial map of the four London locations marking each one as an "X" and labeling it with the correct letter below (A, B, C, or D).

Legend	Location
A	
B	
C	
D	

Appendix G

Silcton Practice/Silcton Free Exploration Script

Instructions delivered by researcher: "The next task is similar to playing a video game. You will be walking through a virtual environment using the mouse and the arrow keys on the keyboard to move around. There are 8 buildings that have blue gems or diamonds in front of them. These buildings are Batty House, Golledge Hall, Harris Hall, Harvey House, Lynch Station, Sauer Centre, Snow Church, and Tobler Museum. You will need to find and remember the names and locations of each of them, as you will be asked questions about them later. To move around, use the arrow keys to move forward, backward, left, and right. You can look around using the mouse. At first, press a key or move the mouse separately until you get used to the way they move [demonstrate]. Before we begin, we're a going to do a practice to make sure we know how to use the controls. Just try stay on the circle path at first and travel around the statue. Now, let's look at one of the diamonds [navigate toward Harris Hall]. Once you are comfortable with the mouse and arrow keys, we can begin. When you're ready to start, click once in the middle of the screen. When you find a building, you can check it off on this page here. You must explore Silcton for a minimum of 10 minutes but can continue to explore for up to a maximum of 20 minutes. Do you have any questions before you begin?"

Appendix H

View of diamonds and Signs in Silcton Virtual Environment

Appendix I

Silcton On-site Direction Estimation Script

Instructions delivered by researcher: "This task is another task similar to the one you did before using locations in the real world that you regularly frequent. In this task you will be standing at one location in Silcton and a prompt at the top of the screen will provide the name of one of the other seven buildings. You will be instructed to rotate the mouse until the crosshair points to the front door of the building you think the prompt is asking for. By clicking the mouse once your answer will register. In some of the trials the front door may be visible from the pointing location, and in other cases it may not be. This means that you must imagine where it would be given your current perspective. Clicking the mouse will also change the name of the building in the prompt. Once you have pointed to all seven buildings from the perspective of the first building you will be automatically repositioned at the next building where you will point using the crosshair to select the seven buildings in the same manner. This will be repeated for all eight buildings. You have as much time as you need as you need to finish this task. Do you have any questions?"

Appendix J

Screenshot of Silcton On-site Direction Estimation Task

Appendix K

Silcton Map Building Task Script

Instructions delivered by researcher: “In this task, you will create a map of the town. This box on the screen is like a bird’s eye view of the town. You can move your cursor over each one to see the name and a front view. For the task, drag and drop each of these buildings to the part of the box where you believe it is located in the town. Use the whole box – so buildings at the edge of the town will be near the edge of the box. Do not place any buildings outside the box. You have as much time as you need to complete the task. Do you have any questions?”

Appendix L

Screenshot of Silcton Map Building Task

Drag and drop the pieces into the box to create a model of the virtual world. Use the entire space of the box.