MAP READING UNDER LOAD: SEX DIFFERENCES IN LEARNING DIGITAL MAPS

by

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B.A., The University of British Columbia, 2013

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in

The Faculty of Graduate and Postdoctoral Studies

(Psychology)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

August 2015

Abstract

Imagine the following scenario: you're at an unfamiliar location and you need to catch the bus to get home, however, you don't know where the bus stop is. What do you do? In the modern world, the typical solution would be to open a map application on your smartphone and use it to determine the best route to your destination. Software developers are constantly improving mapping software with new features and design overhauls, but it is important to take a step back and ask how these factors might affect our ability to learn the information being presented. Are there cognitive factors that may help, or hinder, our ability to learn digital maps? A map reading experiment was devised to test the effect of cognitive load on map learning (Experiment 1). Participants learnt routes and landmarks under both low and high cognitive load. Our results show that high cognitive load hinders males' ability to learn landmarks, while it hinders females' ability to learn routes. A second experiment was conducted to determine the robustness of this effect. Map task difficulty was increased and our results show that the original 3-way interaction disappears when the demand on working memory becomes too high. Overall, our findings are in line with the existing literature on sex differences in map reading, and also indicates that 1) cognitive load plays a role in that relationship, and 2) a threshold exists for the effect once task difficulty is increased.

Preface

This thesis is original, unpublished, independent work by the author, S. Ho. All experiments were approved by the UBC Behavioral Research Ethics Board.

Certificate number: H13-03248

John Bablitz, Shelby Marozoff, Kyle Gooderham, and Sheila Tse assisted with data collection for the experiments, while James Enns and Todd Handy made intellectual contributions at various stages of this research.

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Acknowledgements

I thank my supervisor, Dr. Todd C. Handy, for his support and guidance, and Dr. James Enns for providing a fresh perspective on the interpretation of the data.

Thank you to John Bablitz, Shelby Marozoff, Kyle Gooderham, and Sheila Tse for your insightful comments and numerous hours spent collecting data.

I am thankful to my family for supporting my move to Canada and my decision to study at UBC.

Lastly, I remain indebted to Sara Ahmadian. Without you, this thesis would not exist.

To Sara Ahmadian

You said it was OK to quit graduate school,

but at the same time you encouraged me to keep going.

Chapter 1: Introduction

Due to widespread use of technology, and the speed at which technological advances are made, we now rely on computers and software more to aid our daily lives. An example of this rapid growth can be seen by looking at the number of available applications for mobile devices on the Apple app store. There are an estimated 1.3 million apps currently available on the store, with an annual growth rate of 53% per year over the past 6 years since its inception (Statista, 2014a). The use of software in our daily lives is increasing, whether we use it as a necessity for work or simply for leisure as in cases of social networking. Increasingly, technology is finding a place in domains that exist somewhere between work and leisure. In these cases, technology is used as a utility – something that aids your day to day living. For example, if you wanted to go to a good local restaurant for dinner you can find an app that will provide reviews for the eateries in your area. If instead you wanted to cook at home, there are a multitude of apps that act as large repositories for food recipes.

One prominent example of rapid software adoption is in the domain of digital mapping. As of September 2014, Google Maps is one of the top 10 most used pieces of software on mobile devices, attracting almost 65 million unique visitors per month in the United States (Statista, 2014b). Gone are the days where we rely on memory, or paper maps, to help us navigate around foreign environments. Whether we are planning a trip, walking, or driving, the digital revolution has placed digital mapping software in the driver's seat for map learning and navigation tasks. This cultural shift deserves some attention because digital mapping software is now widely adopted, however, we need to consider the potential drawbacks of using such technology. Are there factors that may hinder how well we can learn from such software? Research in this area is very sparse, but given how much we rely on mapping software it is extremely important to ask questions regarding its limitations (Hegarty, 2013). Here, we suggest that cognitive load can have a detrimental impact on the learning of certain types of map information.

1.1 Spatial information and map reading

The study of spatial information encoding was originally based on behaviourist principles, where the focus was on using reinforcement and punishment techniques to guide rats through a maze. Learning was simply the reinforcement of specific behaviours at specific points in the environment, however, these roots have since been abandoned in favour of a cognitive approach. Tolman (1948) argued that environmental learning requires the creation of mental representations of our surrounding space. He showed that as rats navigate around a maze, they are constructing a cognitive map that consists of the spatial layout of their environment. This cognitive map contains information beyond just the specific routes taken by the rat, as they are able to infer additional Euclidean information about their surroundings. Although Euclidean information is an important aspect of the environment, humans also appear to require the encoding of landmark locations into their cognitive maps (Tom & Denis, 2004; Foo, Warren, Duchon, & Tarr, 2005). Furthermore, these cognitive maps are often not holistic (Hintzman, O'Dell, & Arndt, 1981), although they are readily formed from survey descriptions of environments (Brunyé & Taylor, 2008a; Fields & Shelton, 2006).

The type of information encoded from survey descriptions and physical way-finding can often differ. Thorndyke and Hayes-Roth (1982) showed that participants who learned an environment through a map (survey-level) are able to generate accurate information regarding spatial layout and Euclidean distances between locations (as the crow flies). On the other hand, those learning the same environment through navigation (route-level) have increased knowledge of distances along specific routes. Both survey-level and route-level information appear to be encoded with orientation and perspective specificity (Hintzman, O'Dell, & Arndt, 1981; Meilinger, Frankenstein, & Bülthoff, 2013; Shelton & Pippitt, 2007), regardless of the size of the spatial layout being learnt (Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Shelton & McNamara, 1997). The perspective with which you learn an environment (survey vs. route) can have an adverse effect on memory if a perspective switch is needed for recall (Shelton & McNamara, 2004). "You-are-here" maps have been found to be useful, but only if they are correctly oriented with respect to the users' facing direction (Levine, 1982).

Map reading is dependent upon many contextual factors. Brunyé, Mahoney, Augustyn, and Taylor (2009) demonstrated that arousal can influence the type of map information being learnt. Positive mood leads to increased focus on global features of the map and magnifies the symbolic distance effect (larger distance between items is easier to distinguish than smaller distances). Retrieval demands can change how spatial information is categorized (Wang, Taylor, Brunyé, & Maddox, 2014), and the map reader's personal goals can aid (or hinder) extraction of different types of cartographic data (Taylor, Naylor, & Chechile, 1999).

Map reading ability can also vary between individuals. For example, people with a good "sense of direction" are better able to encode landmark and route information egocentrically, and then later translate that into allocentric survey information during recall (Wen, Ishikawa, & Sato, 2013). Individual factors can also have a negative impact on map reading ability. Lloyd (1989) found that having real life experience with an environment can distort your cognitive representation of the area, resulting in inaccurate memory for distances between landmarks. Sex has also been shown to affect the choice of strategy used for navigation and map reading (Silverman et al., 2000; Dabbs, Chang, Strong, & Milun, 1998). Specifically, males have been shown to use a more cardinal-based approach, whereas females tend to rely more on landmarks (Saucier et al., 2002; MacFadden, Elias, & Saucier, 2003). Sex differences, typically favouring males, have also been found on various mental rotation and spatial tasks (Linn & Petersen, 1985; McBurney, Gaulin, Devineni, & Adams, 1997).

Multiple methods have been used to quantify performance when reading maps and the effectiveness of particular map designs. Although subjective "ease-of-use" ratings have been used, it is more common to find objective measures in the mapping literature. A common test of environmental knowledge is map reproduction (sketch map) and it has been found that maps reproduced by participants often have high test-retest reliability (Blades, 1990), and increased map accuracy often positively correlates with improved way finding performance (Rovine & Weisman, 1989). Many measurements are used in map reproduction tasks: the number of correct turns in a reproduced route (Sanchez & Branaghan, 2009); estimated Euclidean distance between landmarks (Wang, Taylor, Brunyé, & Maddox, 2014); and number of landmarks placed in the correct location (Coluccia, Bosco, & Brandimonte, 2007). Despite the prominent use of sketch maps, there does not appear to be a standardised approach to assessing the efficacy of maps, and this is presumably because map reading is complex and requires distinct cognitive processes, each of which are best captured in a slightly different way.

Although many methods have been devised to test map learning, most studies have been conducted using paper maps. In the modern world, computer based maps have become the norm, and this introduces additional challenges to the study of map reading. Cartographic maps in the digital age offer multiple methods of visualizing information, and recent attempts to look at digital maps have shown that high detail terrain maps can actually hinder learning (Sanchez & Branaghan, 2009). In the case of 3-dimensional digital maps, it has been found that a 2-step mental rotation process is required for comprehension. First, we rotate the map to a track-up orientation (as opposed to North-up), and then rotate around the horizon to an egocentric point of view. High cognitive resource competition can hinder our ability to complete this 2-step mental rotation (Aretz & Wickens, 1992). While there is evidence to suggest that survey information is encoded with orientation specificity, Rossano and Moak (1998) demonstrated that this could be due to the effects of high cognitive load. Cognitive load theory has been applied to many areas of instructional design (Sweller, Van Merrienboer, & Paas, 1998; Paas, Renkl, & Sweller, 2003), and has shown that increasing the amount of irrelevant information on a display can actually hinder learning (Mayer, Heiser, & Lonn, 2001).

1.2 Cognitive load and working memory

Spatial information learning has been closely tied to cognitive load and working memory (WM) demands. Researchers have investigated this relationship using the three part model of working memory (Baddeley, 1992). The model posits that working memory is split into distinct subcomponents: a central executive; a visuospatial sketchpad; and a phonological loop. The central executive coordinates resources between the two slave systems, and dual task paradigms have been used effectively to uncover the role of both slave systems in learning spatial information. For example, if the ability to learn spatial information is reliant upon visuospatial working memory (VSWM), then a VSWM secondary task should impair the ability to learn the information due to competition for finite resources.

Virtual reality methodologies have been used to explore the role WM plays in learning spatial information. Meilinger, Knauff, and Bülthoff (2008) had participants learn a route in a virtual city while performing a concurrent secondary task designed to tax either VSWM or VWM (verbal working memory). Both the VSWM and VWM tasks resulted in poorer route memory accuracy relative to controls. This suggests that encoding of spatial information, at least in a virtual setting, relies on both VSWM and VWM. Similar results have been found when participants were asked to learn environments from text descriptions (Brunyé & Taylor, 2008b) as well as videos (Gras, Gyselinck, Perrussel, Orriols, & Piolino, 2013). Interestingly, learning from route and survey perspectives may rely on different WM subcomponents. Pazzaglia, Meneghetti, De Beni, and Gyselinck (2010) had participants listen to route-based and survey-based descriptions of environments while performing concurrent VSWM and VWM secondary tasks. Both VSWM and VWM secondary tasks hindered learning of route-based information. However, survey-based learning was only negatively impacted by the VWM task, which suggests that survey information may rely primarily upon verbal processes.

Although many studies have shown that spatial information learning is dependent upon both VWSM and VWM, it is possible that mental rotation ability modulates the extent to which one relies on WM. In a study by Meneghetti, Gyselinck, Pazzaglia, and De Beni (2009), participants with low mental rotation ability showed the typical effects of WM taxation (as described above). However, those with high mental rotation ability showed no memory impairment due to VSWM or VWM secondary tasks. It was suggested that high mental rotation ability acts as a buffer against increased load on VSWM and VWM - once these WM subcomponents are taxed, those individuals can rely on their higher mental rotation ability to aid learning.

The majority of working memory studies described thus far have utilized text, video or virtual reality based sources of spatial information. There has been extremely limited research conducted on the effects of cognitive load/working memory on learning visual survey based information (cartographic maps). Coluccia, Bosco, and Brandimonte (2007) offered a key link between cognitive load and the learning of maps. Participants studied a map while performing a concurrent VSWM or VWM task. The results indicated that taxation of VSWM impaired the learning of landmark and road locations, whereas VWM taxation did not show any detrimental effects on map learning. Similar effects were shown in a study by Garden, Cornoldi, and Logie (2002), where participants had to learn segments of a route on a map and learning was, again, only impaired by the VSWM task.

Overall, the literature on WM and spatial learning suggests that taxing VSWM and VWM has detrimental effects on our ability to encode environmental information. What is the underlying mechanism that causes this effect? Why does high cognitive load cause a decrease in map learning performance? Although competition for finite WM resources is likely part of the explanation, it is also possible that the human visual system is being negatively impacted by high WM demands. In visual search tasks, high cognitive load has been repeatedly shown to increase distractor processing. We are more likely to be distracted by distractor items under high load (Lavie, Hirst, de Fockert, & Viding, 2004; Lavie & de

Fockert, 2005; Burnham, 2010). The same results have been replicated beyond singleton distractors, such as in the case of distracting faces (de Fockert, Rees, Frith, & Lavie, 2001) and the Ebbinghaus illusion (de Fockert & Wu, 2009). We also see similar effects in real life situations, such as the reduced ability to detect pedestrians when driving under high load conditions (Lee, Lee, & Boyle, 2009).

One reason that cognitive load affects visual attention is because we do not pay attention to everything in our visual field concurrently. There is an attentional spotlight from which we can effectively extract information from the visual field (Posner, 1980). Importantly, the size of this spotlight has been shown to change depending on load conditions. High cognitive load shrinks the size of this window (Williams, 1982) and our cognitive system preferentially allocates attention to items central in our field of view (Wolfe, O'Neill, & Bennett, 1998). The spotlight shrinking effect has also been replicated in older populations (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler & Ball, 1986). Therefore, it is possible that increased WM demands, and high cognitive load, hinders survey map learning due to a shrinking of the attentional window.

1.3 Hypotheses

We hypothesize that cognitive load affects route and landmark learning differently due to a change in the size of the attentional window. Landmarks are typically widespread and span a large surface of the map area. Whereas a route between 2 map points is narrow, not widespread like landmarks, and in learning it you typically need to follow a single road and its turns until you reach your destination.

We predict that, under cases of high cognitive load, the learning of landmark information from digital survey maps will be *hindered* (relative to the learning of a single route between 2 map points). High cognitive load will shrink the size of the attentional window, so as you saccade between landmarks you would not be able to attend to any of the other landmarks at the same time. It is predicted that this will hinder the learning of spatial relationships between the landmark items. A second reason for this prediction is because high cognitive load leaves you more prone to attentional capture from irrelevant information and eccentric distracting items (Lavie & de Fockert, 2005). At any given landmark, there is irrelevant distracting information 360 degrees around the particular landmark location you are trying to learn, further hindering your memory for the landmark under high load conditions.

On the other hand, we predict that memory for route information will remain unaffected, or possibly even *improve*, under high cognitive load. Although high cognitive load will shrink the size of your attentional window, it should not impact your ability to learn information that is already narrowly spaced such as a route. It is also possible that the distracting effects of non-relevant information will be reduced when learning a route under high cognitive load. A route can be seen as a series of interconnected turning points, which means if you are memorizing the location of these turns there is always 1 piece of information constantly available to you: the direction you came from. This means that as you learn any given turning point, a part of the 360 degree area around the point's location will be the road you were previously on. Unlike with landmarks, this information is not irrelevant to you and can actually aid your memory. Although high cognitive load will leave you more prone to distractors, there is less *irrelevant* information to be distracted by in the case of routes (i.e., a part of the surrounding area is *relevant* information). Therefore, distraction due to high cognitive load should not have as severe of an impact when learning a route.

Chapter 2: Experiment One

In this chapter we describe the first of two experiments designed to assess the relationship between cognitive load and map reading. We predicted that high cognitive load would hinder the learning of landmark information, but not route information. To test that prediction, participants completed route and landmark learning tasks under both low and high cognitive load. Results suggest that cognitive load does not affect the learning of route and landmark information differently. However, an unexpected sex effect was found whereby the original prediction is true, but only in the male population. Females were found to be negatively impacted by high cognitive load, but only when learning route information. The results are in line with existing literature on sex differences in map reading and way finding tasks.

2.1 Methods

Participants

A total of 66 undergraduate students (mean age: 20.3 years, *SD* = 2.5, 50% female) were recruited from the University of British Columbia, all of whom had normal or corrected-to-normal vision. Power analysis indicated that a minimum sample size of 35 is required to achieve power of 0.80, for a Cohen's d of 0.2 in detecting an interaction. All participants received 1.5 course credits for their time. A post-test questionnaire was administered to determine participants' attitudes towards various aspects of the task as well as to collect demographic information.

Experimental sessions comprised of 3 parts: a map reading task, a mental rotation task, and a post-test questionnaire.

Apparatus

All stimuli were displayed using a 19" LCD monitor with a resolution of 1280x1024. Python 2.7.8 was used, with Pygame 1.9.2, to display both the map task and the mental rotation task. The primary operating system was Windows 7.

Map Reading Task

Informed consent was obtained when participants arrived for the session. The map task was divided into 2 halves. The first half tested only one information type (e.g., landmark learning), and the second half tested the other type (e.g., route learning). We alternated the order of these halves from one participant to the next. Each half began with instructions specific to that part of the task (e.g., "In the first half you will be learning landmark information"). Two practice trials were then completed to familiarize participants with the task requirements. The main task itself consisted of 8 main trials, in a format identical to the one used for the practice trials. The only difference between practice trials and main trials was the number of items to be remembered on each map (3 vs. 7). A break was provided after the main trials, after which the second half would begin using the same structure but with the other type of test information. This gave us a total of 16 main trials and 4 practice trials.

At the beginning of each trial participants saw a 6 digit number sequence (Figure 2.1). In the high cognitive load condition, the sequence consisted of 6 random digits sampled from the set 1-9 (inclusive) without replacement, where no subset of the sequence contained any consecutive integers. For low cognitive load the 6 digits were always consecutive and ascending, where all digits belonged in the set 1-9 (inclusive). Whether a given trial will be high or low cognitive load was decided randomly with 0.5 probability of each. Participants were asked to commit the entire number sequence to memory as there was a memory test at the end of the trial.

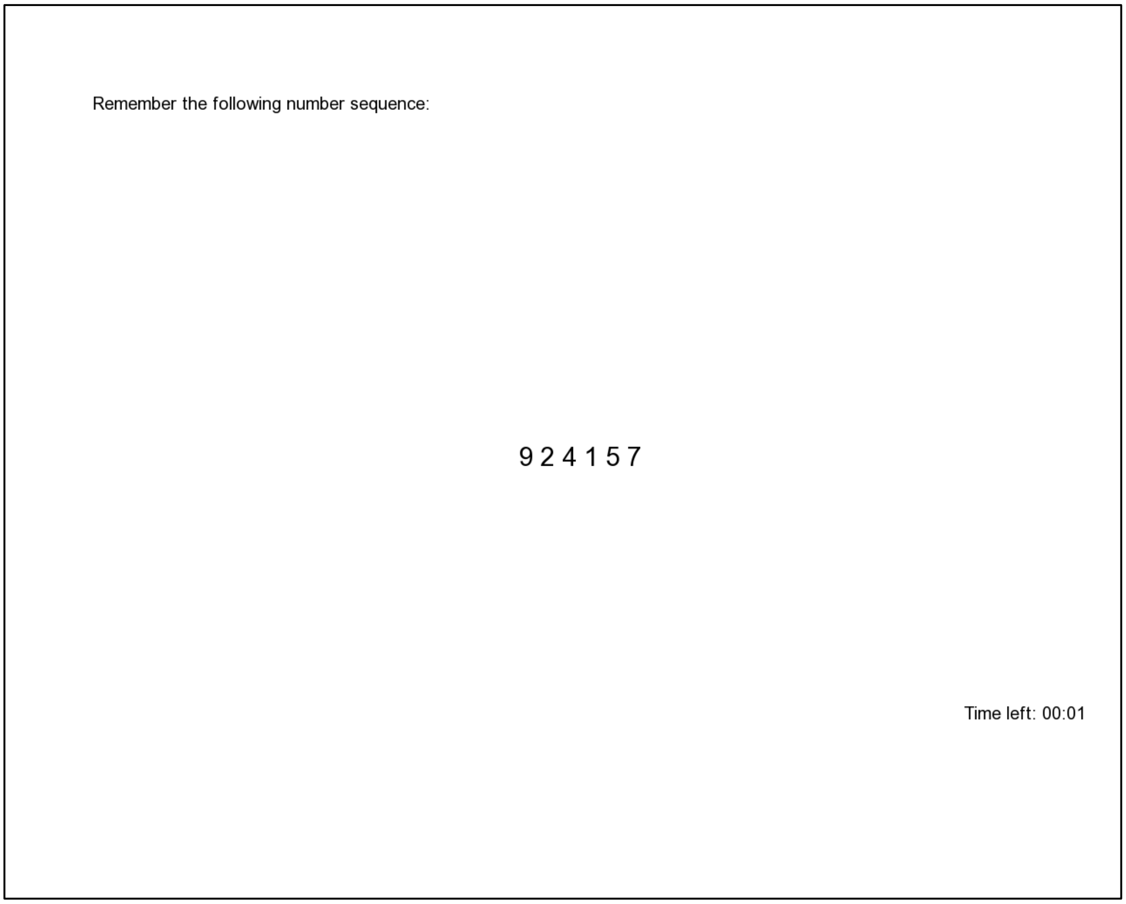

Figure 2.1. Cognitive load learning screen

A map was then shown consisting of both types of information: 7 landmarks and a single route that contained 7 turning points (Figure 2.2). Depending on which half the participant was on, they were asked to learn either the 7 landmarks, or to learn the route.

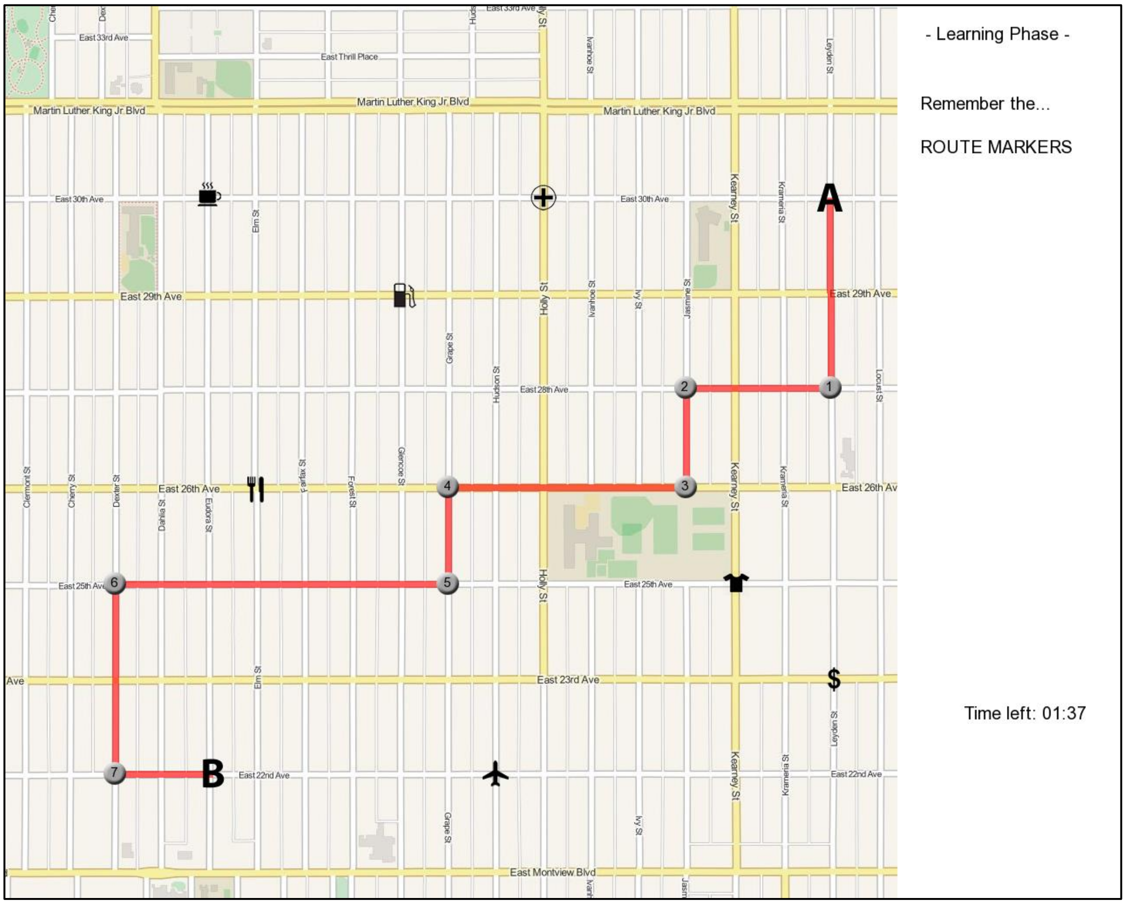

Figure 2.2. Map learning screen

We then removed all the items they were asked to learn from the map, and placed them in a list on the right side of the screen. The unlearnt information remained visible on the map (Figure 2.3). For example, if the participant learnt landmarks during the learning phase, all landmarks were removed from the map itself and placed on screen right, but the route remained visible in the correct location on the map. The map was then rotated 90 degrees clockwise or counter-clockwise (random with 0.5 probability of each). During this test phase, the participant's task was to drag each of the learnt items from the right side of the screen back onto the rotated map to their correct locations. In the case of the route learning trials, as the participant dragged each turning point onto the map, a red line would appear connecting the points together to form a route.

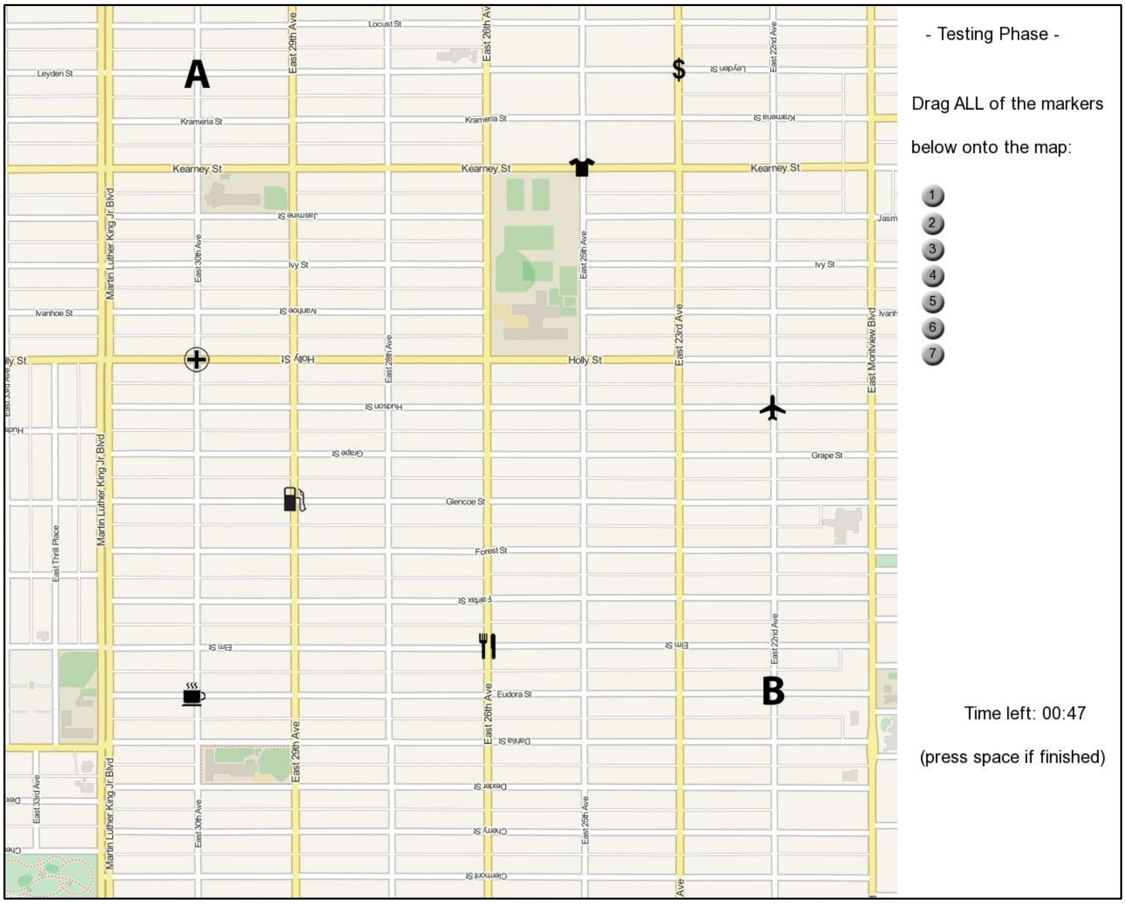

Figure 2.3. Map test screen

Once the map test was completed, a single number appeared on the screen. This numbered was in the original number sequence, and the task was to type the number that *followed* the displayed number in the original sequence (Figure 2.4). This is similar to the load manipulation used by de Fockert, Rees, Frith, and Lavie (2001). Feedback was then given for the number task, which marked the end of the trial. During the initial instructions, the experimenter stressed that learning the number sequence was as important as learning the map information in an attempt to ensure that participants would pay equal attention to each aspect of the task.

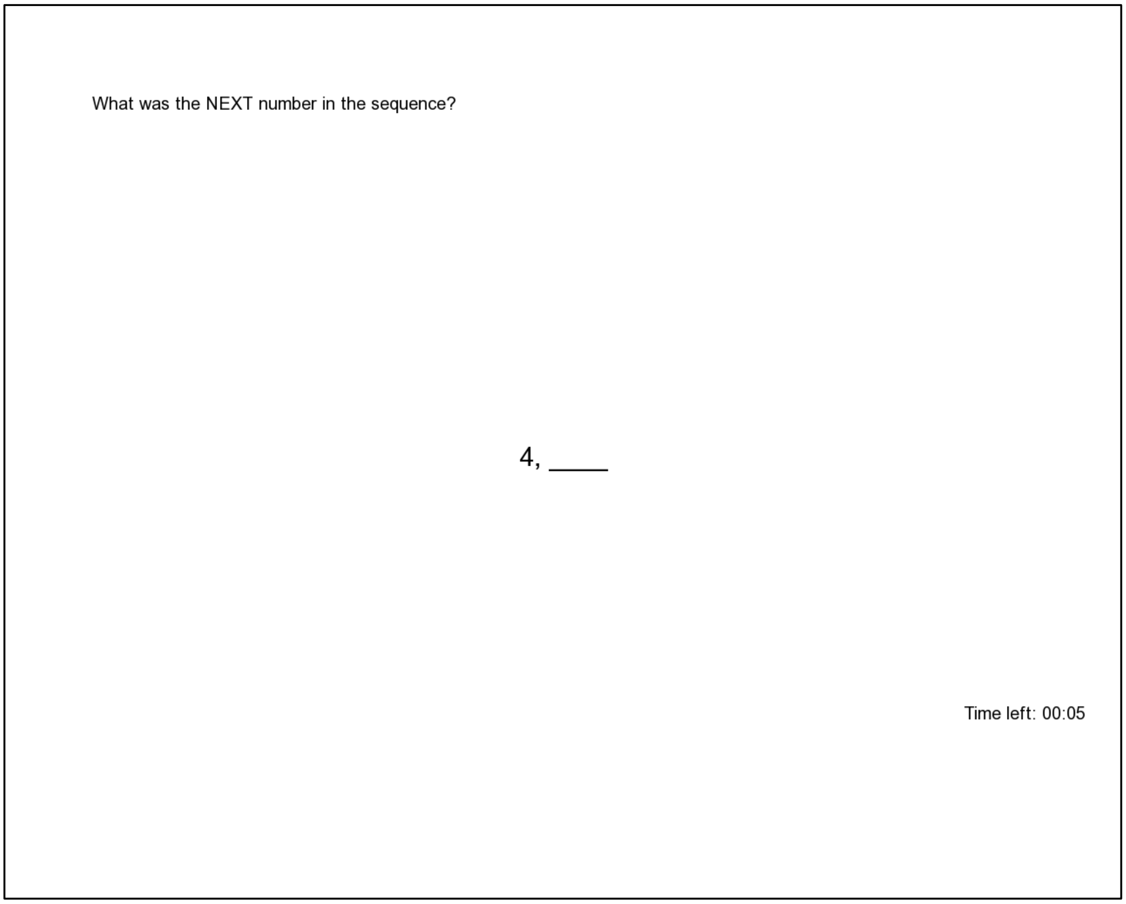

Figure 2.4. Cognitive load test screen

Stimuli Details. The font used was Arial at a Pygame font size of 20, unless otherwise stated. The number sequence on both the cognitive load learning screen and the cognitive load test screen was displayed using a larger font size of 30. The maps used had a dimension of 1024x1024 pixels and were all of real grid-based cities in the United States to 1) lower familiarity with the location shown and 2) ensure the maps had a grid based layout. Practice trials used locations in Vancouver, Canada. Each of the 16 main maps had a predefined set of both landmarks and route locations, which were the same for all participants. However, the maps were randomly assigned into either the landmark half or the route half of the session for each participant. Although each map contained both landmark and route points, only one type of information was tested for each map for any given participant. The routes on all maps were constructed using numbered circles that indicated turning points along the route, and connected together using a red line (RGB: 255,0,0) to form the route itself. These circles were numbered using a Pygame font size of 15. The map was displayed on left side of the screen, leaving the right side empty for placing the removed items during the map testing phase. The feedback screen displayed either the words "Correct" in green (RGB: 0,255,0) or "Incorrect" in red (RGB: 255,0,0). Each of the 4 phases of the trial displayed a timer showing the remaining time in the bottom right hand corner of the screen.

Task Timing. The load and map tasks used the same timings as Ahmed and de Fockert (2012), and Sanchez and Branaghan (2009) respectively. The cognitive load learning phase had a time limit of 3 seconds. An asterisk mask was then displayed in the same location as the number sequence for 0.5 seconds. The map learning phase had a time limit of 120 seconds. An audible beep was played when there were 30 seconds remaining to remind participants of the time. When there were only 10 seconds remaining the timer in the bottom right hand corner flashed red (RGB: 255,0,0) every 1 second until time ran out. Participants were required to spend the entire 2 minutes learning the map in an attempt to standardize learning time across all participants. The map test phase had a time limit of 60 seconds, which could be skipped if participants finished early. Like the learning phase, there was an audible beep at 30 seconds remaining and a flashing timer at 10 seconds remaining. The cognitive load test screen had a time limit of 5 seconds. The entire map task itself (including practice and main trials) took approximately 1 hour to complete.

Variables. The independent variables of interest were map type (landmarks vs. routes) and cognitive load (low vs. high), and were both tested within-subjects. The dependent variable was memory error, operationalized as the distance in pixels between the original location of the landmark/route marker and where the participant placed it during the map testing phase. Given that we are measuring error, a value of 0 indicates a perfect score. If an item was left unplaced and not dragged onto the map (for example, if the participant ran out of time) a value of 1448 was assigned for that particular item. This maximum error value is the largest possible distance between two points on the map.

Mental Rotation Task

Participants were offered a break after completing the map task, after which the mental rotation task (MRT) began. The task is a computer based version of the revised mental rotations task (version A) (Vandenberg & Kuse, 1978; Peters et al., 1995). The experimenter walked through the onscreen instructions with the participant. 3 practice trials were offered before the main trials began. During each trial a target image, consisting of a geometric shape, was presented along with 4 options (Figure 2.5). 2 of the 4 options were an identical shape but rotated around the vertical axis. The remaining 2 options were similar looking shapes (e.g., same number of blocks, same number of turns) but slightly modified such that they could never be rotated to match the target (e.g., some of the turns were in the wrong direction). The participant's task was to mentally rotate each of the 4 options to decide which 2 could be correctly rotated to match the target. A single point was given for the trial if *both* shapes could be identified. If only one correct answer was identified, no point was awarded for that trial. There were a total of 24 trials, split into 2 halves of 12. Each participant received a score out of 24 for this task.

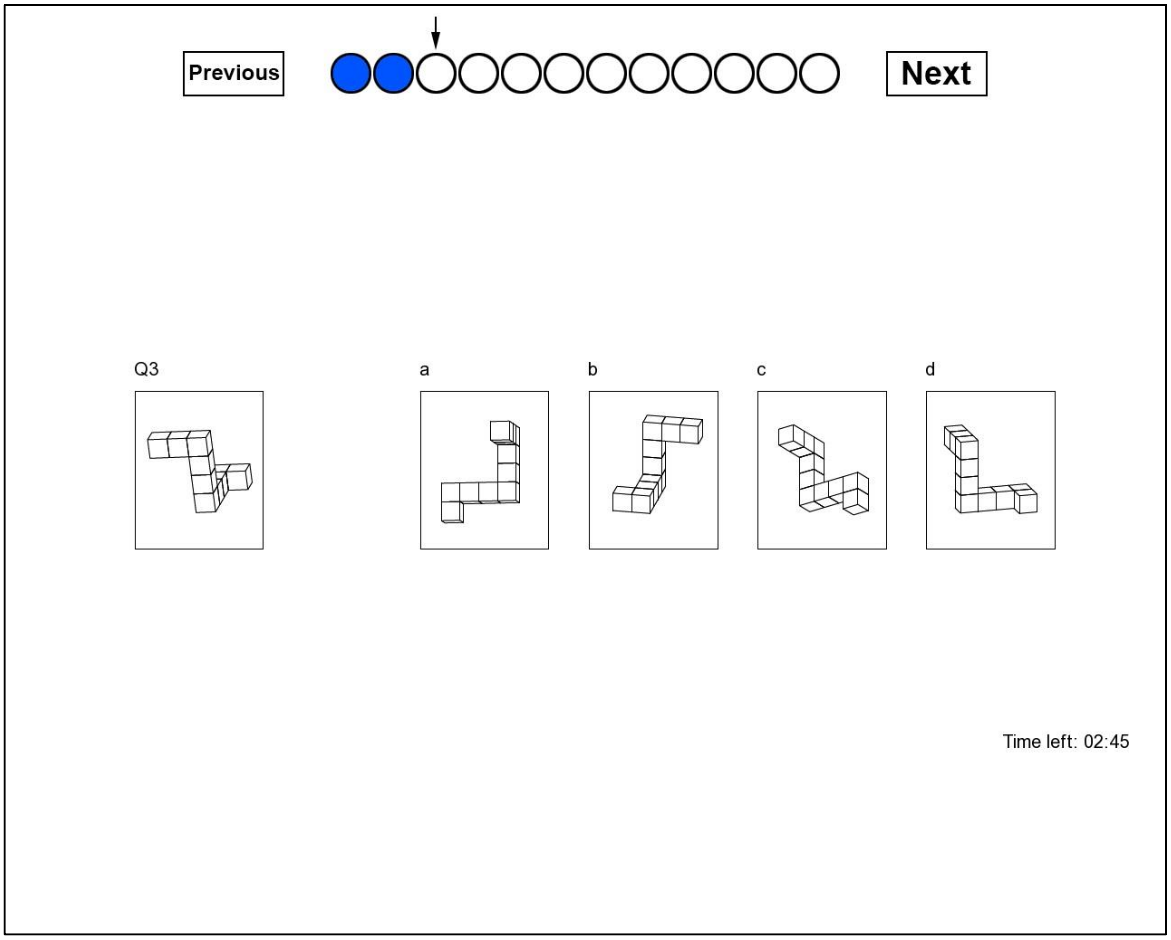

Figure 2.5. Mental rotation task

Stimuli Details. Each of the shapes (target and options) had a dimension of 145x175 pixels. The four options were displayed to the right of the target and upon choosing an option a blue border (RGB: 0,0,255) appeared around that shape.

Task Timing. Participants had 3 minutes to complete 12 trials. A break was then offered, followed by a second set of 12 trials with another 3 minute time limit. These time limits are the original timings as recommended by Peters et al. (1995). A menu was displayed at the top of screen allowing the participant to choose which trial to complete, and all trials within the half could be completed in any order they wish. During each half, an audible beep was played when there were 30 seconds remaining, and the timer flashed red (RGB: 255,0,0) when there were 10 seconds remaining in the half.

Questionnaire

A post-test questionnaire was completed after the MRT. It collected information regarding the participant's attitudes toward the task and day-to-day usage habits of mapping software. Importantly, we asked if participants recognized any of the US cities used during the map task. This information was later used to remove participants that had prior exposure to a city from the analysis.

2.2 Results

We hypothesized that cognitive load will affect route and landmark learning differently, with the specific prediction that high cognitive load will hinder memory for landmarks but not for routes (Figure 2.6). The independent variables were map type (landmarks, routes) and cognitive load (low, high), and we expected to find an interaction between these factors. The dependent variable was memory error measured in pixels.

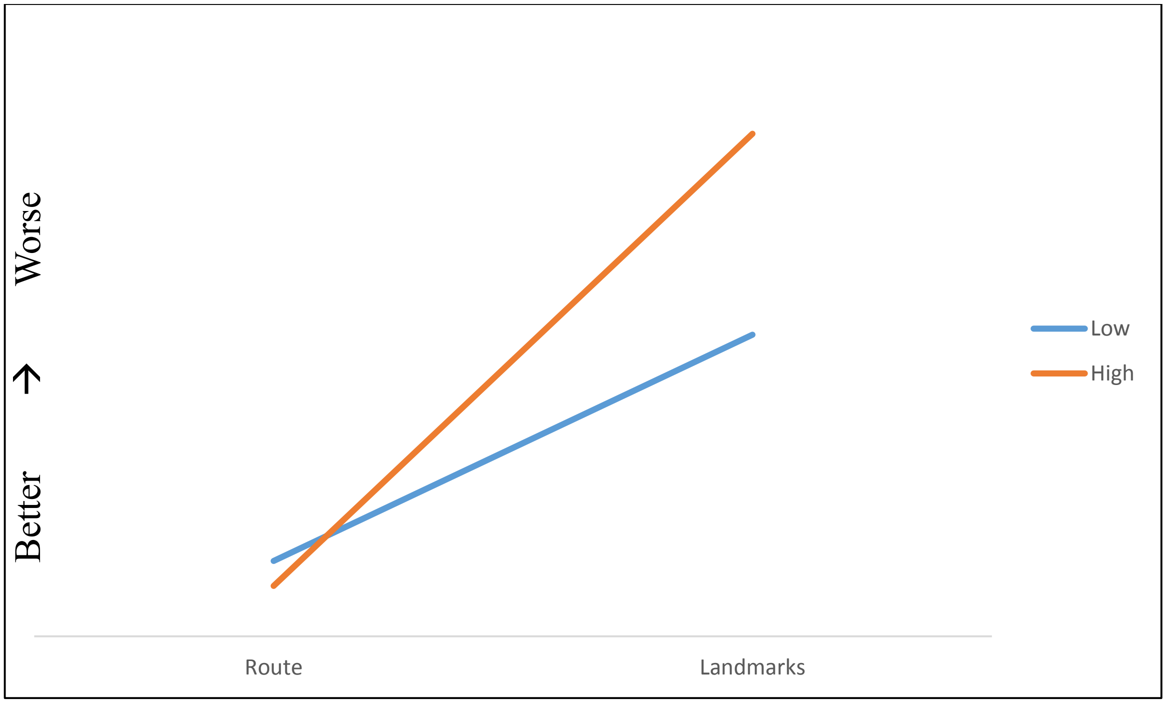

Figure 2.6. Expected results

Participant exclusion criteria

For the following analyses, participants were excluded if they recognized the location a map was representing (as determined with the post-test questionnaire), which led to the exclusion of 2 participants. Participants were also removed if their performance was +/- 2 SD from the mean of any condition, which led to the removal of 7 participants. All practice trials were also excluded from analysis.

Incorrect cognitive load trials

A typical practice is to exclude trials where participants incorrectly completed the cognitive load section of the trial (i.e., they didn't type in the correct number from the sequence). The reason for doing this is to ensure that cognitive load is manipulated correctly.

However, *all* completed trials were included in the following analyses regardless of whether the cognitive load test was completed correctly.

One reason for including all trials was due to the small number of trials completed in an experimental session. Each trial lasted approximately 3 minutes, resulting in a completion time of roughly 1 hour for all 16 trials of the map task (plus 4 practice trials). Given how cognitively demanding the task was, testing participants for a longer period of time would likely lead to undesirable fatigue effects. The 16 map trials break down into 4 conditions (for a 2x2 factorial design) with 4 trials each. If we were to remove trials where the cognitive load test was incorrect, we would end up averaging across fewer than 4 trials for each condition, which leads to a very unstable and inaccurate mean.

The second reason for including all trials was because there were no differences in map accuracy between trials where cognitive load was correctly answered and trials where participants responded incorrectly. Paired samples T-tests were used to compare map accuracy scores in cognitive load correct and cognitive load incorrect trials, for each of the 4 experimental conditions: route/low load ($t(4) = 0.58$, $p = .59$), route/high load ($t(37) = 0.68$, $p = .50$), landmark/low load ($t(8) = 1.27$, $p = .24$), landmark/high load ($t(39) = 0.28$, $p = .78$). Due to many people getting all cognitive load tests correct in the low load conditions, we could not compare their correct vs. incorrect scores and they had to be removed the analysis, hence the low degrees of freedom in the low load comparisons. No significant differences were found in any of the 4 conditions, which when coupled with the first reason noted above, suggested that including both load correct and load incorrect trials would have little detrimental impact on our analyses.

Does cognitive load affect landmark and route learning differently?

To test our main hypothesis, a 2-way within-subjects ANOVA with fixed factors map type (landmarks, routes) and cognitive load (low, high) was conducted on memory error (see Figure 2.7). Importantly, there was no significant interaction between the factors, $F(1, 56) = 0.98$, $p = .33$. However, we did find a significant main effect of map type, $F(1, 56) = 83.58$, $p < .001$, indicating poorer memory recall for landmarks compared to routes. There was also a significant main effect of cognitive load, $F(1, 56) = 4.35$, $p = .042$, meaning memory error was higher under high cognitive load than low load. The lack of an interaction suggests that cognitive load does not affect landmark and route learning in different ways, thus failing to support our initial hypothesis. A significant main effect of map type was expected because both intuition and pilot data suggested that, despite using the same number of items in both landmarks and route trials, landmarks are harder to remember.

Figure 2.7. Map memory error. Error bars indicate standard error of the mean.

Cognitive load task performance

One possible reason we failed to support our initial hypothesis is due to a performance trading strategy being employed by the participants. If the map task, or a specific condition within the map task, was felt to be too difficult by the participant, it is possible that they chose to sacrifice their performance on the cognitive load (number) task in that trial for increased performance on the map test. If that were the case, the cognitive load accuracy scores would look different depending on the map type and cognitive load level. The hardest map condition would lead to the greatest drop in load task performance, therefore we would expect to find an interaction between the factors for the load accuracy scores.

To test whether a trading strategy was being employed, we ran a 2-way within-subjects ANOVA using the same factors as in the initial analysis but using cognitive load accuracy (as a proportion) as the dependent variable (Figure 2.8). While we found a significant main effect of map type, $F(1, 56) = 5.86$, $p = .019$, and a significant main effect of cognitive load, $F(1, 56) = 177.63$, $p < .001$, we did not find a significant interaction, $F(1, 56) = 1.60$, $p = .21$. The lack of an interaction suggests that participants are not trading load task accuracy for map accuracy in the different conditions. This is further supported by looking at the bivariate correlations between map task error and load task accuracy scores for each condition. Route/low: $r(55) = -.40$, $p = .002$, route/high: $r(55) = -.34$, $p = .01$, landmark/low: $r(55) = -.24$, $p = .068$, landmark/high: $r(55) = -.38$, $p = .003$. The negative correlations support the conclusion that no trading strategy was being used. If trading was occurring, we would expect to find a positive correlation in these conditions, but instead we found that as map task error decreased (i.e., memory accuracy increased) load task accuracy increased.

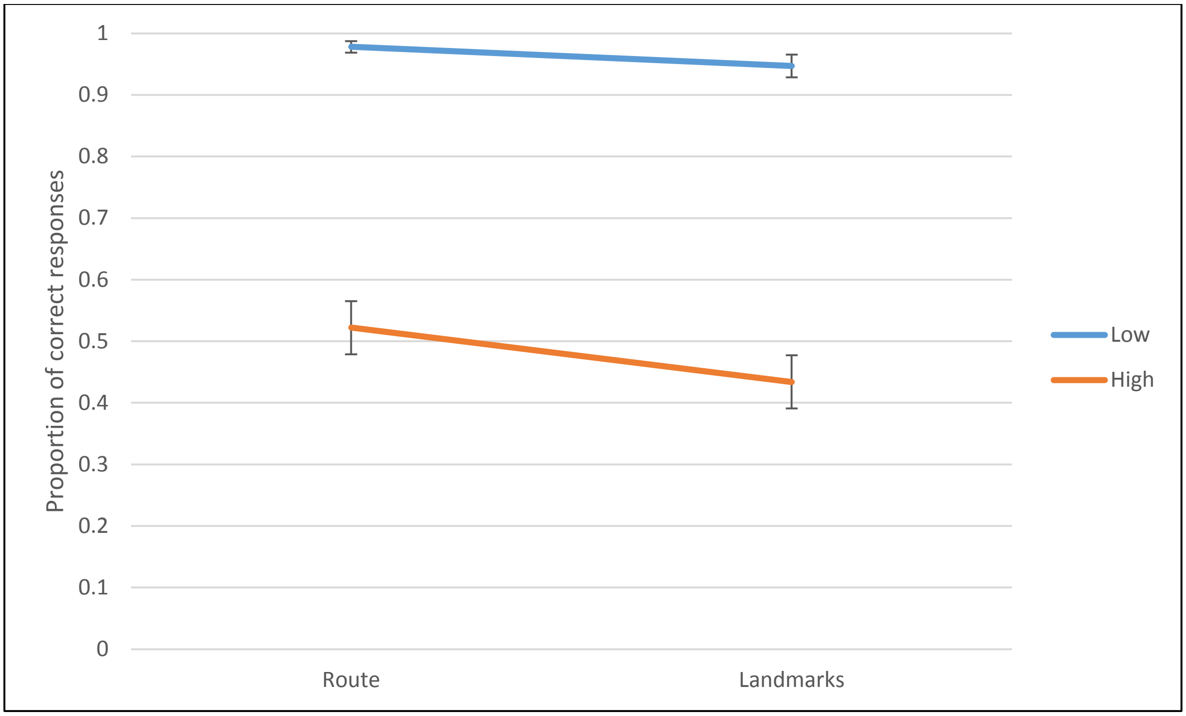

Figure 2.8. Load task accuracy scores. Error bars indicate standard error of the mean.

Does sex moderate the relationship between cognitive load and map type?

The literature shows a sex difference in both the processing of spatial information and the learning of map information. For example, males perform better on tasks that require mental rotation (Cherney, Brabec, & Runco, 2008) and they make more references to cardinal/Euclidean directions when describing routes (Dabbs, Chang, Strong, & Milun, 1998; MacFadden, Elias, & Saucier, 2003), while women have better memory for landmarks (Galea & Kimura, 1993; Tottenham Saucier, Elias, & Gutwin, 2003). These differences extend to the creation of sketch maps, where differences are found in the way males and females reproduce previously learnt environmental information (Huynh, Doherty, & Sharpe, 2010). There is also a difference in the way maps are explored. Tracking the gaze of the 2 sexes as they explored maps showed that females utilize tightly clustered patterns of gaze where each individual cluster was widely dispersed, and males have a looser cluster of gaze with individual clusters remaining close to each other (Christova, Scoppa, Peponis, & Georgopoulos, 2012). Although sex differences are typically less evident in more ecologically valid tasks like map reading (Bosco, Longoni, & Vecchi, 2004), it is important to rule out any sex effects in the current experiment.

To test whether sex acted as a moderator for the relationship between cognitive load and map type during the map task, we conducted a 3-way between-within subjects ANOVA using the same factors as our initial analysis but with the addition of a fixed between-subjects factor of sex (male, female). A significant 3-way interaction was found, $F(1, 55) = 13.55$, $p = .001$. This interaction suggests that the 2-way interaction between cognitive load and map type works different across the 2 sexes. There were no significant 2-way interactions between: map type by sex, $F(1, 55) = 0.01$, $p = .91$; load by sex, $F(1, 55) = 1.53$, $p = .22$; map type by load, $F(1, 55) = 1.07$, $p = .31$. We found significant main effects of map type, $F(1, 55) = 82.05$, $p < .001$, and cognitive load, $F(1, 55) = 4.30$, $p = .043$. However, there was no significant main effect of sex, $F(1, 55) = 0.02$, $p = .89$.

When breaking the 3-way interaction down by sex, we found a significant 2-way interaction in males (simple main effect), $F(1, 28) = 9.93$, $p = .004$ (see Figure 2.9). We originally predicted a 2-way interaction between map type and cognitive load, with high load causing a reduction in accuracy when learning landmarks. The pattern of data found in males is in line with our original prediction. Simple simple main effects analysis revealed no difference between high and low cognitive load in the route task ($p = .70$) but a significant difference at landmarks ($p = .001$). The analysis suggests that cognitive load is affecting routes and landmarks differently in the male population, with no difference when learning routes, but a significant difference when learning landmarks (worst performance being under high cognitive load).

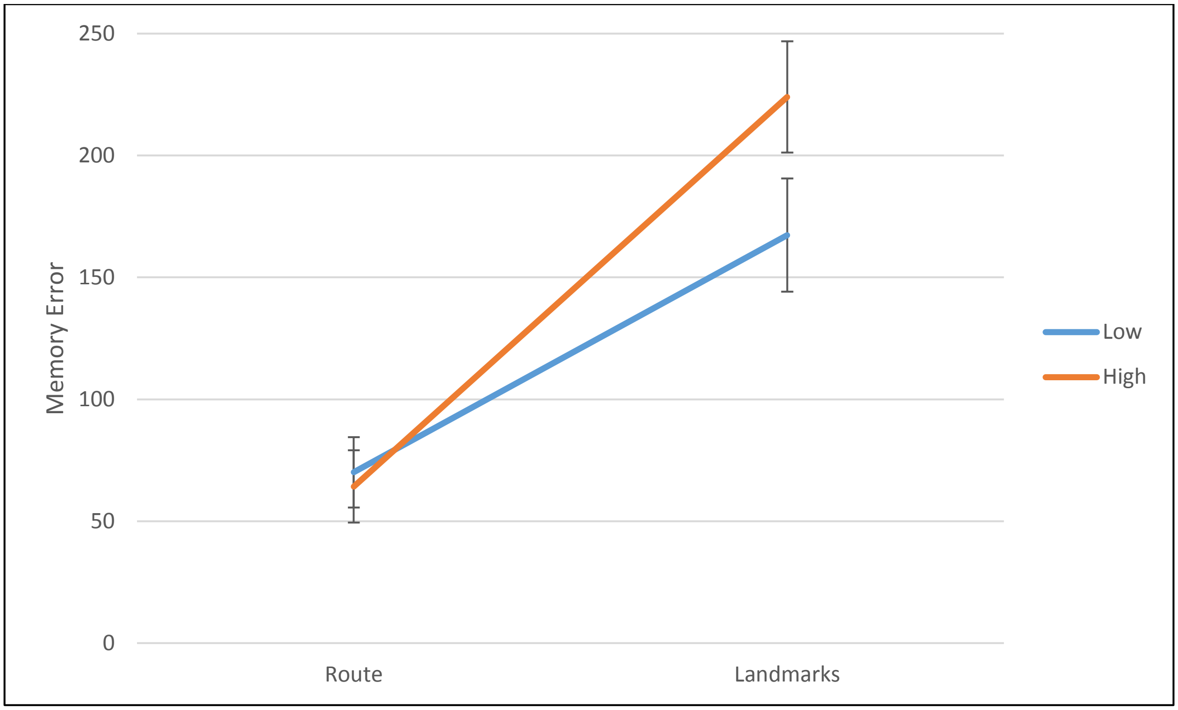

Figure 2.9. 2-way interaction in males. Error bars indicate standard error of the mean.

A non-significant, but trending, 2-way interaction between map type and cognitive load was found in females (simple main effect), $F(1, 27) = 4.03$, $p = .055$ (see Figure 2.10). There was no significant difference between high and low load when learning landmarks ($p = .46$), but a trending difference when learning routes with worse performance under high load ($p = .057$). Unlike males, females showed no difference between high and low cognitive load when learning landmarks. However, a trending difference is found for routes instead. The pattern of data is reversed between sexes, such that differences in cognitive load are only exhibited when learning landmarks for males, and learning routes for females.

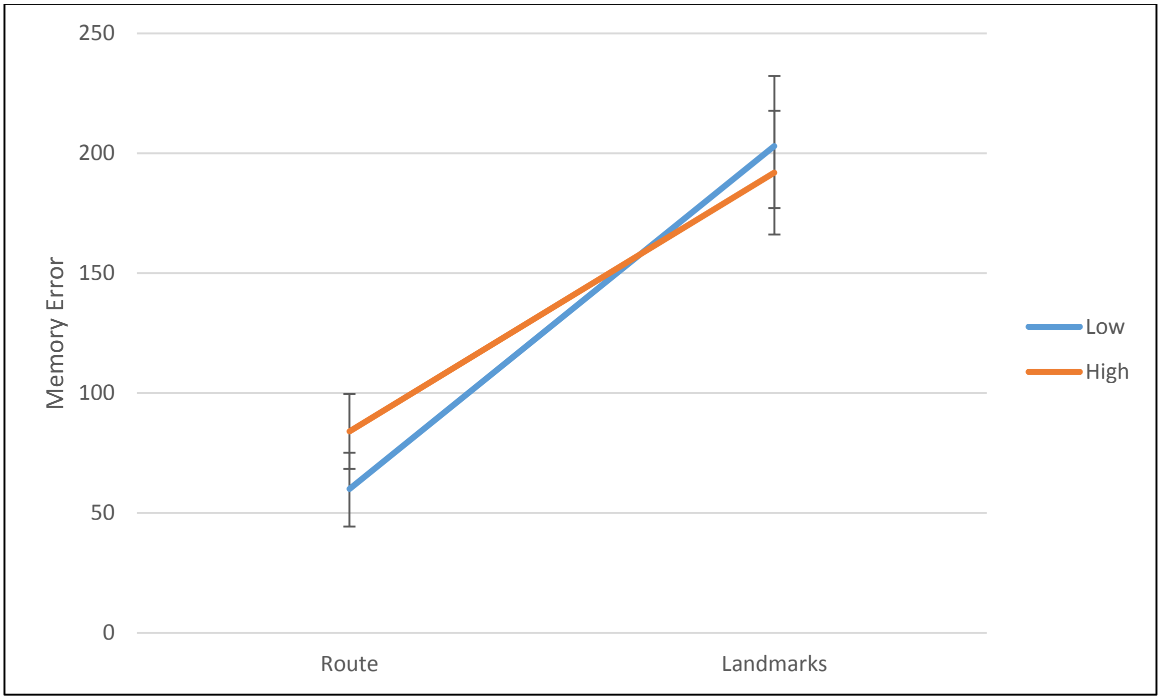

Figure 2.10. 2-way interaction in females. Error bars indicate standard error of the mean.

To determine whether either sex was utilizing a performance trading strategy, we conducted a 3-way between-within ANOVA on map type, cognitive load, and sex, with load accuracy as the dependent variable. We found no significant 3-way interaction between the factors, $F(1, 55) = 0.26$, $p = .62$. There were also no significant 2-way interactions: map by sex, $F(1, 55) = 1.96$, $p = .17$; load by sex, $F(1, 55) = 0.83$, $p = .37$; and importantly, map by load, $F(1, 55) = 1.60$, $p = .62$. While we found no significant main effect of sex, $F(1, 55) = 0.21$, $p = .65$, we did find significant main effects of both map, $F(1, 55) = 6.08$, $p = .017$, and load, $F(1, 55) = 176.61$, $p < .001$. The lack of a 3-way interaction, as well as no 2-way interaction between map type and load, suggests that neither males nor females were utilizing a performance trading strategy during the task.

Is there a difference between good and poor mental rotators?

Bosco, Longoni, and Vecchi (2004) showed that performance difference between sexes on various map reading and orientation tasks can vary as a function of their level of orientation ability. In the good mental rotator condition, men showed better performance than women in a map completion task, however, this sex difference was non-existent in poor rotators. This suggests merging participants across orientation ability could potentially mask interesting sex effects in map based tasks. MRT ability has also been shown to moderate the effect of cognitive load in the learning of spatial information (Meneghetti, Gyselinck, Pazzaglia, & de Beni, 2009). To account for MRT ability, we stratified the participant MRT scores using a median split (median = 12) and used this as a fourth factor in our analysis to determine whether there is a difference in the 3-way interactions between good and poor rotators.

A 4-way between-within ANOVA was conducted on the previous factors (map type, cognitive load, and sex) with the addition of the MRT median split as a binary coded between-subjects factor. The results from the omnibus ANOVA can be found in Table 2.1. A significant 4-way interaction was found, $F(1, 53) = 8.78$, $p = .005$, suggesting that the relationship between map type, cognitive load and sex is different between good and poor rotators. Simple main effects analysis showed a significant 3-way interaction, between map type, cognitive load, and sex, in poor mental rotators, $F(1, 27) = 23.26$, $p < .001$, but a non-significant 3-way interaction for the good rotators, $F(1, 26) = 0.39$, $p = .54$.

Test	F value	p value
4-way interaction	$F(1, 53) = 8.78$	$p = .005$
3-way interactions		
Map * load * sex	$F(1, 53) = 14.76$	$p < .001$
Map * sex * MRT	$F(1, 53) < .001$	$p \approx 1.0$
Load * sex * MRT	$F(1, 53) = 0.42$	$p = .52$
Map * load * MRT	$F(1, 53) = 0.001$	$p = .98$
2-way interactions		
Map * sex	$F(1, 53) = 0.01$	$p = .91$
Map * MRT	$F(1, 53) = 0.01$	$p = .91$
Load * sex	$F(1, 53) = 1.65$	$p = .21$
Load * MRT	$F(1, 53) = 1.42$	$p = .24$
Map * load	$F(1, 53) = 1.56$	$p = .22$
Sex * MRT	$F(1, 53) = 2.19$	$p = .15$
Main effects		
Map	$F(1, 53) = 78.8$	$p < .001$
Load	$F(1, 53) = 4.33$	$p = .042$
Sex	$F(1, 53) = 0.001$	$p = .98$
MRT	$F(1, 53) = 2.75$	$p = .10$

Table 2.1. 4-way omnibus ANOVA results in Experiment 1.

We broke down the 3-way interaction between map type, cognitive load, and sex for the poor mental rotators using a simple simple main effects analysis. The results showed a significant 2-way interaction between map type and cognitive load in males (poor rotators), $F(1, 13) = 12.45$, $p = .004$. The interaction showed a significant difference between low and high load, but only when learning landmarks ($p < .001$). The same analysis was conducted for female poor rotators, and again, we found a significant 2-way interaction between map type and cognitive load, $F(1, 14) = 10.66$, $p = .006$. Unlike with males, a significant difference between low and high load was found when learning routes instead ($p = .039$). Overall, the results suggest that good rotators are not as impacted by map, load or sex differences, whereas poor rotators show stronger 2-way, and 3-way, interactions than if stratified MRT scores were not used as an additional factor. It's possible that those with high mental rotation ability are protected against the detrimental effects of increased cognitive load (Meneghetti, Gyselinck, Pazzaglia, & de Beni, 2009).

A number of conclusions can be drawn from our analyses thus far: 1) Our original hypothesis was not supported as we did not find an interaction between map type and cognitive load, 2) the relationship between map type and load varies depending on sex and 3) that 3-way relationship only exists in poor rotators who score below the median on the MRT task.

2.3 Discussion

We hypothesized that cognitive load would impact the learning of route and landmark information differently, specifically that high cognitive load would hinder the learning of landmark information. Our data does not support this hypothesis, however, sex appears to play a role in the way cognitive load impacts map learning.

Male reliance on cardinal/Euclidean information and female preference for landmarks is well documented (MacFadden, Elias, & Saucier, 2003; Saucier, Bowman, & Elias, 2003;

Saucier et al., 2002; Galea & Kimura, 1993; Dabbs, Chang, Strong, & Milun, 1998; Huynh, Doherty, & Sharpe, 2010). An evolutionary explanation has been offered to explain the difference between the sexes in navigation and map reading tasks. It is likely that differences in spatial ability are a vestige of the separation of hunter-gatherer roles. Males were typically found in hunting roles where orientation and way-finding abilities were important, whereas females were more concerned with safety and raising offspring, so a landmark based strategy is preferred for learning the locations of nearby food sources. To support this, Silverman et al. (2000) conducted a way-finding task where both males and females walked around a woodland area and were asked to point their direction home at various stages. Males outperformed females on this task, as well as on a subsequent MRT task. Brandner (2007) showed that males utilize a widespread strategy in a search and exploration task, whereas females favour a more narrow and local strategy. The female preference for a landmark strategy is likely not a result of improved verbal skill (Eals & Silverman, 1994). Although it is possible that females compensate for poor Euclidean performance by developing a landmark processing advantage, this sex difference is likely an evolved dimorphism and not a compensatory behaviour (Silverman & Choi, 2006).

The current experiment adds support to past findings on sex differences. We found that a difference in cognitive load affects males only when learning landmarks, and affects females only when learning routes. This is in line with the idea that males naturally adopt a cardinal based approach to map reading, whereas females prefer a landmark based strategy. We show that high cognitive load negatively impacts males when learning landmarks and this is likely because landmarks are not the natural strategy used by males in map reading tasks. We do not see a difference between low and high load when males are learning routes because they typically contain cardinal/Euclidean information (male default strategy), and making it harder with high load does not appear to make a difference. Conversely, females default to a landmark based strategy, so making landmark learning more difficult under high cognitive load does not make a difference in terms of their memory accuracy. However, high cognitive load does make route learning more difficult, presumably because routes contain more cardinal information and that is not the strategy naturally employed by females.

Our results support the existing literature on sex differences in map reading, while at the same time showing that cognitive load can amplify the typical sex effects found in this line of research. How robust is this effect? Is there a point at which the task becomes too difficult, and the demand on working memory too high, that this effect disappears? In the next experiment we will examine the robustness of this effect by increasing the working memory demand of the map task.

Chapter 3: Experiment Two

This chapter describes the second experiment in which we examined the relationship between cognitive load and map reading, while considering the role sex plays in that dynamic. The results from experiment one supported the literature on sex differences in map reading, but we wanted to determine whether there was a threshold for the effect.

Working memory has a finite capacity (Miller, 1956; Baddeley, 1992) and increasing perceptual load in a map reading task can reduce the accuracy with which information can be learnt (Sanchez & Branaghan, 2009). Learning is also hindered by the addition of task irrelevant information (Mayer, Heiser, & Lonn, 2001). Learning performance, therefore, can drop once working memory and attentional resources are sufficiently taxed. The story is less clear when we consider sex differences. As discussed in Chapter 2, there is research to suggest that a strong sex difference exists in map reading tasks. However, the accuracy of cognitive maps is not always in favour of males (O'Laughlin & Brubaker, 1998), and sex differences in spatial tasks can be eliminated with practice (Kass, Ahlers, & Dugger, 1998). Furthermore, Bosco, Longoni, and Vecchi (2004) showed that the traditionally found sex differences in spatial ability can be eliminated by increasing the complexity and ecological validity of the task.

Overall, given the limits to working memory capacity and the possibility of eliminating sex differences by increasing realism and complexity, it is unclear whether the moderation of the interaction between map type and cognitive load by sex (as found in Chapter 2) will still exist once map task difficulty is increased. In other words, it is possible that the effect found in the previous chapter may be eliminated once a difficulty threshold has been reached. Few people have studied the role of cognitive load in sex differences when reading maps, so it was difficult to predict the point at which these differences disappear (if they do at all). We increased the map task difficulty (thus increasing the demand on working memory) and expected to find an attenuation in the previously found effect. Results suggest that there is in fact a threshold for the effect. Males and females show no difference in the way cognitive load affects specific types of map information once the difficulty threshold has been reached.

3.1 Methods

Participants

A total of 95 undergraduate students (mean age: 20.2 years, *SD* = 2.7, 51 male) were recruited from the University of British Columbia, all of whom had normal or corrected-to-normal vision. The same minimum number of participants was used as determined by the power analysis in experiment one, however, we aimed for a higher sample size due to the inclusion of the sex factor. All participants received 1.5 course credits for their time. A post-test questionnaire was administered to determine participants' attitudes towards various aspects of the task as well as to collect demographic information.

Apparatus

The same hardware and software configuration was used for both experiments one and two.

Map Reading Task

The map reading task was the same as in experiment one but with 2 major differences. Firstly, instead of learning 7 items on the map during the trial, the task was made more difficult by having participants learn 8 items instead. The number of items to be learnt during the practice trials remained the same. Despite increasing the number of items, the time limits remained the same as experiment one, thus making the map task more difficult overall. The second change was specific to the route learning trials. In experiment one, the distribution of map scores showed that a large number of responses were close to perfect in the route task, with positive skew of 1.52 (Figure 3.1) compared to the landmark task with fewer near perfect scores and a smaller skew of 0.58 (Figure 3.2). In addition to increasing the item count, we decided to make the route task even harder by implementing a second change. As participants dragged the route markers onto the map in experiment one, the computer would automatically connect the items together into a route in real time giving them a visual indication of the route that was being reconstructed. We believed that visually presenting the route to the participant makes route reproduction easier, so in an attempt to equalize the difficulty of the route and landmark trials, we removed the presentation of the connecting lines for experiment two (Figure 3.3). Participants dragged the markers onto the map, and at no point during the testing phase were they connected visually on the screen.

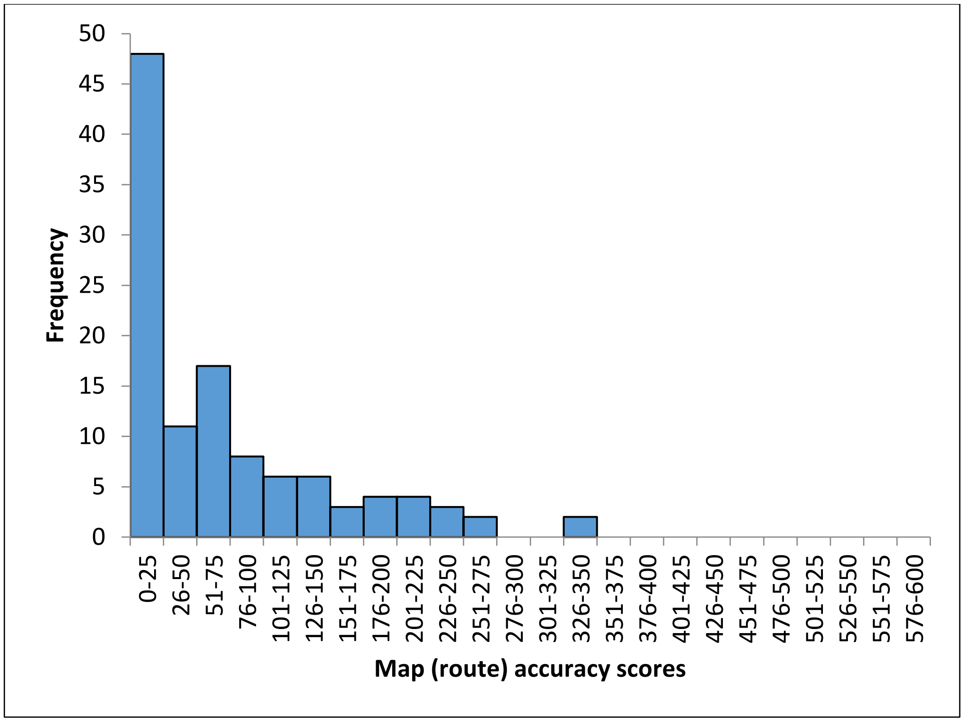

Figure 3.1. Frequency histogram of route scores in experiment one

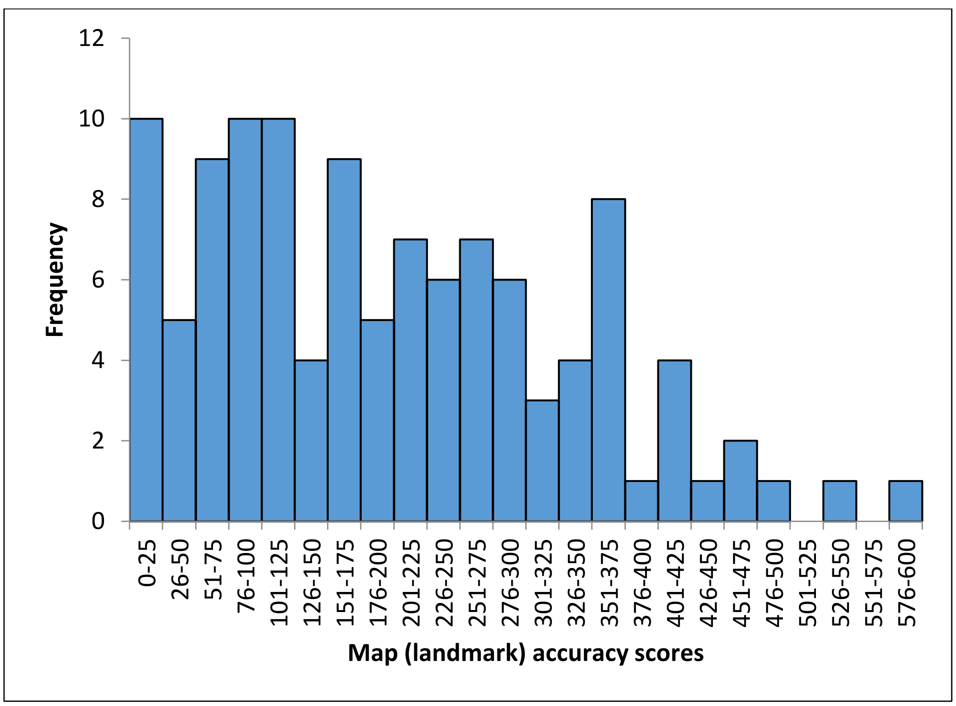

Figure 3.2. Frequency histogram of landmark scores in experiment one

Figure 3.3. Red line removed in experiment two

Mental Rotation Task and Questionnaire

Both the mental rotation task and questionnaire remained the same as in experiment one.

3.2 Results

The goal of experiment two was to determine whether the effect found in experiment one diminishes due to an increase in task difficulty. The independent variables were map type (landmarks, routes), cognitive load (low, high) and sex (male, female), and we expected to find either a weaker interaction between these factors or no interaction at all. If no interaction is present we would expect to find main effects of both cognitive load and map type. The dependent variable was memory error measured in pixels.

Participant exclusion criteria

Participants were excluded from the analyses for the following reasons: 1) computer related problems that prevented data collection (3 excluded); 2) if the participant recognized the location represented by the map (3 excluded); and 3) if they performed +/-2 SD from the mean of the condition (12 excluded). After exclusions we were left with an effective sample size of 77 participants.

Incorrect Cognitive Load Trials

The first step in this analysis was to determine whether we needed to exclude all trials where the cognitive load test was incorrect. Paired samples T-tests were used to compare map accuracy scores in cognitive load correct and cognitive load incorrect trials, for each of the 4 experimental conditions: route/low load ($t(9) = 1.11$, $p = .30$), route/high load ($t(49) = 0.95$, $p = .35$), landmark/low load ($t(15) = 0.54$, $p = .60$), landmark/high load ($t(52) = 0.13$, p

= .90). No significant differences were found in any of the conditions, suggesting that, like in experiment one, we could include every trial in the analysis regardless of whether the cognitive load test was correct.

Was experiment two more difficult?

Given that we decided to test for a threshold by increasing map task difficulty, we had to ensure map learning was in fact more difficult in the second experiment. To check this we conducted a T-test on the overall map accuracy scores using experiment number as the grouping variable. A significant difference was found, $t(132) = 3.04$, $p = .003$, indicating that the mean map score in experiment two was higher than in experiment one (179.73 vs. 133.04). T-tests were conducted to compare the landmark and route scores between the two experiments, a significant difference in difficulty was found for landmarks, $t(132) = 3.08$, $p = .003$, and also for routes, $t(132) = 2.13$, $p = .035$. Both the route and landmark tasks show significantly more unplaced items in experiment two (route: $t(132) = 2.44$, $p = .016$, landmarks: $t(132) = 2.01$, $p = .046$).

For the cognitive load (number) task, experiment two was not found to be harder than experiment one for either routes, $t(132) = 1.03$, $p = .31$, nor landmarks, $t(132) = 0.38$, $p = .71$. This was not entirely unexpected because no change was made to the load task between the two experiments. Although an argument could be made that because the load and map tasks are completed concurrently there should be a performance drop in both tasks, it could also be the case that increased difficulty in experiment two manifests as a drop in accuracy in only the map task as it utilized a more sensitive scale of measurement.

Does cognitive load affect landmark and route learning differently?

Our original hypothesis in experiment one was that changes in cognitive load would impact how well we learn landmark and route information differently (specifically: no impact on routes, but a performance drop when learning landmarks under high load). Although this prediction was not supported in the first experiment, we wanted to ensure this effect did not exist in experiment two.

A 2-way within-subjects ANOVA was conducted using fixed factors map information (route, landmarks) and cognitive load (low, high), with map error as the dependent variable (Figure 3.4). We found significant main effects of map type, $F(1, 76) = 228.20$, $p < .001$, and cognitive load, $F(1, 76) = 7.70$, $p = .007$. However, we found no interaction between the factors, $F(1, 76) = 0.14$, $p = .71$. The lack of an interaction suggests that cognitive load does not affect route and landmark learning differently, and the existence of the main effects are expected, as discussed in Chapter 2.

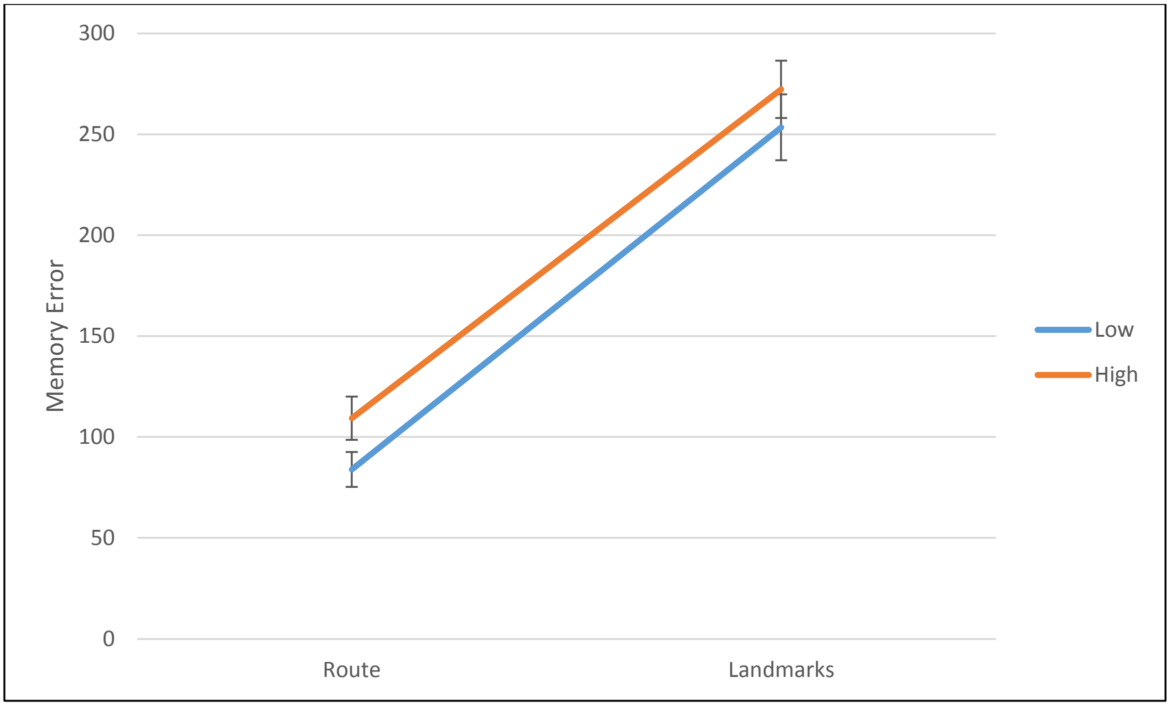

Figure 3.4. Map memory error. Error bars indicate standard error of the mean.

Cognitive load task performance

We wanted to check whether the data pattern found in the previous section was due to a performance trading strategy being used by the participants. To test this we conducted a 2-way within-subjects ANOVA using the same factors, but with cognitive load test accuracy as the dependent variable (Figure 3.5). While we found a significant main effect of cognitive load, $F(1, 76) = 198.41$, $p < .001$, there was no main effect of map type, $F(1, 76) = 0.51$, $p = .48$, and importantly no significant interaction, $F(1, 76) = 0.007$, $p = .94$. The lack of an interaction suggests that participants are not trading performance between the two tasks, otherwise you would expect the more difficult map conditions to have poorer cognitive load accuracy scores.

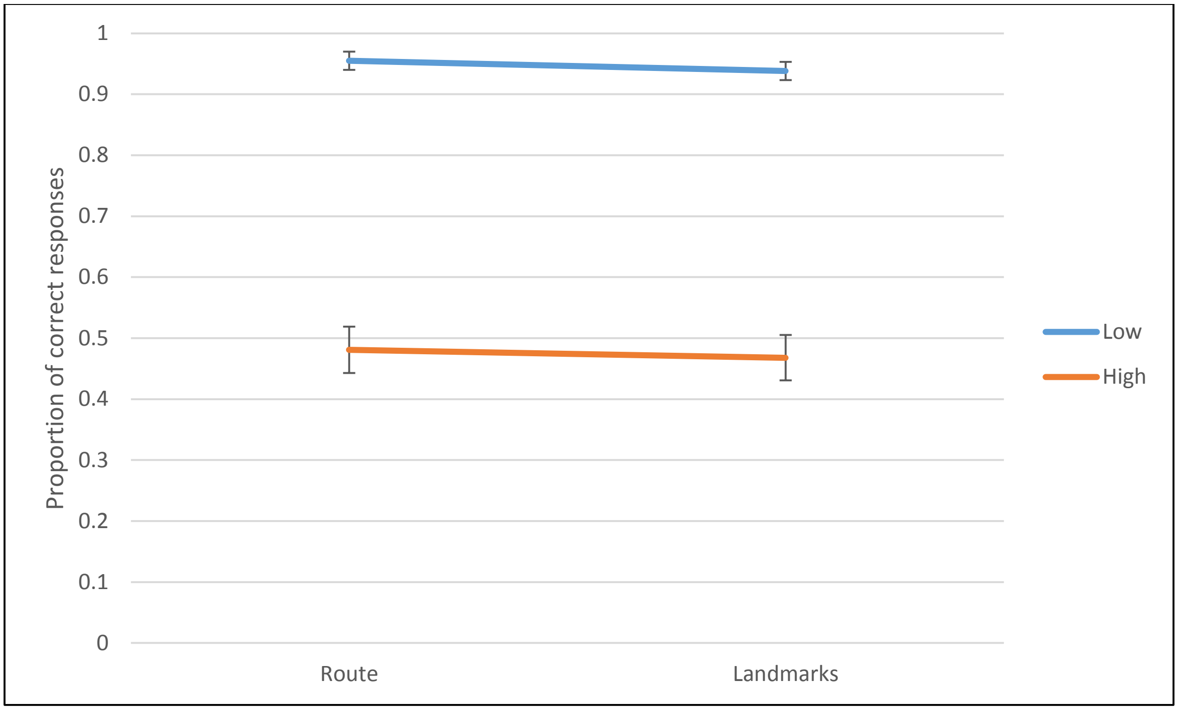

Figure 3.5. Load task performance. Error bars indicate standard error of the mean.

Sex Effects

The results from Chapter 1 demonstrated a moderation of the map by cognitive load interaction by sex. Given that we 1) made experiment two more difficult, 2) the capacity of working memory is limited, and 3) sex differences can be eliminated as a result of increased task complexity, we expect the second experiment to show an attenuation of the effect found in experiment one. If the task is difficult enough, the 3-way interaction between map type, cognitive load, and sex could be eliminated due to increased task complexity and increased demands on working memory.

To test this, we ran a 3-way between-within ANOVA on the map error scores with map type (route, landmarks), cognitive load (low, high) and sex (male, female) as fixed factors. Unlike experiment one, we did not find a significant 3-way interaction, $F(1, 75)$ =

0.94, $p = .34$. There were also no significant 2-way interactions: map by sex, $F(1, 75) = 0.06$, $p = .81$; load by sex, $F(1, 75) = 0.37$, $p = .54$; and map by load, $F(1, 75) = 0.10$, $p = .75$. We did not find a significant main effect of sex, $F(1, 75) = 1.78$, $p = .19$. However, we did find significant main effects of both load, $F(1, 75) = 7.83$, $p = .007$, and map type, $F(1, 75) = 224.89$, $p < .001$. This finding supports our theory that there is a threshold for the original effect as there is no 3-way interaction between the factors. By increasing task difficulty we have eliminated the sex difference in the map type by cognitive load interaction.

Mental Rotation Ability

Given that we were unable to replicate the findings from experiment one, likely due to hitting the threshold of the original effect, we needed to ensure there weren't any alternative explanations for the null findings. Experiment one indicated that the relationship between map type, cognitive load and sex was affected by level of mental rotation ability. We tested for the same effect in experiment two to ensure mental rotation ability was not causing a null effect. A 4-way between-within ANOVA was conducted on map error scores with map type, load, sex, and median split mental rotation task (MRT) scores as fixed factors. The results from this omnibus ANOVA can be found in Table 3.1. Importantly, there was no significant 4-way interaction between the factors, $F(1, 73) = 1.05$, $p = .31$. The 3-way and 2-way interactions involving MRT are also not significant, suggesting no differences between good and poor mental rotators. Therefore, unlike experiment one, MRT ability is not playing a role in any of these relationships.

Test	F value	p value
4-way interaction	$F(1, 73) = 1.05$	$p = .31$
3-way interactions		
Map * load * sex	$F(1, 73) = 0.47$	$p = .50$
Map * sex * MRT	$F(1, 73) = 0.61$	$p = .44$
Load * sex * MRT	$F(1, 73) = 3.90$	$p = .052$
Map * load * MRT	$F(1, 73) = 0.76$	$p = .39$
2-way interactions		
Map * sex	$F(1, 73) = 0.13$	$p = .72$
Map * MRT	$F(1, 73) = 0.26$	$p = .61$
Load * sex	$F(1, 73) = 0.87$	$p = .35$
Load * MRT	$F(1, 73) = 1.57$	$p = .21$
Map * load	$F(1, 73) = 0.34$	$p = .56$
Sex * MRT	$F(1, 73) = 0.15$	$p = .70$
Main effects		
Map	$F(1, 73) = 199.12$	$p < .001$
Load	$F(1, 73) = 4.96$	$p = .029$
Sex	$F(1, 73) = 1.52$	$p = .22$
MRT	$F(1, 73) = 0.02$	$p = .89$

Table 3.1. 4-way omnibus ANOVA results in Experiment 2.

Stratifying MRT scores in experiment one presented an interesting finding: the interaction between map type, load and sex only exists in those with poor MRT scores. It is possible that the null findings in the current experiment are because our sample only contained participants who were good mental rotators and, based on the experiment one findings, we shouldn't expect to find a 3-way interaction if that were the case. Another related issue is range restriction. If there are restrictions in the range of MRT scores between the two experiments it is likely that we will find different results. However, the MRT distributions for both experiments are remarkably similar (Figures 3.6 and 3.7). Descriptive statistics for each of the distributions can be found in Table 3.2. Due to the similarity of these distributions it is unlikely that the null effect in experiment two is because of a difference in the MRT score distributions of the participants. Our MRT distributions are also similar to the results reported in the original study (Peters et al., 1995). The means found in our experiments are slightly higher than originally reported by Peters et al. (1995), but this is likely due to our participants having increased familiarity and exposure to the test in the 20 years since the release of the revised version.

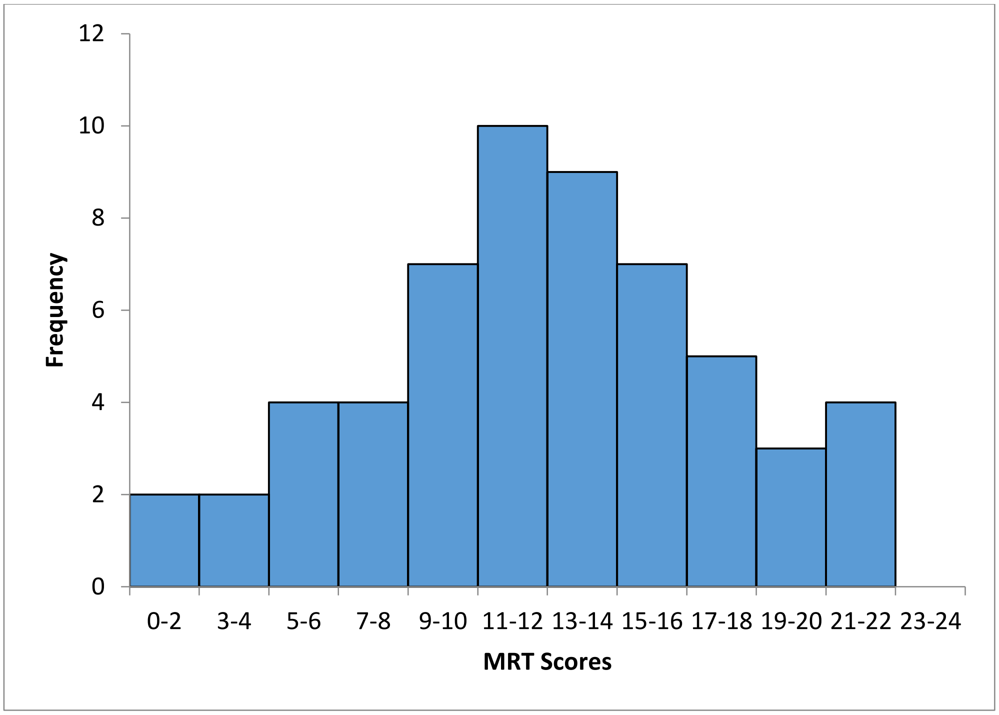

Figure 3.6. MRT score distributions for experiment one.

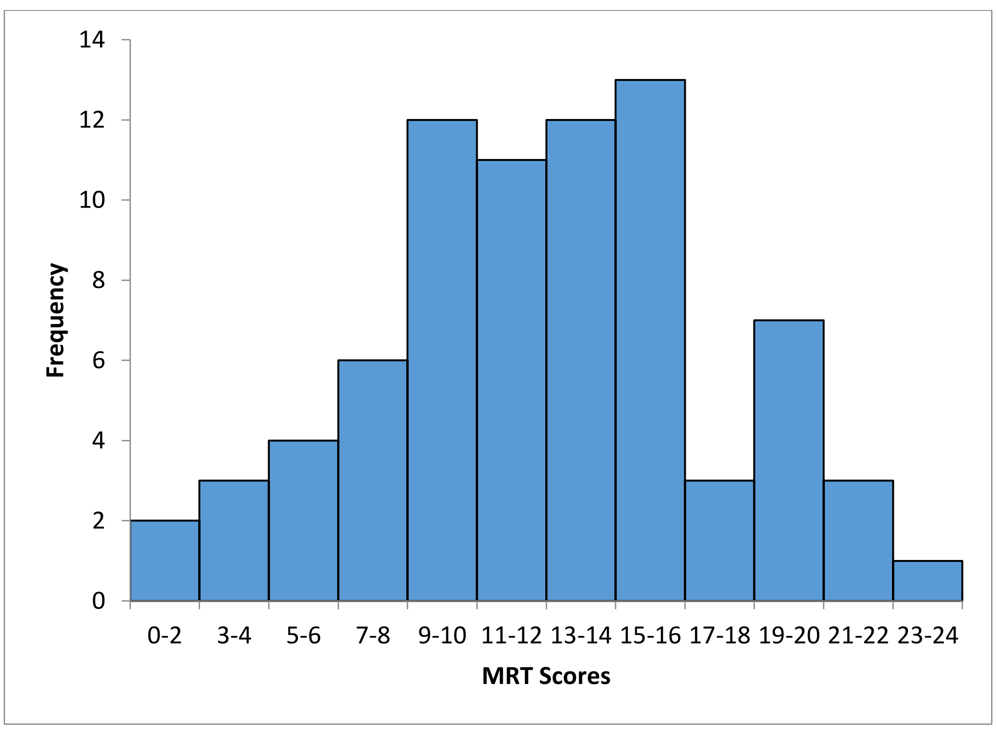

Figure 3.7. MRT score distributions for experiment two.

Statistic	Experiment 1	Experiment 2
Mean	12.35	12.44
Median	12	13
Standard Deviation	5.18	5.08
Range	22	23
Skewness	-.18	-.18

Table 3.2. Descriptive statistics for MRT scores in both experiments.

Participant level differences

It is possible that the null effect in experiment two is due to testing a population that is different from experiment one. Are there any differences between the two groups of participants? We looked for differences between the two experiments on a number of participant level variables: age, how frequently they use paper maps, how much they relied on route information, and how much they rely on landmark information. None of these variables showed significant differences between the two experiments. Mental rotation ability was also tested (as discussed in the previous section).

The only variables that showed a difference was how much the participants used navigation/mapping applications and how much they used technology. We conducted a T-test to test the difference in mapping application usage between the two experiments and found it to be significant, $t(129) = 2.63$, $p = .009$. Specifically, experiment two participants reported using these applications *less* often. Experiment two participants also reported using technology (e.g., laptops, phones) less often, $t(128.99) = 1.99$, $p = .049$. Levene's test indicated unequal variances (F = 5.72, p = .018), so degrees of freedom were adjust from 129 to 128.99.

It is possible that the difference in technology/mapping software usage caused the null effect in experiment two as those variables seemed to be the only reliable differences between samples. However, if this were true, it wouldn't necessarily invalidate the conclusion that the null effect was due to hitting a threshold in the effect. Experiment two participants report using digitals maps and technology less frequently, so placing them in a situation where they're forced to learn a computer based map could in fact increase cognitive load/working memory demands as they are not as familiar with the situation, thus causing them to hit the threshold sooner.

3.3 Discussion

The results from experiment one suggested that the interaction between map type and cognitive load worked differently in males and females. However, given the limits to working memory it was likely that sex effects get attenuated due to task difficulty becoming too high. In experiment two we tested whether such a threshold existed by increasing the difficulty of the map task.

We found that experiment two was in fact more difficult than the first. It is likely that a threshold was reached, after which the task was so difficult that cognitive load and sex differences do not impact learning of the two types of map information – the relationship between map type and cognitive load becomes the same for everybody, regardless of sex.

Although it is possible that finding a null effect in experiment two is due to differences in the samples, we found that participants in both experiments were roughly equivalent on most of the demographic variables we collected. The only difference we found was in how much participants used technology and mapping software.

Chapter 4: Conclusion

4.1 Overview of findings

Over the course of two experiments we tested the role cognitive load and sex played in map reading. We initially predicted that high cognitive load, due to a shrinking of the useful field of view, would hinder landmark learning. However, our results did not support that hypothesis and instead showed that sex plays a big role in moderating how maps are learnt under load. The literature on sex differences in map reading suggest that males rely on cardinal/Euclidean information when learning maps, whereas females tend to default to using landmark cues (Galea & Kimura, 1998; Huynh, Doherty, & Sharpe, 2010; Saucier et al., 2002; Dabbs, Chang, Strong, & Milun, 1998). Our findings suggest that high cognitive load can amplify this effect. When exposed to high load, male map memory is worsened when learning landmarks, whereas female memory is hindered when learning routes instead. This pattern of data supports the literature in this area as high load worsens memory accuracy when learning the non-default information for a given sex. This effect also only exists for those who are poor at mental rotation.

Experiment one demonstrated a sex difference in the map type by cognitive load interaction. However, research shows that typically found sex effects in various spatial tasks can be eliminated under different task conditions (Kass, Ahlers, & Dugger, 1998; Bosco, Longoni, & Vecchi, 2004). Our results from experiment two indicate that there is a threshold for the map type by cognitive load by sex interaction, and once that difficulty threshold has been passed neither sex, nor changes in cognitive load, affect routes and landmarks differently. We ensured that differences in participant demographics were not the cause of this null effect, however, we did find that experiment two participants reported lower usage of both technology and map related software, which may have affected the results.

Both experiments initially showed a main effect of cognitive load. Our cognitive load manipulation was designed to tax verbal working memory (VWM), and we have shown that increasing VWM demand leads to poorer map learning. Overall, this would suggest that VWM plays a role in the learning of survey information, however, given the absence of a visuospatial working memory (VSWM) manipulation, we cannot conclusively determine which working memory subcomponent is more important for encoding. Past research suggests that VWM does not play a role in the learning of survey information (Coluccia, Bosco, & Brandimonte, 2007; Garden, Cornoldi, & Logie, 2002), and posits that encoding is governed by VSWM instead. However, research on this topic is extremely limited and further work should be done to uncover the relative contributions of VSWM and VWM on encoding map based information.

4.2 Implications

Collectively, our results have a number of implications. Firstly, although there is a vast literature on map reading, very little attention has been paid to how technology influences the maps we read today. Digital maps are typically presented on screens, can provide multiple layers of information at a time, and gives us the opportunity to pick the type of information being presented to us. These factors make modern map reading vastly different from traditional paper map reading. By conducting our research on a digital device we were able to more accurately replicate conditions found when reading digital maps in the real world (e.g., computer based, mouse/keyboard input). Furthermore, our results suggest that map reading is sensitive to changes in both cognitive load and sex, so it is important for researchers to take these factors into account when designing map reading experiments.

Secondly, map designers and software engineers could glean some insight into how to make maps more effective. Too often we forget that the end user of a piece of software is a human being. With that comes the many intricacies and limitations of human cognitive processing. Although a lot of time is spent on making maps more aesthetically appealing and functional, we also need to design them to be more cognitively efficient. This is particularly important with digital maps due to their interactive nature. Interactivity can make certain types of map information more accessible, but at the same time it could also increase the cognitive load on a user. For example, when zooming in on a digital map, information from the large spatial scale disappears from the screen but you would typically still need to hold this in working memory as you attempt to integrate information from multiple spatial scales. This increased demand on working memory as a result of a software feature could adversely affect how well the map information is learnt.

4.3 Limitations

There are a few potential confounds in both of our experiments. As previously mentioned, we found that participants in experiment two reported using mapping software less often than those in the first experiment. This could be problematic as it means experiment one participants are more familiar with digital maps and are presumably more practiced at learning from them. This difference would manifest as an additional increase in map task difficulty for experiment two participants, on top of the already increased number of items. It could be argued that the increase in difficulty due to less mapping software exposure would merely strengthen our intended manipulation of higher working memory demand in experiment two. However, it’s also possible that those with more mapping software experience have developed/improved different abilities that aid map learning. For example, as you use more digital maps your ability to detect map features may improve, or your ability to identify certain icons may be hastened. While both of these abilities may increase overall working memory demand if you’re not practiced at performing those tasks, the nature of these abilities are different. In one case you’re dealing with an increase in perceptual load, while the other pertains more to the formation of icon schemas. Ideally we should aim to understand whether 1) an increase in software usage improves specific aspects of map reading, 2) whether those aspects of map reading come from cognitively distinct processes, and 3) how those distinct processes might affect our findings.

A related confound is driving ability/frequency. It is possible that better drivers, or at least more frequent drivers, would have more exposure to map reading or navigation based tasks. They have arguably more experience with learning their environments, routes and landmark features. This difference in driving ability could impact performance on the map task, and unfortunately our post-test questionnaire did not contain any driving related questions.

Each of our condition means were calculated from very few (4) trials. This was done in an attempt to reduce fatigue effects that occur as a result of participants spending too long in a single experimental session. A condition average being calculated from only 4 trials could have led to an unstable average, so future replications may benefit from increasing the trial count and either: 1) spread the experiment over 2 sessions, or 2) run one of the factors as a between-subjects factor.

4.4 Future directions

There are a number of avenues for future research. Further support should be provided for the existence of the threshold effect. Firstly, given the potential confounds with amount of map software usage and driving experience, it would be wise to run a version of the experiment where we controlled both variables using a pre-screen questionnaire and only test participants that have equal levels of experience. Secondly, it would be useful to run a version of the same map task with 6 items, and another with 9 items per trial. That way we can track the size of the interaction effect before and after the threshold.

Research on map reading and working memory show that visuospatial working memory is the primary component involved in encoding spatial information (Coluccia, Bosco, & Brandimonte, 2007; Garden, Cornoldi, & Logie, 2002). Our experiments only manipulated verbal working memory and it would be interesting to see how taxation of visuospatial resources might impact the sex differences we found. Presumably taxing visuospatial working memory would make the map task even harder, but would this amplify the sex difference or eliminate it altogether? This is a very sparse area of research, and more studies are required to elucidate the relationship between sex, working memory taxation and map learning.

Originally we expected high cognitive load to shrink the useful field of view (UFOV). It is unlikely that the mechanism underlying these interaction effects is related to the size of an individual's field of view because if it were then we would not see a significant difference between high and low load during female route learning. However, it would be interesting to see whether learning routes or landmarks affect the UFOV differently as this may provide some insight into why landmarks are harder to learn than routes. We can test this by including an eye-tracked UFOV trial (Ball, Beard, Roenker, Miller, & Griggs, 1988; Williams, 1982) after each map trial.

Assessing the map exploration patterns of males and females under different load conditions is another potential avenue of research. Christova, Scoppa, Peponis, and Georgopoulos (2012) used cluster analysis on eye gaze patterns and found that males and females utilize different styles of map exploration. Females tend to show smaller gaze clusters, where each cluster is widely spaced from each other, whereas males use more loosely focused exploration patterns where each gaze cluster itself is widely spaced apart. Given that cognitive load has been shown to affect the distribution of gaze (Williams, 1982) it would be interesting to see how changes in cognitive load might affect the way maps are explored by both males and females.

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