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Individual Differences in Cognitive Flexibility and Cognitive Map Accuracy

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Abstract

Research has demonstrated broad individual differences in the ability to form a cognitive map of a novel environment. The current study investigated whether individual differences in cognitive map accuracy are driven by differences in cognitive flexibility specifically, the ability to switch between tasks. Using the Silcton virtual environment, participants explored four routes in Silcton and were assessed on cognitive map accuracy using the Silcton onsite pointing task and the Silcton model building task. To assess task-switching, perseveration error from the Wisconsin Card Sort Test (WCST) was measured. There was a significant correlation between the WCST and the onsite pointing task, such that low perseveration error lead to better cognitive map accuracy. Therefore, the current study is the first to reveal an association between cognitive flexibility in the form of task-switching and individual differences in cognitive map accuracy.

Individual Differences in Cognitive Flexibility and Cognitive Map Accuracy

Spatial navigation is an essential ability used for finding one's way through complex environments, for planning routes to far destinations and for returning back to original locations (Wolbers & Hegarty, 2010). Spatial navigation can be described as a multifaceted process based on external spatial representations such as diagrams or maps and internal spatial representations that include the ability to perceive spatial information from multisensory cues, create spatial representations that are encoded in short-term and long-term memory and then using these representations to guide navigational behaviour (Wolbers & Hegarty, 2010). As well, Wolbers and Hegarty (2010) suggest that this internal mental representation, can be thought of as creating a "cognitive map" which can be further described as the ability to mentally visualize a "bird's eye view" representation of an environment.

The term "cognitive map" was coined by Tolman (1948), when he discovered that rats had the ability to successfully use novel routes to obtain food rewards. From this discovery, he theorized that in order for the rats to use these novel routes to retrieve treats, they must be capable of mentally visualizing all possible routes that could lead to their goal destination. As research has shown that humans are able to navigate using unfamiliar routes, it was suggested that humans must also possess the ability to form a cognitive map (Bennett, 1996; Montello, 1998). Therefore, research has investigated individual differences in the ability to form a cognitive map, demonstrating that some individuals possess the ability to create a cognitive map while others do not (Weisberg & Newcombe, 2016).

Early research in the formation of cognitive maps suggested that learning a novel environment involved the acquisition of three types of knowledge occurring in a series of steps (Siegal & White, 1975). The first step involved acquiring landmark knowledge, which consists of distinct objects that are stored in memory to be recognized later. The second step is acquiring route knowledge, which consists of a series of landmarks that are connected to one another by paths or routes. The final step is acquiring survey knowledge, which integrates the separate routes and landmarks into one representation of the environment. Siegel and White (1975) additionally stated that acquiring survey knowledge assisted in the formation of a cognitive map of the environment. However, Montello (1998) argued that cognitive maps are acquired continuously rather than serially, as both landmark and route knowledge can be understood upon first exposure to a novel environment. Montello found that individuals who have had equivalent levels of exposure to an environment, can possess individual differences in the extent and accuracy of their spatial knowledge, as a result of differences in the degree of knowledge integration. Therefore, he suggested that there may be individual differences in the ability to integrate routes from the novel environment into a cognitive map.

As a test of Montello's theory, Ishiwaka and Montello (2006) investigated the ability to integrate two separately traveled routes into one mental representation in college students. In the study, students were driven along two routes through a neighbourhood that was previously unfamiliar to them and were directed to remember distinct landmarks within the routes over the course of 10 weeks. After the fourth week, participants were then driven through a short connecting route. Following each session, participants were asked to estimate the distance between the landmarks as well as draw a map of the area. Ishiwaka and Montello discovered that while some participant's knowledge of the routes had significantly improved over the course of 10 weeks, others did not change over time or did not improve at all. Therefore, concluding that there are individual differences in the accuracy and development of integrating routes into one representation.

Weisberg, Schinazi, Newcombe, Shipley and Epstein (2013) further demonstrated individual differences in the integration of separate routes into a cognitive map using a virtual environment software known as Silcton, that was created to resemble the task developed by Ishiwaka and Montello (2006). As such, Silcton uses a real-world setting to allow individuals to virtually travel along two separate routes while learning the names of target buildings on each route and then travel along two connecting routes, in an effort to integrate the information learned into one mental representation. In the study, participants were shown the virtual world and were instructed to navigate through two separate routes, as they attempted to learn the names and locations of eight target buildings that were located throughout the two separate routes. Once participants learned the building's name and locations, they were directed to another set of two separate routes that connected with the two previously learned routes. To test the ability of integrating separate routes into one single map, participants were instructed to estimate the direction of each learned building based on the current building they were standing in front of. In this task, target buildings were either within the same route or between routes of the building a participant was standing in front of, to measure within and between route knowledge. In addition, participants were instructed to construct a map of the virtual environment from a bird's eye view perspective as a direct measure of cognitive map accuracy. Results from the study provided further evidence to support individual differences in cognitive map accuracy, as some participants demonstrated an accurate ability to estimate landmark direction and create a map of the environment while others were less accurate.

Weisberg et al. (2013), used the results from the direction estimation task for within the routes and between the routes in Silcton to separate participants into three different groups. These groups included integrators, representing individuals who performed well on judgements for within-routes and between-routes, non-integrators, representing individuals who performed well on within-route judgements but not between-route judgements and imprecise navigators, representing individuals who lacked the ability to understand both within and between route knowledge. Weisberg and Newcombe (2016), suggested that the individual differences between the three groups could be the result of differences in verbal and spatial working memory. To test this theory, participants were categorized as either integrators, non-integrators or imprecise navigators. Each group was then instructed to travel through the Silcton virtual environment completing the same tasks as before. Results from the study revealed that imprecise navigators had lower levels of spatial and verbal memory compared to non-integrators and integrators. It was theorized that the decrease in spatial and verbal working memory could result in a decrease in the ability to create an accurate within-route mental representation. Using this, Weisberg and Newcombe hypothesized that in order to understand within route knowledge, an individual must possess knowledge regarding the landmarks as well as the spatial surroundings and to understand between route knowledge, an individual must possess survey knowledge. Further, it was suggested that for an individual to form a cognitive map, they must be able to integrate the knowledge learned within the routes and connect this to the knowledge learned between the routes, to form a mental representation of the area as a whole.

The results of Weisberg and Newcombe (2016) supported Siegal and White (1975), suggesting that individuals learn novel environments serially, as the study found that landmark and route knowledge is necessary for understanding within-route knowledge and that survey knowledge is necessary for understanding between-route knowledge. However, as Weisberg and Newcombe (2016) found that imprecise navigators scored lower on tasks involved in spatial and verbal working memory compared to non-integrators and integrators, they suggested that imprecise navigators may be unable to effectively learn the buildings' names, meaning that they never acquired within-route knowledge, which is necessary for creating a cognitive map. Since integrators and non-integrators showed no significant difference on scores for spatial and verbal working memory, between-route knowledge may relate less to understanding within-route knowledge and rather, relate more to the integration of the within and between route knowledge. Therefore, the ability to learn and integrate the routes and buildings into working memory, may be important for creating a cognitive map.

An alternative explanation for the results of Weisberg and Newcombe (2016) suggested that maybe integrators view an environment from different representations i.e. globally or locally and then draw on these representations when required. In fact, Wolbers and Hegarty (2010) suggested that individuals may use different strategies to learn the representation of a novel environment. For instance, the first strategy includes using an egocentric reference frame to memorize local landmarks within the routes known as a "route-based" strategy and the second strategy uses an allocentric reference frame, which allows individuals to plan direct paths to unseen goals, known as a "survey-based" strategy. Wolbers and Hegarty believed that individual differences in navigation occurred in the preferences for using a route-based or survey-based strategy while navigating. Therefore, they theorize that successful navigators are those who can flexibly switch between the different strategies on the basis of what is required in a given situation. Additionally, they thought that this flexibility is necessary for the ability to connect learned routes to novel unforeseen routes as well as develop a malleable cognitive map that can adapt according to changing environments. As such, Wolbers and Hegarty further theorized that integrators may be stronger at connecting within-route knowledge to between-route knowledge because they can mentally switch between a survey-based and route-based environmental representation and integrate them into one mental representation, to form a more accurate cognitive map than non-integrators or imprecise navigators.

The ability to flexibly switch between using a route-based strategy and a survey-based strategy to form an accurate cognitive map may be possible because of an aspect of executive functioning known as cognitive flexibility. Although Weisberg and Newcombe (2016) suggested that individual differences in learning a novel environment may be due to differences in working memory, it may be that cognitive flexibility is also an important contributor for building an accurate cognitive map. Cognitive flexibility allows individuals to adjust their attention and behaviour to adapt to changing environments. This means that as individuals navigate through an environment, their working memory will continuously update information regarding the environment while cognitive flexibility allows for changes in their attention in an effort to adapt to changes in the environment (Dajani & Uddin, 2015). For example, in the case of a roadblock, working memory would update this information as cognitive flexibility would direct the individual's attention to alternative routes within the environment that could be used to travel to the desired goal (Dajani & Uddin, 2015).

An important aspect of cognitive flexibility is known as task-switching, which allows individuals to switch their attention to different activities while simultaneously re-allocating that attention to what is necessary (Hoffman, Schmeichel & Baddeley, 2012; Liefooghe, Barrouillet, Vandierendonck & Camos, 2008). As a result, task-switching paradigms such as the Wisconsin Card Sort Test (WCST) (Grant & Berg, 1948) have been used as a measure of cognitive flexibility. Although the WCST was originally designed to assess prefrontal lobe dysfunction in patients with temporal lobe lesions, the WCST is widely used as measure of cognitive flexibility, as task-set switching is a critical component of the test, since the goal is to understand when a switch to the sorting pattern has been made (Nyhus & Barcelo, 2009). Therefore, to perform well on the task, participants must recognize when a change to the sorting pattern has been made and then appropriately adapt their sorting to follow the new pattern.

As previous studies have yet to investigate task-switching as a necessary ability for creating an accurate cognitive map, the purpose of the study was to investigate the relationship between cognitive flexibility and cognitive map accuracy. In the current study, participants were instructed to navigate through the virtual world Silcton and completed tasks assessing their spatial navigation and cognitive map accuracy. In line with Weisberg et al. (2013), the initial task involved participants travelling on two separate routes as they learned the names and locations of eight target buildings and then traveled through two additional separate routes that connected to the ones previously traveled, creating a map of the area. As well, participants completed the Silcton onsite pointing task to assess their directional knowledge of the location of each building as well as the Silcton model building task, to assess their ability to form a map of the virtual environment. In addition, participants completed the WCST to assess cognitive flexibility in the form of task-switching. It was hypothesized that successful integration of routes and landmarks to create a cognitive map involves a strong level of cognitive flexibility. Therefore, it was predicted that if participants performed well on the onsite pointing task and the model building task, then they would possess the ability to integrate the landmarks and routes into a cognitive map, demonstrating strong navigation abilities. It was further predicted that if individuals who performed well on the onsite pointing task and the model building task also performed well on the WCST, then cognitive flexibility must be important for building an accurate cognitive map.

Methods

Participants

Participants were 55 undergraduate students (54 females and 1 male) currently enrolled in Psychology 1010A and Psychology 1015B at Brescia University College. Their ages ranged from 17 to 29 years old (M =19.20, SD = 1.92). Participants were recruited from an online database (SONA) and received two course credits for participating in the study.

Materials

The tasks were administered using a Toshiba Satellite Pro laptop with a 15.6" screen and an NVIDIA GeForce video card. A demographic survey was administered on a sheet of paper. All tasks involving virtual world navigation were administered using the web-based virtual world Silcton. The Wisconsin Card Sort Test was administered using the web-based software PsyToolKit (Stoet, 2010). For consistency purposes, a script was used to explain the instructions for the practice of the Silcton route exploration as shown in Appendix A, the Silcton route exploration task as shown in Appendix B, the Silcton onsite pointing task as shown in Appendix C, the Silcton model building task as shown in Appendix D as well as the Wisconsin Card Sort Test as shown in Appendix E.

Demographic Survey. Participants were asked to provide their demographic information regarding their age and sex on a paper questionnaire.

Silcton Route Exploration Task (Weisberg et al., 2013). Participants first travelled around a central statue (fountain) in Silcton and used the computer arrow keys and mouse to walk as practice before moving through the virtual environment. Once they understood the controls, participants were instructed to travel along four different routes in Silcton by following the red arrows displayed on the ground. Concurrently, participants were advised to remember the name and location of four target buildings shown on each route that were marked with a blue floating diamond. Participants first travelled from the start of route A until they reached the end of the route and then turned around to travel back to the beginning of route A. Participants then travelled along route B the same way they travelled route A. Once completed, participants travelled along the connecting routes of C and D. Routes C and D each connected to different points of routes A and B. Participants were given unlimited time to complete each of these route tasks.

Silcton Onsite Pointing Task. At the top of the screen, one of seven building names appeared. Participants were instructed to rotate the mouse until the crosshair pointed in the direction of the building that was listed at the top of the screen and click the mouse to provide their answer. Clicking the mouse also changed the name of the building and participants would then click to the name of that building. Once all seven buildings were pointed to, participants were instantly repositioned to the second route and followed the same steps as before. The order in which participants learned the buildings will match the order of the locations they are prompted to. The onsite pointing task was scored by measuring the smallest possible angle between the correct answer and the participants' estimate, providing an error value in degrees for each trial. Once again, participants were given unlimited time to complete the task.

Silcton Model Building Task. Immediately following, participants were given a blank box on the computer screen with bird's eye view images of each of the eight buildings beneath it. The participants were told that the box represents the virtual environment as a whole. Participants used the mouse to drag and drop each building to where they thought it belonged in the virtual environment. No time limit was provided, and participants were allowed to move the buildings an unlimited amount of times, however, the orientation of the buildings could not be changed. Participants were told that they could place the buildings in whatever position they believed to be correct. Accuracy was calculated by the Silcton software using a bidimensional regression procedure that compared the accuracy of the participant's map to the actual map to produce an R^2 value.

Wisconsin Card Sort Test (Grant & Berg, 1948; Stoet, 2010). The Wisconsin Card Sort Test consisted of 128 virtual cards with each card displaying one of four possible shapes (triangle, star, circle and cross) that varied in number value (1,2,3,4) and in colour (green, yellow, blue and red). The goal of the task was to correctly match the card given and sort that card by either colour, shape or number value to learn the correct sorting rule. Participants were given a card and were instructed to use that card and click using the mouse, onto one of the four cards displaying the one of four patterns, in an attempt to discover the sorting rule. If the participant incorrectly sorted the card, a sound vocalizing the word "no" as well as the word "wrong" appeared and participants were prompted to try again. If participants correctly determined the sorting rule, a happy sound appeared as well as the word "good". Participants used trial and error and the feedback provided by the software, to determine the correct sorting rule. Once participants completed ten consecutive and correct sorts, the sorting rule changed unbeknownst to the participants, and participants were once again asked to discover the new sorting rule. The task finished once 60 trials were completed or when all 128 cards were used. Each trial began with the same card (two yellow stars) and sorting rule (shapes), and the sorting rules that followed was consistent for each participant. The dependent measure for this task was the perseveration error. Perseveration error occurred when the participant sorted the cards using the previous pattern, even after they were informed by the feedback that their answer was incorrect.

Procedure

Participants were given a letter of information and signed a consent form. Participants were then given a demographic survey. Once completed, participants sat in front of a laptop and were instructed to use the mouse and arrow keys to practice moving within the Silcton virtual environment. Once participants were comfortable with the controls, they were instructed to complete the Silcton route exploration task, the Silcton onsite pointing task and then the Silcton model building task in that order. Finally, participants completed the Wisconsin Card Sort Test. Once all tasks were completed, participants were debriefed on the study. On average, participants completed the study within 45 minutes.

Results

To test the hypothesis that good performance on the WCST would predict good performance on the onsite pointing task, a two-tailed Pearson correlation and a linear regression analysis were conducted. Good performance on the WCST meant that participants achieved low perseveration error score and good performance on the onsite pointing task meant that participants achieved low direction estimation error. First, the correlation analysis revealed a significant weak positive correlation between scores on the WCST ($M = 7.98$, $SD = 3.31$) and the onsite pointing task ($M = 40.90$, $SD = 11.73$), $r(53) = .37$, $p = .006$, suggesting that low perseveration error on the WCST was associated with low direction estimation error on the onsite pointing task. The linear regression analysis displayed in Figure 1, revealed that score on the WCST was a significant predictor of scores on the onsite pointing task, ß = .37, $p = .006$ and accounted for 13% of the variance, $R^2 = .13$, $F(1,54) = 8.18$, $p = .006$.

A second two-tailed Pearson correlation analysis was used to test the hypothesis that good performance on the WCST would predict good performance on the model building task. Good performance on the model building task meant that participants were highly accurate when building a map of the environment. The analysis revealed no significant correlation between

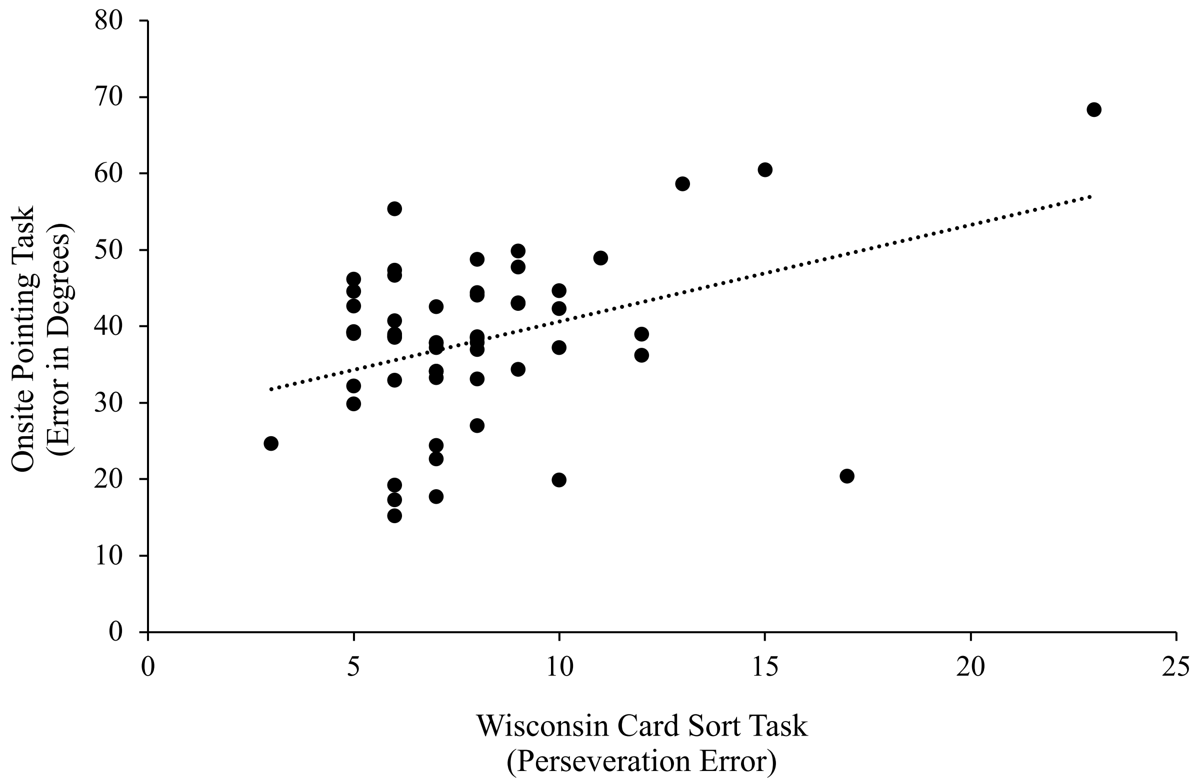

Figure 1. Scatterplot with a line of best fit demonstrating the relationship between perseveration error score (x-axis) and direction estimation error scores (y-axis).

perseveration error score on the WCST and higher accuracy score on the model building task (*M* = .42, *SD* = .23), $r(53) = -.06$, $p = .668$.

Since Head, Kennedy, Rodrigue and Raz (2009) revealed age-related differences for perseveration error score on the WCST between individuals age 19-33 and older than 60 such that adults aged 19-33 achieved lower perseveration error than adults older than 60, a two-tailed Pearson correlation analysis was used to investigate whether age could have predicted perseveration error score on the WCST. The analysis revealed no significant correlation between age (*M* = 19.2, *SD* = 1.92) and perseveration error score on the WCST, $r(53) = .213$, $p = .118$ demonstrating that age did not predict perseveration error score on the WCST.

A final two-tailed Pearson correlation analysis was used to assess the interrelatedness of the Silcton onsite pointing task and the Silcton model building task for measuring the ability to form accurate cognitive maps. The analysis supported the hypothesis that achieving low direction estimation error on the onsite pointing task would predict higher accuracy on the model building task, as a significant moderate negative correlation between scores on the onsite pointing task and score on the model building task was found, $r(53) = -.61$, $p < .001$, suggesting that low direction estimation error for the onsite pointing task was associated with increased accuracy on the model building task. A linear regression analysis further revealed that scores on the onsite pointing task significantly predicted scores on the map building task, ß = -.61, $p < .001$ as shown in Figure 2 and accounted for 37% of the variance, $R^2 = .61$, $F(1, 54) = 31.15$, $p < .001$.

Discussion

The results of the study found that there was a significant correlation between perseveration error score on the WCST and cognitive map accuracy on the onsite pointing task, such that low perseveration error significantly predicted low direction estimation error on the

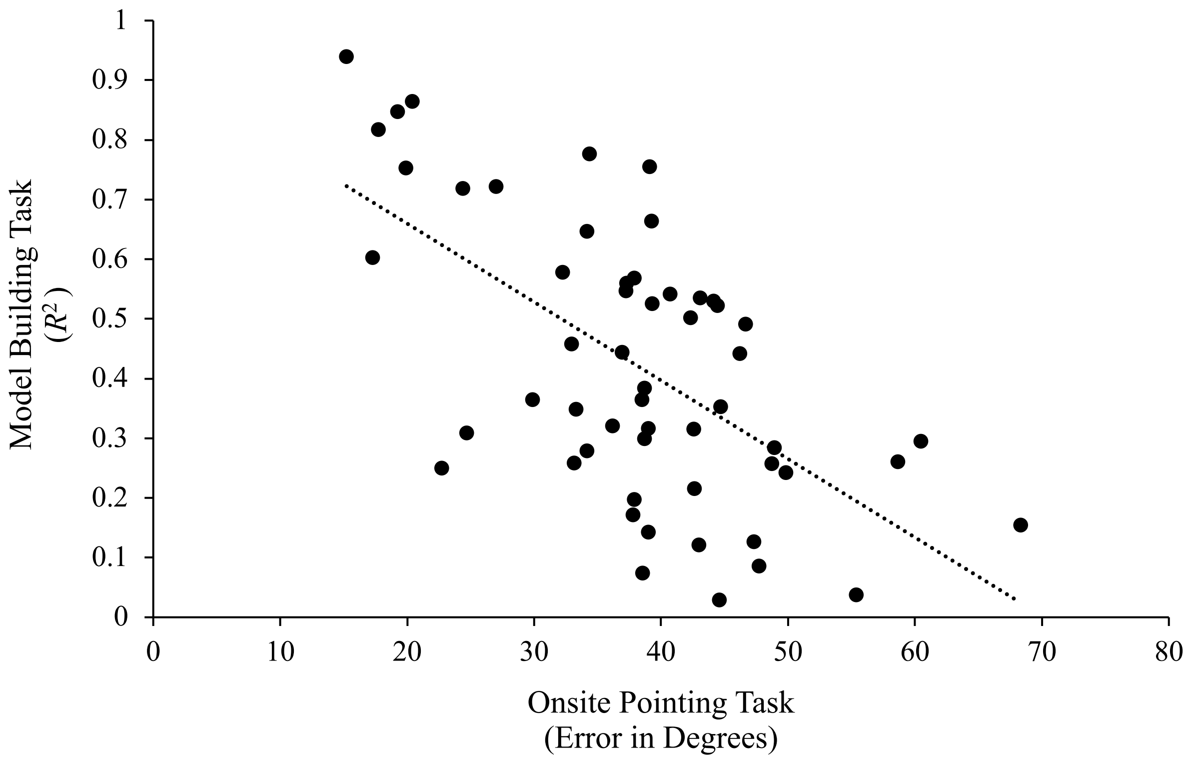

Figure 2. Scatterplot with a line of best fit demonstrating the relationship between the direction estimation error scores (x-axis) and model building accuracy scores (y-axis).

onsite pointing task. This suggests that participants who were better at task-switching were able to estimate the locations of the buildings in Silcton more accurately and therefore, created a more accurate cognitive map. In addition, there was a significant correlation between the onsite pointing task and the model building task, such that low direction estimation error on the onsite pointing task predicted higher accuracy on the model building task. This result provides evidence in support of these tasks as reliable measures for assessing the ability to form a cognitive map. However, there was no relationship between the WCST and the model building task, such that low perseveration error score was not associated with accuracy on the model building task. Therefore, it appears that task-switching on its own, may not be a reliable measure for assessing cognitive map accuracy on the model building task, as there may be more than the skill of task-switching that is required to complete this task. Finally, there was no significant relationship between participants' age and their perseveration error score on the WCST.

In addition to the results of the study supporting previous research demonstrating individual differences in the construction of a cognitive map of a novel environment (Ishiwaka & Montello, 2006; Weisberg et al., 2013; Weisberg & Newcombe, 2016), the results further suggest that these individual differences may be driven by differences in cognitive flexibility. Wolbers and Hegarty (2010), suggested that while participants navigate through a novel environment, different strategies such as route-based or survey-based can be used to learn the representation of the environment. As such, they hypothesized that the best navigators may be those who can flexibly switch between using a route-based strategy and a survey-based strategy to represent an environment and therefore, this flexibility may be necessary for generating a cognitive map. The results of the current study support this hypothesis as participants who were better at task-switching achieved low direction estimation error on the onsite pointing task, indicating that a more accurate cognitive map was created. This suggests that participants who were better at task-switching may have been able to flexibly switch the representation of the virtual environment between using a route-based and a survey-based strategy and were therefore more accurate when estimating the target building's direction. As such, it appears that task-switching ability is associated with the accuracy of generating a cognitive map of a novel environment.

One possible explanation for why performance on the WCST predicted the ability to form a cognitive map may be the result of the neural mechanisms underlying both cognitive flexibility and constructing a cognitive map. In addition to both tasks recruiting the prefrontal cortex (Wolbers & Hegarty, 2010; Banich, 2009), they more specifically require recruitment of the hippocampus (Head et al., 2009; Schinazi, Nardi, Newcombe, Shipley & Epstein, 2013). The WCST in particular, is widely used to assess damage to the medial temporal lobe in the hippocampus, as damage to this area results in individuals lacking the ability to recognize when a pattern in the card set has been switched, resulting in higher perseveration error (Banich, 2009). Therefore, the hippocampus is integral for cognitive flexibility. In addition, research has shown that the creation of a cognitive map relies on the retrosplenial cortex and the hippocampus and in particular, the anterior hippocampus appears to be involved in the speed at which individuals form a cognitive map (Wolbers and Hegarty, 2010; Wolbers and Buchel, 2005). Additionally, research by Schinazi et al. (2013), investigating the neuroanatomy of the hippocampus for cognitive maps revealed that individuals with larger posterior hippocampi were significantly better at estimating the location of a building based on their imagined location, than individuals with smaller posterior hippocampi. As there may be a link between cognitive flexibility and creating a cognitive map such that recruitment of the hippocampus underlies both processes, neuroimaging or lesion studies should be used to investigate whether the activation of the hippocampus for both tasks facilitates performance. As well, this would provide evidence to support that damage to the hippocampus results in poor performance on task-switching as well as tasks involved in spatial navigation.

Although the Silcton onsite pointing task and the Silcton model building task require participants to use integrated spatial representations, there are differences between the tasks which could have resulted in differences in the strength of the relationship between each measure and the WCST. Specifically, the onsite pointing task requires participants to use within-route knowledge and between-route knowledge in order to recognize the location of the buildings prompted, which may rely more on the ability to task-switch (Weisberg et al., 2013). In comparison, the model building task relies on a more mentally aerial view of the environment, which may not elicit direct switching of the environmental representations (Weisberg et al., 2013). Therefore, it may be that task-switching ability is not as important for the model building task as is the ability to view the environment from a bird's eye view and as a result, perseveration error score on the WCST was unable to predict performance on the model building task.

As stated by Weisberg et al. (2013), the use of virtual world environments for investigating individual differences in spatial navigation and cognitive maps is beneficial as they can be easily replicated, are inexpensive, can be used on large samples and can be used to control extraneous variables. Additionally, assessing individual's ability to form an accurate cognitive map can be measured using either a real-world navigation task or a virtual environment. For instance, the Weisberg et al. (2013) virtual environment task was based on a real-world experiment by Ishiwaka and Montello (2006) and was able to generate similar results. Therefore, this suggests that the results from the current study may be a good representation of results that would appear in a real-world setting.

One limitation to consider in the study is that individual differences for direction estimation judgements of buildings within the routes and direction estimation judgements of buildings between the routes for the onsite pointing task were not separately analyzed. As within-route judgements are a measure of route representation and between-route judgements are a measure of map representation (Weisberg et al., 2013), it is unknown whether there is a relationship between the ability to task-switch and accuracy on the route judgements. For instance, Weisberg et al. (2013) discovered individual differences for both within and between-route judgements as there were participants who performed well on both within and between-route judgments, participants who performed well on within-route judgments but not between-route judgments and finally, participants who performed poorly on both pointing judgments. Therefore, there may be differences in cognitive flexibility for these three groups of participants, such that individuals who performed well on both between-route and within-route judgements are also more cognitively flexible.

Although research suggests that there are no significant sex differences for performance on the Virtual Silcton tasks (Weisberg et al., 2013; Nazareth, Weisberg, Margulis & Newcombe, 2018; Youngson, Vollebregt & Sutton, 2019**),** research has demonstrated inconclusive evidence for significant sex differences on task-switching. In particular, Boone, Ghaffarian, Lesser, Hill-Gutierrez and Berman (1993) found that women performed significantly better than men on the WCST, achieving fewer general error scores and lower perseveration error. On the other hand, Saylik, Raman and Szameitat (2018) used a very similar task to the WCST called the Intra/extradimensional shifts task (IED) and revealed that men outperformed women.

Additionally, other research has demonstrated that men take a longer time on tasks that require task-switching than women and that the brain areas active in task switching are different for each sex (Kuptsova, Ivanova, Petrushevsky, Fedina & Zhavoronkova, 2014). However, as the current study did not investigate sex differences on performance of the WCST, it is unclear whether the females in the study would have outperformed males on measures of task-switching or vice-versa. Given the inconclusive evidence and no significant sex differences revealed for the Silcton measures, it would be interesting to investigate whether females and males who are able to create an accurate cognitive map, are also more cognitively flexible. The result would provide further evidence to support a lack of sex-differences for creating a cognitive map and being cognitively flexible and rather, support that individual differences in cognitive map accuracy are the result of differences in cognitive flexibility.

Individual differences in the relationship between cognitive map accuracy and cognitive flexibility may be further driven by age-related differences. Research demonstrates age-related differences in cognitive flexibility such that young individuals aged 19-33 are more cognitively flexible than adults older than 60 (Boon et al., 1993; Head et al., 2009). However, Nazareth et al. (2018), found that by age 12, children's ability to generate a cognitive map was at the same level as adults and that children could be grouped into varying degrees of cognitive map accuracy similar to adults. Newcombe (2019) further suggested that by age 12, the ability to accurately form a cognitive map emerges and that the variations in cognitive map accuracy seen in adulthood are stabilized by this age. Interestingly, Huizinga and van der Molen (2007) investigated developmental changes in task-switching between young children and older adults and found that task-switching abilities reached adult levels by the age of 11. Therefore, it may be that changes in cognitive map accuracy stabilize as a result of cognitive flexibility stabilizing with development. However, it may also mean that frequently engaging in tasks that relate to task-switching may facilitate further development and therefore enhance cognitive map accuracy. As such, future research should investigate whether frequently participating in task-switching paradigms could enhance cognitive map accuracy over time as well as investigate the age-related differences for cognitive map development and cognitive flexibility.

Overall, the results of the study provide evidence to support a relationship between cognitive flexibility and the ability to form a cognitive map. In addition to being the first study to illustrate this relationship, the results revealed that measures of cognitive flexibility may be used as a predictive measure for cognitive map accuracy. These results are important as they provide further knowledge regarding the relationship between spatial navigation ability and other cognitive domains. In general, understanding where individual differences in navigation arise is important as it can be beneficial for improving devices that assist with navigation such as GPS or Google Maps, since individuals continue to rely on using outside assistance for navigating. As well, understanding these individual differences may help to develop interventions for improving cognitive map accuracy, such that improving cognitive flexibility by engaging in task-switching paradigms may facilitate positive changes in spatial navigation.

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Appendix A

Silcton Route Exploration Practice Script

The 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. Walk around the statue in a circle.

Appendix B

Virtual Environment Exploration Task Script

Now that you've had some practice to become 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 each route, travel to the end of the route and then back to the beginning. (Read this at the start of the Connector routes) For the next two 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. Do you have any questions?

Appendix C

Silcton Onsite Pointing Task Script

This task is a perspective taking task. 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 to finish this task. Do you have any questions?

Appendix D

Silcton Model Building Task Script

In this task you will create a map of the town. This box on the screen represents a bird's eye view of Silcton. At the bottom you will see the buildings from the virtual environment. You can move your cursor over each building to see the name and front view. For the task, drag and drop each of these buildings to the part of the box where you believe the building is located in the town. Use the whole box, so if buildings were on the edge of town, you can place the building at 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 E

Wisconsin Card Sort Test Script

In this task, you will need to match a card to one of the four cards presented at the top of the screen. Click one of the four cards that match the card on the bottom left. Follow your selection, as you will be provided feedback. If your match was not correct, you will need to try a different rule.

(Example shown on screen) For example, if you match according to colour, you would click the first card. If you match according to shape, you would select the second card and if you match according to number, you would select the fourth card.

You will need to find out whether to match according to colour, number, or shape. Once you have figured out what rule to use, you can relax for a while, but the matching rule will change now and then. Once again, if the computer gives you an error message, you will need to change the rule. There are 60 trials.

Press “Q” once you are ready to begin and let me know when you are finished. Once you have finished, please do not touch any keys as the data will be erased. Do you have any questions?