Abstract

CASE, MICHAELA ROSE. Navigation: Gender Differences in Virtual Environments. (Under the direction of Dr. Douglas J. Gillan.)

The purpose of this study was to decompose the navigation performance differences between males and females to address the lack of consistency in navigation research gender differences. Previous research on such gender differences is inconclusive and shows that some measures can be gender biased. This research utilized a collection of spatial ability and navigation measures to facilitate the decomposition of gender differences. Sixty six college students (31 males, 35 females) participated in this study. The independent variables were gender, feedback presence, and type of object used as a landmark. The dependent variables were map distance estimates, map angle estimates, navigation distance estimates, navigation angle estimates, and navigation time.

Participants completed two spatial ability tests (MRT and PTSOT), an anxiety measure (SAS), and a video game experience questionnaire as pre-tests. A virtual environment was used for the navigation tasks and on-screen maps were used for the map tasks. Results were as inconsistent as previous research. Two-way ANOVAs and Hierarchical multiple regression analyses showed that differences and interactions varied by dependent variable showing instances where males outperformed females, females outperformed males, and a lack of gender differences.

Navigation: Gender Differences in Virtual Environments

by
Michaela Rose Case

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APPROVED BY:

Jason C. Allaire

Anne C. McLaughlin

Douglas J. Gillan
Committee Chair

Dedication

To my parents, for never doubting me.

Biography

Michaela was born on September 10, 1986 in Upland, California and eventually moved to Bolivia, North Carolina. After graduating from South Brunswick High School in 2005, she enrolled in North Carolina Wesleyan College. In 2009, she graduated magna cum laude with a Bachelor of Science degree in Mathematics and a Bachelor of Arts degree in Psychology. After completing college, she joined North Carolina State University in Fall 2009 to pursue a Master of Science degree in Psychology, in the Human Factors program. She worked as a teaching assistant from Fall 2009 through Fall 2011 when she began an internship with Lenovo. She will be joining Lenovo as she continues at North Carolina State University towards a doctorate degree in Psychology.

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Introduction

Gender differences in spatial abilities have been researched for decades. Males tend to exhibit better spatial abilities than females (e.g., Halpern, 2000) and females exhibit stronger verbal skills than males (e.g., Halpern, 2000; Naglieri & Rojahn, 2001). Given that navigation is based on spatial abilities, males might be expected to have stronger navigation skills. However, research shows mixed results as to which gender is actually better at navigation tasks. Some studies show males are better (Tlauka, Brolese, Pomerov, & Hobbs, 2005), some show females are better (Barkely & Gabriel, 2007; Chai & Jacobs, 2009), and others show there are no gender differences (Gillner & Mallot, 1998).

Evolution

Evolutionists have developed two explanations for why gender differences exist in spatial abilities and navigation performance. Most widely accepted are the hunter-gatherer roles that males and females followed throughout history (Dabbs, Chang, Strong, & Milun, 1998; Silverman & Eals, 1992). In this model, males are typically the hunters which required them to travel into unknown areas to find game. The males would not take direct routes to search for the game but would use a direct route to return home (Dabbs et al., 1998). As the gatherers, females would maintain the home and forage in the area nearby. In doing so, females would use the same routes since they did not have to track game but rather returned to the same set of locations.

The second evolutionary explanation for these gender differences is how each gender traditionally found mates (Gaulin & FitzGerald, 1986; Dabbs et al., 1998). A prehistoric male would have maintained a larger territory to maximize his potential to find mates (Gaulin & FitzGerald, 1986). Males who were able to maintain a large territory were able to find more mates and produce more offspring. Maintaining a larger territory requires strong spatial and navigation skills so these genes were passed on to the next generation. Because males did the traveling, females were likely to have stayed in substantially smaller areas. These differences in travel exposure caused males to develop stronger spatial abilities and navigation skills. According to evolutionary theory, males should be better at navigating in general; however, research has found this is not always the case. Deeper analyses of cognitive differences, navigation, and spatial ability measures could help explain why gender differences exist in navigation research.

Gender Differences in Cognition

Many cognitive gender differences do not become consistently apparent until puberty, especially those in spatial abilities (Halpern, 1997; Hyde, Fennema, & Lamon, 1990; Roberts & Bell, 2002; Voyer, Voyer, & Bryden, 1995). Spatial abilities are measured in many different ways which is problematic since gender differences are not generalized to all types of spatial abilities (Catteneo, Postma, & Vecchi, 2006). Rather, these gender differences only occur in the specific group of spatial ability tasks that involve mental manipulation of material (Vecchi & Girelli, 1998; Cherney, 2008). The following examines non-spatial cognitive gender differences that may help explain the differences in spatial abilities and navigation.

Attention to detail. Attention to detail is important in many measures of navigation ability such as landmark identification, direction estimates, and distance estimates. Many studies examining gender differences in attention to detail show females are more competent than males. One example, facial recognition tests, requires attention to detail because faces are similar with subtle differences. In face recognition tests, females outperform males in accuracy with more hits and fewer false alarms when indicating which faces they have and have not seen before (Guillem & Mograss, 2005). Since recognizing the correct faces takes high attention to detail, it supports that females make more detailed memories than males (Guillem & Mograss, 2005). The less detailed memories are easily influenced by familiarity (Schacter, Norman, & Koustaal, 1998) and interference (Kramer, Delis, Kaplan, O'Donnel, & Prifitera, 1997; Palmer & Folds-Bennett, 1998; Guillem & Mograss, 2005). This suggests that for detailed memory tasks such as face recognition, males' memories are more influenced by familiarity and interference than females.

Various other studies show females tend to have more detailed memories than males. In research by Naglieri and Rojahn (2001), females exhibited better letter-word identification, passage comprehension, dictation, and proof-reading. Their results suggest females have stronger verbal skills and pay more attention to detail than males when reading. In a study of emotional memories, Canli, Desmond, Zhao, and Gabrieli (2002) showed that gender differences in recall can be moderated by level of emotion. The more emotional a memory was, the more vividly females remembered it (Canli, et al., 2002). When both genders rated emotions equally, females had better recall for the more intense emotional memories. When emotion was low, there were no gender differences which shows only females' memories are improved by emotions. In a false memory production study of themed word lists, Bauste and Ferraro (2004) did not find any gender differences. This supports significant gender differences in accurate recall, not false memory production. These examples all support attention to detail as an influence of performance on recall and recognition tasks. As such, females should be more attentive to details during navigation.

Studies of attention to detail with female dominant performance all tend to have contextual relevance such as tasks that test memory of newly acquired facts, recently learned tasks, face recognition, and name recognition (Herlitz, Nilsson, & Bäckman, 1997). In the experiment by Herlitz and colleagues (1997), newly acquired facts were false statements about famous people; recently learned tasks were a recall of the tests participants performed throughout the experiment; and faces and names were of random children. All of these measures are tasks that people may perform in their daily lives. Another experiment with an example of contextual relevance tested gender differences in attention to detail of a fake new TV show that was similar to "Nightline," a show that was equally watched by all participants (Meyers-Levey & Maheswaran, 1991).Their results showed that females had better memory of details about the fake show than males. The participants were tested by answering if a fact about the fake show was true or not. When the fact was extremely wrong, there was no gender difference but when the fact was similar, females significantly outperformed the males (Meyers-Levey & Maheswaran, 1991). This supports Guillem and Mograss's (2005) claim that females have more attention to detail and male memories are subject to influence by familiarity and interference. In terms of navigation, this should give females the advantage.

Although this supports that females have more attention to detail than males, it raises another point. In the female-dominated tasks of attention to detail, they have realistic applications: remembering faces, reading for comprehension, emotional memories, and facts about a TV show. Another aspect of these differences was the type of information required for the responses. Simply identifying faces, memories, and facts that were provided is different from asking the participants to use expected previous knowledge in response to the current task. For example, when tasks require participants to estimate distances with metric information, males are more accurate than females (Iachini, Sergi, Ruggiero, & Gnisci, 2005). This metric information was not provided during the experiment so participants have to use their previous knowledge to manipulate the conceptualized distances into the appropriate metric units.

Object recognition and replacement. Research shows females are more accurate in identifying and recalling object and image details (McKelvie, 1986; Sheehan, 1967; Voyer, Postma, Brake, & Imperato-McGinley, 2007). It is when the objects change form that gender differences begin to vary. This was exemplified in a series of experiments conducted by Catteneo, Postma, and Vecchi (2006), where gender differences were examined in virtual object and word location memory. For one experiment, participants had to complete an object replacement task where they had a study session then were tested by replacing the items, in the form of icons or words, to their respective locations. There were four conditions:

study object icons, tested with object icons; study object words, tested with object words; study object icons, tested with object words; study object words, tested with object icons. When there was no change from object study form to test form, overall performance was better. There were no significant gender differences in any of the conditions (Catteneo et al., 2006).

In the next experiment, two more conditions were added: study object icons, tested with half object icons and half object words; study object words, tested with half object icons and half object words. When half of the objects changed from words to icons and vice versa, males were more accurate than females (Catteneo et al., 2006). When all of the icons were changed to words and vice versa, there were no gender differences (Catteneo et al., 2006). Introducing distracters into the study phase decreased overall performance of both genders. When there was any transformation of object form, distracters caused the females to perform significantly worse than males (Catteneo et al., 2006). According to the authors, this shows that when cognitive load was increased by a distracter and mentally manipulating spatial information, males significantly outperform females in object replacement tasks (Catteneo et al., 2006). Unlike the attention to detail studies, the task was not typical and there was no relationship between the objects (except that they all had short names). This means the task did not have a direct realistic application.

In object replacement experiments with no indication of possible locations such as the one conducted by Catteneo and colleagues (2006), males outperformed females in terms of absolute error distance (Postma, Izendoorn, & De Haan, 1998; Postma, Winkel, Tuiten, &

van Honk, 1999; Voyer et al., 2007). However, when correctly replacing objects to a set of indicated possible locations, gender differences are absent or even reversed (Postma et al., 1998; Postma et al., 1999). When there are cues to show the participant where the item might belong, females outperform males in accuracy. In an object replacement task that used themed rooms with appropriate objects, females outperformed males in replacing the objects in their respective rooms (Goede & Postma, 2008). Each room showed three possible places for the item and participants indicated which location was the correct one. There were no gender differences in object identity, only object location (Goede & Postma, 2008). This is another example of an experiment with realistic application where females outperform males. Since males outperform females when there is no indication of possible locations, it seems counterintuitive that they would perform worse than females when possible locations are indicated. The reason why females outperformed males in the Goede and Postma (2008) experiment was because it had realistic application of possible places.

In the experiment by Iachini and colleagues (2005), participants were tested on recognizing non-related objects and their locations. To test recognition, participants had to pick out the original objects from a pile of distracters. Replacement was tested by having the participants physically take the objects they recognized to their locations in an empty, circular room. There were no gender differences on recognizing the correct objects. As for replacement, males were better at placing the objects in their correct positions when measured by distance. However, angle measurements between the replaced objects did not have gender difference. This brings about the issue of performance measures. Depending on how performance is measured, different genders may have the advantage. For example, this experiment shows that both genders placed the objects in the correct orientation but females were less successful at placing the objects the correct distance apart. If angles were used as a performance measure, there would be no gender differences but if distances were the measure then males would be better.

Realistic application has been slightly investigated in terms of types of objects. For objects that have gender associations, males and females perform differently in replacement tasks. In a meta-analysis conducted by Voyer and colleagues (2007), object replacement tasks favored females when the objects were common or geometric. For feminine, gender-neutral, and uncommon objects, there were no significant gender differences (Voyer et al., 2007). The only time males consistently outperform females is when the objects are masculine (Voyer et al., 2007). Also, females were better than males in object relocation tasks when time and accuracy were the dependent variables (Voyer et al., 2007). This brings about the issue of performance measures in object recognition and replacement tasks.

Mental transformation and rotation. Males have exhibited stronger skills in tasks requiring mental transformation and rotation of images and objects (Harshman, Hampson, & Berenbaum, 1983; Harshman & Pavio, 1987; Paivio & Harshman, 1983). Specifically, males outperform females consistently on the commonly used Shepard and Metzer Mental Rotation Test (1971) (Cherney, 2008; Cherney & Collaer, 2005; Halpern, 1997; Linn & Petersen, 1985; Masters & Sanders, 1993; Voyer et al., 1995). However, females exhibit significantly more improvement than males in pretest-posttest experiments of mental rotation (Cherney, 2008). This causes the gender gap to substantially narrow from pretest to posttest (Cherney, 2008; Feng, Spence, & Pratt, 2007). The type of mental rotation has also been shown to influence the amount of gender difference in performance.

Roberts and Bell (2002) examined gender differences in mental rotation of three different types of figures: two-dimensional (2D) alphanumeric characters, a 2D gingerbread man, and a 3D basketball player. Performance on all three of the mental rotation tasks showed no gender differences. Unlike the commonly used Mental Rotation Test (MRT) (Shepard & Metzer, 1971) which uses arrangements of cubes, these mental rotation tasks used alphanumeric characters, a gingerbread man, and a basketball player which are all considered common objects. Similar to the idea that females are better at relocating common objects, in this case it could have eliminated the gender difference in mental rotation ability. However, the female advantage in relocating geometric objects does not appear to translate for performance on the MRT.

Similar to the commonly used MRT is the Educational Testing Services 2D Card Rotation Test (CRT) (Sanders, Soares, & D'Aquila, 1982). For this test, participants are shown an abstract figure and then the figure is either rotated or reflected. Participants must then indicate which change was made to the figure. Even though this is similar to the MRT, there are no gender differences in performance (Cherney, 2008). Responses on the CRT are dichotomous: reflected or rotated. Responses on the MRT are more complicated because each figure is accompanied by two correct responses and two distracters. This difference is similar to that in the object relocation tasks where potential places and cues were provided instead of open-ended. Like the open-ended object relocation tasks, the MRT relies more on previous knowledge and familiarity to be successful.

In Cherney's (2008) study to examine the mental rotation differences, participants were divided into three training conditions: 3D video game, 2D video game, or paper and pencil puzzles. The MRT and the CRT were given as pretests and posttests. Cherney's (2008) results showed that both genders improve similarly on the CRT but only females improved on the MRT. Participants in both video game conditions, not the paper and pencil puzzle condition, improved on the MRT; however, participants in all conditions improved on the CRT (Cherney, 2008). This shows how video game experience can influence performance on the MRT and moderate the male advantage in mental rotation skill (Cherney, 2008; Terlecki & Newcombe, 2005).

Context and gender associations. Typically, navigation studies with realistic environments, such as buildings, do not have significant gender differences (Rossano & Moak, 1998; Wilson, Foreman, & Tlauka, 1997). This brings about the importance of context in navigation tasks. In an experiment examining the influence of context on gender differences in memory, Herrmann, Crawford, and Holdsworth (1992) used themed lists. Their results showed that given the same lists of items, genders perform differently depending on the list's context. This study had a list of generic words either titled "Grocery list" or "Hardware store". When the list was titled "Grocery list", the females had better recall but when the same list was labeled "Hardware store", the males had better recall. Another part of the study used a set of generic directions either labeled "Shirt" or

"Workbench". When the directions were labeled "Shirt", the females remembered more of the directions but when the same directions were labeled "Workbench", the males had better memory. This research is a prime example of how context and gender associations can influence gender differences in cognitive skills performance. More interesting is that although both genders performed better on their respective lists and directions, males were more influenced by the context than the females.

A context biased study found that males outperformed females in recall of the layout and operation of an electron microscope, an internal-combustion engine, and a refrigeration unit (Geiger & Litwiller, 2005). Participants were given a passage accompanied by a diagram, each contained exclusive information about the function and structure of each object. Although females would be expected to learn more from passages than males (Halpern, 2000), results showed that males acquire more information from diagrams and passages than females when learning about these devices. Even though there were gender differences, it is important to note that electron microscopes, internal-combustion engines, and refrigeration units are considered masculine devices. As shown by Crawford and Holdsworth (1992), this gender preference could have caused the males to perform better than if the diagrams and passages pertained to feminine or neutral devices.

Virtual environments and video games. Research shows that playing video games yields significant spatial ability improvements (Green & Bavelier, 2003). People who play video games on a regular basis, especially from the action-adventure genre, have a wider useful field of view, stronger visual processing skills, better task-switching skills, and have more attentional resources than people who do not play video games regularly (Green & Bavelier, 2003). Action-adventure video games focus on time constraints and accuracy which parallels the measures of most navigation studies. Video game experience is not only experience with virtual environments but also experience with the input devices. These advantages translate to navigation studies that use virtual environments.

From playing video games, spatial abilities can be significantly improved, including performance on the MRT as described earlier (Subrahmanyam & Greenfield, 1994; Terlecki & Newcombe, 2005). Specifically, Terlecki and Newcombe (2005) showed that both males and females can continue improving spatial abilities through videogame training even after the duration of a semester; however, females tend to show significantly more improvement than males. Since most video game players are male (Cherney & London, 2006; Terlecki & Newcombe, 2005), this could be due to a ceiling effect with males since females tend to have less prior video game experience.

The majority of virtual environment navigation research that show significant male advantages use unrealistic environments such as mazes (Astur, Oritz, & Sutherland, 1998; Moffat, Hampson, & Hatzipantelis, 1998; Sandstrom, Kaufman, & Huettel, 1998). Using a virtual Morris Water Maze (MWM), Astur and colleagues (1998) measured gender differences in performance of relocating a platform floating at a random location in the water. Their results showed that males were faster when the platform was not visible but genders were equal when the platform was visible. For both the visible and invisible conditions, males had substantially lower heading error than females. Interestingly enough, males traveled more distance in both conditions and it was considered better than the females who traveled less distance. Traveling more distance could be negative because the males could have been traveling aimlessly until they came across a familiar viewpoint. In the invisible condition, males crossed the platform significantly more times than females before finding it. Although the males were faster at finding the invisible platform than the females, they traveled more distance. It is possible that traveling less distance is a characteristic of females in unfamiliar places or females were not as comfortable with the controls in the virtual environment as males. Females could have spent the extra time looking for the platform before actually moving towards it whereas males could have moved more until they found the specific orientation.

Another study that used a virtual MWM was performed by Sandstrom and colleagues (1998). In this experiment, participants were tested in three different environments: stable landmark, where the room was octagonal and had the same landmarks as the training phase; geometric, where the room was trapezoidal but had no landmarks; and random landmark, where the room was trapezoidal but the landmarks changed position every trial. Overall, males were faster at finding the platform in the geometric and random landmark conditions but there were no gender differences in the stable landmark condition. These results showed that females rely on accurate landmarks whereas males utilize both landmarks and geometric information. However, the females needed significantly more time in training to orient themselves with the virtual environment and input devices. This lack of fluency in virtual environments could have impeded female performance and caused them to focus on the landmarks instead of the walls which were farther away.

One study used a realistic virtual environment, a shopping center, to compare spatial knowledge of males and females (Tlauka, Brolese, Pomeroy, & Hobbs, 2005). Since it is contextually relevant, it would be assumed that females would do better at the task; however, the results showed otherwise. During pre-training to orienting themselves with the controls in the virtual environment, the females took significantly longer than the males. Overall, females had significantly longer orientation and navigation times. Since longer orientation time was significantly correlated with longer navigation times, it seems logical that the gender difference in navigation time was due to the orientation time; however, the researchers did not test this potential mediation. Their results showed that overall, females made more incorrect decisions than males but again, the researchers do not address how this could relate to the gender differences in orientation time. Lacking familiarity with the controls could have caused the females to have more difficulty when navigating the virtual shopping center which in turn would increase their navigation times. The context, a shopping center, could have influenced the males' motivation to complete the task quickly since it was a feminine setting and males are influenced by context.

In Tlauka and colleagues (2005) experiment, males also outperformed females in time to make a directional estimate and map-drawing accuracy. The map-drawing was done with a protractor but time to complete this task was not measured and the researchers did not control for protractor experience. Different from the previous research discussed earlier, there were no significant gender differences in the accuracy of directional and distance estimates. Although this study claims males outperformed females in a realistic environment, the measures failed to examine the male-dominated skills with the controls in the virtual environment as well as those needed for post-tests. The advantage seems to have been due to the familiarity with the input devices.

Non-gamers can improve. Training non-gamers with action-video games significantly improves useful field of view, visual processing, task-switching, and increase attentional resources (Green & Bavelier, 2006). Testing the effects that video game experience can have, research was done to test a virtual environment of a submarine to supplement training for student submariners in the military (Stone, Caird-Daley, & Bessel, 2009). Results showed that when an interactive virtual submarine environment supplemented instruction, student submariners performed better on their submarine safety and performance exams (Stone et al., 2009). This research shows that not only can non-gamers improve but video games can enhance skills beyond typical training techniques.

Research shows that video game players have a wider useful field of view (UFOV) and higher MRT scores than non-video game players (Feng et al., 2007). In an experiment by Feng and colleagues (2007), males outperformed females on these measures but most of the males were video game players and most of the females were non-video game players. Gender differences in the video game players group was much smaller than the non-players group. A second experiment showed that when people trained with an action-video game, they exhibited a significantly improved UFOV (Feng et al., 2007). After playing the action-video game, gender differences in UFOV ability was not significant whereas pretest showed significant gender differences in favor of males (Feng et al., 2007). As for the MRT, males continued to be significantly better than females although the difference was greatly reduced from pretest to post-test. This shows females improved significantly more than males on the MRT which supports video game experience as a mediator for the gender difference in performance measures.

Navigation

Arguably the most important application of spatial abilities, navigation is essential for people to perform most of their everyday tasks. Strong navigation skills are essential for any persons controlling a ship, aircraft, or any other vehicle. Anyone who moves through their environment needs navigation skills. As mentioned above, gender differences in spatial abilities appear to translate to navigation. Although some of the research is mixed, results most consistently favor males in virtual environments (Chai & Jacobs, 2009; Gillner & Mallot, 1998). Typically, the measures to assess navigation ability, such as metric information and mental rotation skills, also tend to favor males (Iachini et al., 2005; Cherney, 2008). In order to understand why these gender differences are more prominent in virtual navigation than physical navigation, it is important to take a closer look at what is being measured and how it’s being measured.

Cognitive maps. Previous research has proposed that people do not directly interact with a system, “they interact with their mental model of that system” (Gillan, 1994, pp. 256) (Norman, 1988). To understand how a person navigates, the mental model, or cognitive map, of a space has been studied. The concept of a cognitive map is expansive and encompasses all of the different types of information people use when navigating (Kitchin & Blades, 2002). Determining the environmental cues that make the cognitive map would show how males and females use different information to navigate the same space.

The ‘cognitive map’ is not necessarily like “a cartographic or any other type of map”, the term ‘map’ is used as a descriptor of the arrangement of information used to conceptualize the space (Kitchin & Blades, 2002, pp. 2). This conceptualization includes the set of descriptions representing a given space (such as landmarks) and the spatial relationships between the descriptors, hence a form of ‘map’ (Kitchin & Blades, 2002). Previous research performed by psychologists and geographers show that a cognitive map is the result of acquiring and applying spatial knowledge to a mental model of a space (Bell & Saucier, 2004). A cognitive map is malleable, facilitating changes and different perspectives to be imagined of the same space (Bell & Saucier, 2004). However, gender differences may be in how the cognitive map is constructed and mentally manipulated.

The foundation of cognitive maps relies on the fact that structural knowledge of a geographic space is relational and acquiring structural knowledge is the process of conceptualizing these relationships (Davis, Curtis, & Tschetter, 2003). Thus, obtaining structural knowledge of the geographic space can be described in a three step process: first, determine the structural relationships; second, make mental representations based on those relationships; and third, evaluate the mental representations by comparing to reference materials such as experience or pre-defined maps of the space (Davis et al., 2003).

Experience in a space plays a significant role in an individual's ability to navigate that space more efficiently (Walter et al., 1998). It can be assumed that individuals with greater familiarity have a better cognitive map of the space. This exposure may be more useful for conceptualizing some constructs than others. So depending on what constructs each gender use to form a cognitive map, they may need different levels of exposure to form a useful cognitive map. Utilizing and manipulating a cognitive map is required in order to conduct typical navigating tasks such as wayfinding, discovering short cuts, and maintaining orientation (Bell & Saucier, 2004; Morganti, Carassa, & Geminani, 2006). Previous research ties a person's ability to utilize and manipulate a cognitive map to his/her other spatial abilities (Asselen, Fritschy, & Postma, 2006; Bell & Saucier, 2004; Morganti et al., 2006; Voicu & Schmajuk, 2000; Walter, Hunter, & Knapp, 1998).

In order to navigate successfully, people use landmark, metric, and sensorimotor information to compile their cognitive map (Asselen et al., 2006). Landmark information refers to any visual characteristic of the space such as colors and objects. Metric information refers to geometric descriptions of a space such as distances. Sensorimotor information refers to what the person physically feels as they navigate the space such as vibrations and temperature. A compilation of this information and spatial relationship between them is used to form the cognitive map which facilitates the process of storing the information in memory (Asselen et al., 2006; Kitchin & Blades, 2002). It is assumed that cognitive maps contain this combination of spatial and non-spatial information which can be difficult to quantify. Consequently, research has neglected to measure all of the types of information that compile a cognitive map. Research has not determined which types of information are more essential for a more useful cognitive map and these could differ by gender (Bell & Saucier, 2004).

Measuring cognitive maps in previous research has been performed by asking people to draw a map of the desired space, use an orientation to indicate the location of objects in the space, navigate through the space, and/or make judgments on the distance between two objects in that space (Kitchin & Blades, 2002; Gillan, 1994). These methods are chosen because they can be validated with geographically correct maps and distances; however, they are not necessarily measures of actual navigation ability and the types of knowledge that may be necessary for a useful cognitive map (Bell & Saucier, 2004). According to Goldin and Thorndyke (1982), acquiring accurate geometric knowledge of a space is mostly the result of using a map as a training device. Measuring more than what can be compared to geographically correct information would guide research to a better understanding of how people translate spatial knowledge into a cognitive map (Bell & Saucier, 2004). This is beyond the scope of this research so this will only focus on the gender differences in typical measures of an accurate cognitive map.

Landmarks. Navigation research has shown that information concerning landmarks is the first spatial attribute people encode (Asselen et al., 2006). When exploring a new area with access to a map, people note landmark locations on the map to develop a more accurate cognitive map (Chadwick, Gillan, Simon, & Pazuchanics, 2004). Conversely, when there are no landmarks or features in the area, people become “insurmountably confused” and cannot navigate accurately (Chadwick et al., 2004, pp. 691). How people cognitively conceptualize landmarks has not been determined. Since landmarks in research tend to be objects, the way they are conceptualized can be related to the previously discussed cognitive gender differences in object recognition and relocation. Some landmarks may be more appealing and useful to one gender than the other.

Research by Asselen and colleagues (2006) showed that there is no difference in landmark recognition and landmark ordering tasks between people who intentionally and incidentally learn landmarks. Asselen and colleagues (2006) claim these results support the idea that route knowledge acquisition is mostly an automatic process so people may not realize they are doing it. In order to develop a more complete cognitive map of a given space, it is necessary for people to integrate the configurational information of the landmarks (Bell & Saucier, 2004).

Since research shows that females use landmarks to navigate and males use metric information when navigating (Galea & Kimura, 1993; Sandstrom et al., 1998), an experiment controlled for the cues used when navigating a physical school campus (Saucier et al., 2002). Participants were given directions and escorted by a researcher as they followed the directions through the campus. Performance was measured in time and number of errors. Females following the metric directions made significantly more errors and took significantly longer than females following landmark directions and males following either set of directions. Males also outperformed females on the MRT. Notably, mental rotation ability was correlated with metric performance but not landmark performance (Saucier et al., 2002). There was not a significant difference in navigational anxiety but it was close with females having more anxiety than males. Unexpectedly, landmark familiarity performance did not correlate with the landmark directions performance. Meaning even though males were able to identify more landmarks, females were still able to indicate the direction of landmarks. In this experiment, returning to the last successful point accompanying the feedback could have been discouraging to the females.

To further examine these differences, the researchers performed a second study using a 2D grid with images of objects in each grid-square to emulate navigation. Once again, females in the metric-based directions made significantly more errors than males in the metric-based directions. Males in the landmark-based directions made significantly more errors than males in the metric-based directions. Males in the metric condition had faster times than males in the landmark condition and females in the metric condition. Females in the landmark condition outperformed females in the metric condition and males in the landmark condition. Here, there was no difference in landmark recognition. Overall, Males tend to be better with metric information and females tend to be better with landmark information (Coluccia & Louse, 2004; Saucier et al., 2002).

Genders tend to utilize landmarks differently and so integrate the configural information differently. As described by the research conducted by Sandstrom and colleagues (1998), females are more landmark dependent than males. Other research supports that females use landmarks when navigating whereas males tend to use geographic information (Dabbs, Chang, Strong, & Milun, 1998). Since most landmarks are objects, the female advantage in object recognition and replacement tasks helps explain the gender differences in landmark usage.

***Mapping*.** One way to measure an individual's configurational spatial knowledge, 2D data related to creating a standard map, like Cartesian maps, are collected (Chadwick et al., 2004). Previous research claims that map drawing and navigation abilities are related since people who have poor navigation performance tend to draw inaccurate maps (Chadwick et al., 2004). Not only does this contradict research discussed earlier claiming a cognitive map is not like a Cartesian map, other research shows that geographic knowledge tends to be the result of map experience (Goldin & Thorndyke, 1982). Since males have been shown to use geographic information more so than females, it is appropriate that males tend to perform better on mapping tasks (Dabbs et al., 1998). Since measuring map-drawing ability can be difficult and different methods of measurement produce different results, it could be confounding the relationship with navigation performance.

The most common method of measuring a cognitive map is asking people to draw a map of a particular space. There are three different types of map-drawing tasks: basic sketch map, normal sketch map, and cued sketch map. For the basic sketch map, a participant is given a blank piece of paper and asked to sketch an area but not told which features to include (Kitchin & Blades, 2002). The normal sketch map is similar to the basic map with the inclusion of asking the participant to draw particular features (Kitchin & Blades, 2002). These methods can confound geometric knowledge with drawing ability (Tobler, 1976). Interpreting the results can be difficult since there is no established scale or system for the participants to use when drawing a map which causes each map to be different for each individual (Morganti et al., 2007). This brings about the difficulty of how to "quantitatively evaluate the drawings" (Marganti et al., 2007, pp. 1984). In order to quantitatively measure the map-drawing results, a researcher must first make a distinction between the lack of drawing ability and the lack of geometric knowledge (Marganti et al., 2007).

For the third map-drawing task, cued sketch map, a participant is given enough information about the space to know the scale and orientation but asked to fill in specific components of the environment (Kitchin & Blades, 2002). This can eliminate the scaling problem and, depending on the detail required for the requested features, it can also minimize the distortions caused by a lack of drawing ability. Controlling these parts of the task makes quantitative evaluation of the map easier but reduces the amount of recall and distortion that can be derived from the participant's cognitive map or memory of the space. All map-drawing tasks are metric-based which has been shown to favor males (Iachini et al., 2005). However, females dominate or are equal in angle measurements between landmarks which shows orientation is more important than distances for females to navigate successfully (Iachini et al., 2005).

Pointing. Orientation skills are necessary for a person to maintain spatial awareness as their position changes and as such, are a key element of navigation ability (Bell & Saucier, 2004). In order for a person to remain oriented in a space, the individual uses external information in addition to an internal cognitive map (Bell & Saucier, 2004). Pointing tasks are one of the most common and widely supported orientation tasks used in cognitive mapping research (Waller, Hunt, & Knapp, 1998a; Kitchin & Blades, 2002). Conceptually, a pointing task consists of giving a person an orientation and asking him/her to indicate the direction of a location (Kitchin & Blades, 2002). This orientation can be physical or imagined before indicating the direction of the desired location (Kitchin & Blades, 2002).

Previous research has shown that this task is applicable for people with normal and impaired vision (Anooshian & Young, 1981; Kirasic, Allen, & Siegel, 1984; Herman, Rother, Miranda, & Getz, 1985; Begelow, 1991; Espinosa, Ungar, Ochiata, Blades, & Spencer, 1998; Kitchin & Blades, 2002) which supports pointing tasks as a strong direction task to use in testing. Differences in results emerge with the various ways to conduct a pointing task. Some researchers use protractors, others use specialized dials, and virtual environments typically have participants change the camera angle to face the target. There are three different types of pointing methods commonly used to determine the configuration of locations in a cognitive map (Bell & Saucier, 2004).

In one method, the individual uses ‘dead reckoning’ to indicate a straight line estimate to a location (Bell & Saucier, 2004). This ‘dead reckoning’ estimate does not take pathway knowledge into consideration (Bell & Saucier, 2004). Since ‘dead reckoning’ distance is not the actual path between targets, it has to be abstracted from the pathway knowledge. Such an abstraction exhibits gender differences because males tend to develop a cognitive map based on metric and cardinal information whereas females use landmarks and egocentric directions (Dabbs et al., 1998). Another method, path integration, is an indication of the beginning of a pathway or direction the individual would need to travel in order to reach the desired location (Bell & Saucier, 2004). Path integration may be a useful method in basic navigation tasks; however, this does not explain how people find and utilize shortcuts (Bell & Saucier, 2004).

The third type, complex path integration, supports the idea of simultaneous maintenance of multiple starting points (Bell & Saucier, 2004). This method involves more mental manipulation of the space than either path integration or dead reckoning (Bell & Saucier, 2004). With complex path integration, each environmental feature is stored with its relation to other environmental features (Bell & Saucier, 2004). These environmental features can be arranged in “pairs, strings, and more complex arrays” which can then be used by individuals to navigate a space or find a shortcut (Bell & Saucier, 2004, pp. 255). The flexibility of complex path integration facilitates the incorporation of new experiences to modify the stored environmental features to develop short-cuts and new pathways (Bell & Saucier, 2004). Due to the necessary mental manipulation, skills associated with a complex path integration network should be the same as those used to manipulate a cognitive map (Bell & Saucier, 2004).

As expected, performance on pointing tasks increase as an individual becomes more familiar with a space (Marganti et al., 2007). This result supports the idea that pointing tasks exhibit orientation skills required for individuals to develop an accurate cognitive map (Marganti et al., 2007). Pointing tasks tend to favor males (Bryant, 1982; Lawton, 1996) regardless of the way the task is performed (Coluccia & Louse, 2004). This shows that pointing tasks measure the skills required for males to develop accurate cognitive maps.

Since females tend to be better with angles when drawing maps or space arranging, the male advantage could be due to the devices used for pointing tasks.

Distance estimates. The most common mental models of relative distances are derived from geometric properties (Cooke, 1992). The predominantly used property, magnitude of distance, can be estimated in many different ways (Kitchin & Blades, 2002). One method, scaling estimation, is performed by asking participants to estimate distances on a known scale (feet, inches, etc.) (Kitchin & Blades, 2002). Another is ratio estimation which has participants use a line that represents the length of the space, then mark on the line the ratio of the distance between landmarks (Kitchin & Blades, 2002). These estimation techniques are highly dependent on the participant's understanding of scales and distances (Kitchin & Blades, 2002). Studies that do not take the participants' previous knowledge of scales and metric information into consideration miss key individual differences in performance.

Other methods are based on comparisons and as such do not require a participant to have accurate geometric knowledge. The simplest of which is paired comparison which has a participant compare distances in pairs to determine which is longer (Kitchin & Blades, 2002). Slightly more complicated is ranked comparisons which ask participants to rank distances between locations (Kitchin & Blades, 2002). Another method, rating distances, asks participants to use a set of predetermined values to rate the distances between locations (e.g., a likert scale) (Kitchin & Blades, 2002). Lastly, partition scales are used to ask participants to categorize distances between landmarks in groups of similar distances (Kitchin & Blades, 2002).

Depending on an individual's orientation when making relative distance estimates, some of the estimates could be inaccurate. When the individual uses his/her cognitive map to determine how far one location is from another, they are using a 'goal-activation' method (Voicu & Schmajuk, 2000). The goal-activation method causes the cognitive map to be activated successively, with locations closer to the goal activated first and more prominently than places farther from the goal (Voicu & Schmajuk, 2000). This method is the explanation for why people learn sequences of stimuli when navigating (Deutsch, 1960; Voicu & Schmajuk, 2000). Due to this goal-activation method, asking participants to compare landmarks that are unrelated or non-sequential could yield inaccurate responses. This could be especially true for females in non-realistic environments with objects or landmarks that lack associations. Also, whether the distance is the path from one point to the next or if it is the dead reckoning distance makes a difference in accuracy. For straight line distance estimations, there are no gender differences (Coluccia & Louse, 2004).

Frame of reference. There are two general frames of reference in navigation: egocentric and allocentric (Klatzky, 1998). Egocentric frame of reference arranges a space around the perceiver whereas allocentric arranges a space from an external reference point (Klatzky, 1998). Although allocentric maps, like cartographic maps, are typically used to learn a space, most research does not support this representation in a cognitive map (Gillner

& Mallot, 1998; Foo, Warren, Duchon, & Tarr, 2005; Wang & Spelke, 2000; Zetzshe, Wolter, & Schill, 2008).

For example, a study performed by Zetzshe, Gallibraith, Wolter, and Schill (2007) showed that when geometric laws were violated in a virtual environment, participants' navigation capabilities were not influenced and the participants did not even notice the violations. Zetzshe and colleagues (2007) claim that their results show there is not an allocentric cognitive map but rather a more abstract, non-planar arrangement of locations with pathways between them from the egocentric perspective. Contrastingly, a research experiment performed by Bell and Saucier (2004) showed that people using a map as a training device are able to acquire configural knowledge more rapidly than people who train by exploring the environment because the map produces an allocentric cognitive map. With such conflicting conclusions, the actual cognitive representation of navigation knowledge may be conceptualized in a sense of both egocentric and allocentric frame of references.

Gramann, Müller, Eick, and Schönebeck (2005) compared egocentric and allocentric frame of reference differences in navigation performance. Results showed that if there are only one or two turns between an origin and destination, participants who use allocentric and egocentric frames of reference perform comparably when indicating direction of the origin from the destination (Gramann et al., 2005). However, when there were three turns, the participants who used an egocentric frame of reference were significantly less accurate when indicating the direction of the origin from the destination (Gramann et al., 2005).

In a military experiment on perspective and awareness of surroundings, Thomas and Wickens (1999) compared a third person point of view (allocentric) to the first person point of view (egocentric). Although participants in both conditions felt equally confident, the third person point of view was significantly more accurate in describing their surroundings. This shows that the allocentric frame of reference is more accurate than the egocentric. This shows how gender differences could be explained by the frame of reference usage.

Another frame of reference study in a virtual environment using random objects for landmarks had three exploration conditions: free-roam, map, and static (Arthur & Hancock, 2001). The free-roam condition allowed participants to explore the virtual environment to learn the landmark locations. This facilitated the formation of an allocentric frame of reference-based cognitive map. The map condition allowed participants to look around from a single point and have access to a map of the area for reference. This condition facilitated an allocentric-egocentric hybrid cognitive map. The static condition only allowed participants to look around from a single location in the virtual environment to learn the landmark locations. This condition facilitated an egocentric cognitive map. Time spent learning the landmark locations was not limited. Participants in the free-roam condition spent more time than any other condition. After learning the locations of landmarks, participants were shown potential layouts of the landmarks and asked if each was correct. In the map and static conditions, response time in determining potential layouts increased as the orientation angle increased. As for accuracy, the free-roam condition was significantly better than both of the other conditions. Although those participants spent more time learning the locations, they were able to develop an allocentric cognitive map. These results serve as support for an allocentric cognitive map surpassing an egocentric cognitive map

Gender differences. Physiological psychology research has attempted to decompose gender differences in navigation. Since gender differences in navigation are inconsistent (Barkley & Gabriel, 2007; Chai & Jacobs, 2009; Gillner & Mallot, 1998; Waller, Hunt, & Knapp, 1998b), gender-related hormones may be mediated by other factors in navigation. Biological differences between genders show that low levels of testosterone results in better navigation skills in males whereas the opposite is true for females (Bell & Saucier, 2004). This supports the idea of an optimal testosterone level for navigation tasks. Since research shows that females use landmarks to navigate and males use metric information when navigating (Galea & Kimura, 1993; Sandstrom et al., 1998) it is possible that the measures of navigation are biased in favor of males.

Most of the research that supports males as having stronger navigation skills uses virtual environments (Chai & Jacobs, 2009; Gillner & Mallot, 1998). Only the study performed by Waller and colleagues (1998b) made comparisons between the same group of males and females on virtual and physical navigation tasks. The results from the study by Waller and colleagues (1998b) showed that it was only in the virtual environments that males outperformed females. This could be due to males having more experience with virtual environments (i.e., video games) or the virtual environments may be missing the environmental cues used by females when navigating. Either way, this shows that using virtual environments in navigation experiments may not be as accurate for females as it is for males.

Stereotype Threat. One aspect of navigation research that lacks control is the phenomena known as 'stereotype threat'. As defined by Goff, Steele, and Davies "stereotype threat is the sense of threat that can arise when one knows that he or she can possibly be judged or treated negatively on the basis of negative stereotype about one's group" (2008, pp. 92). Only the group associated with the negative stereotype is affected by stereotype threat (Schmader, 2010). Research has shown that alleviating stereotype threat increases the performance of the targeted populations without changing the performance of the other populations (Kiefer & Sekaquaptewa, 2007; Schmader, 2010). Since the stereotype is that males are better at spatial and navigation tasks, females may be experiencing 'stereotype threat' which could lower their performance. This may be especially true when using virtual environments because males are stereotypically better at video games (Atkinson-Bonasio, 2010; Bulik, 2006).

In an examination of the effects of stereotype threat on visuospatial tasks, Campell and Collaer (2009) compared three conditions of stereotype threat: present, absent, and nullified. When the stereotype threat was present, participants were informed that males are typically better at the tasks. In the absent condition, participants were not told anything about gender stereotypes. The nullified condition attempted to reverse the stereotype by informing participants that there are no gender differences in the tasks. Males in the present and absent conditions, performed significantly better than females. There were no significant gender differences in the nullified condition. More interestingly, male performance was not significantly different in any of the conditions. Only female performance in the nullified condition was significantly different from performance in the present and absent conditions. This implies that females are the targeted stereotype in visuospatial tasks which are related to spatial abilities. Essentially, stereotype threat causes target populations to feel anxious, doubtful, and uncomfortable (Vick, Seery, Blascovich, & Weisbuch, 2008). Instead of measuring stereotype threat directly, navigation studies examine fear and anxiety.

Fear and anxiety. Research supports that females are intimidated by tasks that require masculine abilities such as spatial tasks (Meyer & Koehler, 1990). In all navigation tasks, physical and virtual, females report higher anxiety and fear of getting lost (Bryant, 1982; Coluccia & Louse, 2004; Lawton, 1996; Maguire, Burgess, & O'Keefe, 1999; Schmitz, 1997). Participants who have higher anxiety and fear move more slowly through the environment which helps explain why males tend to be faster than females (Schmitz, 1997). This difference in fear and anxiety ratings show males are more confident in navigation skills than females (Coluccia & Louse, 2004). Spatial abilities used in navigation are lowest for individuals with high fear and anxiety, feminine traits as measured by the Mf MMPI-2 scale form (Pancheri & Sirigatti, 1995), and are female (Nori, Mercuri, Giusberti, Bensi, & Gambetti, 2009). This is because females with high anxiety and fear in navigation tasks tend to have feminine traits. Therefore, the effect of gender and spatial ability is partially mediated by the masculine/feminine trait and level of fear and anxiety (Nori et al., 2009). Should stereotype threat be nullified, female performance should improve and become comparable to male performance.

Measures of Spatial Ability

Measures of spatial ability have been divided into two groups: Orientation and object manipulation (Kozhevnikov & Hegarty, 2001). Commonly used measures that are considered object manipulation are the MRT (Shepard & Metzer, 1971), Guilford-Zimmerman Spatial Orientation Test (Guilford & Zimmerman, 1948), Cube Comparison Test (Ekstrom, French, & Harman, 1976), Card Rotation Test, and Paper Folding Test (Kozhevnikov & Hegarty, 2001). Common measures for orientation are the Santa Barbara Sense of Direction (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2001), Object Perspective Test (Hegarty & Waller, 2004), and Map Perspective Test (Kozhevnikov & Hegarty, 2001).

Relationships between spatial ability measures and navigation ability have been researched by using an unmanned aerial vehicle (UAV) simulator (Rodes, Gugerty, Brooks, & Cantalupo, 2009). Measures of navigation ability were cardinal direction estimate, route following, and map-drawing (Rodes et al., 2009). Spatial ability measures were the CRT for mental rotation, Paper Folding for spatial visualization, and Building Memory (Ekstrom, French, & Harman, 1976) for spatial memory. The CRT was a significant predictor of accuracy and speed of cardinal direction estimates. The Building Memory test was significantly correlated with the accuracy of cardinal direction estimates. Higher scores on the CRT and the Building Memory Test were indicative of better reaction times and route following during the task which shows more confidence in the task. This shows how each test can contribute to different measures of navigation ability. With such subtle differences, spatial ability measures could be favoring male performance in such tasks.

Aoki, Oman, Buckland, and Natapoff (2007) conducted a navigation experiment comparing how the Cube Comparison and Perspective Taking tests measure spatial ability. The scores on the Cube Comparison and Perspective Taking tests were correlated with each other showing they measure similar abilities. Surprisingly, they were also negatively correlated with computer usage (more computer use meant lower scores). These measures could be more predictive of actual navigation ability instead of virtual proficiency and have less bias in favor of video game players.

Measures of object manipulation show the most consistent gender differences in favor of males whereas orientation measures are not consistent (Voyer et al., 1995). The Paper Folding Test does not show significant gender differences (Voyer et al., 1995); however, it does not predict navigation as well as other measures (Rodes et al., 2009). Research shows gender differences in spatial abilities are decreasing over time, except for the MRT, and deserve to be re-analyzed (Voyer et al., 1995). The way the tests of spatial ability are tested and scored could affect the gender differences (Voyer et al., 1995). New, less biased measures have been developed but the MRT continues to be the most common measure for mental rotation ability.

MRT evaluation. Even though it is less predictive of navigation ability and shows gender bias in favor of males, the MRT is the predominant measure of spatial ability (Ross, Skelton, & Mueller, 2006). Previous research on scoring the MRT shows that time constraints and scoring procedure influence gender differences on MRT performance (Voyer, 1997). Since each item on the MRT has two possible answers, participants must have both answers correct for the item to be scored as correct. When partial credit is given to each correct answer, gender differences greatly narrow (Voyer, 1997). Other research shows that the male advantage is expressed regardless of how the MRT is scored (Masters, 1998).

In a comparison of the MRT and the Perspective-Taking/Orientation Test (PTSOT), Kozhevnikov, Motes, Rasch, and Blajenkova (2006) showed that the PTSOT was more predictive of performance on several navigation tasks than the MRT. The PTSOT was significantly correlated with route-retracing accuracy, finding short-cuts, and pointing accuracy whereas the MRT was only significantly correlated with retracing a route (Kozhevnikov et al., 2006). When PTSOT and MRT scores were in a model to predict route-retracing accuracy, PTSOT was the only significant factor (Kozhevnikov et al., 2006). These results show that when testing navigation ability, the PTSOT is more predictive than the commonly used MRT (Kozhevnikov et al., 2006). Therefore, the PTSOT is more useful than the MRT when measuring mental rotation ability related to navigation. Due to these differences, research should use measures other than the MRT to determine other contributors to spatial ability in navigation and the PTSOT is an option (Kozhevnikov et al., 2006).

Virtual Environments

Not all navigation research that uses virtual environments show gender differences (Darken, & Sibert, 1996; Rossano & Moak, 1998; Wilson et al., 1997). Spatial ability and interface proficiency account for most of the gender differences in virtual environment navigation experiments that have gender differences (Waller, 2000). In a study of knowledge transfer from a virtual to physical maze, there were no significant gender differences (Ross, Skelton, & Mueller, 2006). Although females made slightly more mistakes in the virtual maze than the physical maze, it was not significant (Ross et al., 2006). Research where males and females have similar video game experience do not express gender differences in navigation performance measures (Levy, Astur, & Frick, 2005). These support the idea that gender differences in virtual environment navigation ability can be mediated by other abilities (Waller, 2000). Namely, training spatial abilities or increasing video game experience could reduce these gender differences (Waller, 2000; Kass, Ahlers, & Dugger, 1998).

Environment size. As virtual environment size increases, orientation times increase for both males and females (Stankiewicz, Legge, Mansfield, & Schlicht, 2006). In large virtual environments, males reproduce more accurate maps. This could be magnifying the gender difference since males had more experience playing video games in these studies (Castelli, Corazzini, & Geminiani, 2008; Stankiewicz et al., 2006). How to move from target to target (route knowledge) had no significant gender differences but target geographic location (survey knowledge) favored males (Castelli et al., 2008). This could be due to females having to focus on one type of knowledge to successfully complete the task in the larger virtual environments. Smaller virtual environments do not have as pronounced gender differences.

Available cues. Landmarks, number of turns, and field of view are all important cues during navigation. By manipulating the cues available in an environment, researchers modify gender differences. In one such research experiment, performance was measured by the number of moves and time to complete a virtual maze (Cutmore et al., 2000). When the participant found the exit of the maze or five minutes elapse, whichever came first, the trial would end (Cutmore et al., 2000). Having a time limit also served as a cue to the participants the rate at which they should be attempting to complete the trials. There were no gender differences and the number of moves was correlated with navigation time for both genders. Once again, longer time was associated with more spatial anxiety and lower spatial ability.

In a second experiment with three maze conditions, the researchers showed that males required fewer moves to reach the maze exit in all conditions (Cutmore et al., 2000). For estimates of the total distance from origin to maze exit, there were no gender differences in accuracy. Further analyses showed that only in the landmark condition (each room in the maze had a different picture) it took longer for the females to become more efficient than it did for the males (Cutmore et al., 2000). In the compass condition (a compass heading was provided) and the no-cue condition, the genders did not differ in improvement (Cutmore et al., 2000). This shows that males and females use landmark knowledge differently in mazes.

In a study of only males, the effect of night vision goggles on navigation was examined (Gauthier, Parush, Macuda, Tang, Craig, & Jennings, 2008). The night vision goggles made participants' vision monochromatic and restricted their field of view by eliminating peripherals. The difference participants experienced is similar to that simulated by virtual environments. Similarly, participants using the night vision goggles made significantly more mistakes and took longer to complete the navigation tasks than the group without the goggles. However, the night vision goggles group improved more than the control group similar to how females show more improvement in virtual environments than males. This could be exposing a ceiling effect of the control group similar to males in virtual environments. Interestingly, the night vision goggle group was better at orientation and distance estimates when the landmarks were not in the same room (Gauthier et al., 2008). This could be due to the restricted field of view which might be limiting the cues that participants are able to remember in each room. This idea has not been tested in virtual environments where there are not typically multiple objects near each other.

In a virtual maze task with mazes located in the middle of common rooms (bedroom, living room, office) where an abundance of distant landmarks were available (desk, lamp, bookcases, etc.), there were no gender differences in performance in terms of time and errors (Levy, Astur, & Frick, 2005). Although these distant landmarks were not targets in the task, females may have used those cues to maintain awareness and peak performance. In addition to more available cues, this virtual environment had realistic settings. These factors could have been enough to improve female navigation performance to surpass male performance. Conversely, a virtual navigation test that used a uniform forest and a desert showed males were more accurate in distance estimates (Foo et al., 2005). Neither of these environments had distinguishable cues to maintain orientation. When a distinguishable landmark was provided in that same desert and forest, there were no longer any gender differences in distance estimates (Foo et al., 2005). This was another example of how females are more dependent on available cues in virtual environments than males.

When screen size was manipulated, the larger screens significantly narrow the gender gap virtual environment navigation ability (Tan, Czerwinski, & Robertson, 2006). Like the night vision goggles, the smaller screen eliminated perceived peripherals and produces similar errors in navigation. Overall results showed that larger screens improved both genders but improved females more, enough so that their performance was comparable to males.

Rendering quality. Another experiment by Cutmore and colleagues (2000) showed that the fidelity of a virtual maze mediated gender differences in performance. In this experiment, performance was measured by travel distance and task times. Female performance was significantly better in the high fidelity condition than the low fidelity condition. Male performance was not significantly different between the high and low fidelity conditions. In the low fidelity condition, males outperformed females on both performance measures. In the high fidelity condition, there were no significant gender differences. This shows how fidelity can influence female performance in virtual environments with high fidelity potentially mediating gender differences.

Feedback and Motivation

Previous navigation research tends to neglect the effects of feedback and motivation in task performance. An exception is the experiment performed by Kass and colleagues (1998) where participants were in one of three practice conditions: feedback from the researcher, instruction manual, and no practice. Participants were tested in a periscope simulator to determine orientation of a simulated submarine. Viewing time through the periscope was limited. When determining orientation, participants were encouraged to work quickly but given unlimited time to respond. A second test was given three weeks later to determine retention of skills. Overall, males were more accurate in orientation estimates than females. The training conditions produced significantly different results for females but not for males. Females performed best in the feedback training condition showing how female performance can be modified by feedback. In the feedback condition, there were no significant gender differences. It was only the instruction manual and no practice conditions that males outperformed females. This shows that females benefit more from feedback than males. Since previous navigation research neglects these aspects, it is possible that the results are biased for male performance. Also, the positive feedback may be inadvertently nullifying the stereotype threat.

In an experiment on incidental learning for navigation, males and females were guided through an unfamiliar building and told they would be asked about their opinion of the building at the end (Lawton, Charleston, & Zieles, 1996). Participants were told to hold all questions about the building until they reached the destination. Once at the destination, participants were told to find the origin. To determine performance, route choice, time, and verbal cues from the participant were measured. There were no gender differences in any of these measures. A pointing task was done at the destination to the origin and this was the only measure where females were worse than males (Lawton et al., 1996). This shows that males and females conceptualized the space similarly when they were not motivated to learn the layout for navigation tasks.

Using a virtual maze, Schmitzer-Torbert (2007) compared performance in response learning. This means that participants were placed in different places in the maze and had to find the same target. If they went to where it was previously located, they were using place strategy but if they used the same directions, they were using response strategy (Schmitzer-Torbert, 2007). In order to be successful at the task, response learning was required. Initially, males outperformed females but after 18 trials there were no longer significant gender differences (Schmitzer-Torbert, 2007). A second experiment was done to test the influence of feedback in performance. When the participants were reinforced for using the correct strategy, females outperformed males for the first 30 trials. By simply adding the feedback, gender differences were reversed. Overall, males used more consistent routes than females which indicated males are more likely to engage in route strategy but females are more likely to engage in place strategy (Schmitzer-Torbert, 2007). With feedback, gender differences were moderated even though the task required route strategy and females are more likely to use place strategy.

In the experiment conducted by Saucier and colleagues (2002), participants were accompanied by a researcher while using directions to navigate a campus. When participants made an error, the researcher informed the participant and they returned to the location prior to the error. Participants in this experiment did not exhibit gender differences in any of the performance measures other than landmark identification. Procedures in the training phase were the same as the test phase except feedback was only provided in training. The lack of gender differences could have been caused by the implementation of feedback and training that was equivocal to the testing.

Another virtual environment navigation experiment motivated participants to find hidden targets in a maze (Levy, Astur, & Frick, 2005). Motivation to complete the task was to find all of the “rewards” in the maze. Upon finding each target, a brief session of virtual fireworks accompanied by colorful bold text of “Reward” appeared on the monitor. It may seem trivial, but these “rewards” are different from previous navigation research and serve as motivational feedback. There were no time differences in navigation between males and females. A combination of the available landmarks and motivation could have affected the lack of gender differences.

Training for the Test

Many navigation studies do not train participants before testing. This is forcing participants to use expected previous knowledge. Using the Spatial Visualization Test (Middle Grade Mathematical Project, 1983), research compared benefits in training with three different models of structures made with blocks: interactive, animated, and standard paper-drawn models (Rafi, Samsudin, & Said, 2008). In pretests, there were no significant gender differences. With the interactive training, males outperformed females. With animated training, there were no gender differences. With the paper-drawn models, females outperformed males in the spatial ability test. This shows that males and females benefit differently from different types of training. Males benefit more from manipulating viewing angles and females benefit more from being presented with multiple viewing angles.

In the experiment by Sturz, McKelly, and Brown (2010), participants were tested in the same condition in which they were trained. The goal of the research was to compare object location performance in a virtual environment and a physical environment. The environment consisted of a room of bins arranged in a 5x5 grid. The objects to be located were hidden in the bins. The bins that contained objects made a basic pattern and the pattern was the same in all three conditions but did not necessarily contain the same bins. All conditions exhibited significant performance improvements. Performance between the physical bins and the virtual bins was not significantly different. This overall improvement could have been due to the training being exactly like the testing.

In the virtual and physical navigation experiment by Waller and colleagues (1998b), participants were thoroughly instructed in the measures that would be tested later. They practiced pointing for bearing estimates and distance estimates were practiced in feet in a physical environment. Even though tasks were not practiced in the virtual environment, bearing estimates in the physical maze were correlated to those in the virtual maze. Similarly, distance estimates in the physical maze were correlated to distance estimates in the virtual maze. There were no time limits and participants who spent longer time in the training, had significantly greater errors in bearing and distance estimates. Males had less overall bearing error than females. Females' bearing error was highest in the virtual maze. Males and females showed similar trends for distance estimates with physical maze best and virtual maze worst. There were not significant gender differences in bearing and distance estimates in the physical maze, but there were in the virtual maze. Since female performance in the virtual maze was worse, it could help explain the training difference. Training was only in the physical environment which did not have significant gender differences, unlike the virtual environment.

The virtual navigation research conducted by Foo and colleagues (2005) is another experiment where participants practice the measures that are tested. Specifically, participant navigation performance was measured by distance estimates between landmarks. By having participants practice the distance estimates, males and females did not differ significantly. Another experiment that showed no significant gender differences in virtual environment navigation ability had participants practice map-drawing and distance estimates until they felt comfortable before beginning testing (Jansen-Osmann & Berendt, 2002). Studies such as these support gender differences in effects of training, with females more affected than males.

Aims of this Research

Gender differences are inconsistent in navigation research (Barkley & Gabriel, 2007; Gillner & Mallot, 1998; Tlauka, et al., 2005) and some of the measures and procedures are gender biased (Ross, Skelton, & Mueller, 2006; Voyer et al., 1995; Voyer et al., 2007). Furthermore, little research has been done to determine what makes either the spatial ability or navigation ability measures biased. This research aims to decompose the navigation performance differences between males and females to determine the sources of gender differences. In addition to this decomposition, a fear and anxiety measure will be used to determine the presence of stereotype threat. The results of this research will help to illuminate some of the pitfalls of previous navigation research as well as provide some direction for future navigation research of gender differences.

Hypothesis. The hypothesis that motivated the present study is that gender differences in five navigation performance measures (map distance estimates, map angle estimates, navigation distance estimates, navigation angle estimates, and navigation time) will be moderated by landmark type and feedback presence. Pre-test measures of spatial ability, anxiety, and video game experience were also examined as covariates of navigation ability.

Method

Participants

Thirty-two male and 37 female students (M_{age} = 20.45, sd_{age} = 5.39) were recruited from a large, southeastern university for the experiment. All participants had normal or corrected to normal vision. Two females did not finish the experiment due to nausea in the virtual environment and one male did not understand the tasks in the virtual environment. Their data were removed from the study, so the sample consisted of 31 males and 35 females.

Materials

Pre-tests. The demographics questionnaire was a modification of the one that was used by Terlecki and Newcombe (2005). The following tests were chosen as pre-tests: the MRT (Vandenberg & Kuse, 1978) to measure mental rotation ability and the PTSOT

(Hegarty & Waller, 2004; Kozhevnikov et al., 2006) to measure object manipulation and orientation abilities. To measure fear and anxiety, the Spatial Anxiety Scale (SAS), developed by Lawton (1994), was used. The SAS served as the measure of stereotype threat. The administration of the demographics questionnaire was always first, followed by the MRT, PTSOT, and SAS in an order that was counterbalanced between participants.

For the MRT, participants were asked to match a 3D figure to two possible rotations. For each figure, there were two targets and two distracters. All participants were given a practice session before beginning the actual MRT. The test was divided into two parts, each containing 10 items. Participants were allowed three minutes to complete each part. Because the present research is focused on gender differences, the MRT was scored using the traditional scoring method and the ratio scoring method described by Voyer (1997). In the traditional method, only answers where participants correctly identified both targets were scored correct, which tends to favor male performance (Voyer, 1997). The ratio method determines scores by the ratio of correct responses out of the items attempted. This prevented items participants did not reach within the time limit from counting against them. Also, there was partial credit for any correctly identified target instead of the “all or nothing” of the traditional method. Using the ratio method tends to reduce gender differences in performance on the MRT (Voyer, 1997). The possible scores for the traditional method ranged from 0 to 20 and the possible scores for the ratio method ranged from 0 to 2. Higher scores indicated better performance for both scoring methods.

The PTSOT provided an image of an arrangement of objects on the top of a piece of paper and then asked participants to perform a pointing task using a circle on the bottom of the paper. Participants were provided with the name of an object in the center of the circle and the name of a second object at the top of the circle. With this orientation, participants indicated the direction of a third object by drawing a line from the center object's name to the edge of the circle. This test required participants to complete 12 of these scenarios within five minutes. Each individual's PTSOT score was computed by the average difference between the indicated direction and the actual direction of the each third object. The possible scores for the PTSOT ranged from 0 to 180, where lower scores indicated better performance. Previous studies do not show gender differences in this task (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001).

The SAS is a short survey consisting of eight questions to determine an individual's spatial anxiety. Each question proposes a common scenario and participants rated how anxious s/he would feel if s/he was in that situation on a five point Likert scale (1 = not at all, 5 = very much). There was no time limit for this survey. Scores were computed by the sum of the responses and ranged from eight to 40. Lower scores on this survey indicated lower levels of spatial anxiety. Females tend to have higher spatial anxiety than males (Bryant, 1982; Coluccia & Louse, 2004; Lawton, 1996; Maguire, Burgess, & O'Keefe, 1999; Schmitz, 1997).

Virtual environment. Given that virtual maze research tends to favor male performance (Astur, Oritz, & Sutherland, 1998; Chai & Jacobs, 2009; Gillner & Mallot, 1998; Moffat, Hampson, & Hatzipantelis, 1998; Sandstrom, Kaufman, & Huettel, 1998; Waller et al., 1998b), a virtual maze environment was used to accentuate a possibility of gender differences. Platinum Arts LLC granted permission via e-mail for Sandbox Free 3D Game Maker (Platinum Arts LLC, 2010) to be used in this experiment. Based on the Cube 2 engine, Sandbox is a high fidelity, open source program used to create 3D virtual environments. A ZT desktop computer (AMD Phenom II Quad-Core 3.2 GHz processor, 8.00 GB DDR2 RAM, Radeon HD 5570 graphics card, running on a 64-bit Windows 7 operating system) was used to run the program for the experiment. The desktop was connected to a 22” monitor (1280x720 resolution and 16:9 aspect ratio) via an HDMI cable. Input devices were a trackball mouse and standard keyboard. The mouse was used to move the camera angle and only the arrow keys on the keyboard (up, down, left, and right) were used to move through the environment (forward, backward, left, and right respectively).

There were two sets of seven different landmarks: Common and uncommon. The common landmarks were a couch, a mug, a bench, a toilet, a chair, a flat screen television, and a potted plant. Uncommon landmarks were a cannon, a fish, a cluster of mushrooms, a sword, a water dispenser, a large bowl, and a spike-covered ball. Two different maze layouts were adapted from the mazes in the experiment conducted by Schmitzer-Torbert (2007) for this experiment (see Appendix A). Each layout was used twice, once with the common landmarks and once with the uncommon landmarks for each participant. Regardless of maze layout and landmark set, the landmarks were arranged so that they were always the same distance apart with the same orientation. That way, when each participant was assigned to one of each maze layout and one of each set of landmarks, the measures could be compared across maze layouts and landmark types.

If the distance from the participant's point of view to the floor was two units, then the training environment was 35 x 100 units, maze layout A was 76 x 92 units, and maze layout B was 76 x 100 units. In all of the environments, the walls were nine units high without a ceiling and visibility was unlimited.

Navigation performance data. Of the five navigation performance measures used in this experiment, two were from the map tasks conducted in Microsoft PowerPoint (2010) and three were from the navigation tasks conducted in Sandbox (Platinum Arts LLC, 2010). Both the map and navigation task contained distance and angle estimates as performance measures. The average distance estimate error for both tasks was calculated using the following formula:

$$\text{Distance estimate error} = \frac{\sum \left|\text{estimated distance - actual distance}\right|}{\text{Number of interlandmark distances}}$$

Angle estimate error for both tasks was calculated similarly:

$$\text{Angle estimate error} = \frac{\sum \left|\text{estimated angle - actual angle}\right|}{\text{Number of interlandmark angles}}$$

Distances were measured to the nearest tenth of an inch in the map task and to the nearest foot in the navigation task. Angles were measured to the nearest degree in both the map and navigation tasks. The navigation task also included a time component which was the amount of minutes from the beginning of the navigation testing to the end.

Design

All participants experienced the same pretests and training procedures. During the training of the virtual environment, all participants received feedback on their performance. While being tested, half of the males and half of the females received feedback. All participants experienced both maze types and both sets of landmarks in the testing phase. The order of the maze layouts was counterbalanced across participants. Therefore, there were four groups for the two between-participants variables (gender and feedback) and all participants were measured with the within-participants variable (landmark set) (see Figure 1).

Procedure

Consent form and pre-tests. Researchers were provided with a script and one participant was tested at a time. Before starting the experiment, participants read a consent form and were informed that during the virtual environment tasks, their actions on the computer screen would be recorded. Participants were told that the recorder only records the monitor and not them, physically. All participants choose to participate and signed two copies of the consent form: one for the participant and one to keep on record. Once the consent form was signed, participants were told that they were part of a research project on video game design and given the demographics questionnaire. Next, the pretests (MRT, PTSOT, and SAS) were administered to participants one at a time. As stated previously, the order of the pre-tests were counterbalanced.

Training. The participants were informed that the training consisted of four phases and no time limits. In the first phase, the researcher showed participants how to move through the environment using the mouse and keyboard. Then participants were instructed to practice moving about in a large, open space until they felt comfortable with the controls. When the participant verbally expressed they felt comfortable, the researcher began the second phase. If participants did not provide a verbal expression and were visibly using the controls well, the researcher prompted the participant with the offer to continue to the next phase. Once participants confirmed they were comfortable with the controls, as determined by a verbal response, the researcher asked participants to move into the area of the second phase.

In the second phase, there were six color coded tiles arranged in a straight line on the ground: Red, orange, yellow, green, blue, and purple. On the same side of each tile was a barrel that was five, 10, 19, 33, 39, and 46 units away, respectively of each colored square. Participants were informed that in this experiment they would be doing distance estimates and pointing tasks. Then they were asked to stand on the first tile (red) and face the respective barrel. They were informed that facing the barrel was like the pointing task and they would need to aim the crosshairs on the center of the barrel. Then participants were told the barrel was five units away from the red tile and that a unit could be thought of as one foot [like the experiment performed by Waller and colleagues (1998b)]. Participants were then direct to the second tile (orange) and to face the respective barrel. The researcher informed participants that this distance was 10 feet (equivalent to 10 units). Next the participants were asked to move to the next four tiles and guess the distance to the respective barrels. After each guess, the researcher informed the participants of the correct distance. Upon completing the distance estimates, participants were allowed to move from tile to tile freely to gain familiarity with the distances. Once participants expressed they were ready to continue, they were then guided into phase three.

In phase three, there was a wooden box and a wooden barrel on opposite sides of a wall. Participants were asked to walk about the box, wall, and barrel to provide a dead reckoning distance estimate from the box to the barrel (18 feet). While standing at the box, participants were informed that all of the walls were four feet thick and then asked what they thought the distance was from the box to the barrel (18 feet). Just like phase two, participants were provided with correct distance estimates after guessing. Then, participants moved into the fourth phase.

Phase four was most like the testing phases. Here, there were three objects: A wooden box, a wooden barrel, and a wooden barrel lying on its side. The wooden box and the standing barrel were 35 feet apart on the same side of the wall while the sideways barrel laid on the opposite side of the wall (12 feet from the box and 37 feet from the standing barrel). Again, participants were allowed to wander around the objects to gain familiarity with the distances and orientations. Once they indicated that they were ready, the researcher asked them to guess the distances and indicate the direction of each object from the sideways barrel. The sideways barrel was chosen because it was not visible from the other two objects, making the experience more like the testing phase. Before leaving the last training phase, participants were informed that they would receive feedback in the testing phase (or not if they were in the "no feedback" condition). Participants were given the option to revisit their choice of the training phases before continuing to the testing phase. Once training was completed, the researcher then moved participants into the appropriate testing maze.

Testing navigation. Two layouts of virtual environments were used for testing in this experiment (see Appendix A). Both layouts were been adapted from the mazes in the experiment conducted by Schmitzer-Torbert (2007). Each maze contained a set of seven objects to serve as landmarks. There were two sets of landmarks: common and uncommon. The common landmarks consisted of a couch, mug, toilet, bench, television, potted plant, and chair. The uncommon landmarks were a cannon, a spike covered ball, a fish, a cluster of mushrooms, a large metal wok, a water dispenser, and a sword.

All participants were given a five minute time limit to find the objects and learn their arrangements. Once the five minutes had passed, participants were asked to move to a specified object. From this object, participants were asked to point to and give a distance estimate for each of the other objects. If participants were in the "feedback" condition, they received feedback like the training. If participants were in the "no feedback" condition, they did not receive any feedback during the testing phase.. Once participants finished the pointing and distance estimate tasks for that landmark, they were asked to move to the next landmark and repeated the procedure for each landmark. The order of the landmarks was counterbalanced between participants. Timing of the participant's navigation performance began when they were asked to locate the first landmark and ended when they gave their final response of the last landmark. Once participants completed a maze layout, they were given a map-placement task on the layout with those objects. Each participant completed two mazes, one of each layout. This allowed all participants to experience both set of landmarks.

Experiment conclusion. Upon completion of the navigation tests, participants were debriefed on the true objective of the study: To examine gender differences in virtual environment navigation. Participants were encouraged to ask any questions and leave feedback before departing. Most participants requested to see a copy of the aggregated results upon the completion of the thesis. Those participants provided their e-mail addresses for future contact.

Results

Pre-Tests

Pre-test analyses indicated that the overall sample was fairly normally distributed for the ratio scoring of the MRT (see Figure 4) and the SAS (see Figure 7). However, the traditional scoring of the MRT (see Figure 2) and the PTSOT (see Figure 5) exhibited oddly shaped distributions. A logarithmic transformation was conducted on the traditional scoring of the MRT (see Figure 3) and the PTSOT (see Figure 6) to produce distributions that were closer to normal (see Table 3). When divided by gender, males and females tended to exhibit similar distribution patterns on all of the pretests measures except for video game experience (see Table 1). More males claimed to currently play video games than females (see Figure 8). Two males did not follow the directions for the PTSOT and so their PTSOT scores were excluded. Two females did not report their video game experience and so their Video Game Experience scores were excluded. See Table 1 for overall pre-test distribution descriptions.

Navigation Performance Measures

Overall performance measures tended to be positively skewed indicating that participants tended to perform well on all measures (see Table 2). Map distance estimates (see Figure 9), map angle estimates (see Figure 11), navigation distance estimates (see Figure 13), navigation angle estimates (see Figure 15), and navigation time (see Figure 17) exhibited skewed distributions. A logarithmic transformation was conducted on the map distance estimates (see Figure 10), map angle estimates (see Figure 12), navigation distance estimates (see Figure 14), navigation angle estimates (see Figure 16), and navigation time (see Figure 18) (see Table 3). When divided by gender, males and females tended to exhibit similar distributions for the performance measures.

Test of Hypothesis

The major hypothesis of this research was that gender differences in the five spatial knowledge measures – map distance estimates, map angle estimates, navigation distance estimates, navigation angle estimates, and navigation time – would be moderated by the presence of feedback and the type of landmark, resulting in significant interactions between gender, feedback, and landmark for all five measures. The inclusion of the pre-test measures (traditional and ratio scoring of the MRT, PTSOT, SAS, and video game experience) were to be examined as potential covariates. A t-test revealed that the sets of landmarks were not as different as originally anticipated (see Table 4) and so this variable was removed from the analyses. Pre-test measures that were correlated to the dependent variable were included in each analysis. No pre-test measures were correlated to navigation distance or navigation time (see Table 5) so each was analyzed with a two-way ANOVA. Map distance, map angle, and navigation angle, were each analyzed by conducting a four step hierarchical regression. For these analyses, gender was entered in step one to determine if there was a main effect. Feedback was added in step two and the gender by feedback interaction was added in step three. Only pre-test measures that were significantly correlated to the dependent variable were added in the fourth step of each analysis.

Neither the map task angle or distance estimates exhibited any significant effects in the first three steps of the hierarchical regression (see Table 6). At the fourth, the predictive model for map distances, $F(7, 54) =$, $p < .05$, $R^2 = 232$, (f^2) = .303, and map angles, $F(7, 54) =$, $p < .05$, $R^2 = 232$, (f^2) = .302, achieved significance. Although both achieved medium effect sizes as defined by Cohen's (1988) conventions, without any uniquely significant predictors, meaningful information about each independent variable is lacking. This suggests that some of the pretests shared too much variance to be uniquely meaningful, suggesting that future research should be conducted to compare these measures.

In the first step of the hierarchical regression, gender was a significant predictor only for navigation angles, $F(1,60) = 14.58$, $p < .001$, $R^2 = .195$, $f^2 = .532$. Gender remained a significant predictor of navigation angles in all four steps of the hierarchical regression modeling. The large effect size (Cohen, 1988) implies that this is a strong effect. Males (M = 9.4, SD = 2.6) were more accurate than females (M = 15.8, SD = 10.1) by a mean of 6.4 degrees (see Figure 19). Feedback and the gender x feedback interaction did not add a significant amount of explained variance to the model (see Table 7). However, a significant amount of explained variance was added to the model in the fourth step, $F(4, 54) =$, $p < .05$, $R^2 = .159$, $f^2 = .382$, producing a model with a much larger effect size, $F(7, 54) =$, $p < .001$, $R^2 = .382$, $f^2 = .619$. This result suggests that at least some of the variance explained by the pretest measures in the last step was meaningful. Like the map distance and angle analyses, this lack of unique contribution from the pre-test measures supports future comparisons of these variables.

Navigation distance and navigation time were analyzed utilizing two-way ANOVAs. For navigation distance, there was only a significant effect for feedback, $F(1, 62) =$, $p < .001$, $\eta^2 = .299$. With a medium effect size (Cohen, 1988), the feedback effect was moderate. Participants with feedback ($M = 11.6$, $SD = 4.7$) were more accurate by an average of 8.5 feet than participants without feedback ($M = 20.1$, $SD = 11.0$) (see Figure 20). Navigation time exhibited a significant main effect for feedback, $F(1, 60) =$, $p < .001$, $\eta^2 = .331$, where participants with feedback ($M = 17.9$, $SD = 5.5$) were an average of 5.6 minutes slower than participants without feedback ($M = 12.3$, $SD = 4.0$) (see Figure 21). This was not surprising because the navigation time of the participant with feedback included the time to give feedback. However, the goal was to see the gender x feedback interaction which was not affected by including the feedback presentation time because it was the same for both genders. For navigation time, the presence of feedback produced more variance in male performance and caused them to take longer to complete the tasks (see Figure 22). This gender x feedback interaction was significant, $F(1, 60) =$, $p < .05$, $\eta^2 = .100$. The small effect size (Cohen, 1988) indicates the interaction effect was weak.

Discussion

Dependent on gender differences, feedback and landmark effects, the results of this research only partially supported the hypothesis that gender differences in the five spatial knowledge measures – map distance estimates, map angle estimates, navigation distance estimates, navigation angle estimates, and navigation time – would be moderated by the presence of feedback and the type of landmark. The landmarks did not have an effect which did not support the findings of Catteneo and colleagues (2006) or the present study research hypothesis. This was unexpected because previous research shows that gender differences can be affected by object type in object replacement tasks (Voyer et al., 2007)

Surprisingly, gender differences were only present in navigation angle so any moderation was not possible in the other measures. When the pre-test measures (traditional and ratio scoring of the MRT, PTSOT, SAS, and video game experience) were included in the model, the gender differences in navigation angles persisted, supporting a true gender difference. For all of the hierarchical regression analyses, none of the pre-tests appeared to uniquely influence gender or feedback. All-in-all, the general lack of gender differences in the majority of the measures was not supportive of the hypothesis.

Pre-Tests

The general heightened performance on the pre-tests was no surprise because the sample was comprised of college students which should exhibit above average performance. Similar distributions were present in previous spatial ability studies that used college students as participants (Cherney, 2008; Roberts & Bell, 2002; Ross, Skelton, & Mueller, 2006).

Interestingly, the skewed pre-test measure, the PTSOT, was supported as ‘gender neutral’ by previous research (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001). This skewness produced a floor effect in the results which appeared to remove any gender differences. Previous research that supported the PTSOT as ‘gender neutral’ produced a similar floor effect (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001). It is possible that the minimized gender differences in these previous studies were not due to a neutral scoring method but rather this floor effect.

Future research on gender differences in these and other spatial ability measures should include descriptions of their distributions. As it stands, the little information available on those distributions indicates that gender differences are minimized when measures are made easier. Using measures with such a skewed distribution is not as accurate or meaningful as those that produce more normal distributions. Ironically, it is possible that the supposed ‘gender neutral’ measure was actually gender biased because it did not reflect a representative distribution. To accurately support the absence or presence of gender differences, it is important to find variables on which both are normally distributed. With the skewness of the present ‘gender neutral’ test, it is difficult to make any claims about gender bias in this measure. Future research should strive to find tests that produce normal distributions before making gender comparisons. Furthermore, future research should consider further comparisons of the pre-test measures used in this study to determine the more effective predictors of navigation performance.

Navigation Performance Measures

Overall heightened performance was exhibited on the navigation performance measures most likely for the same reason as the pre-tests. Similar to previous navigation research, (Castelli, Corazzini, & Geminiani, 2007; Chadwick et al., 2004; Galea & Kimura, 1993; Sandstrom et al., 1998; Saucier et al., 2002; Tlauka et al., 2005) all of the tasks focused on the landmarks. This decision was supported by research that shows landmarks to be the first spatial attribute people encode (Asselen et al., 2006) and both genders tend to utilize landmark information well (Saucier et al., 2002).

The map tasks. Results from this study did not support the gender differences found in previous research on map tasks (Chai & Jacobs, 2009; Gillner & Mallot, 1998). For both the map distance and angle estimates, the gender and feedback did not appear to have had an effect on performance. The lack of gender differences when angles were the performance measure support previous research but the lack of gender differences for the distance performance measure opposes previous research (Iachini et al., 2005; Postma, Izendoorn, & De Haan, 1998; Postma, Winkel, Tuiten, & van Honk, 1999; Voyer et al., 2007). It was expected that the feedback during the navigation would produce better memories for the landmark locations. Conversely, the amount of feedback did not appear to affect map task accuracy. It is possible that the feedback was not effective for the map tasks because it was only present during the navigation portion of the experiment.

The navigation tasks. Unlike the map tasks, the navigation tasks performance measures each exhibited a different result. For navigation distance estimates, it appears as though performance was only influenced by feedback. The persistence of this difference when controlling for the pre-test measures suggests that participants utilized the feedback to overcome any other possible differences. Future research should further investigate potential differences in the rate that males and females utilize feedback in navigation tasks, similar to the research by Schmitzer-Torbert (2007).

As the only measure with persistent gender differences, the navigation angle results supported research showing that males tend to perform better than females when angles are the performance measure in navigation-related pointing tasks (Bryant, 1982; Coluccia & Louse, 2004; Dabbs et al., 1998; Lawton, 1996). This gender differences persisted through the inclusion of the pre-tests measures, including the video game experience and spatial abilities as measured by the MRT and PTSOT, which opposes previous research that suggested a lack of gender differences when orientation characteristics are used to measure performance (Iachini et al., 2005; Postma et al., 1998; Postma et al., 1999). Future research should continue to consider angle measuring methods when analyzing gender differences in navigation-related pointing tasks.

Navigation distance performance results only supported an effect of feedback. The feedback would have been utilized by participants to adjust their estimates so it is understandable that those with feedback were more accurate. It would be more interesting to see if feedback produced a change in the accuracy of participants throughout the task. For example, it is possible that participants without feedback became less accurate between trials while participants with feedback became more accurate. Future research should be conducted to further investigate such a change in navigation performance.

Lastly, it appears as though the presence of feedback caused participants to take significantly longer in the navigation tasks, specifically the males. This finding deviates from previous research which shows males tend to be faster than females (Saucier et al., 2002; Tlauka et al., 2005) or gender differences are absent (Astur, Oritz, & Sutherland, 1998; Cutmore et al., 2000; Lawton et al., 1996; Levy, Astur, & Frick, 2005). It appears as though when feedback was absent, the gender differences were smaller which supported the findings of some previous research (Astur, Oritz, & Sutherland, 1998; Cutmore et al., 2000; Lawton et al., 1996; Levy, Astur, & Frick, 2005). Feedback was not manipulated in the previous research which makes this finding an interesting possible explanation for some of the inconsistencies in gender differences in navigation performance. Especially because this difference persisted through the control of the pre-tests.

Conclusion and Limitations

This research was limited by a small sample size and a lack of decomposition of feedback characteristics. In keeping with previous navigation studies that utilized feedback comparisons (Kass, Ahlers, & Dugger, 1998; Saucier et al., 2002), this study did not do a formal breakdown of the feedback components. It is possible that this lack of granularity could have reduced the interpretability and meaningfulness of the findings related to feedback. However, because the same type of feedback was used for all participants in the feedback condition, it was assumed to be a constant across the group. Therefore, it is not expected that the lack of decomposition would have affected any possible interactions.

The research hypothesis that gender differences in the five navigation performance measures (map distance estimates, map angle estimates, navigation distance estimates, navigation angle estimates, and navigation time) would be moderated by landmark type and feedback presence was not supported. Although the findings did not support the research hypothesis, they illuminated some interesting variations in gender in virtual environment navigation. Previous research showed that males tend to outperform females in virtual environment navigation tasks (Astur, Oritz, & Sutherland, 1998; Moffat, Hampson, & Hatzipantelis, 1998; Sandstrom, Kaufman, & Huettel, 1998; Tlauka et al., 2005). The results of this research provided a decomposition indicating a lack of gender differences on most performance measures and hinted at the potential influence of feedback on gender differences.

According to the findings of this study, depending on the navigation performance measures, gender differences can be strikingly different. If taken individually, the findings of this study could be used to support previous research supporting different types of gender differences. The navigation angle accuracy could be used to support research that shows males are better at navigation tasks (Tlauka, Brolese, Pomerov, & Hobbs, 2005), or navigation time could be used to support research that shows females are better at navigation tasks (Barkely & Gabriel, 2007; Chai & Jacobs, 2009) when feedback is manipulated, or the map tasks could have been used to support research that shows there are no gender differences in navigation tasks (Gillner & Mallot, 1998).

The findings of this study were as various as the anthology of navigation research on gender differences. The present study was successful in beginning the decomposition of gender differences in virtual environment navigation by exemplifying the effects of spatial abilities, video game experience, stereotype threat, and feedback. Although the present study suffered from the limitations of a small sample size and a feedback manipulation that lacked granularity and appeared to neglect the map tasks, the findings provide direction of future research. The results suggest it is important for future research on gender differences in navigation to consider methods that may be less gender biased and continue the examination of the gender differences in various spatial ability and navigation performance measures. Future research should be more meticulous with the spatial ability measures and testing procedures to avoid further gender bias in research. Such an approach will be necessary to explain the diverse gender differences that exist in previous navigation research. Thus far, navigation research has been focused on showing whether or not gender differences exist. The field would greatly benefit from a drive to answer the real question: Under what conditions do gender differences exist in navigation?

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Tables

Table 1. *Pre-test Distributions (N = 66; N_{Males} = 31 [29 for PTSOT, 30 for Video Game Experience], $N_{Females}$ =35 [33 for Video Game Experience])*

Pre-Test		Mean	S.D.	Skew	Kurtosis
MRT (traditional)	Overall	0.452	0.228	0.185	-0.977
	Males	0.565	0.207	-0.085	-0.801
	Females	0.353	0.199	0.473	-0.978
MRT (ratio)	Overall	1.558	0.311	-0.718	-0.284
	Males	1.683	0.231	-0.748	-0.027
	Females	1.447	0.332	-0.392	-0.895
PTSOT	Overall	29.81	23.114	1.992	3.535
	Males	21.705	12.28	2.043	4.959
	Females	36.527	27.628	1.461	1.099
SAS	Overall	20.303	5.32	0.094	-0.146
	Males	19.807	5.474	0.239	0.188
	Females	20.743	5.221	-0.02	-0.221
Video Game Experience	Overall	0.587	0.496	-0.363	-1.930
	Males	0.833	0.379	-1.884	1.657
	Females	0.364	0.489	0.594	-1.757

Note. Higher scores on the MRT (traditional) and MRT (ratio) indicated better performance. Lower scores on the PTSOT indicated better performance. Lower scores on the SAS indicated lower spatial anxiety. Video Game Experience scores were dichotomous with zero indicating the participant does not currently play video games and one indicated the participant does currently play video games.

Table 2. *Performance Measure Distributions (N = 66; N_{Males} = 31, $N_{Females}$ =35 [33 for Navigation Time])*

Measure		Mean	S.D.	Skewness	Kurtosis
Map Distance	Overall	0.41	0.35	2.11	4.85
	Males	0.31	0.19	1.37	0.79
	Females	0.49	0.43	1.6	2.1
Map Angle	Overall	10.65	9.53	1.89	3.41
	Males	7.95	5.27	1.36	0.43
	Females	13.05	11.68	1.39	1.07
Navigation Distance	Overall	15.75	9.33	2.59	9.62
	Males	16.82	12.55	2.17	5.11
	Females	14.81	5.05	-0.13	-0.81
Navigation Angle	Overall	12.79	8.19	2.73	8.97
	Males	9.42	2.64	0.66	-0.31
	Females	15.77	10.13	1.97	4.2
Navigation Time	Overall	15.17	5.59	1.11	1.37
	Males	15.59	7.07	0.99	0.22
	Females	14.79	3.78	0.39	-0.04

Note. Distance and angle measures are of the estimation error: Higher scores mean lower accuracy. The time is in minutes.

Table 3. *Distributions of log transformed variables (N = 66; N_{Males} = 31 [29 for PTSOT], $N_{Females}$ =35 [33 for Navigation Time])*

Pre-Test		Mean	S.D.	Skew	Kurtosis
MRT (traditional)	Overall	-0.41	0.26	-0.64	-0.6
	Males	-0.28	0.19	-0.83	-0.04
	Females	-0.53	0.27	-0.23	-1.18
PTSOT	Overall	1.38	0.27	0.73	0.12
	Males	1.29	0.21	0.53	0.65
	Females	1.46	0.29	0.54	-0.57
Map Distance	Overall	-0.5	0.29	0.78	-0.32
	Males	-0.57	0.23	0.72	-0.53
	Females	-0.44	0.33	0.55	-0.89
Map Angle	Overall	0.9	0.32	0.7	-0.53
	Males	0.83	0.25	0.69	-0.39
	Females	0.96	0.36	0.44	-1.1
Navigation Distance	Overall	1.14	0.22	0.21	0.43
	Males	1.14	0.27	0.48	0.02
	Females	1.14	0.17	-0.72	-0.43
Navigation Angle	Overall	1.05	0.2	1.15	1.26
	Males	0.96	0.12	0.2	-0.88
	Females	1.13	0.23	0.75	-0.07
Navigation Time	Overall	1.15	0.15	0.23	-0.41
	Males	1.15	0.19	0.34	-0.93
	Females	1.16	0.11	-0.21	-0.38

Note. Distance and angle measures are of the estimation error: Higher scores mean lower accuracy. The time is in minutes.

Table 4. *Comparison of common and uncommon landmarks (N = 66 [64 for Navigation Time])*

Variable	Mean (SD)		df	t
	Common	Uncommon		
Log Map Distance	-0.51 (0.32)	-0.56 (0.31)	65	-1.29
Log Map Angle	0.91 (0.36)	0.83 (0.33)	65	-1.77
Log Navigation Distance	1.12 (0.20)	1.15 (0.25)	65	1.35
Log Navigation Angle	1.06 (0.23)	1.02 (0.22)	65	-1.37
Log Navigation Time	1.16 (0.16)	1.15 (0.16)	63	-0.60

Note. *p < .05, **p < .01, †p < .001

Table 5. *Significant* correlations *between analyzed measures* (*N = 66; N_{Males} = 31 [30 for Video Game Experience, 29 for PTSOT], $N_{Females}$ = 35 [33 for Navigation Time and Video Game Experience]*)

Variable Pair		r	Variable Pair		r
Video Game Experience	Log MRT (traditional)	-.384**	Log MRT (traditional)	MRT (ratio)	.845†
	MRT (ratio)	-.361**		Log PTSOT	-.449†
	Log Map Distance	.313*		Log Map Distance	-.271*
	Log Map Angle	.324*		Log Map Angle	-.275*
	Log Navigation Angle	.470†		Log Navigation Angle	-.315**
Log PTSOT	Log Map Distance	.303*	MRT (ratio)	Log PTSOT	-.608†
	Log Map Angle	.320*		Log Map Distance	-.393**
	Log Navigation Angle	.346**		Log Map Angle	-.387**
Log Map Distance	Log Map Angle	.981†		Log Navigation Angle	-.399**
	Log Navigation Angle	.763†	Log Navigation Distance	Log Navigation Time	-.318*
Log Map Angle	Log Navigation Angle	.766†			

Note. * p < .05, ** p < .01, † p < .001

Table 6. *Regression analysis* (β) *for map task performance (N = 62)*

	Map Distance			
Variable	Step 1	Step 2	Step 3	Step 4
Gender	0.239	0.234	0.23	0.126
Feedback		-0.13	-0.135	-0.044
Gender x Feedback			0.007	-0.115
Video Game Experience				0.147
MRT (traditional)				0.217
MRT (ratio)				-0.492
PTSOT				0.066
R^2	0.057	0.074	0.074	**.232***
ΔR^2		0.017	0	**.158***
	Map Angle			
Variable	Step 1	Step 2	Step 3	Step 4
Gender	0.233	0.228	0.21	0.08
Feedback		-0.126	-0.145	-0.056
Gender x Feedback			0.031	-0.088
Video Game Experience				0.173
MRT (traditional)				0.16
MRT (ratio)				-0.415
PTSOT				0.109
R^2	0.054	0.07	0.07	**.232***
ΔR^2		0.016	0	**.161***

*p < .05, ** p < .01, † p < .001

Table 7. *Regression analysis* (β) *for navigation angle performance (N = 66)*

Variable	Navigation Angle Step 1	Step 2	Step 3	Step 4
Gender	**.442†**	**.438†**	**.575****	**.412***
Feedback		-.106	.031	.103
Gender x Feedback			-.229	-.310
Video Game Experience				.231
MRT (traditional)				.161
MRT (ratio)				-.353
PTSOT				.130
R^2	**.195†**	**.207****	**.223****	**.382†**
ΔR^2		.011	.016	**.159***

*p < .05, ** p < .01, † p < .001

Table 8. *ANOVA of navigation distance accuracy (N = 66) and time (N = 64)*

	Variable	df	MS	F
Navigation Distance	Gender	1, 62	0.000	0.000
	Feedback	1, 62	0.920	**26.428†**
	Gender x Feedback	1, 62	0.090	2.575
Navigation Time	Gender	1, 60	0.001	0.034
	Feedback	1, 60	0.451	**29.670†**
	Gender x Feedback	1, 60	0.101	**6.651***

*p < .05, ** p < .01, † p < .001

Figures

	Feedback		Feedback	
	Common Landmarks	Common Landmarks	Common Landmarks	Common Landmarks
Males	A	A	C	C
Females	B	B	D	D

Figure 1. Experiment Design (A, B, C, and D represent different groups of participants. Between-participants variables were gender and feedback presence. Within-participants variable was landmark type).

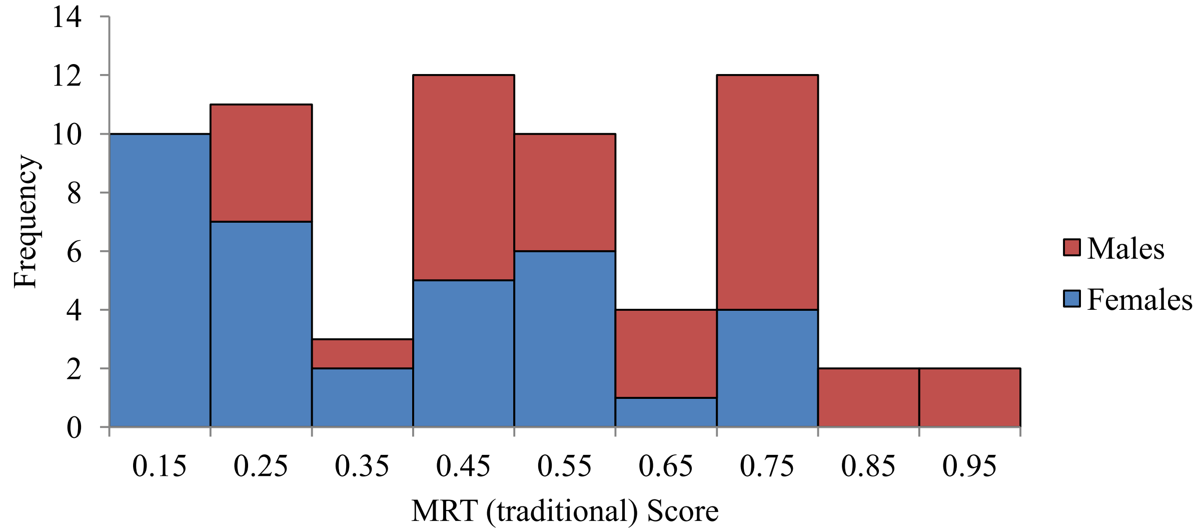

Figure 2. MRT (traditional) Score Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

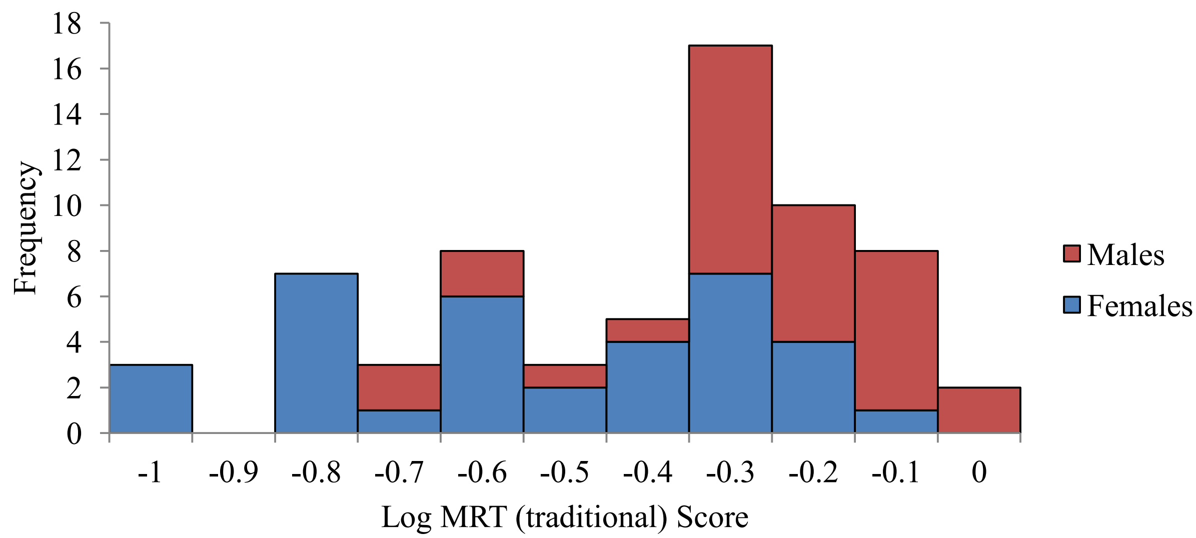

Figure 3. Log MRT (traditional) Score Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

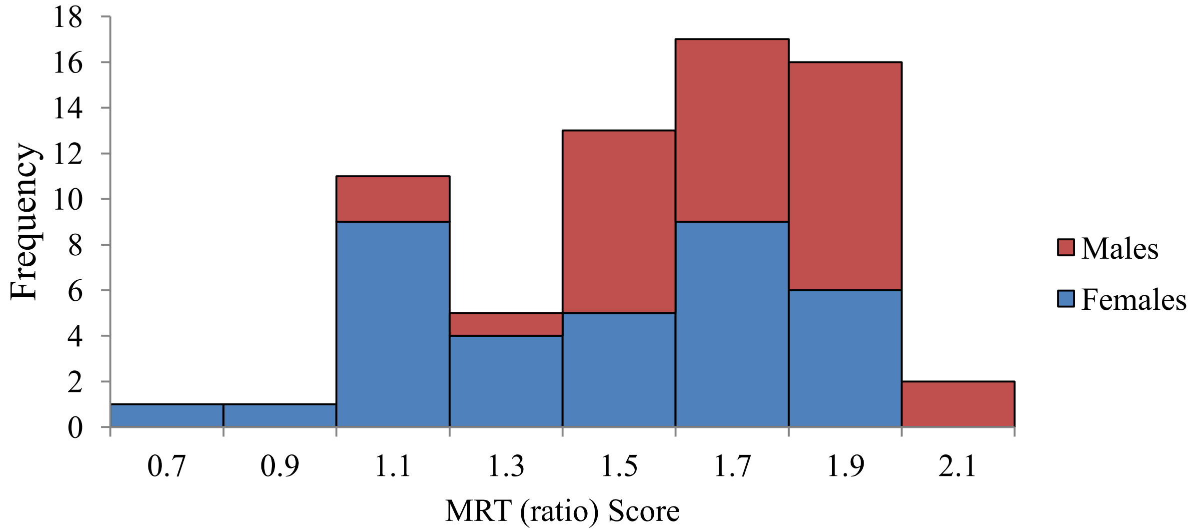

Figure 4. MRT (ratio) Score Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

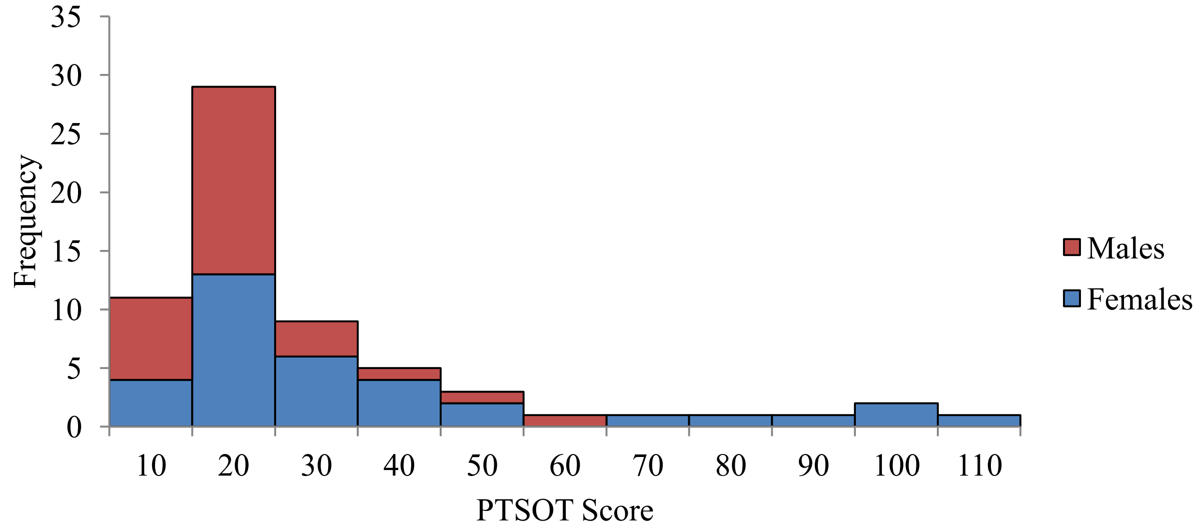

Figure 5. PTSOT Score Distribution ($N = 64$; $N_{Males} = 29$, $N_{Females} = 35$).

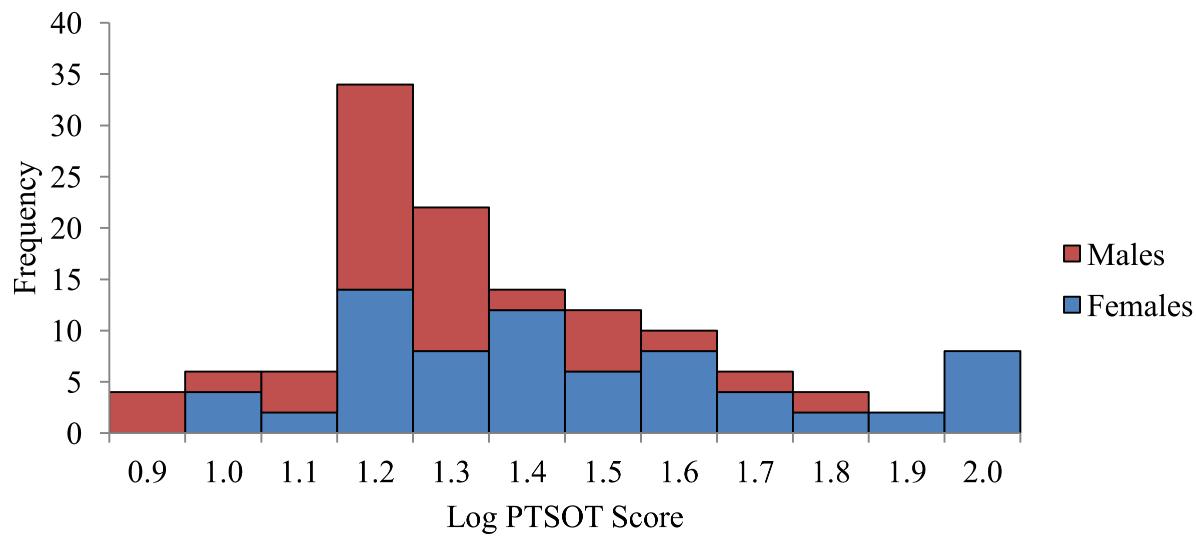

Figure 6. Log Transformed PTSOT Score Distribution ($N = 64$; $N_{Males} = 29$, $N_{Females} = 35$).

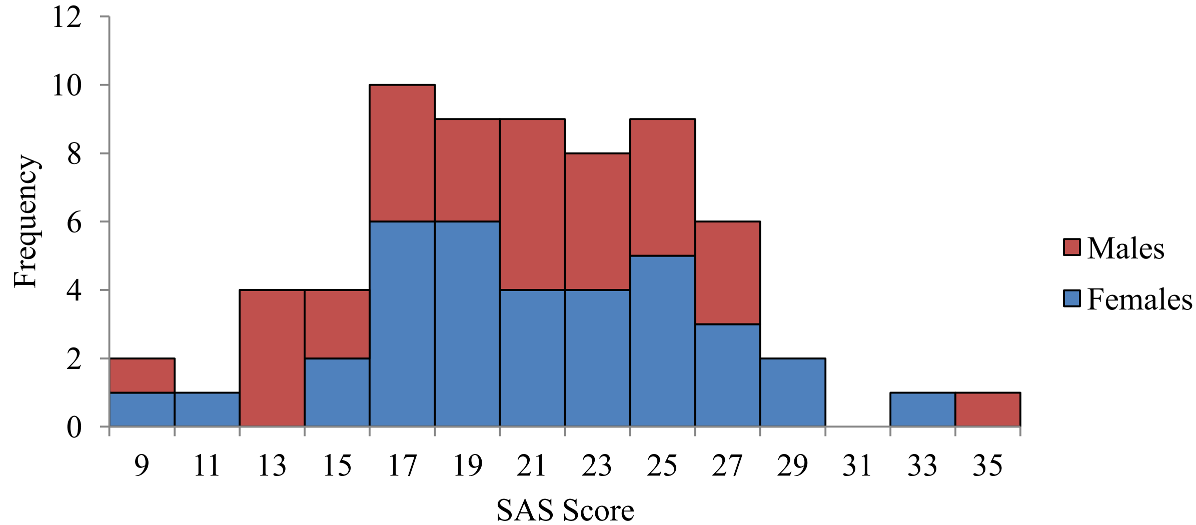

Figure 7. SAS Score Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

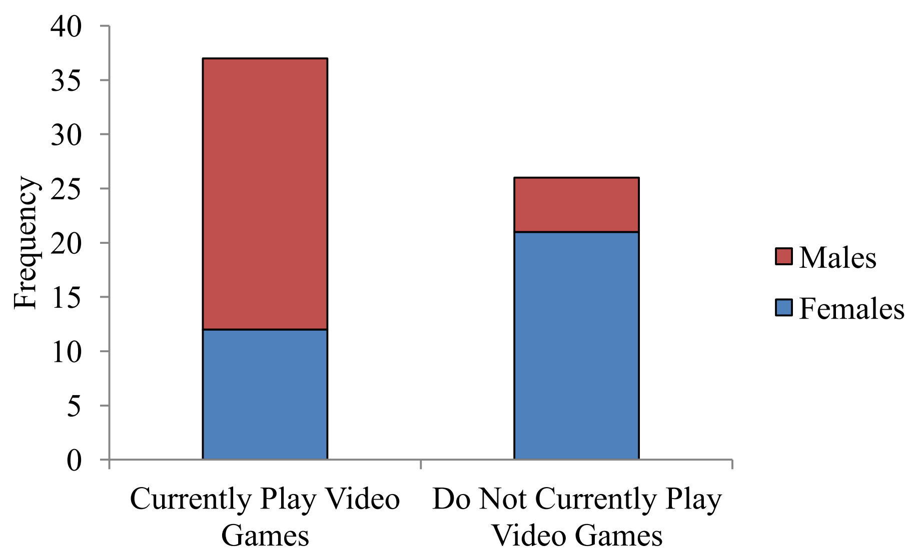

Figure 8. Video Game Experience Distribution ($N = 63$; $N_{Males} = 30$, $N_{Females} = 33$).

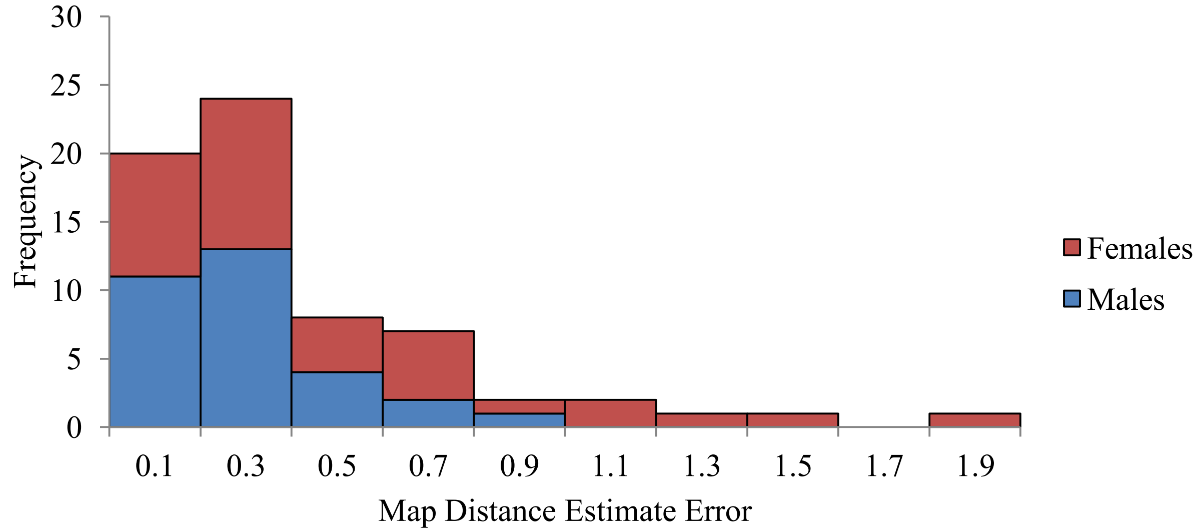

Figure 9. Map Distance Estimate Error Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

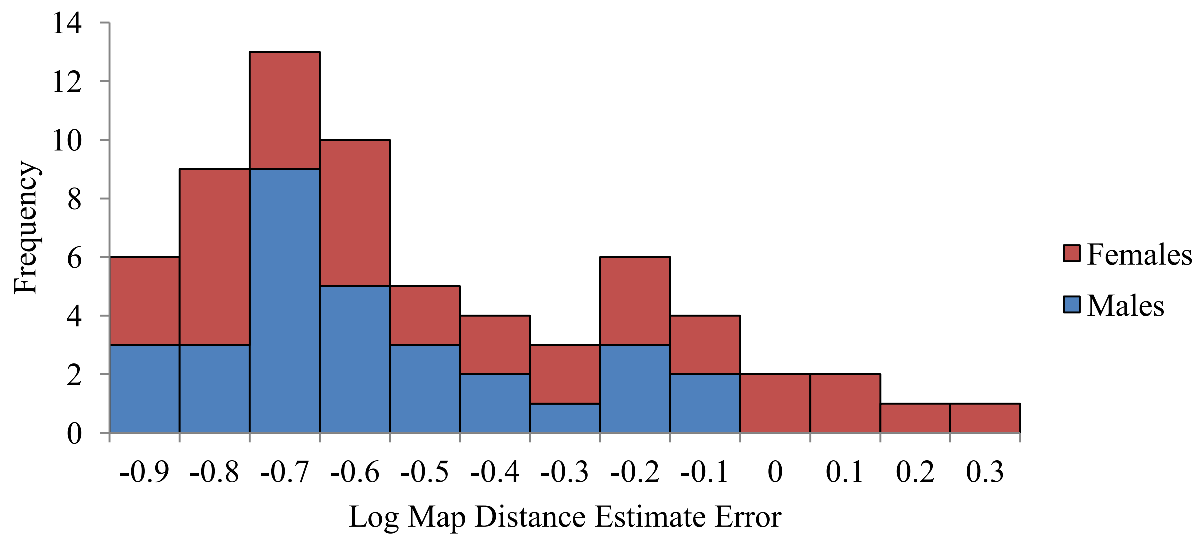

Figure 10. Log Map Distance Estimate Error Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

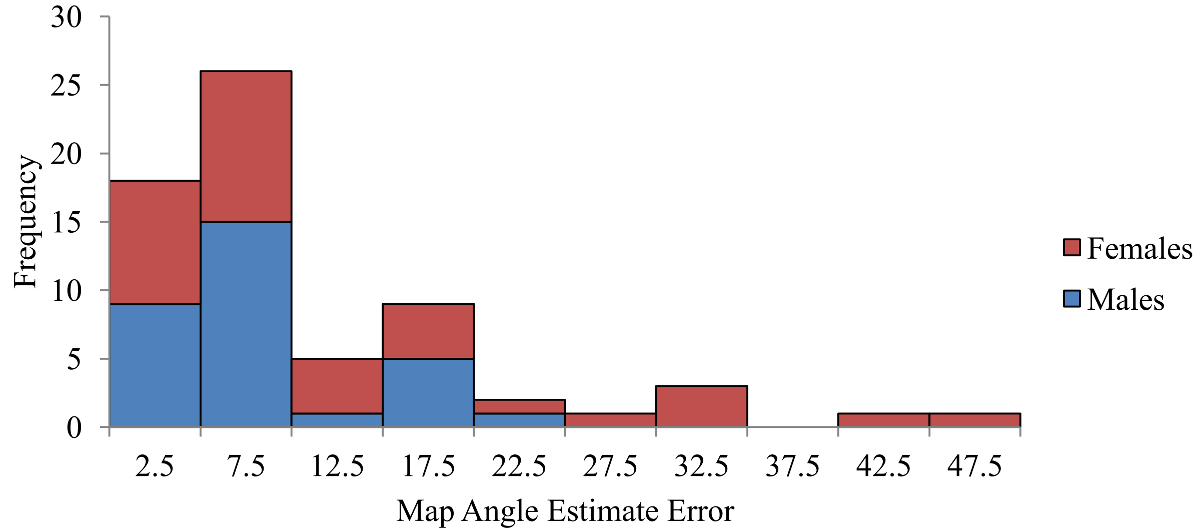

Figure 11. Map Angle Estimate Error Distribution (N = 66; N_{Males} = 31, $N_{Females}$ = 35).

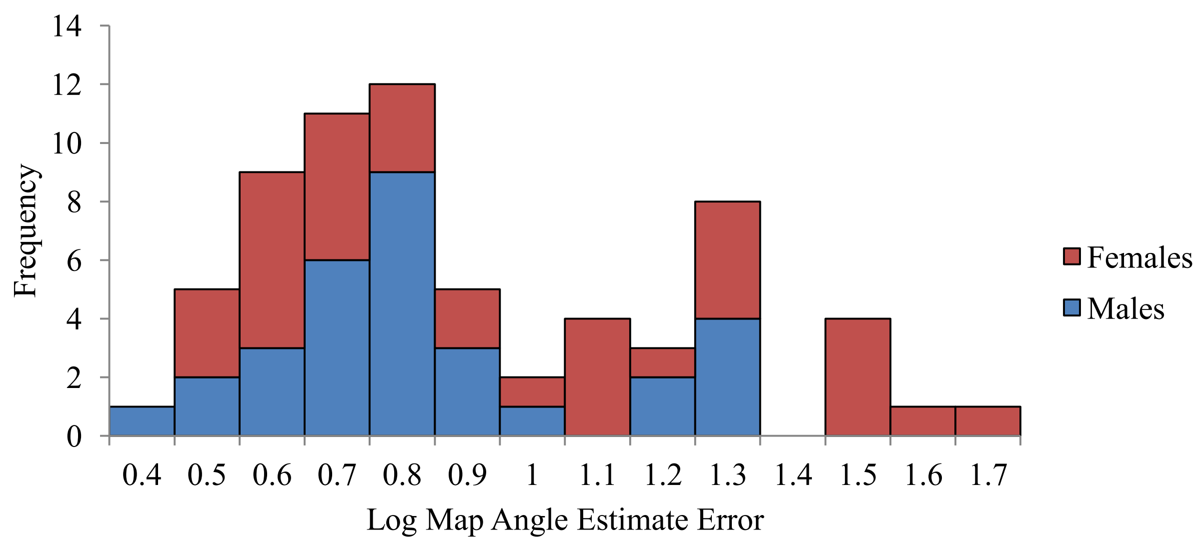

Figure 12. Log Map Angle Estimate Error Distribution (N = 66; N_{Males} = 31, $N_{Females}$ = 35).

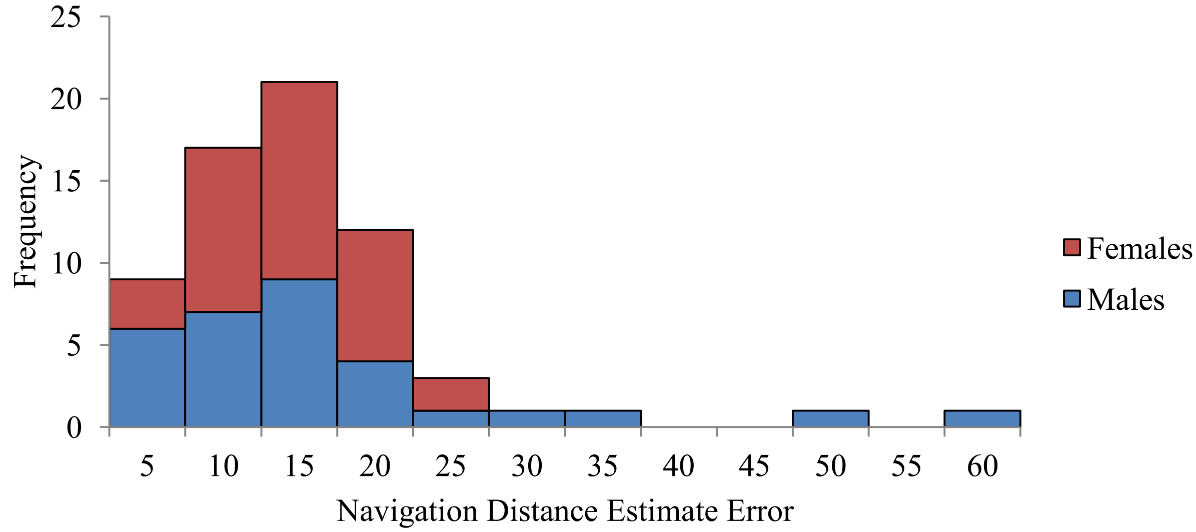

Figure 13. Navigation Distance Estimate Error Distribution (N = 66; N_{Males} = 31, $N_{Females}$ = 35).

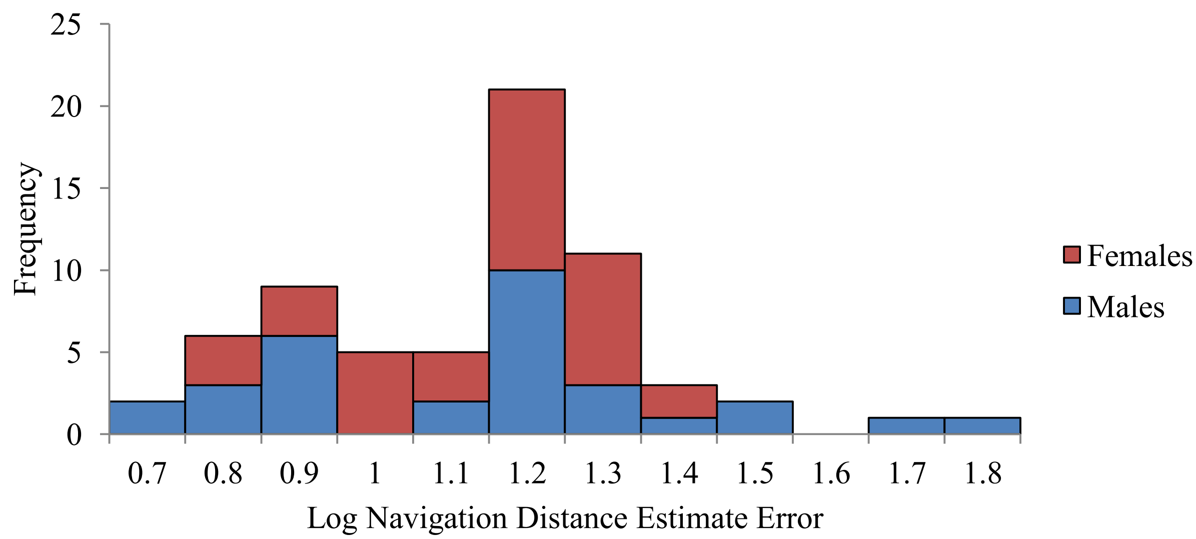

Figure 14. Log Navigation Distance Estimate Error Distribution (N = 66; N_{Males} = 31, $N_{Females}$ = 35).

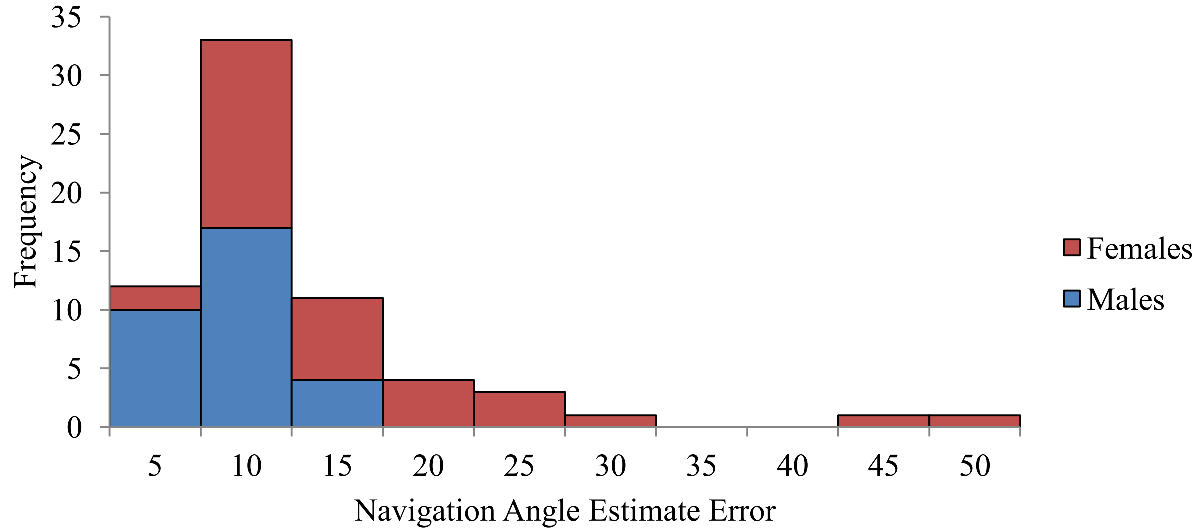

Figure 15. Navigation Angle Estimate Error Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

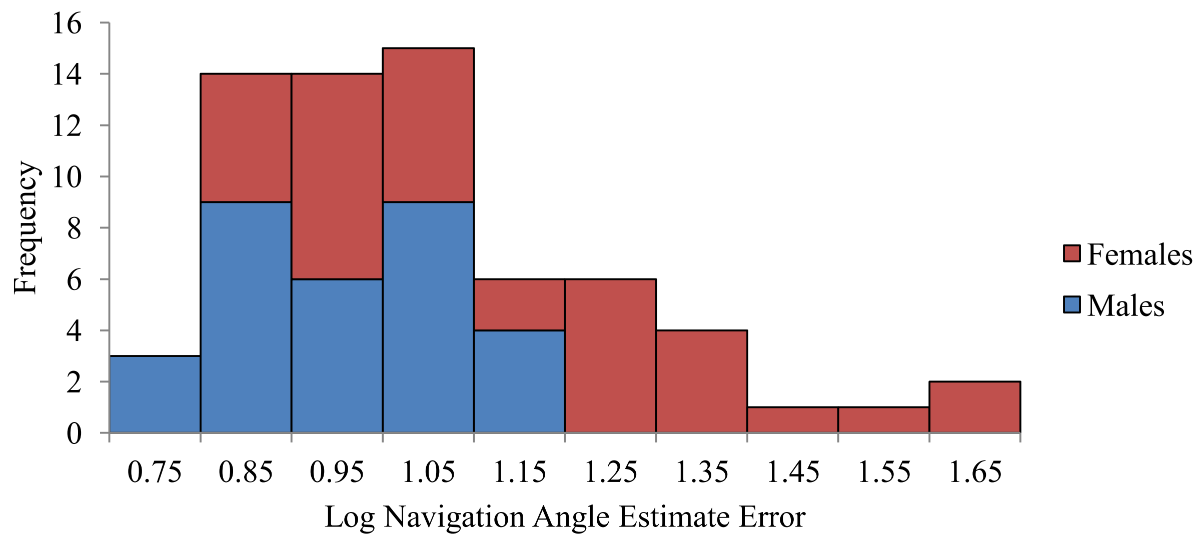

Figure 16. Log Navigation Angle Estimate Error Distribution ($N = 66$; $N_{Males} = 31$, $N_{Females} = 35$).

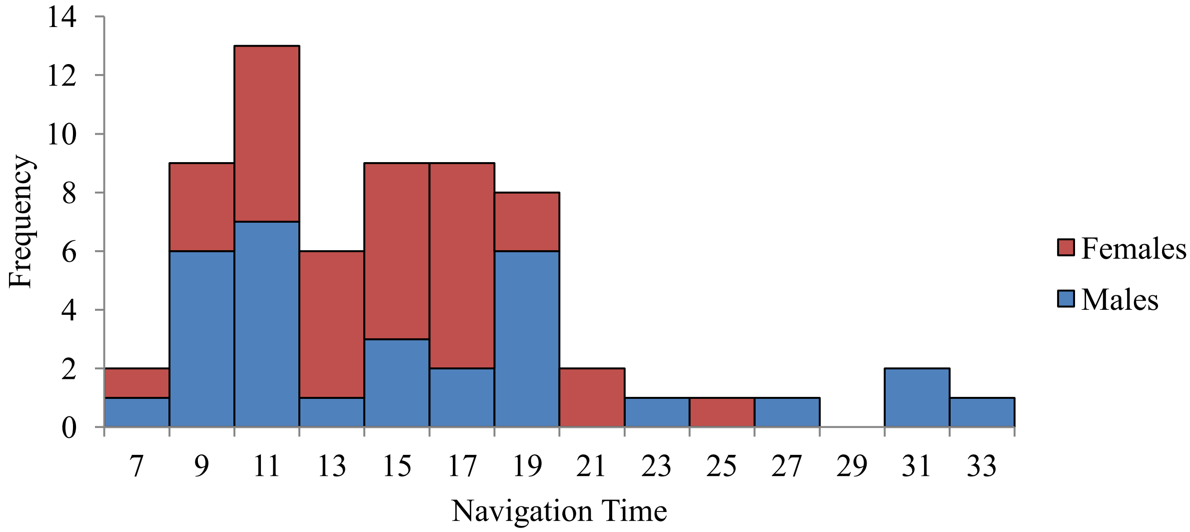

Figure 17. Navigation Time Distribution ($N = 64$; $N_{Males} = 31$, $N_{Females} = 33$).

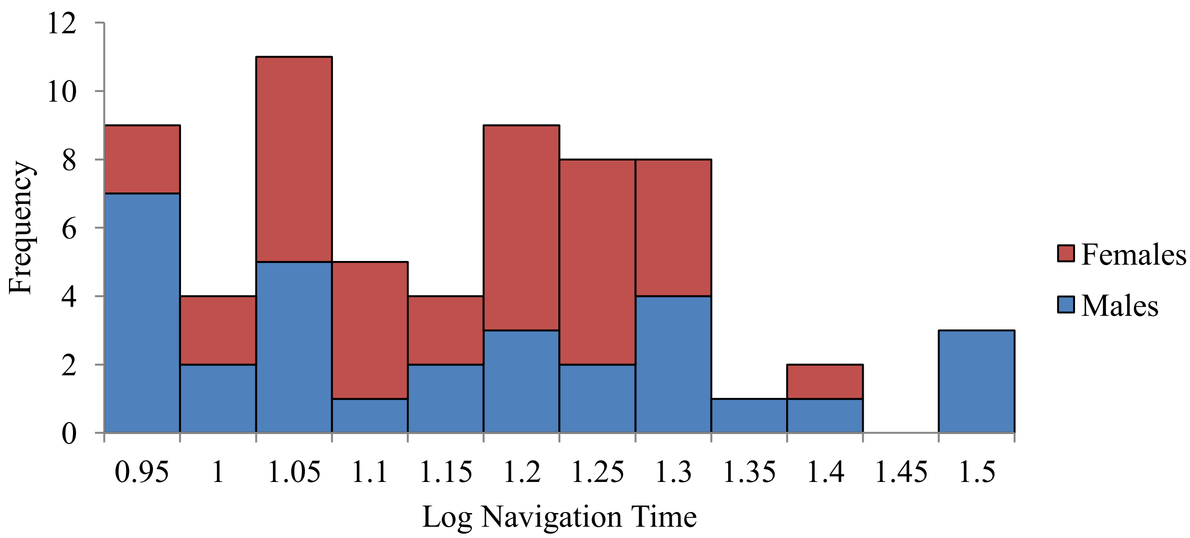

Figure 18. Log Navigation Time Distribution ($N = 64$; $N_{Males} = 31$, $N_{Females} = 33$).

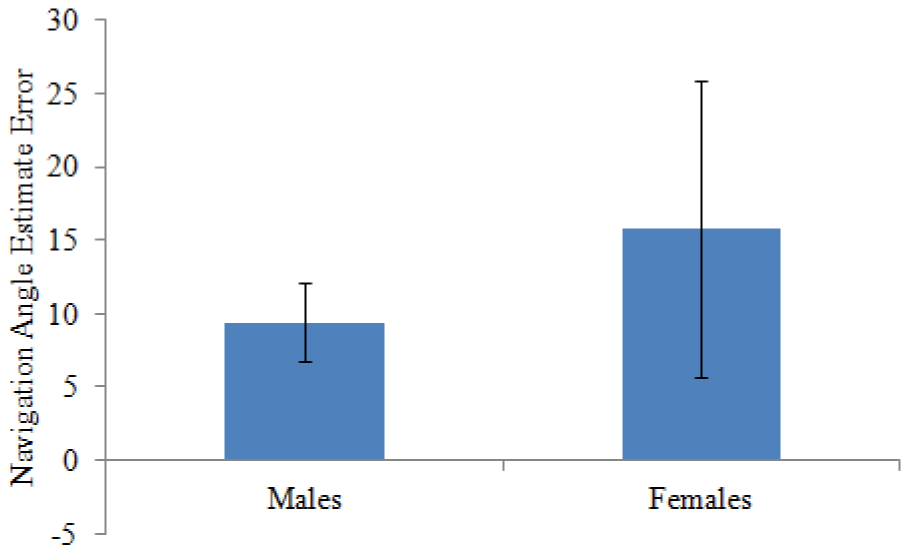

Figure 19. Gender Effect in Navigation Angle Estimate Error ($N = 64$; $N_{Males} = 31$, $N_{Females} = 33$). The Y-axis represents the mean and the error bars represent the standard deviation.

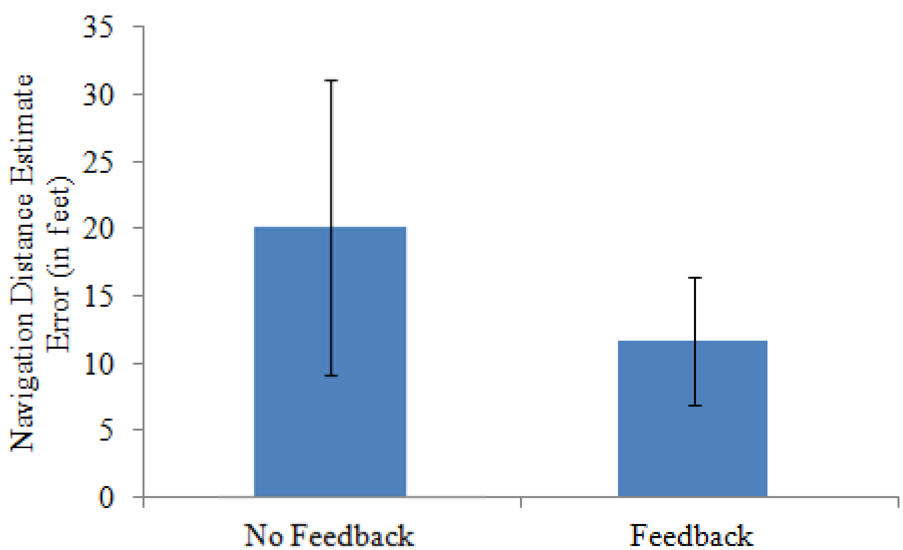

Figure 20. Feedback Effect in Navigation Distance Estimate Error ($N = 64$; $N_{Males} = 31$, $N_{Females} = 33$). The Y-axis represents the mean and the error bars represent the standard deviation.

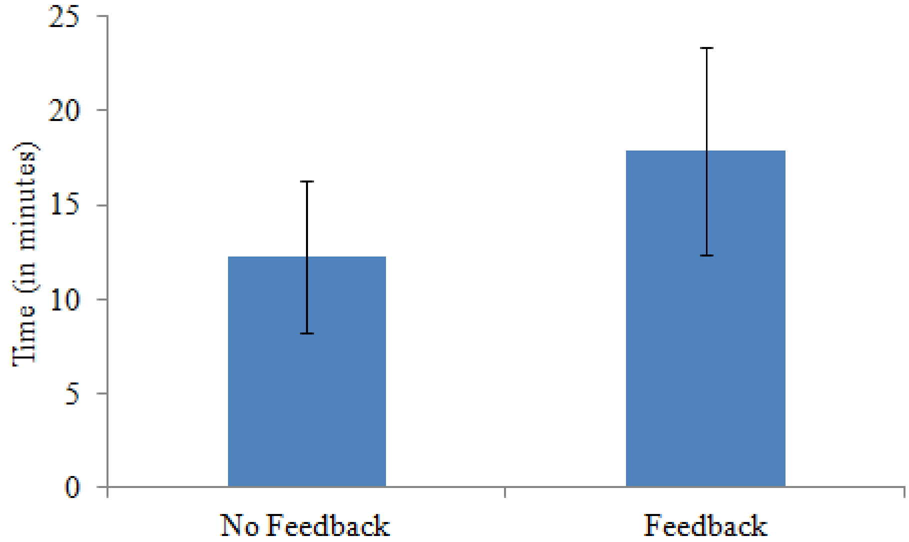

Figure 21. Feedback Effect in Navigation Time (N = 62; N_{Males} = 31, $N_{Females}$ = 31). The Y-axis represents the mean and the error bars represent the standard deviation.

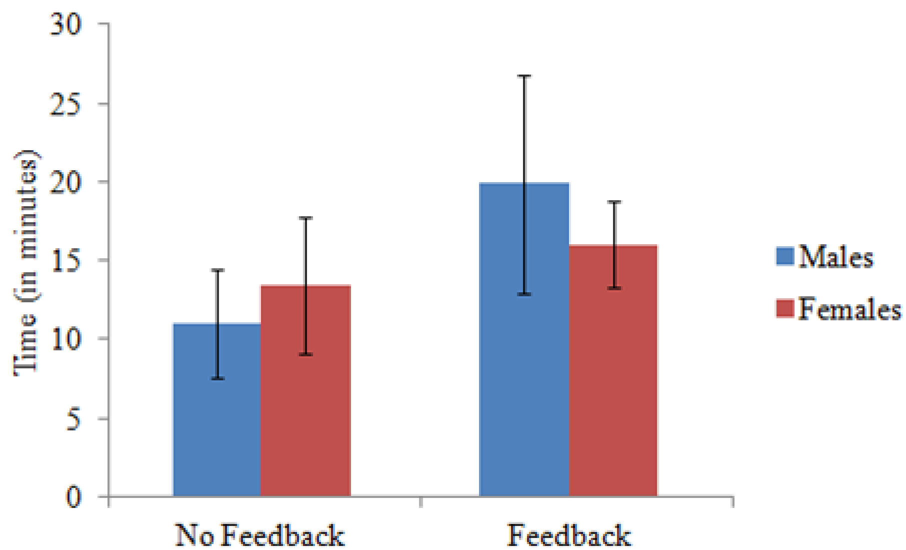

Figure 22. Gender x Feedback Interaction in Navigation Time (N = 62; N_{Males} = 31, $N_{Females}$ = 31). The Y-axis represents the mean and the error bars represent the standard deviation.

Appendix

Appendix A. *Maze Layouts*