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Individual Differences in the Formation of Cognitive Maps Based on Different Environments

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Abstract

Individual differences in the ability to build a mental cognitive map of an unfamiliar environment have been studied using both real-world environments (e.g., Ishikawa & Montello, 2006) and virtual environments (VEs) such as Silcton (Weisberg et al., 2014). The current study investigated whether the accuracy of a person's cognitive map of their real-world, familiar environment was associated with the cognitive map they formed of an unfamiliar virtual environment in the lab. Forty-nine female undergraduate students provided frequently visited locations in their city of residence and explored the Silcton VE. They then completed direction estimation tasks that assessed the accuracy of their cognitive map of the familiar, real-world locations and the target locations in the novel Silcton VE. Linear regression showed that real-world direction estimation accuracy predicted Silcton direction estimation accuracy, suggesting that the same underlying skills are used for representing familiar environments and building representations of unfamiliar environments.

Individual Differences in the Formation of Cognitive Maps Based on Different Environments

One of the most fundamental cognitive functions in humans and animals is the ability to navigate in the complex environments (reviewed by Wolbers & Hegarty, 2010). For animals, navigation is an essential task that is important for their survival, like finding food and avoiding predators (reviewed by Wolbers & Hegarty, 2010). In humans, navigation is critical for the everyday life, such as traveling to work or school, going shopping or for a walk (Siegel & White, 1975). People orient in the environment by using spatial cues (i.e., landmarks) of their surroundings such as buildings, trees, and paths that form cognitive maps of that environment (Bennett, 1996; Siegel & White, 1975; reviewed by Wolbers & Hegarty, 2010).

The term ‘cognitive map’ can be defined as a mental representation of the layout of a large-scale environment (Bennett, 1996; Siegel & White, 1975; Tolman, 1948). A cognitive map provides a bird-like view representation of the environment that helps with daily navigational tasks, such as knowing one’s current location and desired destination, judging distances and directions to and from locations (Bennett, 1996; O’Keefe & Nadel, 1978; Tolman, 1948). Another essential feature of cognitive maps is the ability to make novel shortcuts between the two locations that one has never directly travelled between (Bennett, 1996; O’Keefe & Nadel, 1978; Tolman, 1948). For example, Tolman (1948), the first to invent the term ‘cognitive map’, found evidence of such while observing rats that could make novel short-cuts between two points in a maze by taking routes that they never travelled in before. Further, O’Keefe & Nadel (1978) expanded the concept of short-cutting in their study where rats were distinguished based on the way they travel to the goal location. It was found that animals with cognitive maps had flexible and consistent line of movement, even with distractions, towards their goal; where the rats who were travelling from landmark to landmark provided inflexible line of movement to the goal location (Bennet, 1996; O’Keefe

& Nadel, 1978). In humans, direction estimation between the locations is used as an indicator of a cognitive map accuracy since it relies on similar processing as taking novel short-cuts in animals (e.g., Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Ishikawa & Montello, 2006; Weisberg & Newcombe, 2016; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). In addition, sketch maps, a bird-like view representation of the environment, are used to assess the accuracy of the cognitive maps formed (e.g., Ishikawa & Montello, 2006; Schinazi, Nardi, Newcombe, Shipley, & Epstein, 2014).

There are two main frameworks exist that attempt to explain how cognitive maps are formed in a new large-scale environment (Ishikawa & Montello, 2006). Siegel and White (1975) proposed that cognitive maps develop through stage-like processes over time, where a new stage cannot begin until the previous one is acquired. In the first stage, individuals acquire information about objects and scenes in the environment, such as the name of a building and the colour of a tree (Siegel & White, 1975). In the second stage, individuals fulfill the missing parts between the locations acquired in the first stage, creating route knowledge, that helps in forming sequences of landmarks and decisions associated with them, such as go straight for two blocks and turn left at the bus stop (Siegel & White, 1975). In the third and final stage of the framework, cognitive maps are formed by acquiring distances and directional relationships between landmarks (Siegel & White, 1975). Siegel and White (1975) proposed that not everyone is capable of achieving the third stage, because it requires individual routes to be scaled and linked into a comprehensive representation of the environment. Many researchers supported the idea of stage-like theory up until early 1990s (e.g., Aguirre & D'Esposito, 1997; Allen, Kirasic, Siegel, & Herman, 1979; Cousins, Siegel, & Maxwell, 1983; Golledge, 1991; Hazen, Lockman, & Pick, 1978). However, Montello (1998) pointed out that individuals with even a minimal exposure to the new environment could still develop cognitive maps. For instance, individuals could travel to goal locations and back, take novel short-cuts, and estimate distances and directions between landmarks (e.g., Klatzky, Loomis, Golledge, Cicinelli, Doherty, & Pellegrino, 1990; Landau, Spelke, & Gleitman, 1984; Loomis, Klatzky, Golledge, Cicinelli, & Pellegrino, 1993). Thus, Montello's (1998) continuous framework suggests that landmark, route, and cognitive map knowledge could be acquired simultaneously rather than in stages. Despite the differences, both frameworks gave rise to the research literature in spatial navigation (e.g., Ishikawa & Montello, 2006; Risotto & Tonucci, 2002; Weisberg et al., 2014).

Risotto and Tonucci (2002), for instance, found remarkable individual differences in spatial memory abilities of elementary school children in familiar real-world environment. Researchers concluded that children who walk to school on their own achieved the best performances compared to when they were accompanied by adults or driven by a car. This was measured by drawing a sketch map (drawing of landmarks seen on the route) and drawing their movements on a blank map of the bird-like view of the environment (Risotto & Tonucci, 2002). Meaning that individuals who directly exposed and engaged in the environment - perform better on spatial tasks than those who were passively exposed to that familiar environment. Further, Schinazi et al. (2013) conducted a study where participants were actively exposed to a novel real-world environment by walking participants across the city. In the first week, individuals learned two separated routes, followed by two weeks of learning two connecting routes, where connecting routes are used to provide information on how the two separated routes are related (Schinazi et al., 2013). Schinazi et al. (2013) concluded that most individuals improved their performance on spatial memory tasks in a three weeks' span. Therefore, a continuous exposure to the environment could facilitate the improvement in the accuracy of the formation of cognitive maps.

Weisberg and Newcombe (2016) suggested that experimentation in a real-world environment could encounter practical challenges that limit sample size, making it difficult to investigate spatial navigation. Thus, Weisberg et al. (2014) devised a desktop non-immersive virtual environment, called Spatial Intelligence and Learning Center Test of Navigation (Silcton) modeled to match environment and paradigm used by Schinazi et al. (2013). In Silcton participants were asked to travel the two main separated routes followed by two connecting routes (Weisberg et al., 2014). While travelling through the two main routes, participants were instructed to remember the names and locations of four buildings per route, in the total of eight buildings (Weisberg et al., 2014). For the connecting routes, participants were instructed to pay special attention to how the two sets of buildings were positioned in the environment (Weisberg et al., 2014). After participants finished exploring the four routes, their spatial knowledge of the environment was tested with a pointing task (similar to JRDs used by Schinazi et al., 2013) and a model-building task (Weisberg et al., 2014). Weisberg et al. (2014) replicated the findings that address individual differences in the formation of cognitive maps that were found in real-world environment studies (e.g., Ishikawa & Montello, 2006; Schinazi et al., 2013).

However, individual differences in the formation of cognitive maps in familiar and unfamiliar environments are still not well understood. For instance, the longitudinal study by Ishikawa and Montello (2006) examined individual differences in the formation of cognitive maps over 10 weekly sessions. In the first three sessions, participants were individually exposed to the two routes in the unfamiliar environment (Ishikawa & Montello, 2006). Participants were asked to pay attention and remember the names of the landmarks they saw while traveling. In session four, they were also introduced to the connecting route where participants were asked to integrate the two separated routes (Ishikawa & Montello, 2006). After each session participants were asked to complete spatial memory tasks, including distance and direction estimation tasks, and drawing sketch maps (Ishikawa & Montello, 2006). Ishikawa & Montello (2006) found that participants' overall performance did not improve over the 10 weeks' span noting that some participants did have a significant overall improvement. Researchers further found three distinct groups based on participants' performance over time (Ishikawa & Montello, 2006). They found that there were participants who performed well from the beginning and continued to perform well throughout the experiment (Ishikawa & Montello, 2006). There were also participants who failed to acquire knowledge of spatial environment and therefore could not form the accurate cognitive map (Ishikawa & Montello, 2006). Participants in the third group whom performance was intermediate, improved slightly overtime, but most of the them still could not perform as well as participants in the first group (Ishikawa & Montello, 2006). These findings suggest that there are individual differences in the formation of cognitive maps making some people better in spatial navigators than others. It may also suggest that performance in the unfamiliar environment can predict performance in the familiar one. However, there is not enough research that investigated how performance on spatial memory tasks in the familiar, real-world environment could be related to the unfamiliar VE.

The present study investigated whether the accuracy of a person's cognitive map of their real-world, familiar environment was associated with the cognitive map they formed of an unfamiliar VE in the lab. Participants completed tests that assessed their spatial memory abilities in direction estimation and map building accuracy using both real-world locations and landmarks in Silcton. Direction estimation task for real-world environment (similar to SOT; Hegarty & Waller, 2004) was assessed using frequently visited locations that participants traveled to in order to create retrieval of information from memory that is used in Silcton direction estimation task. Map building ability was assessed using sketch maps in a real-world familiar environment, and Silcton model building task and Silcton sketch map were used to assess spatial navigation for unfamiliar VE. It was anticipated that real-world performance would predict Silcton VE performance in direction estimation and map building tasks. As a secondary research questions, I was also interested in whether time lived in the place of residence would predict spatial ability performance in real-world direction estimation and sketch map tasks. It was anticipated that the longer individuals resided in the city, the better they would perform on spatial ability tasks (e.g., Schinazi et al., 2013; Stephan, Jäschke, Oberzaucher, and Grammer, 2014). Also, I was interested whether there would be an effect in the order of Silcton map building and Silcton sketch map on the map building accuracy in the lab. It was anticipated that participants who drew Silcton sketch map first followed by Silcton map building task would perform better on Silcton map building, because they would use landmarks they additionally drew in a sketch map as a reference point that could potentially aid them in having more accurate map of the environment.

Method

Participants

Forty-nine undergraduate students (1 male, 48 females; mean age = 19.48, *SD* = 3.02, range = 17-32) taking an introductory to Psychology course from Brescia University College in London, Ontario were recruited to participate in this study using the Brescia Psychology Research Participation System. Participants were randomly assigned into one of two groups, forming the group that completed Silcton map building first (where participants were asked to complete the Silcton map building task prior to drawing the Silcton sketch map) and the group that completed Silcton sketch map first (where participants were asked to draw a Silcton sketch map followed by Silcton map building task). Participants were tested individually and received two research credits (one credit per thirty minutes of participation) in return for participation in the study.

Materials

Demographic Questionnaire. The demographic questionnaire gathered information including the participant's age, sex, and time lived in London. The demographic questionnaire information for participants numbered one to eighteen was collected as part of another study.

Location Gathering for Real-World Tasks. After reading instructions on how to complete the task (see researcher's script in Appendix A), participants were asked to provide four to ten locations they frequently traveled to in their daily life in the City of London and the frequency with which they visited those locations in a typical week (see location gathering sheet in Appendix B). The four locations with the highest frequency were subsequently used for the real-orld direction estimation task and the real-world sketch map task. If there were more than four locations provided with the same frequency of the visit, then the first four locations with the highest frequency were recorded and used for the real-world tasks. Google Maps was used to assure the accuracy of the locations provided, and aid participants who did not remember addresses very well. There was no time limit for this task.

Real-World Direction Estimation Task. The real-world direction estimation task was a paper-and-pencil task that measured how well participants could estimate the directions between the frequently visited locations based on memory (see the real-world direction estimation booklet in Appendix C). 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 that were obtained from the location gathering booklet. On each of the eight trials, there was a label (A, B, C, or D) in the middle of a circle corresponding to one of the locations, and another label was at the top of circle corresponding to another frequently visited location. Participants were asked to imagine standing at one location in the center of the circle facing another location at the top, and to draw an arrow from the center of the circle to the direction of the other two locations from this specific facing direction. There was no time limit for this task. Responses were scored by comparing the participants' estimated angles in degrees with the actual angle in degrees to calculate their absolute error where a higher error indicated poorer performance and a lower error indicated better performance.

Real-World Sketch Map. After reading instructions on how to complete the task (see researcher's script in Appendix D), participants were asked to complete the real-world sketch map task. The real-world sketch map task was a paper-and-pencil task that measured how well participants could create a map of four frequently visited locations they had provided in the location gathering booklet by drawing each one of the locations in the empty box that represented a bird's-eye-view of the City of London (see real-world sketch map task in Appendix E). Participants drew each of the buildings inside the box where they believed those places are located and did not place any landmarks outside of the box. Participants were asked to indicate each location with an "X" and accurately label it A, B, C, or D. Also, participants could draw any other landmarks, including roads, trees, parks, road signs if it helped improve their accuracy. There was no time limit for this task.

Gardony Map Drawing Analyzer (GMDA) was used to determine the overall accuracy of real-world sketch maps drawn (Gardony, Taylor, & Brunyé, 2016). The actual real-world map was created by using the latitude and longitude coordinates of the real-world locations provided by the participants. Landmark locations on the sketch map were specified in a basic mode where landmarks were represented by a single 2 - D point (x, y). The software then compared real-world sketch maps that participants drew to actual real-world environments. GMDA 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 scores indicating higher configural accuracy of the participant's map with the actual map of the environment.

Silcton Virtual Environment Practice and the Route Learning (VE; Weisberg et al., 2014.) The Silcton VE practice and route learning followed by spatial memory ability tasks were administered via 15” Toshiba Satellite Pro R50-C laptop running Windows 8.1 with a 64-bit Intel Core Processor @ 2.40GHz. Participants completed the Silcton free exploration task on the laptop computer. The Silcton VE consists of buildings that differ in architectural design, winding paths that connect those buildings and non-building objects, such as trees, benches, signs, and trash cans to mimic real-world unfamiliar environment (see Silcton VE landmark examples in Appendix F). Participants used the arrow keys to navigate around the map (forward, backward, left, and right), and a mouse was used for rotation to enable participants to see environment in 360°. The researcher demonstrated how use the arrow keys and the mouse, and participants had a chance to practice and become familiar with the controls. Once participants felt comfortable with navigation, the route learning phase began.

In the route learning phase, participants explored four different routes within the same map. Participants were instructed to locate and remember the names of the eight building with a blue diamond floating above the route and next to a nearby sign with building’s name for the first two routes, locating four buildings per route. Participants were instructed that the two routes were in separate parts of the same VE and that subsequent testing would occur on all eight buildings (see researcher’s script in Appendix G and Silcton learning phase example in Appendix H). After learning all eight buildings, participants traveled on two paths that connected the first two routes to each other and were told to pay attention to how the two sets of buildings were positioned in the VE. Participants were told that these two routes would provide additional spatial information. For all routes, participants traveled from the start to the finish and back to the start and had minimum 10 to maximum 20 minutes for exploration.

Silcton Direction Estimation Task. This task was part of the Silcton VE software suite and was administered on a laptop. The task measured participants' direction estimation ability using the eight target buildings from Silcton (see researcher's script in Appendix I). For Silcton direction estimation task participants were asked to estimate the direction of the buildings they have learned in Silcton route learning phase. On each trial, the name of the building appeared at the center of the circle while the other name of the building was at the top of the circle. Participants were instructed to imagine standing at the center of the circle facing another building that is at the top of the circle, the list of all eight buildings was presented in a vertical line in the middle of a circle as titles that could be dragged and dropped around the circle indicating the direction of each building they learned in VE (see Appendix J). Participants could roll the cursor over to get the views of all the buildings and had to complete eight of these circles, so each building served as the center of the circle once. There was no time limit for this task. Responses were analyzed within the Silcton VE software by comparing the participants' estimated angle in degrees with the actual angle in degrees to calculate their absolute error where a higher error indicated poorer performance and a lower error indicated better performance.

Silcton Map Building. This task was part of the Silcton VE software suite and was administered on a laptop (see Silcton map building task in Appendix K). Participants were asked to create a map of eight buildings they learned in the route learning phase by dragging and dropping each one of the buildings in the empty box that represents a bird's-eye-view of Silcton. Participants could locate each of the buildings inside the box where they believed those places are located and not placing any landmarks outside of the box. An overhead view of each of the eight buildings was positioned below the box, so participants could run their cursor over the buildings to see the front view of each building. There was no time limit for this task. Responses were analyzed within the Silcton VE software resulting in R^2 value ranging from 0 - 1.0 with higher scores indicating higher accuracy of the participant's map with the actual map of the virtual town.

Silcton Sketch Map. After reading instructions on how to complete the task (see researcher's script in Appendix L), participants were asked to complete the Silcton VE sketch map task. The Silcton sketch map task is a paper-and-pencil task that measured how well participants could create a map of eight locations, they have learned in the VE route learning phase, by drawing each one of the locations in the empty box that represented a bird's-eye-view of the city (see Silcton sketch map task in Appendix M). Participants were asked to indicate each location with an X and accurately label them by corresponding letter. The list of the buildings was presented for participants (Batty House, Golledge Hall, Harris Hall, Harvey House, Lynch Station, Sauer Centre, Snow Church, and Tobler Museum). Also, participants could draw any other landmarks including roads, trees, benches, and road signs if it helped to improve their accuracy. There was no time limit for this task.

Gardony Map Drawing Analyzer (GMDA) was used to determine the overall accuracy of Silcton sketch maps drawn (Gardony, Taylor, & Brunyé, 2016). The actual Silcton VE map was created by using the graphical interface and arranging landmark boxes on a perfect map of the actual environment. Landmark locations on the sketch map were specified in a basic mode where landmarks were represented by a single 2 - D point (x, y). The software then compared Silcton sketch maps that participants drew to actual Silcton VEs. GMDA 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 scores indicating higher configural accuracy of the participant's map with the actual map of the virtual town.

Procedure

Participants were given a letter of information describing the experimental procedure and were encouraged to ask questions if they were unsure of the procedures and signed their informed consent form. Participants first completed the demographic questionnaire followed by location gathering task for real-world pointing tasks. After gathering the information about frequently visited locations, participants completed the real-world direction estimation and the real-world sketch map tasks. Next, participants were introduced to the Silcton VE and were given a chance to practice using the control keys and the mouse followed by the Silcton VE route learning phase where participants had to learn the names and locations of the buildings. Immediately after the route learning task, they completed the direction estimation task. Then participants in the Silcton map building first group completed Silcton VE map building task followed by Silcton sketch map, and participants in the Silcton sketch map first completed the Silcton VE sketch map first followed by the VE map building. 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 approximately took 60 minutes.

Results

Data were analyzed using SPSS. A Pearson correlation analysis was completed to determine the associations between age, time lived in London (in months), frequency of frequently visited location in London, error scores on Real-World direction estimation and Silcton direction estimation, accuracy scores on the Real-World sketch map, the Silcton model building, and the Silcton sketch map (see Table 1). There was a significant moderate positive correlation between age and time lived in London, indicating that as participants got older, they had resided in London for a longer period. There was also a significant moderate negative correlation between age and performance on the real-world sketch map task, which indicated that as participants got older, they drew less accurate maps of the environment for the real-world sketch map task. Next, there was a significant moderate positive correlation between time lived in London and frequency of regularly visited locations in London,

Table 1.

Means, Standard Deviations, and Correlations for Demographic Questionnaire, Real-World Direction Estimation, Real-World Sketch Map, Silcton Direction Estimation, Silcton Map Building, Silcton Sketch Map, and Task Order

				Real-World measures		Silcton measures					
	Age	Months Lived in London	Frequency of Visited Locations	Direction Estimation	Sketch Map	Direction Estimation	Map Building	Sketch Map	*M*	*SD*	*N*
Months Lived in London	.35*								85.00	109.84	47
Frequency of Visited Locations	.19	.40**							1.80	.72	49
Real-World Direction Estimation	-.16	-.12	-.18						59.49	25.52	48
Real-World Sketch Map	-.30*	-.02	.02	-.48**					.71	.27	48
Silcton Direction Estimation	.08	.29	.17	.32*	-.20				73.35	8.19	49
Silcton Map Building	-.14	-.12	-.08	.18	.02	-.12			.42	.24	49
Silcton Sketch Map	-.22	-.07	-.10	.03	.09	-.11	.76**		.44	.26	49
Task Order	-.15	-.01	-.06	.06	-.02	.24	.21	.08	1.49	.51	49

Note. * $p < .05$, ** $p < .01$. Bivariate correlations between demographic questionnaire and dependent variables in the study. Real-World direction estimation and Silcton direction estimation are scored as mean error, so higher values indicate worse performance.

indicating that the more time participants resided in London the more often they visited the frequently visited locations in the city. There was also a significant moderate negative relationship between real-world direction estimation and real-world sketch map performances (see Figure 1). It indicates that participants who performed well in the real-world direction estimation task also performed well in the real-world sketch map task. Next, there was a significant strong positive relationship between Silcton VE map building performance and Silcton VE sketch map performance, indicating that participants who did well in the Silcton map building task also did well in the Silcton sketch map task (see Figure 2).

In addition, a Pearson correlation analysis showed a strong positive correlation between real-world direction estimation and Silcton VE direction estimation performance. A linear regression was carried out to investigate the relationship between the performance in real-world direction estimation and Silcton direction estimation tasks (see Figure 3). A linear regression analysis revealed that real-world direction estimation performance was a significant predictor of Silcton direction estimation performance, $\beta = .32$, $p = .03$ accounting for 10.10 % of variance in Silcton direction estimation, $R^2 = .10$, $F\ (1, 47) = 5.15$, $p = .03$.

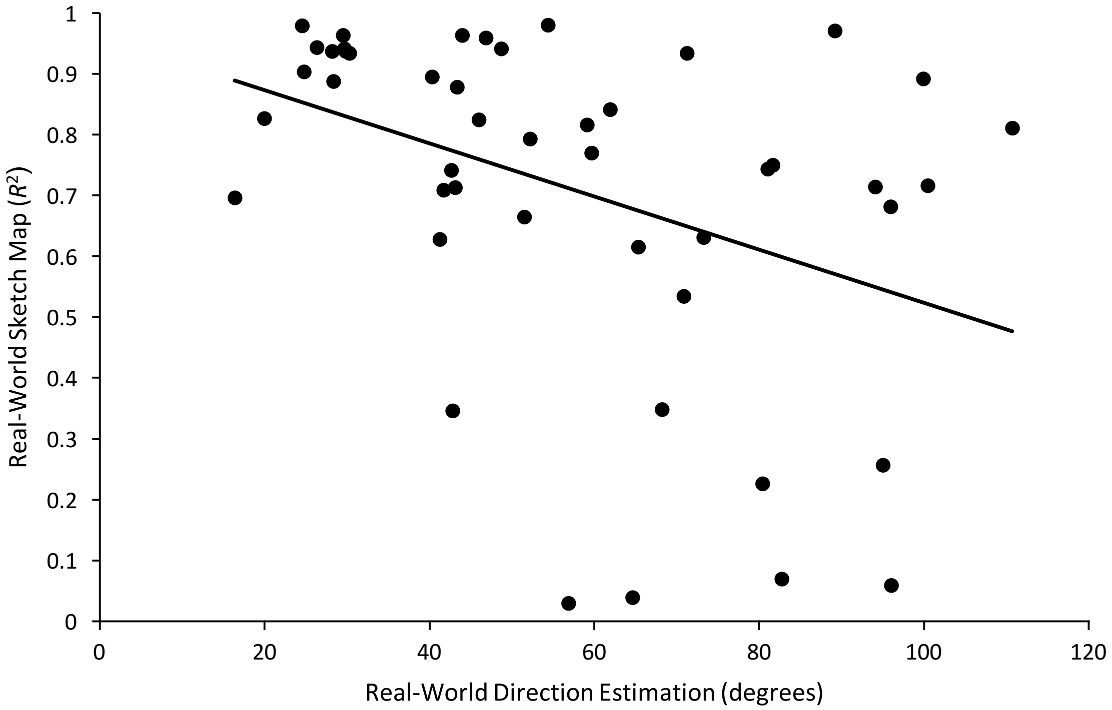

Figure 1. Scatterplot and line of best fit for accuracy scores on Real-World sketch map (y-axis) and the error scores on Real-World direction estimation (x-axis). Higher scores on Real-World direction estimation tasks indicate poorer performance.

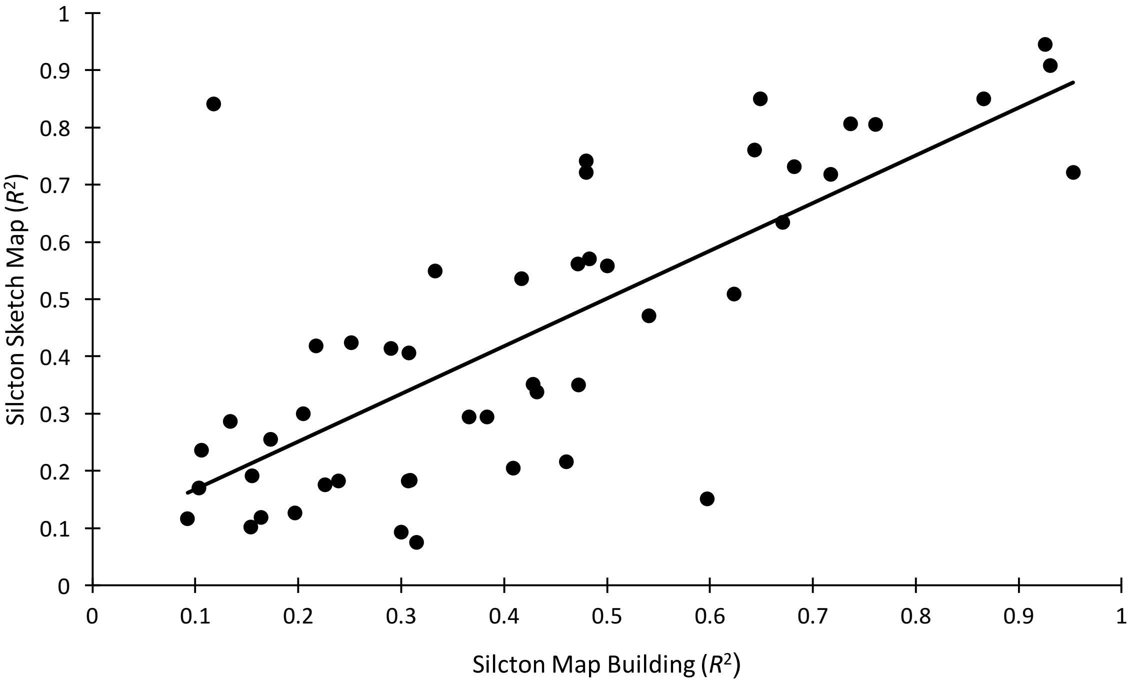

Figure 2. Scatterplot and line of best fit for accuracy scores on Silcton sketch map (y-axis) and Silcton map building (x-axis).

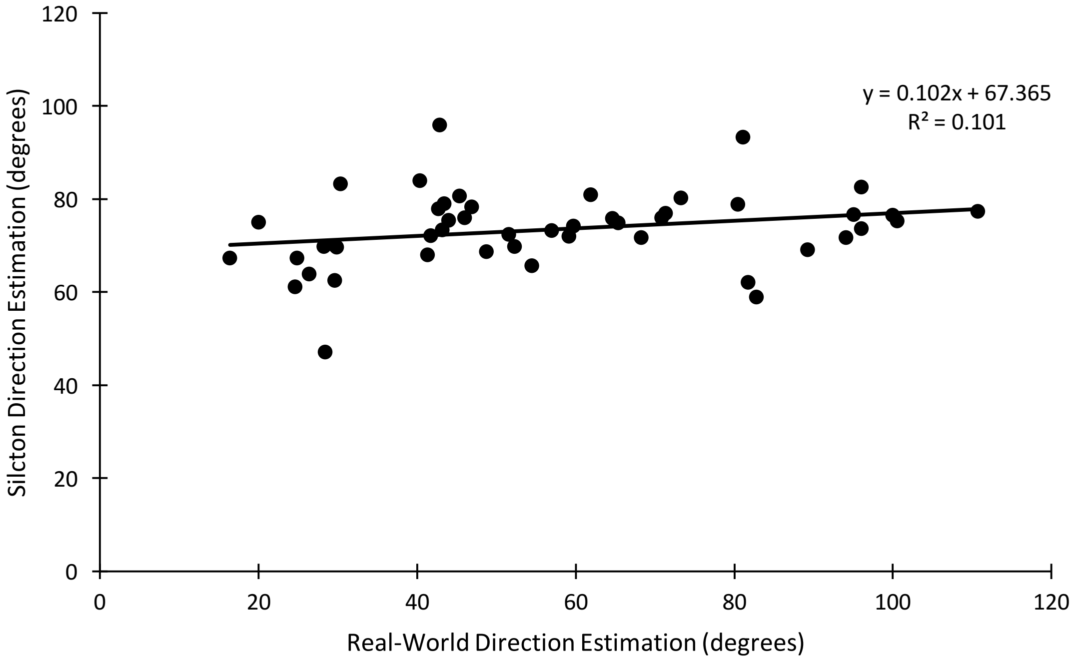

Figure 3. Scatterplot and line of best fit for error scores on Silcton direction estimation (y-axis) and the Real-World direction estimation (x-axis). Higher scores on Silcton and Real-World direction estimation tasks indicate poorer performance.

Independent samples t-tests were conducted to determine whether there were order effects on performance in map building and sketch map tasks in the Silcton VE. The first test did not show a significant difference between the group who completed Silcton map building first and the group who completed the Silcton sketch map first on Silcton map building task, $t\ (47) = -1.44$, $p = .16$. The second independent t-test also found no significant difference in order effects on Silcton sketch map task, $t\ (47) = -0.56$, $p = .66$.

Discussion

The present study investigated whether the accuracy of a person's cognitive map of their real-world, familiar environment was associated with the cognitive map they formed of an unfamiliar VE in the lab. Main hypothesis has been partially supported, indicating that real-world direction estimation accuracy predicted Silcton direction estimation accuracy, suggesting that the same underlying skills were used for representing familiar environments and building representations of unfamiliar environments. However, there was no association between real-world sketch map and Silcton map building nor Silcton sketch map tasks, suggesting that there could be a different factor, such as familiarity effect, that accounts for no relationship between familiar environments and unfamiliar environments. Interestingly, time lived in the real-world location did not predict real-world performance in direction estimation and sketch map tasks, suggesting that the accuracy of their cognitive maps was not associated with familiarity and exposure to the environment. Also, there was no significant difference in the test order between the group that did the Silcton map building task first and the that did the Silcton sketch map task first in the accuracy of the cognitive map formation. On the other hand, significant strong positive relationship was found between Silcton VE map building and Silcton VE sketch map performances, suggesting that VE map building task is an accurate measure of spatial navigation.

The results of the study also indicated that there was a positive moderate relationship between real-world direction estimation and real-world sketch maps, suggesting there may be a common underlying mechanism across measures.

The present study demonstrated that the accuracy of a person's cognitive map of their real-world, familiar environment was associated with the cognitive map they formed of an unfamiliar VE in the lab. It was found that the real-world direction estimation accuracy predicted Silcton direction estimation accuracy. This finding suggests there are individuals that form more accurate cognitive maps no matter in what environment there are in. Ishikawa and Montello (2006) found similar results in the real-world environment where participants were gradually exposed to the novel environment for 10 weeks. They found that people who performed well in novel real-world environment continued to perform in the similar fashion even after continuous exposure to the environment (Ishikawa & Montello, 2006). The current study also showed that no association between real-world sketch map and Silcton map building nor Silcton sketch map tasks. This result is supported by the study of Stephan et al. (2014). They found the accuracy of female participants' sketch maps increased as duration of residence in city they resided. In addition, accuracy of cognitive maps was influenced by home range size and number of frequently visited places (Stephan et al., 2014). However, time lived in place of residence did not affect the accuracy of sketch maps in male participants (Stephan et., 2014). It may suggest that in order to draw more accurate map of the environment, female participants need more exposure to that environment. In addition, the moderate relationship between the real-world direction estimation and the sketch map tasks was found, suggesting that both tasks assess the accuracy of cognitive maps formed in a similar way. However, there was no relationship found between Silcton direction estimation and Silcton map building nor Silcton sketch map tasks, suggesting that Silcton direction estimation task is not related to map building tasks in the virtual, unfamiliar environment. Even though it can be concluded that performance on real-world sketch maps in familiar environment cannot predict the performance on Silcton map accuracy tasks in unfamiliar environment, the reasons as to why need more investigation. It can be suggested that the results found are due to not having enough exposure to the unfamiliar environment.

Interestingly, time lived in the place of residence did not predict performance on real-world direction estimation and sketch map tasks, suggesting that the accuracy of their cognitive maps was not associated with familiarity and exposure to that environment. This finding is consistent with the results found by Ishikawa and Montello (2006). Researchers found no overall significant improvement in performance on spatial memory tasks across 10 weeks' span. However, they did find individual differences in the formation of cognitive maps, forming three groups: accurate navigators, poor navigators, and improved navigators (Ishikawa & Montello, 2006). Improved navigators did show a significant development on distance and direction estimation tasks as well as sketch maps (Ishikawa & Montello, 2006). Similar results were found in the study investigating home range in an urban environment and spatial abilities in Vienna residents (Stephan et al., 2014). Researchers discovered that the accuracy of participants' sketch maps increased as duration of residence in Vienna also increased. This finding was true only for female participants. This idea was also supported in familiarity effect phenomena proposed by Holahan (1978). The familiarity effect suggests that the more exposure individuals get of an environment the more accurate their cognitive map is of that environment. Since in the present research participants were not divided into the groups based on their performance, it is difficult to conclude whether continuous exposure to the environment would influence performance in spatial memory tasks.

The results showed there were no order effects on performance in map building and sketch map tasks in Silcton VE, meaning the group who drew sketch map first did not have better map building accuracy than the group who completed the map building task first. Past research suggested that landmarks are important for building accurate cognitive maps, because they can be used as reference points for navigation (e.g., Lovelace, Hegarty, & Montello, 1999; Weisberg et al., 2014). Lovelace et al. (1999) found that for unfamiliar environments, landmarks were highly correlated with quality of cognitive maps. In Silcton sketch map tasks participants were asked to draw the landmarks they learned during route learning, they could also draw any additional landmarks that could aid their map accuracy. Where in Silcton map building participants could not use any additional landmarks. Therefore, it was thought that participants in the group that completed the Silcton VE sketch map task first followed by Silcton VE map building task would perform better on Silcton map building and Silcton sketch map tasks. However, result did not provide support for this hypothesis. Interestingly, there was a significant strong positive relationship between Silcton VE map building performance and Silcton VE sketch map performance, indicating that participants who did well on Silcton map building task also did well on Silcton sketch map task. These two findings suggest that there is no difference in performance between the tasks, meaning that landmarks in unfamiliar environment may not play a big role in the formation of accurate maps. It further suggests that Silcton map building task is a valid measure for testing spatial memory ability.

There are a few limitations in the present study that can be addressed with further research. There is large amount of evidence suggests that there are individual differences in the formation of cognitive maps (e.g., Ishikawa &Montello, 2006; Stephan et al., 2014; Weisberg et al., 2014, Weisberg & Newcombe, 2016). Researchers that find individual differences in the cognitive maps, also divide participants into the three groups according to their performance, forming a group of people who perform well on the tasks, another group that contains people who are imprecise in their spatial ability but could possible improve, and the last group whom do not perform well, and therefore cannot form a cognitive map of the environment (e.g., Ishikawa &Montello, 2006; Weisberg et al., 2014, Weisberg & Newcombe, 2016). In the current study participants were not separated into the groups according to their performance to further investigate individual differences. Future research can be conducted examining the relationship between real-world spatial ability tasks and time lived in the city of residence in imprecise navigators (imprecise navigators can improve their performance with the higher exposure to the environment; Ishikawa &Montello, 2006).

Also, it was suggested that female participants need more exposure to the environment to form the more accurate cognitive map of the environment compared to males (Stephan et al., 2014). The current study showed no relationship between real-world sketch and Silcton model building tasks in female participants, supporting the finding of Stephan et al. (2014). Given these findings, future research should further investigate the sex differences in sketch map tasks in familiar and unfamiliar environments. Another route in exploration of individual differences in sketch maps could be done by investigating participants' academic background. There is an evidence that spatial ability is a significant and unique predictor of entrance into engineering, technology, sciences, and mathematics disciplines (e.g., Wai, Lubinski, & Benbow, 2009) something that was not looked at the current study. More recent evidence from self-reported measures, obtained by Santa Barbara Sense of Direction scale (SBSOD), observed individual differences in spatial abilities across academic disciplines (Hegarty, Crookes, Dara-Abrams, & Shipley, 2010). It was found that scientists and geographers have significantly higher spatial ability than psychologists and biologists (Hegarty et al., 2010). Future research could improve current understanding of individual differences in the formation of cognitive maps by examining the relationship between spatial memory abilities and academic disciplines.

In conclusion, performance on direction-estimation task in the familiar, real-world environment predicted the accuracy of person's cognitive maps in Silcton direction estimation task in the unfamiliar, virtual environment. There was no relationship between model building tasks across environments, suggesting that in order for female participants to form the more accurate representation of the environment, they will need more exposure to that environment. These findings provide an important information regarding individual differences in the formation of cognitive maps across environments. In addition, present research provided support for validity of Silcton map building task. Given the current results, more research is needed to investigate the relationship between real-world spatial ability tasks and time lived in the place of residence. Also, the relationship between academic disciplines and performance on model building could be investigated in the future as well as the association between the model buildings tasks and environment by looking at the sex differences.

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Appendix A

Script for Location Gathering

Researcher reads the instructions verbatim to the participant: “For the next couple of tasks I will need locations of places within London that you go to frequently in your daily life. For example, these locations could be a campus building or Home/residence building. Other locations may include places such as: your workplace, a mall, a gym, a grocery store, or other places you visit 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. I require a minimum of four locations you frequently visit in your daily life for the next tasks; however, I would encourage you to provide as many locations as you feel you with a maximum of 10 locations. Do you have any questions before we begin?”

Appendix B

Location Gathering booklet

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 C

Real-World Direction Estimation Task

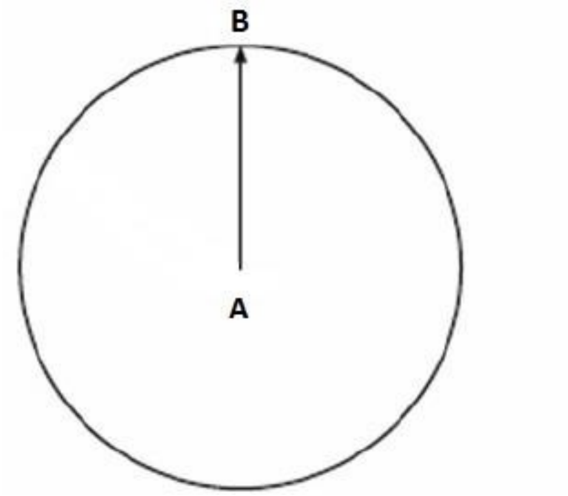
Participant #_________________ Researcher initials: ____________________________

Real World Direction Estimation Task

Instructions: In this task, you will imagine you are standing at one of the locations you frequently visit in the center 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 center of the circle indicating the direction of both remaining locations 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.

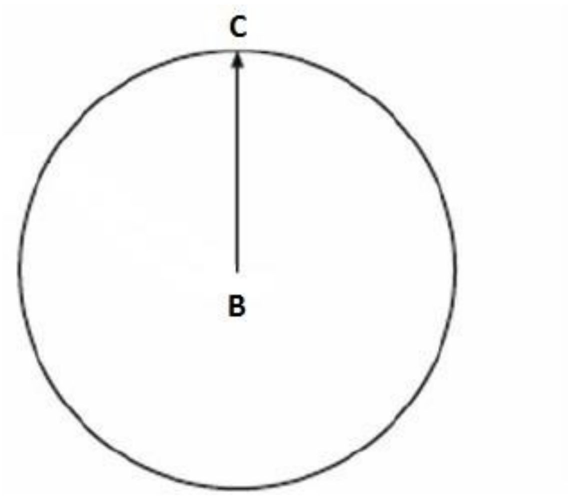
Legend	Location
A	
B	
C	
D	

Trial #1



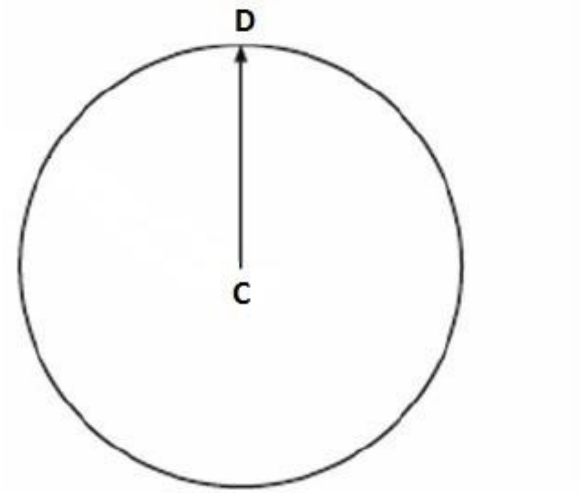
Directions: Imagine you are standing at location A facing location B now point to location C and location D.

Trial #2



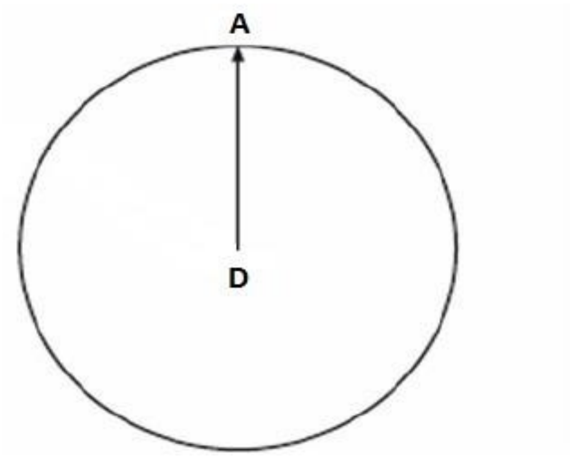
Directions: Imagine you are standing at location B facing location C now point to location A and location D.

Trial #3



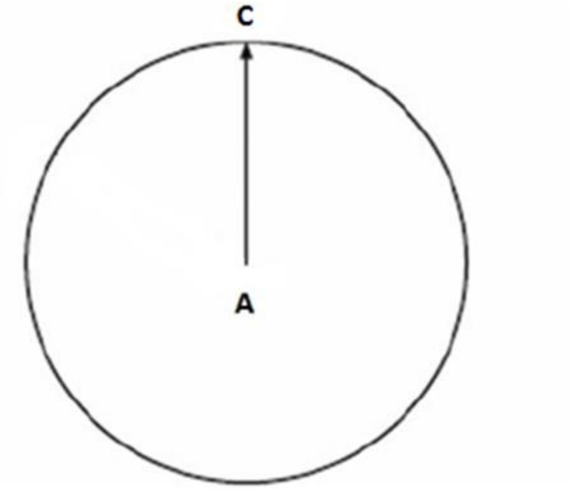
Directions: Imagine you are standing at location C facing location D now point to location A and location B.

Trial #4



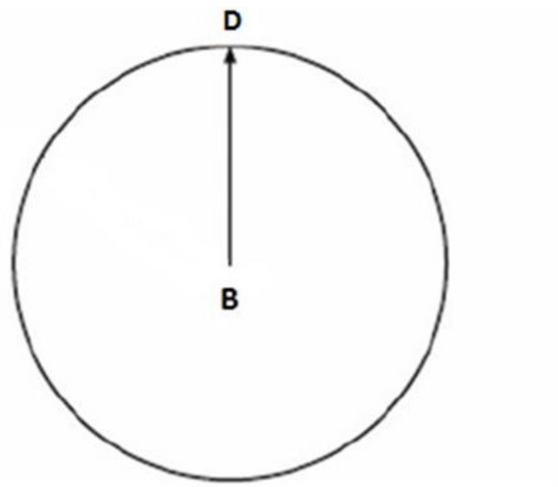
Directions: Imagine you are standing at location D facing location A now point to location B and location C.

Trial #5



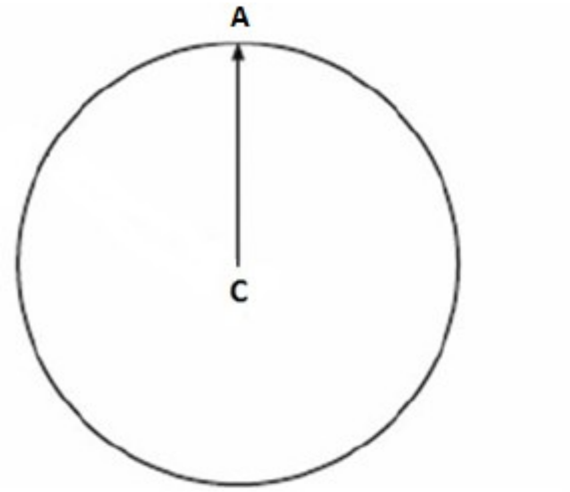
Directions: Imagine you are standing at location A facing location C now point to location B and location D.

Trial #6



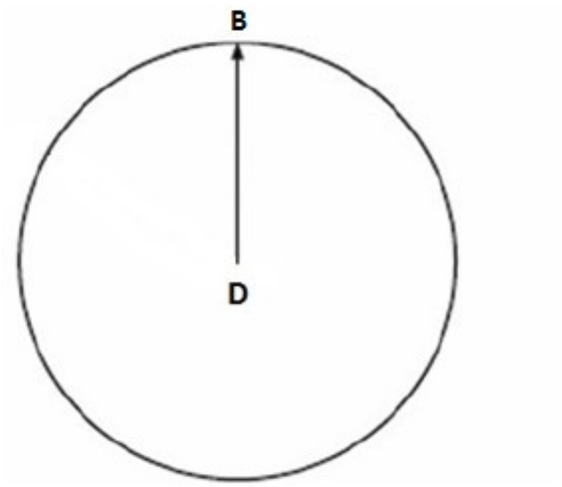
Directions: Imagine you are standing at location B facing location D now point to location A and location C.

Trial #7



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

Trial #8



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

Appendix D

Script for Real-World Sketch Map task

Researcher reads the instructions verbatim to the participant: “In this task, you will create a map of the four locations you visit most often in your daily life. This empty box represents a bird’s eye view of the city of London. You can draw each of these buildings (points to the buildings in the legend) 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 an “X” 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 before you begin?”

Appendix E

Real-World Sketch Map Task

Participant # _____

Real World Sketch Map

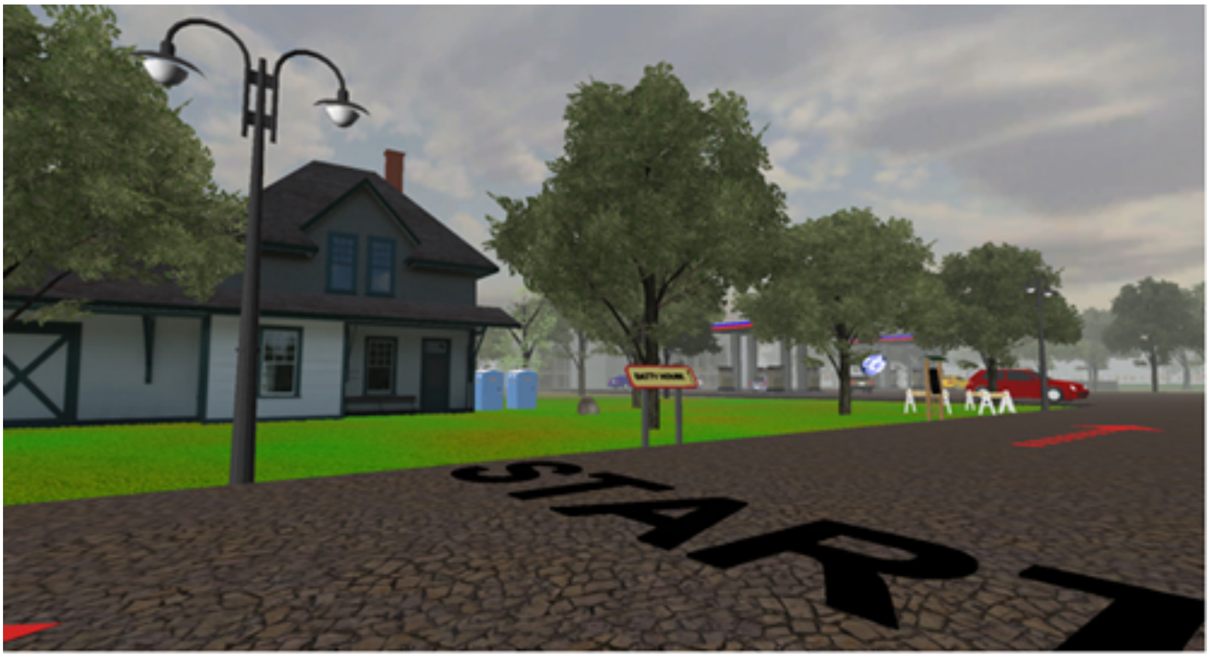
North

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 F

Example of Silcton landmarks



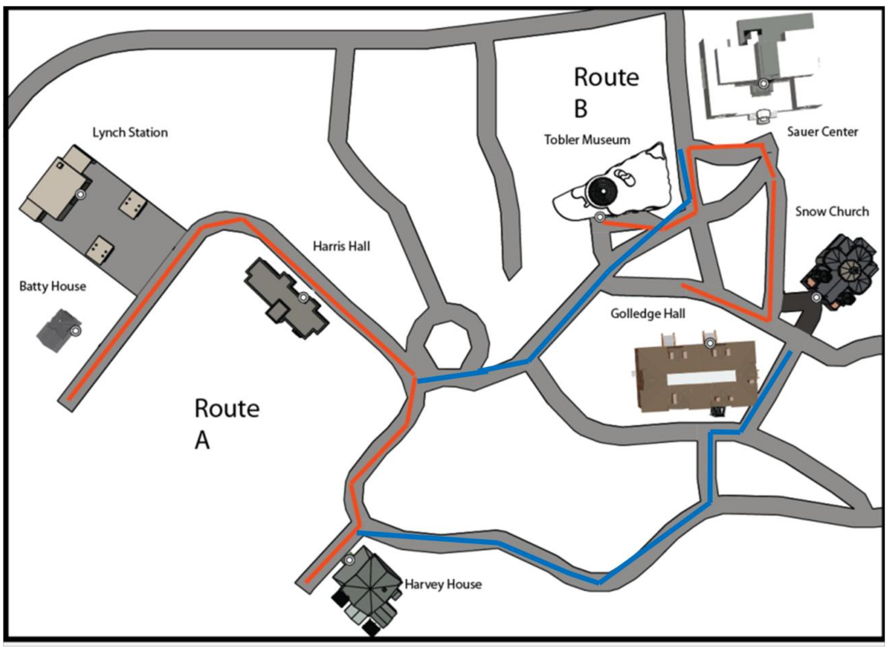
Appendix G

Script for Silcton Practice and Route Learning

Researcher reads the instructions verbatim to the participant: "Now that you've had some practice and became familiar with the controls, you will have the opportunity to explore 4 different routes through the same town. For the first two routes, you will need to remember the names and locations of 4 buildings per route for a total of eight buildings, as the tasks that follow will test your knowledge of these buildings. The names of the 8 buildings are Batty House, Golledge Hall, Harris Hall, Harvey House, Lynch Station, Sauer Centre, Snow Church, and Tobler Museum. These buildings are marked with a blue diamond near a sign outside their front door. These two routes are in separate parts of the same town. For the next two connecting routes, you will not need to remember any additional buildings, but try to pay special attention to how the two sets of buildings are positioned in the town. These routes will provide additional information to help you remember the locations of the buildings. For each route, travel to the end of the route and then back to the beginning."

Appendix H

Example of Silcton Route-Learning



Layout and names of buildings. Red routes indicate MAIN ROUTES. Blue routes indicate CONNECTING routes.

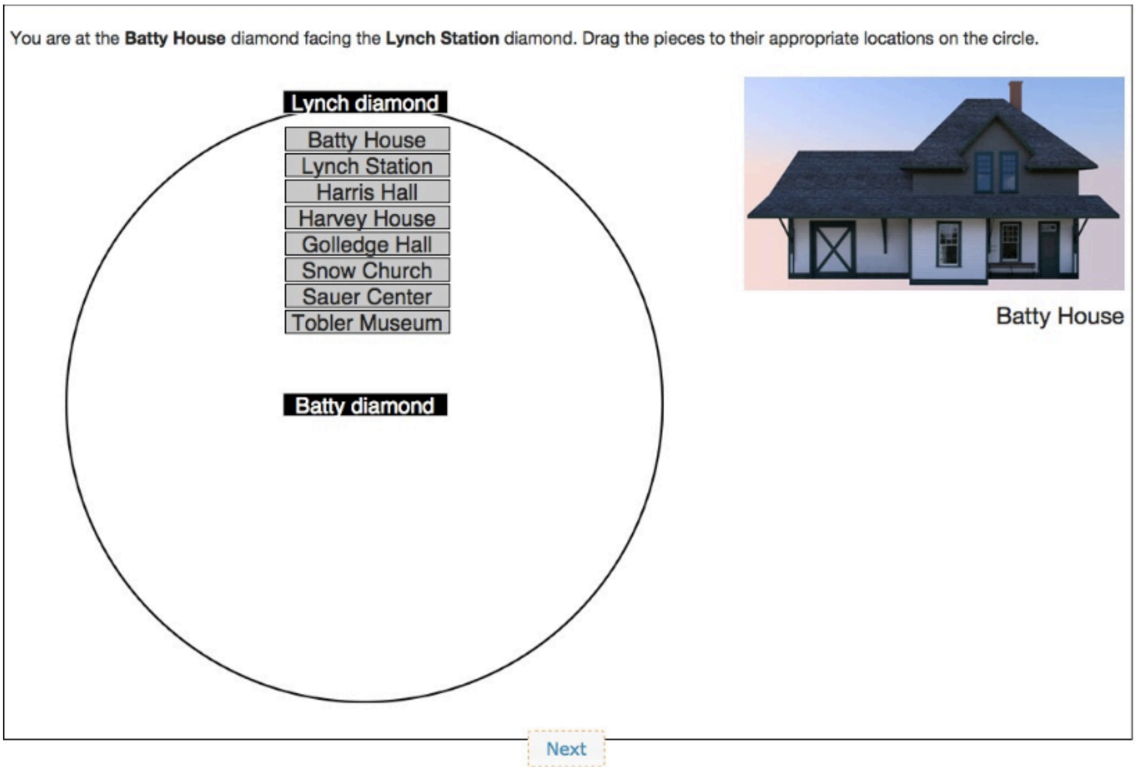
Appendix I

Script for Silcton Direction Estimation Task

Researcher reads the instructions verbatim to the participant: " This task is similar to the one you've already done with the circles for real-world locations. For this one, you will have to imagine that you are standing at a certain building that you probably saw when you were exploring the virtual town. This building is in the center of the circle (researcher points to the screen showing the building in the center of the circle). You will have to imagine that you are facing another building that is at the top of the circle (researcher rolls cursor over to show that participant can get views of buildings that way). Then, you drag and drop the names of buildings to place the remaining buildings along the circle in the directions they are from your imagined position in the town. There will be eight different circles for you to complete. Do you have any questions?”

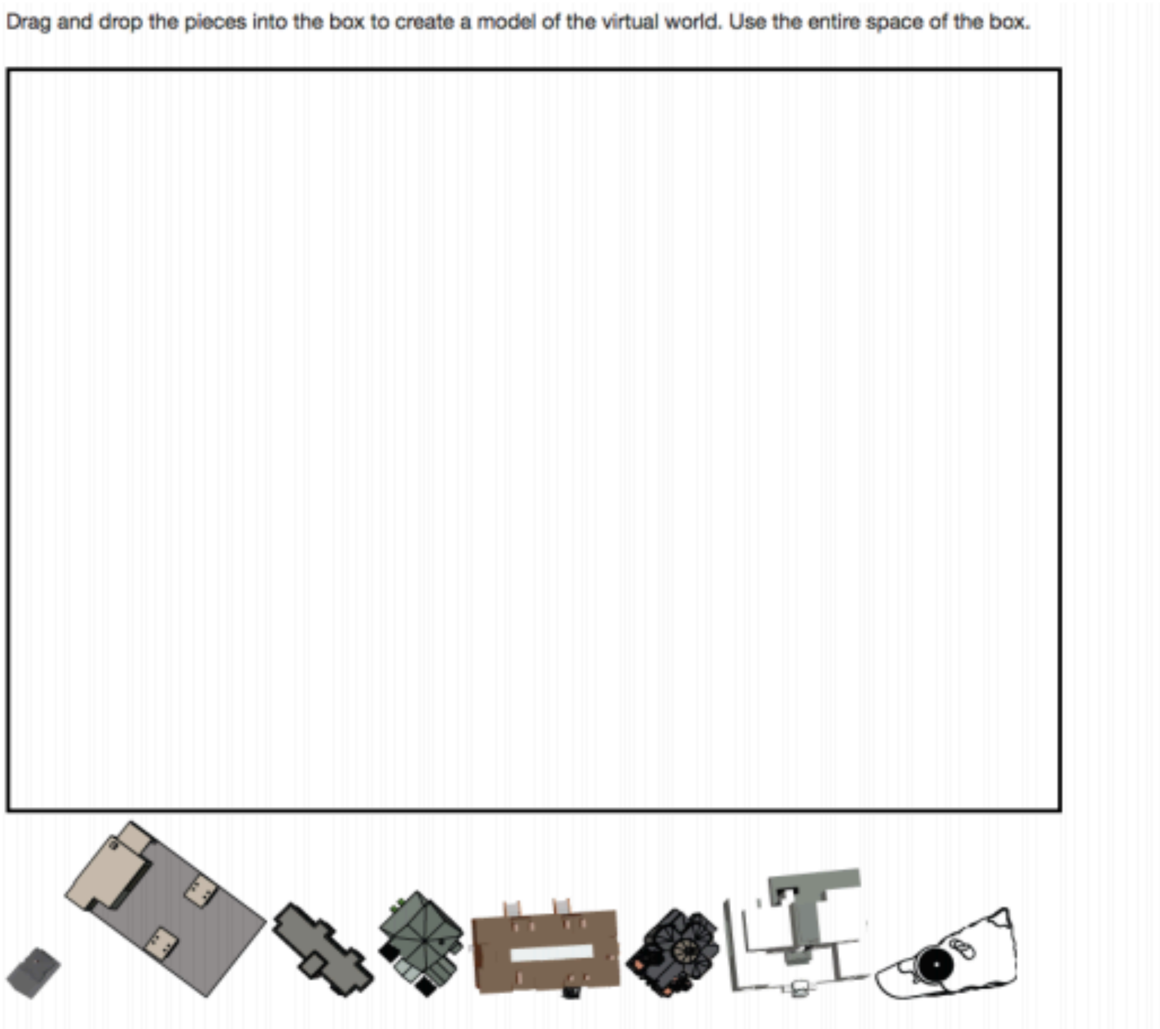
Appendix J

Example of Silcton Direction Estimation Task



Appendix K

Silcton Map Building Task



Appendix L

Script for Silcton Sketch Map Task

Researcher reads the instructions verbatim to the participant: “This task is similar to the one that you done with the frequently visited locations. In this task, you will create a map of the eight locations that you explored in Silcton. This empty box represents a bird’s eye view of the town. 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 an “X” and labeling it with the correct letter (A, B, C, D, E, F, G, and H). 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 M

Silcton Sketch Map Task

Silcton Sketch Map

North

Directions: Please, draw an aerial map of the eight buildings you learned in Silcton virtual environment marking each one as an "X" and labeling it with the correct names. The list of the buildings is provided below.

Legend	Location
A	Batty House
B	Golledge Hall
C	Harris Hall
D	Harvey House
E	Lynch Station
F	Sauer Centre
G	Snow Church
H	Tobler Museum