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Are gender differences in navigation ability determined by spatial anxiety?

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Abstract

The ability to navigate is crucial for humans to function independently in their lives. Furthermore, research has shown that there are gender differences in participants' navigation ability. However, according to Gabriel et al. (2011) gender differences in participants' navigation ability are determined by their level of spatial anxiety, high or low. However, they have assessed the participants' navigation ability using a small-scale navigation. As a result, the present study was designed to further investigate the effect of spatial anxiety on navigation ability, using a large-scale navigation task, Virtual Tübingen task. This would allow us to get a better understanding of factors that affect navigation in humans. The Virtual Tübingen assess the 102 recruited participants' navigation ability using twelve subtask. These subtask can be classified in two of the three navigation categories encountered in patients with impaired navigation: path and location based navigation. Spatial anxiety was measured using the Spatial Anxiety subscale of the Wayfinding Questionnaire. Based on our findings neither gender nor spatial anxiety had a significant effect on the participants' overall navigation ability. Nevertheless, the participants with a low level of spatial anxiety outperformed those with a high level on a subtask within the path based navigation category: indicate the direction in which a navigated route continued. Surprisingly, we obtained evidence showing that participants with a high level of spatial anxiety are better than those with a low level at a subtask within the location based navigation: pointing at the endpoint of a navigated route. Furthermore, females outperformed male participants on a subtask within the location based navigation category: point to the starting position the navigated route. Our findings indicate that the female advantage we obtained on this subtask could be determined by the participants' levels of spatial anxiety. Thus, our results suggest that there is partial evidence indicating that spatial anxiety could determine gender differences in specific large-scale navigation task within the navigation category, location based

Keywords: navigation, Virtual Tübingen, spatial anxiety, gender, gender differences, navigation categories, location based navigation, path based navigation, large-scale navigation, virtual reality.

Introduction

When you are at home and need to go to work, school or the grocery store, you make use of your navigation abilities. Even though navigation or moving from one location to another often seems like an effortless action, studies researching navigation show that it is a complex process (Claessen & van der Ham, 2017; Claessen, van der Ham, Jagersma, & Visser-Meily, 2016a; Moffat, 2009; Wolbers & Hegarty, 2010). Navigation relies on several cognitive functions like: planning, memory, spatial skills, decision making and attention, that needs to work together in order to successfully navigate to a familiar or unfamiliar location (Claessen et al., 2016a; Gabriel, Hong, Chandra, Lonborg, and Barkley, 2011).

Research has shown that acquired brain injury, such as a stroke can have a negative effect on the ability to navigate; in about a third of the stroke patients (van der Ham, Kant, Postma & Visser-Meily, 2013). A particularly important part of the brain involved in navigation is the hippocampus (Kremmyda et al., 2016; MacMillan et al., 2003). The link between hippocampus and navigation was initially discovered in animal studies (O'Keefe & Nadel, 1979), mostly using rats (Barnhart, Yang, & Lein, 2015; Jeffery, 1998; Morris, Garrud, Rawlinst, & O'Keefe, 1982; O'Keefe, 1975). These studies found that the hippocampus of rats is involved in their ability to successfully navigate their environment. Moreover, research has shown that damage to the hippocampus can impair animals, like rats' ability to successfully navigate in a maze task (Barnhart et al., 2015; Jeffery, 1998; O'Keefe & Nadel, 1979; O'Keefe, 1975). In addition, there is evidence indicating that the right side of their hippocampus functions more or less in the same way as that of humans (O'Keefe & Nadel, 1979; Grön, Wunderlich, Spitzer, Tomczak & Riepe, 2000; Maguire, Spiers, Good, Hartley , Frackowiak, & Burgess, 2003). Support for these findings comes from studies showing that damage to the hippocampus of humans can impair their ability to successfully navigate in an environment (Burgess, Maguire, O'Keefe, 2002; Gron et al., 2000; Glikmann-Johnston, Saling, Reutens, & Stout, 2015; Maguire et al., 2003; Spiers, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2001)

Besides being involved in the navigation performance of humans and animals the hippocampus seems to be linked with anxiety disorder in humans as well (Damsa, Kosel, & Moussaly, 2008). Damsa et al. (2008) reviewed about a thousand studies focusing on the effect of anxiety disorder on the human brain and found that anxiety disorders can lead to a reduced hippocampus volume. Specifically, they observed a reduction in the left side of the hippocampus. Thus, the right side of the hippocampus which is involved in navigation does not seem to be affected by anxiety disorders (O'Keefe & Nadel, 1979; Maguire et al., 2003).

However, past studies have implied that there is a specific domain within the anxiety disorders, spatial anxiety (Kremmyda et al., 2016), that is negatively related to human's ability to navigate successfully (Lawton, 1994, 1996). This claim was based on previous findings indicating that people who experience spatial anxiety are less motivated to explore an unfamiliar location (Lawton, 1994). In addition, people who experience spatial anxiety seem take more time to navigate to their desired location. Consequently, Lawton (1994, 1996) investigated whether spatial anxiety: the amount of anxiety that people experience in their daily life when navigating in their environment, is negatively to their ability to navigate. In line with their expectations, these studies found tentative evidence indicating that there is a negative relationship between navigation and spatial anxiety in humans. Unfortunately, there has not been much empirical research on the link between spatial anxiety and human navigation.

Given that the role of spatial anxiety on navigation is limited, the aim of the present study was to investigate the effect of spatial anxiety on participants' navigation ability. In order to achieve the aim of the current study, we formulated three research objectives. The first objective of this study was to investigate whether the navigation ability of people with high levels of spatial anxiety is worse than those with low levels of spatial anxiety. This objective was based on claims that high levels of spatial anxiety is negatively related to navigation as well as specific categories within navigation (Chang ,2013; Hund & Minarik, 2009; Nowak et al., 2015; Ramirez et al., 2010). Our second objective was to determine if the navigation ability of male participants is better than females. This research objective was founded on research showing that male participants perform better than female on tasks measuring participants' overall navigation ability (Chang ,2013). Male superiority has also been found on specific task measuring participants' navigation ability: navigating a virtual maze, the mental rotation task, Wayfinding Questionnaire (Collucia & Louse, 2004; Nowak et al., 2015; Sneider et al., 2015). Furthermore, there is also a lack of research on the effect of spatial anxiety in determining gender differences in the navigation ability of the participants

(Gabriel et al., 2011). As a result of the above mentioned, the third objective of the present study was; investigate if spatial anxiety determined gender differences in the navigation ability of the participants. We will start by presenting the findings of the effect of spatial anxiety on specific navigation tasks as well as on participants' overall ability to navigate. Then, we will present the findings of the effect of spatial anxiety on determining gender differences in navigation.

Recently, attempts have been made to study the effect of spatial anxiety on humans navigation ability (Chang, 2013; Hund & Minarik, 2009; Ramirez, Gunderson, & Beilock, 2010). However, these studies have mainly focused on the effect of spatial anxiety on specific navigation tasks. These tasks, measuring participants' navigation ability, can be divided in three main functional categories: land mark, location, and path based navigation, according to a review on human navigation in neurological patients (Claessen & van der Ham, 2017). *Landmark based navigation* entails the perception, processing, and encoding of landmarks, like buildings and scenes. *Path based navigation* is the ability to learn and remember how different paths are connected to a certain location. *Location based navigation* is the ability to learn and remember locations of landmark, and their relationship with each other.

The effect of spatial anxiety on task falling within the location based navigation category, navigating a virtual maze, or moving a toy car in a fictional model of a town (Hund & Minarik, 2009; Nowak, Murali, & Driscoll, 2015), appears to significantly affect the navigation ability of participants with high levels of spatial anxiety. These findings are in line with Collucia and Louse (2004) who reviewed studies investigating the effect of spatial anxiety on similar tasks within the location based navigation category.

Moreover, the effect spatial anxiety has also been investigated on tasks measuring landmark based navigation, like the mental rotation task (Gabriel et al., 2011; Ramirez et al., 2010). The results of these studies has shown that spatial anxiety can have a significant effect on task falling within landmark based navigation. Contrary to these results, Saucier et al. (2002) found evidence indicating that spatial anxiety does not have an effect on the landmark based navigation task, mental rotation. However, they attributed their failure to find an effect to their measurement of spatial anxiety, which was taken after the participants completed the mental rotation task. According to Lawton (1994) and Saucier et al. (2002) the participants' measurement of spatial anxiety should have been taken before the assessment of their navigation ability.

Since we could not find studies that has researched the role of spatial anxiety on path based navigation, the present study looked at studies that have investigated the effect of spatial anxiety on participants' navigation ability. Chang (2013) has researched the effect of spatial anxiety on humans ability to navigate to a tourist site in Venice, Italy. She found that high levels of spatial anxiety can have a negative effect on the ability to navigate successfully to a tourist site.

The findings of these studies show that participants who experience high levels of spatial anxiety will perform worse than those experiencing low levels of spatial anxiety on navigation in general as well as on specific subtasks within the location and land mark navigation categories (Chang, 2013; Collucia & Louse, 2004; Gabriel et al., 2011). In addition, these studies have also found evidence indicating that high levels of spatial anxiety are more prevalent among females than their male counterparts. This is in line with the results of previous studies, which have investigated gender differences in spatial anxiety (Lawton, 1994, 1996; Nowak, Murali, & Driscoll, 2015). However, Saucier et al. (2002) found no evidence for gender differences with regards to high and low levels of spatial anxiety.

Besides gender differences in spatial anxiety, previous studies have shown that male participants outperforms female participants on overall their overall ability to navigate as well as on specific navigation categories (Chang, 2013; Gabriel et al., 2011; Lawton & Kallai, 2002; Nowak et al., 2015; Sneider et al., 2015). Given that participants' with high levels of spatial anxiety, navigate better than those with low levels of spatial anxiety, it is plausible that gender differences in navigation ability could be influenced by the amount of spatial anxiety that the participants experience (Hund & Minarik, 2009; Ramirez et al., 2010). Consequently, researchers started to wonder whether gender differences in spatial anxiety are associated with their reported differences in navigation ability (Chang, 2013; Nowak et al., 2015; Sneider et al., 2015). A study that has investigated this was Gabriel et al. (2011). They found evidence indicating there are gender differences on task focusing on landmark based navigation, mental rotation task, as well as on spatial anxiety. Moreover, they have shown that high and low levels of spatial anxiety can determine gender differences in the participants' navigation ability.

In conclusion, research has shown that gender differences can be observed in: spatial anxiety, navigation, and specific navigation categories (Chang, 2013; Hund & Minarik, 2009; Ramirez et al., 2010). More specifically, there is evidence showing that male participants navigate better and experience less spatial anxiety than females. These findings led to the research of Gabriel et al. (2011), who found that high and low levels of spatial anxiety can determine gender differences in a specific navigation category, land mark based navigation.

Nevertheless, these findings have a few limitations. Chang (2013) assessed participants' navigation ability in a real world environment: walking in an outdoor and indoor environment. According to Chang (2013) and Claessen, Visser-Meily, de Rooij, Postma, and van der Ham (2016b) there are many factors that affect participants' navigation ability in real world environments. For example, real world navigation tasks cannot control for factors such as safety, the amount of people, traffic, and weather in that environment. These factors, which cannot be controlled for, can affect a participant's navigation ability, thus biasing the data (Chang, 2013; Claessen at al., 2016b). Consequently, the assessment of navigation in a real world environment is considered problematic.

Another limitation is the fact that both Gabriel et al. (2011) and Ramirez et al. (2010) used a small-scaled spatial ability task to assess participants' navigation ability on specific navigation categories. However, small-scale spatial task does not appear to be the best way to measure navigation. Studies show that these tasks have a weak relationship with humans' navigation ability in real world environments (Claessen & van der Ham, 2017; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006). Studies assessing humans' ability to navigate recommend the use of large-scale navigation tasks because they are better equipped to predict navigation in real life (Claessen at al., 2016b). Yet, the studies which have assessed the role of spatial anxiety on large-scale navigation test, have used a virtual maze task based on the Morris water navigation task (Nowak et al., 2015; Sneider et al., 2015). Even though these virtual maze tasks are widely used to assess human navigation (Nowak et al., 2015; Sneider et al., 2015), these tasks were initially designed to assess navigation in animals (Burgess, Maguire, & Keefe, 2002). Moreover, the virtual maze task seems capable of assessing only one of the three navigation categories in humans, location based navigation (Claessen & van der Ham, 2017). Thus, the virtual maze task fails to acknowledge the complexity of human navigation, by only focusing on one of the three navigation categories (Claessen et al., 2016a; Moffat, 2009; Wolbers & Hegarty, 2010). Finally, we only found one study that has researched the role of spatial anxiety in determining gender differences in navigation (Gabriel et al., 2011). However, this study used a small-scaled spatial ability task to assess the participants' navigation ability which, as previously mentioned has a weak relation with humans' ability to navigate (Kozhevnikov et al., 2006).

To be able to determine the role of spatial anxiety of the navigation ability of female and male participants, the present study formulated three hypothesis. First of all, participants who experience high levels of spatial anxiety will perform worse on task measuring their navigation ability. If the expected results are obtained it would suggest that human navigation can be negatively influenced by high levels of spatial anxiety, which in turn can also affect their ability to navigate independently in their daily life. Secondly, the navigation ability of male participants is better than that of female participants. Such a finding can provide further support for a male advantage in task measuring navigation. Lastly, gender differences in task measuring the participants' navigation ability are due to the fact that male participants experience less spatial anxiety than females. If high and low levels of spatial anxiety can determine the navigation ability of participants, the assessment of spatial anxiety should be considered when dealing with in patients with navigation problems

Method

Participants

The present study is part of a larger experimental research focusing on the effect of navigation training on participants' navigation ability. Our colleagues from the larger study gave us permission to use the data from fifty of their participants. The rest of our participants we gathered using three main recruitment strategies: posting our flyers on social media, posting flyers at the University of Leiden and Hogeschool Leiden, we also personally invited students to participate in our research. In addition, SONA, a research recruitment website from the University of Leiden, was also used to recruit participants. Using these recruitment strategies we were able to recruit 102 participants (66 female and 36 male) participants. The mean age of the overall sample was 22.11 (*SD* = 2.81).

Participants could participate if they were between 18 and 30 years old, and had access to a computer with internet connection. A college degree or other forms of higher education was also necessary to be able to take part in this study. Moreover, a requirement for participation was being healthy, thus an absence from psychiatric complains. The participants that met the requirements of the study and agreed to participate, had to sign an informed consent before beginning the research.

Materials

Spatial Anxiety questionnaire. The amount of spatial anxiety that participants experience was measured using a subscale of the Wayfinding Questionnaire, the Spatial Anxiety questionnaire (van der Ham et al., 2013). The Spatial Anxiety questionnaire is a valid and reliable self-report measure to assess participants' level of anxiety when navigating in their daily life (Claessen, Visser-Meily, de Rooij, Postma, & van der Ham, 2016c). It consisted of 8 items. An example of one of these items was ‘’I am afraid to get lost in an unknown city’’; by giving a response on a scale ranging from 1 to 7, the participants indicated how they felt about an item. A score of 1 indicated that a question was not applicable to the participant, and a score of 7 indicated that a question was fully applicable to the participant. Moreover, the scores on the spatial anxiety questionnaire were reversed in such a manner that low scores indicated high spatial anxiety and high scores indicated low spatial anxiety.

Previous research on spatial anxiety have used an average cut off score of ≤ 3 to able to group the participants in high and low score on the Spatial Anxiety questionnaire (Claessen et al., 2016c). In the present study the participants with a high score on spatial anxiety questionnaire, obtained an average score of at least 4. On the other hand, the participants with a low score on spatial anxiety, obtained an average score below 4 on the questionnaire. Finally, we assume that the participants’ level of spatial anxiety will be highest during the first session. As a result, only the data from the first session will be used to determine the participants’ level of spatial anxiety.

Navigation ability (composite z-score Virtual Tübingen subtasks). The participants’ navigation ability was measured using an adapted version of the Virtual Tübingen task, which is a valid and reliable tool to measure human navigation (Claessen et al., 2016a; Claessen at al., 2016b). The Virtual Tübingen task has two phases, a learning phase and a testing phase. During the learning phase, the participants watched a video on the German city Tübingen lasting between 5 to 6 minutes. This video was presented in two different navigation perspectives, allocentric and egocentric. Egocentric perspective is when a participants’ body is used as a point of reference to navigate in their environment (Burgess et al., 2002; Nowak et al., 2015). On the other hand allocentric perspective requires a participant to use the relationship between landmarks distances; for example the distance between McDonald's and the central station, to navigate in an environment.

The testing phase of the Virtual Tübingen assesses the participants knowledge of the video that they have previously watched. During this phase the participants’ are exposed to seven subtask; each subtasks had eight trials. Based on the review of Claessen and van der Ham (2017) the subtasks of this version of the Virtual Tübingen task falls within two functional navigation categories, path and location based navigation. The subtasks, Route Sequence and Route Continuation, falls within the path based navigation category. On the other hand, the subtasks: Route distance, Point to Start, Point to End, and Location on Map, seems to focus on the location based navigation category.

The first subtask of the Virtual Tübingen task was *Route Sequence*, here participants used arrows: left, right or straight ahead, to replicate the order of the route that they have just been exposed to in the video. Participants' score was determined by their percentage of correctly indicated arrows. The second one was *Route Continuation.* Here participants indicated the direction: left, right or straight ahead, in which the route continued, based on 8 different screen images of the previously watched video. Participants' score was the percentage of correct responses on the trials. *Route distance* was the third subtask. In this task participants had to indicate the distance between two scenes. Participants' score on this subtask was calculated by averaging the percentage of deviation between the actual distance and the distance that the participant chose on the trials. The fourth subtask, *Point to Start*, showed the participants 8 scenes of the video they have just been exposed to. Based on these scenes they had to indicate where the starting point of the route was using a 360 degrees rotational device. Participants' score was determined by averaging the score between the response that participant indicated and the correct response on each trial. This rotational device was also used in the fifth subtask, *Point to End*. Here the participants were shown 8 images of the route. Based on these images they had to indicate where the route ended, by using the device. Participants' score was determined by averaging the difference in score between the response that participant indicated and the correct response on each trial. In the last subtask, *Location on Map*, participants were asked to use a map to indicate the position of a scene that they have previously watched in the video. Participants' score on this subtask was calculated by averaging the difference in score between the location the participant indicated on the map and the real distance to the correct location.

In the present study the participants' average score or score in percentages on the twelve subtasks of the Virtual Tübingen could have been obtained by chance. Meaning, that on a subtask of the Virtual Tübingen only fifty percent of the participants' answers were correctly answered. Nevertheless, the main interest of the current study was getting a single measurement of the participants' navigation ability based on the twelve subtask of Virtual Tübingen. Consequently, the participants' score on the these subtasks were transformed into a composite z-score for navigation, called navigation ability.

As previously mentioned, only the data from the first session of the Virtual Tübingen and was used in this study. The data from the first session was used because we assumed that it will give us an accurate measurement of the participant's navigation ability. Moreover, data from the first session will be used to avoid influence of training on the second session (Green & Bavelier, 2003).

Procedure

The first session of this experiment took most of the participant about two and a half hours to complete, which included a ten minute break after the assessment of the participants' navigation ability. The study started with the participants answering a few general questions on a computer regarding their age, sex, educational level, etc. These questions were asked to ensure that participants met the research conditions. Next, the participants were exposed to the Wayfinding Questionnaire which has three subscale measuring: Spatial Anxiety (8 questions), Navigation and Orientation (11 questions) and Distance Estimation (3 questions) (van der Ham et al., 2013).

As part of the larger study the Wayfinding questionnaire was followed by the Virtual Starmaze paradigm, which was played on a personal computer (Igloi et al., 2009). Upon completion of this task we inspected the participants data output. The output data of the Virtual Starmaze paradigm indicated which navigation strategy the participants used, egocentric or allocentric, when navigating the maze. Afterwards, the participant continued with the twelve subtasks of the Virtual Tübingen, which measured their navigation ability in two different navigation perspectives, allocentric and egocentric (Claessen et al., 2016a). As part of the larger study, participants were also exposed to: psychoeducation on navigation, the Mental Rotation task, Perspective-taking, Digit-span task, and Corsi Block-Tapping task during the first session of this experiment.

For their participation, the participants were compensated with credit points or money. Moreover, two weeks after the first session participants were asked to come back for a second testing session, as part of the larger experiment. During this second session, the participants were exposed to the Wayfinding Questionnaire, the Virtual Starmaze paradigm task, and Virtual Tübingen task, for a second time. This session lasted about an hour. Thereafter, the participants received a debriefing about the experiment as well as a compensation for their participation.

Design

As previously mentioned this research is part of a larger study which, has two testing sessions. However, this study will only be focusing on some of the data obtained during the first testing session of the research. More specifically, we were particularly interested in the data obtained from the Virtual Tübingen task; measuring the participants' navigation ability. Furthermore, the Spatial anxiety subscale of the Wayfinding Questionnaire was used to determine the participants' level of spatial anxiety, high or low. Based on the findings of previous work (Claessen et al., 2016c), the current study used an average cut off score of ≤ 3 to divide the participants in a high and low spatial anxiety group. The maximum score on this questionnaire was a score of 7.

To analyze the collected data the present study used a 2x2 design with gender (male and female), and two levels of spatial anxiety, high and low score on the Spatial Anxiety questionnaire, as between subject factors. Finally, our research design was in agreement with the Declaration of Helsinki, and has been approved by the Ethical Commission of Psychology at the Leiden University, the CEP.

Statistical analyses

IBM SPSS 23 was used to analyze the data. Furthermore, the present study considered test results with a two tailed alpha level of .05 or less as a significant finding. In addition, we also used ηp^2 (partial eta squared) when we reported our results. The effect sizes of the partial eta squared can be divided in: small = ≤ .05, medium = between .06 and . 12, and large = ≥ .13 (Claessen et al., 2017).

The present study started by checking the data for outliers, since these can affect the results and its interpretation. For each subtask of the Virtual Tübingen we checked whether a participants' score deviated 3 or more standard deviation from the mean. These score were considered outliers. If a participant score on a subtask fell within the outlier range, these score were replaced by missing values.

Next, the present study compared the demographic characteristics of the participants: age, gender, and the educational level of the participants, using a chi-square test and an independent t-test. The chi-square test and independent t-test were also used to compare demographic differences in the high and low spatial anxiety groups as well as in participants' navigation ability on the Virtual Tübingen task. Next, we used a between subject analysis of variance (ANOVA) to assess the effect of spatial anxiety on the navigation ability of the participants. The independent variable of this ANOVA was group 1; participants with a high score on the spatial anxiety questionnaire, and group 2; participants with a low score on the spatial anxiety questionnaire. The composite score, navigation ability, was used as the dependent variable of this test. Furthermore, we expected to find gender differences in the navigation ability of the participants. In addition, we conducted a between subject ANOVA to determine whether there are gender differences in navigation ability of the participants. The independent variable of this ANOVA was gender (male and female participants), and dependent variable was participants' navigation ability on the Virtual Tübingen task. Regarding our third assumption, we conducted a between subject analysis of covariance (ANCOVA) to determine whether gender differences in navigation ability was influenced by the participants average score on spatial anxiety. The dependent variable of this ANCOVA was the composite score on navigation ability, and the independent variable was gender (male and female). The covariate of this analysis was the participants mean score on the Spatial Anxiety questionnaire.

Before we performed these analyses we checked if they violated any of their statistical assumptions. For the ANOVA, we looked at: normal distribution of the dependent variable for each category of the independent variable, and homogeneity of variance. When we performed the ANCOVA, the following assumptions were checked: normal distribution of the dependent variable for each category of the independent variable, homogeneity of variance, homogeneity of regression slopes, and independence of treatment and covariate.

Results

Participants

The final sample of this study consisted of 101 participants, 65 female and 36 male participants (see Table1). One of the participants (a female) was excluded because, she did not understand the instructions of the Virtual Tübingen task. As a result most of her scores on the following subtasks: Route continuation, Route distance, Point to start, and Point to end**,** fell within the outlier range or were obtained by chance. Outliers were z-scores deviating more than three standard deviations from the mean. For the remaining 101 participants in our final sample, we checked and replaced scores falling within the outlier range to missing values.

In addition, we also checked for possible gender differences in our demographics (see Table 1). The independent t-test showed that there was a significant difference between male and female participants with regard to age t (8) = 2.93, p = .004. With regard to the participants educational level the current study used the Verhage educational scale (1964). Verhage classifies education levels in seven categories: (1) primary school not completed. (2) completed primary school. (3) secondary school not completed. (4) completed secondary school of a low level. (5) completed secondary school of an average level. (6) completed secondary school of the highest level. (7) University degree. Nevertheless, when using the chi square test, no significant difference was obtained between female and male participants level of education ($\chi2$ = 3.37, p = .34).

Table 1. *Gender-divided and overall sample demographics*

	Female (N = *65)*	*Male* (N = *36)*	*All participants* (N = *101)*
Age in years, mean (SD)	21.52 (2.51)	23.19 (3.1)	22.13 (2.82)
Verhage's Educational levels, mean (SD)	6.64 (.48)	6.56 (.5)	6.61 (.49)

Note. The educational level of the participants were classified according to Verhage scale (1964); ranging from 1, no primary education, to 7, University degree.

Spatial Anxiety

On the Spatial Anxiety questionnaire the participants obtained an average score ranging between 2.18 and 6.18 (M = 4.41, SD = .89), these scores were normally distributed. Furthermore, female (M = 4.3, SD = .85) and male (M = 4.6, SD = . 95) participants' average score on this questionnaire were comparable (t<1), which is in disagreement with our hypothesis. Participants with high (66.3 %) and low scores (33.7 %) on spatial anxiety did not differ with regard to gender ($\chi 2$ = 0, p = .96), nor age (t<1). Whether a participant obtained a high or low score on spatial anxiety was determined by an average cut off score of ≤ 3 (Claessen et al., 2016c). A high score on spatial anxiety meant that a participant obtained an average score of at least 4. On the other hand, a participant with a low score on spatial anxiety, obtained an average score below 4 on the questionnaire. In addition, the current study reversed the scores on the spatial anxiety questionnaire in such a manner that low scores indicated high spatial anxiety and vice versa.

Participants' navigation ability (composite z- score the Virtual Tübingen)

On the Virtual Tübingen task the participants' navigation ability ranged from -7.45 to 8.65. These scores had a mean of 0 (SD = 3.1), and were normally distributed. Moreover, the participants' navigation ability did not differ as a function of gender (t>1).

The effect of spatial anxiety on navigation ability

The analysis of variance (ANOVA) showed that the amount of spatial anxiety that participants experienced had no significant effect on their navigation ability, $F(1,99) = .351$, $p = .5$, $\eta p^2 = .004$ (see Figure 1).

The present study also conducted an explorative analysis. Given that the twelve subtasks of the Virtual Tübingen can be classified in two specific navigation categories (Claessen & van der Ham, 2017), the goal of these analyses was to investigate the effect of spatial anxiety on each subtask. This will allow us to get insight in the effect of spatial anxiety on specific subtasks within the navigation categories, path and location based navigation. More specifically, a between subject analysis of variance (ANOVA) was used to determine the effect of high and low spatial anxiety on the each subtasks of the Virtual Tübingen (see Table 2). Before we performed these analyses, we checked if the data violated any of its assumptions, and found that the twelve subtasks of the Virtual Tübingen were not normally distributed for each category of spatial anxiety. Nevertheless, the ANOVA is robust against violation of normality, thus, there was no reason to discontinue this analysis. We performed the analysis and found that spatial anxiety had a significant effect on one particular subtask within the location based navigation category, Point to End $F(1,99) = 4.23$, $p = .04$, $\eta p^2 = .043$. Post hoc comparison using the using Tukey HSD showed that participants with high levels of spatial anxiety ($M = .29$, $SD = 1.01$) performed significantly better than those with low levels of spatial anxiety ($M = -.14$, $SD = .97$) on the Point to End Subtask of the Virtual Tübingen. Moreover, spatial anxiety also had an effect on one subtask within the path based navigation category, Route continuation $F(1, 96) = .939$, $p = .01$, $\eta p^2 = .127$. Our Post hoc analysis using Tukey HSD indicated that participants with a low level of spatial anxiety ($M = .18$, $SD = .94$) performed significantly better than those with a high level of spatial anxiety ($M = -.35$, $SD = 1.03$) on the Route Continuation subtask of the Virtual Tübingen**.** However, the effect of spatial anxiety on these navigation categories appear to be limited to specific navigation perspectives, allocentric or egocentric.

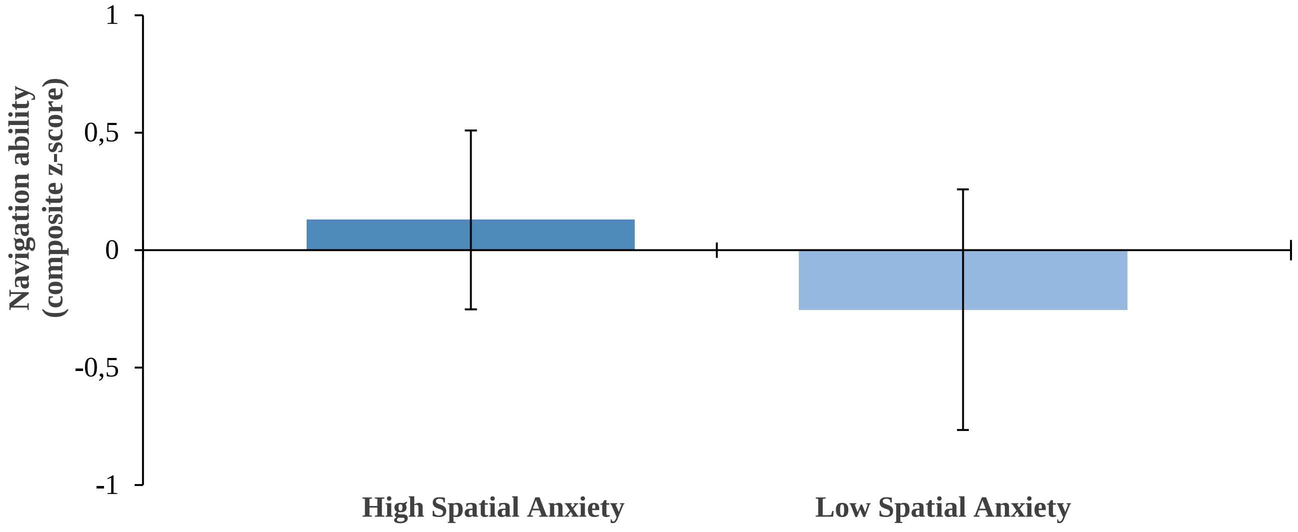

Figure 1. Bar graph shows the means score difference between participants with a high and low score on the Spatial Anxiety questionnaire. The obtained standard error of the mean (SEM) are represented by error bars. Note: the scores on the Spatial Anxiety were reversed in such a manner that low scores indicated high spatial anxiety and vice versa. Navigation ability was a composite score based on the twelve subtask of the Virtual Tübingen. N= 101.

Table 2. *Analysis of variance (ANOVA) between high and low levels of spatial anxiety and the twelve subtasks of the Virtual Tübingen subtasks*

		Navigation perspective							
		Egocentric				Allocentric			
Virtual Tübingen Subtasks	**Spatial Anxiety Score**	*M (SD)*	*F*	η_p^2	*p*	*M (SD)*	*F*	η_p^2	*p*
Route Sequence	High	.05 (.98)	.593	.006	.443	.08 (1.04)	1.153	.012	.286
	Low	-.11 (1.04)				-.15 (.90)			
Route Continuation	High	.06 (.97)	.617	.006	.434	.18 (.94)	6.733	.064	.011*
	Low	-.11 (1.03)				-.35 (1.03)			
Route Distance	High	.03 (.98)	.220	.002	.640	.08 (.99)	1.413	.014	.237
	Low	-.07 (1.06)				-.17 (1)			
Point to Start	High	-.04 (.93)	.265	.003	.608	-.02 (1.13)	.072	.001	.789
	Low	.07 (1.14)				.04 (.70)			
Point to End	High	-.14 (.97)	4.373	.043	.039*	.02 (.98)	.079	.001	.779
	Low	.29 (1.01)				-.04 (1.04)			
Location on Map	High	-.08 (1)	1.134	.011	.290	-.10 (.98)	1.930	.019	.168
	Low	.15 (.99)				.19 (1.03)			

Note. The scores on the Spatial Anxiety questionnaire were reversed in such manner that low scores indicated high spatial anxiety and vice versa. Moreover, the participants' scores on the twelve subtasks of the Virtual Tübingen were transformed to z-scores. These subtasks had a between-group degree of freedom of 1. N = 101. * $p \leq .05$; Partial eta squared (η_p^2) effect size: small = $\leq .05$, medium= between .06 and .12, large = $\geq .13$.

The effect of gender on navigation ability

Before performing an analysis of variance to determine the effect of gender on participants' navigation ability, we checked, if our data violated any assumption of the test. Our data met all the requirements for the ANOVA. Next, we did the analysis, which indicated that gender type had no significant effect on the participants navigation ability $F(1,99) = 1.61$, $p = .21$, $\eta p^2 = .016$ (see Figure 2).

Given that we did not find an effect for gender on our composite measurement of navigation, we performed an explorative analysis. The goal of this analyses was to investigate the effect of gender on the subtasks of the Virtual Tübingen, which can be classified in two specific navigation categories, path and location based navigation (Claessen & van der Ham, 2017). A between subject analysis of variance (ANOVA) was conducted to determine the effect of gender on these twelve subtasks. With the exception of normality, which this test is robust to, None of the ANOVA's assumptions were violated. Based on our findings gender only had a significant effect on one specific subtask, Point to Start $F(1,99) = 4.33$, $p = .04$, $\eta p^2 = .044$, within the location based navigation category (see Table 3). Post hoc analysis using Tukey HSD showed that female participants ($M = .15$, $SD = .95$) performed significantly better than their male counterparts (M = -.28, SD = 1.04) on the Point to Start subtask of the Virtual Tübingen. But this effect was only observed in one of the navigation perspectives, egocentric, in which the subtask was performed.

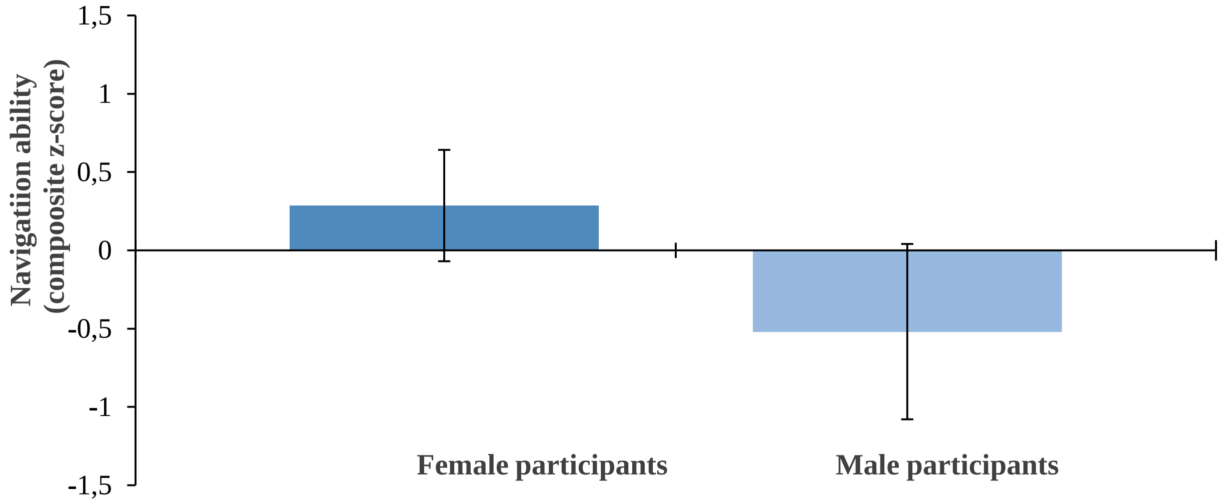

Figure 2. Bar graph shows the average means score difference between female and male participants. The obtained standard error of the mean (SEM) are represented by error bars. Note. Navigation ability was a composite score based on the twelve subtask of the Virtual Tübingen. N = 101.

Table 3. *Analysis of variance (ANOVA) between gender and the twelve subtasks of the Virtual Tübingen subtasks*

		Navigation perspective							
		Egocentric				Allocentric			
Virtual Tübingen Subtasks	**Gender**	*M (SD)*	*F*	ηp^2	*p*	*M (SD)*	*F*	ηp^2	*p*
Route Sequence	Male	-.14 (.98)	1.252	.013	.265	-.06 (1.08)	.203	.002	.654
	Female	.08 (1.01				.03 (.96)			
Route Continuation	Male	.13 (.90)	.914	.009	.342	.17 (1.07)	1.604	.016	.208
	Female	-.07 (1.05)				-.09 (.95)			
Route Distance	Male	.10 (1.03)	.535	.005	.467	-.09 (1.07)	.413	.004	.522
	Female	-.05 (.99)				.05 (.96)			
Point to Start	Male	-.28 (1.04)	4.332	.044	.037*	-.13 (.68)	.917	.009	.341
	Female	.15 (.95)				.07 (1.14)			
Point to End	Male	-.09 (1.12)	.404	.004	.528	-.01 (1.04)	.003	-	.956
	Female	.05 (.94)				0 (.99)			
Location on Map	Male	-.16 (1.17)	1.504	.015	.222	.04 (1.12)	.098	.001	.755
	Female	.09 (.89)				-.02 (.94)			

Note. Participants' score on the twelve subtasks of the virtual Tübingen were transformed to z-scores. These subtasks had a between-group degree of freedom of 1. N = 101. * $p \leq .05$; Partial eta squared (ηp^2) effect size: small = $\leq .05$, medium= between .06 and .12, large = $\geq .13$.

Spatial anxiety's influence on differences in navigation ability

To investigate if gender differences in the ability to navigate were determined by the amount of spatial anxiety that participants experienced. An analysis of covariance (ANCOVA) was used. The present study started by checking if the data violated any ANCOVA assumptions. We discovered that the assumptions, linear relationship between dependent variable and covariate for each independent variable were violated.

However, this test does not have a parallel non-parametric version thus, we opted to continue our analysis. Our findings indicated that the covariate, spatial anxiety, was not related to the participants' navigation ability $F(1, 98) = .07$, $p = .80$, $r = .01$. Moreover, the present study did not obtain a significant effect for gender on the participants navigation ability after controlling for the influence of spatial anxiety $F(1,98) = 1.66$, $p = .20$, $\eta p^2 = .017$.

Furthermore, we conducted an explorative analysis to determine the role of spatial anxiety on gender differences in the twelve subtasks of the Virtual Tübingen. Since these subtask are focused on path and location based navigation categories, this analysis would allow us to get a better understanding of spatial anxiety's role in determining gender differences in specific navigation categories. In order to investigate whether gender differences on these subtasks were determined by spatial anxiety, the present study performed a between subject multivariate analysis of covariance (MANCOVA). Prior to performing the analysis the current study checked if the data violated any of the MANCOVA assumptions: multivariate normality, homogeneity of variance, homogeneity of variance-covariance, homogeneity of regression slopes, linear relationship between dependent variable and covariate. The current study found that the data violated the following two assumptions, multivariate normality and linear relationship between dependent variable and covariate. Nevertheless, the MANCOVA is robust against violation of normality, and there is not a non-parametric version of this analysis. As a result, the present study chose to continue with the analysis. Using the MANCOVA's Pillai's trace, we found that there was no significant effect for gender on the twelve subtasks of the after controlling for spatial anxiety $V = 0.12$, $F(1, 96) = .939$, $p = .44$, $\eta p^2 = .127$. However, we did find a trend ($p = .07$) for gender differences on one subtask of the Virtual Tübingen, Point to start, after controlling for spatial anxiety (see Table 4). More specifically, post hoc analysis using Tukey HSD indicated that female ($M = .12$, $SD = .91$) participants performed significantly better than male participants ($M = -.22$, $SD = .99$) on the Point to Start subtask of the Virtual Tübingen, after controlling for the effect of spatial anxiety. This trend was only observed in the egocentric perspective of the Virtual Tübingen. Moreover, we applied the Bonferroni correction to reduce the possibility of making a Type I error, since the analysis was performed on twelve different dependent variables, the Virtual Tübingen subtasks.

Table 4. *Followed-up analysis of covariance (ANCOVA) summary table showing the effect of gender on*

		Navigation perspective							
		Egocentric				Allocentric			
Virtual Tübingen Subtasks	**Gender**	*M (SD)*	*F*	η_p^2	*p*	*M (SD)*	*F*	η_p^2	*p*
Route Sequence	Male	-.21 (.97)	1.982	.020	.162	-.08 (1.09)	.456	.005	.501
	Female	.08 (1.02)				.03 (.96)			
Route Continuation	Male	.10 (.92)	.560	.006	.456	.20 (1.03)	1.428	.015	.235
	Female	-.10 (1.04)				-.11 (.95)			
Route Distance	Male	.11 (1.01)	.617	.006	.434	-.12 (1.09)	1.043	.011	.310
	Female	-.06 (1.00)				.04 (.97)			
Point to Start	Male	-.22 (1.00)	3.203	.033	.077	-.19 (.54)	1.508	.016	.223
	Female	.12 (.91)				.08 (1.15)			
Point to End	Male	-.04 (1.10)	-	-	.995	.02 (1.06)	.003	-	.957
	Female	.04 (.94)				.02 (.99)			
Location on Map	Male	-.15 (1.15)	.634	.007	.428	.05 (1.15)	.446	.005	.506
	Female	.09 (.90)				-.05 (.93)			

the twelve subtasks of the Virtual Tübingen *after controlling for the effect of spatial anxiety.*

Note. The covariate, spatial anxiety, was the participants means score on the Spatial Anxiety questionnaire. Participants' score on the twelve subtasks Virtual Tübingen were transformed to z-scores. These subtasks had a between-group degree of freedom of 1. Bonferroni correction was applied to reduce the possibility of Type I error. N = 101. * $p \leq .05$; Partial eta squared (η_p^2) effect size: small = ≤ .05, medium= between .06 and .12, large = ≥ .13.

Discussion

Previous studies have shown tentative evidence that there is a negative relationship between the navigation ability of participants and their level of spatial anxiety (Lawton, 1994, 1996; Lawton & Kallai, 2002). However, there has not been much empirical research on this matter. As a result the primary goal of this study was to investigate whether the navigation ability of humans are influenced by the amount of spatial anxiety that they experience. In order to achieve this goal we formulated three research objectives.

First, investigate whether the navigation ability of people with high levels of spatial anxiety is worse than those with low levels of spatial anxiety. We formulated this objective based on claims that high levels of spatial anxiety is negatively related to navigation as well as specific categories within navigation (Chang ,2013; Hund & Minarik, 2009; Nowak et al., 2015; Ramirez et al., 2010). Secondly, the present study wanted to determine if male participants ability to navigate is better than their female counterparts. This objective was founded on evidence showing that male participants outperforms females on tasks measuring specific navigation categories and navigation (Chang ,2013; Collucia & Louse, 2004; Nowak et al., 2015; Sneider et al., 2015). Our third objective was; investigate whether spatial anxiety determined gender differences in the navigation ability of the participants. This objective was based on the study of Gabriel et al. (2011), they found evidence that gender differences in the participants navigation ability was determined by their level of spatial anxiety, high and low. Nevertheless, most of these studies have used small-scaled spatial task, and not large-scale navigation task to assess the navigation ability of the participants (Gabriel et al., 2011; Hund & Minarik, 2009; Lawton, 1994, 1996; Nowak et al., 2015; Sneider et al., 2015). Large-scale navigation tasks are more similar to human navigation than small-scale tasks (Claessen & van der Ham, 2017; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006). As a result little is known about the effect of spatial anxiety on large-scale navigation tasks (Claessen et al., 2016a).

These findings led the current study to formulate three hypotheses. First, participants who experience high levels of spatial anxiety will perform worse on task measuring participants' navigation ability. Secondly, male participants' navigation ability are better than female participants. Third, gender differences in task measuring navigation ability are due to the fact that male participants experience less spatial anxiety than females.

Spatial anxiety and navigation ability

Contrary to this study's expectation high and low levels of spatial anxiety did not affect the participants' overall navigation ability on the Virtual Tübingen task. According to the results we obtained, the amount of spatial anxiety that a participant experience does not play a role in his or her navigation ability. A possible explanation why this study did not find an effect for spatial anxiety on the participants' navigation ability, could be due to our measurement of navigation. The present study measured the participants' navigation ability using a large-scale navigation task, the Virtual Tübingen, which is valid and reliable tool to assess human navigation (Claessen at al., 2016b). However, it is quite possible that our composite measurement of navigation, navigation ability, could be lacking internal validity. Our composite measurement of navigation ability consisted of twelve subtasks focusing on two navigation categories, location and path based navigation (Claessen & van der Ham, 2017). This is completely different from what past studies have done; assessing the effect of spatial anxiety on navigation in general (Chang, 2013) or on a single navigation category (Hund & Minarik, 2009; Nowak et al., 2015; Ramirez et al., 2010). Consequently, this study used explorative research to investigate the role of spatial anxiety on specific subtasks within the navigation categories, location and path based navigation. The results of these analyses indicated that the effect of spatial anxiety on navigation is limited to specific subtask within location and path based navigation categories. Moreover, our findings; the effect of spatial anxiety is limited to specific navigation task, is in line with the results of previous studies on this subject (Hund & Minarik, 2009; Nowak et al., 2015; Ramirez et al., 2010). In addition, we have also discovered that the effect of spatial anxiety on participants' navigation ability is highly dependent on the navigation perspective, allocentric or egocentric, in which the task is performed. Consequently, future research on this subject should also take navigation perspectives, allocentric and egocentric, into account when researching participants' navigation ability.

Based on these findings the current study would like to recommend future researchers in this field to investigate the role of spatial anxiety on a large-scale navigation tasks that are focused on all three navigation categories: landmark, path, and location based navigation. This can give us a better understanding of spatial anxiety's effect on human navigation (Claessen at al., 2016b; Claessen & van der Ham, 2017).

Spatial anxiety and gender differences in navigation ability

The present study also investigated the effects of spatial anxiety on gender differences in navigation. We started by testing the second assumption of this study; male participants have better navigation ability than female participants. This assumption was founded on past studies that have found gender differences on task measuring overall navigation (Chang, 2013), as well as specific navigation categories, such as location based navigation (Nowak et al., 2015; Padilla et al., 2017; Sneider et al., 2015). However, we did not find any support for this assumption. Our results indicated that the navigation ability of male participants does not significantly differ from female participants. This finding directly contradicted the assumption of the present study. Therefore, we conducted an explorative analysis focusing on gender differences in specific subtasks of the Virtual Tübingen task, within path and location based navigation categories. Consistent with previous studies, we found evidence indicating that the effect of gender is limited to a specific subtask, Point to Start, within the location based navigation category (Nowak et al., 2015; Padilla et al., 2017; Sneider et al., 2015). Again, this effect was only observed in one navigation perspective, egocentric perspective.

Overall, our results suggest that male participants perform better than female participants on task measuring navigation in general (Chang, 2013) as well as on specific tasks within specific navigation categories, location and path based navigation (Coluccia & Louse, 2004; Nowak et al., 2015; Padilla et al., 2017; Ramirez et al., 2010; Sneider et al., 2015). In addition, the findings of the present study shows that there are no gender differences in participants' navigation ability when the measurement of navigation is a composite score based on subtasks that only take two navigation categories into account. Nevertheless, we still do not know whether there are gender differences in the third navigation category, landmark based navigation (Claessen & van der Ham, 2017). As a result, we suggest researchers who are interested in further investigating this subject to take all three navigation categories; landmark, location and path based navigation, into account when researching gender differences in participants' navigation ability (Claessen & van der Ham, 2017). This could increase both the public and researchers understanding of whether gender differences are limited to one or more navigation categories.

The third assumption of the current study was; gender differences in task measuring participants' navigation ability are due to the fact that male participants experience less spatial anxiety than female participants. However, the present study did not find evidence indicating that spatial anxiety determined gender differences in the participants' navigation ability. This assumption was founded on the study of Gabriel et al. (2011), who found that spatial anxiety determined gender differences on small-scaled spatial ability task measuring a specific navigation category, landmark based navigation. Thus, there are two reasonable explanations why the present study did not find an effect for spatial anxiety on gender differences on navigation. First, contrary to the study of Gabriel et al. (2011) we used a large-scale navigation task, the Virtual Tübingen task, to assess the participant's navigation ability. Second, the version of the Virtual Tübingen used in the present study only took the navigation categories, location and path based into account, and not landmark. This just further illustrates how specific the effect of gender and spatial anxiety can be on participants' navigation ability.

As a result, the present study conducted explorative research to investigate whether spatial anxiety determined gender differences on the twelve subtask of the Virtual Tübingen

(Claessen & van der Ham, 2017). The results of our explorative research showed that spatial anxiety did not determine gender differences on these subtasks. However, we did observe a trend with regard to gender differences on one subtask, Point to Start, within the location based navigation category, after controlling for the effect of spatial anxiety. But, this effect was only observed in one of the navigation perspectives, egocentric. These results imply that there is tentative evidence indicating that spatial anxiety can determine gender differences in specific subtask within a specific navigation category, location based navigation (Claessen & van der Ham, 2017).

Yet, the lack of empirical research on the role of spatial anxiety on gender differences in navigation, makes it difficult for the current study to evaluate it's finding with previous studies. Therefore, we urge researchers in this field to further investigate if spatial anxiety determines gender differences on large-scale navigation tasks that are focused on all three navigation categories (Claessen & van der Ham, 2017). By doing so, we will be able to better comprehend the role of spatial anxiety in determining gender differences in human navigation (Claessen at al., 2016b) which, is a complex system (Moffat, 2009; Wolbers & Hegarty, 2010).

However, the use of large-scale navigation task, like the Virtual Tübingen, has both its advantages and disadvantages. In general, this task offers a lot of benefits for the assessment of navigation in humans (Claessen et al., 2016b; Claessen & van der Ham, 2017). For example, it is a valid tool for researchers to assess participants' navigation ability on more than one navigation category using various subtasks. In the present study the subtasks of the Virtual Tübingen were assessing both path and location based navigation (Claessen & van der Ham, 2017). Furthermore, this task permits studies to gain control over their environment and to intervene as quick as possible if necessary, which cannot be done in a task measuring navigation in real world (Chang, 2013; Claessen et al., 2016). The Virtual Tübingen also allows researchers to get a measure of the participants' navigation ability that moderately overlaps with humans navigation in real life situations.

On the other hand, a limitation of the Virtual Tübingen tasks we used was that it did not take the navigation category, landmark based navigation, into account (Claessen & van der Ham, 2017). Nevertheless, recent studies have shown that hybrid reality is a better option regarding the assessment of participants' navigation ability (van der Ham, Faber, Venselaar, van Kreveld, & Loffler, 2015). Hybrid reality is considered a better option because it allows a participant to physically navigate in a real world environment. In addition, it also has the benefits of large-scale navigation, like the Virtual Tübingen tasks. Moreover, the use of large-scale navigation tasks also offers researchers control over harming factors in their participants environment. These added features are what makes hybrid reality a better alternative when measuring the navigation ability of humans. Moreover, recent studies have shown that navigating in hybrid reality closely resembles physical navigating in real life (van der ham et al., 2015). As a result, hybrid reality tasks could provide researchers with the means to assess the three main categories of navigation: path, land and location based navigation, in a more realistic way (Claessen & van der Ham, 2017; van der Ham et al., 2015). Thus, hybrid reality seems like the perfect tool for the assessment of navigation ability in humans. Based on these findings the current study would like to advise future researchers assessing participants' navigation ability to make use of hybrid reality when doing so.

Conclusion

All by all, our results indicate that gender and levels of spatial anxiety, high or low, do not have a significant effect on participants overall ability to navigate a large-scale navigation task, like the Virtual Tübingen. However, we obtained evidence indicating that gender and levels of spatial anxiety does have an effect on specific subtask of the Virtual Tübingen: Route Continuation, Point to Start, and Point to End. These subtasks appears to fall within two of the three navigation categories encountered in patients with an impaired navigation ability, path and location based navigation. In addition, our data showed that spatial anxiety can determine gender differences on a specific subtask within the location based navigation category, Point to Start. Based on these findings the current study is the first to demonstrate that gender differences in navigating a large-scale navigation tasks within the location based navigation category, can be determined by participants' level of spatial anxiety.

References

Bracken, M. B. (2008). Why animal studies are often poor predictors of human reactions to exposure. *Journal of the Royal Society of Medicine, 101,* 120-122.

Burgess, N., Maguire, E. A., & O'Keefe, J. (2002). The Human hippocampus and spatial and episodic memory. *Neuron*, *35*, 625- 641.

Chang, H. (2013). Wayfinding strategies and tourist anxiety in unfamiliar destinations. *Tourism Geographies, 15,* 529-550.

Claessen, M. H. G., & van der Ham, I. J. M. (2017). Classification of navigation impairment: a systematic review of neuropsychological case studies. *Neuroscience and Biobehavioral Reviews*, *73,* 81–97.

Claessen, M. H. G., van der Ham, I. J. M., Jagersma, E., & Visser-Meily, J. M. A. (2016a). Navigation strategy training using virtual reality in six chronic stroke patients: a novel and explorative approach to the rehabilitation of navigation impairment. *Neuropsychological Rehabilitation*, *26*, 822-846.

Claessen, M. H. G., Visser-Meily, J. M. A., de Rooij, N. K., Postma, A., & van der Ham, I. J. M. (2016b). A direct comparison of real-world and virtual navigation in chronic stroke patients. *Journal of the International Neuropsychological Society*, *22*, 467-477.

Claessen, M. H. G., Visser-Meily, J. M. A., de Rooij, N. K., Postma, A., & van der Ham, I. J. M. (2016c). The Wayfinding Questionnaire as a self-report screening instrument for navigation-related complaints after stroke: internal validity in healthy respondents and chronic mild stroke patients. *Archives of Clinical Neuropsychology*, *31,* 839–854

Claessen, M. H. G., Visser-Meily, J. M. A., Meilinger, T., Postma, A., de Rooij, N. K., & van der Ham, I. J. M. (2017). A systematic investigation of navigation impairment in chronic stroke patients: evidence for three distinct types. *Neuropsychologia* (in press).

Collucia, E., & Louse, G. (2004). Gender differences in spatial orientation: a review. *Journal of Environmental Psychology, 24,* 329-340.

Dallérac, G., & Rouach, N. (2016). Astrocytes as new targets to improve cognitive functions. *Progress in Neurobiology, 144,* 48-67.

Damsa, C., Kosel, M., & Moussaly, J. (2008). Current status of brain imaging in anxiety disorders. *Current Opinion in Psychiatry, 22*, 96-110.

Gabriel, K. I., Hong, S. M., Chandra, M., Lonborg, S. D., & Barkley, C. L. (2011). Gender differences in the effects of acute stress on spatial ability. *Sex Roles, 64*, 81-89.

Glikmann-Johnston, Y., Saling, M. M., Reutens, D. C., & Stout, J. C. (2015). Hippocampal 5-HT1A receptor and spatial learning and memory. *Frontiers in Pharmacology*, *6,* 1-31.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534-537.

Hund, A. M., & Minarik, J. L. (2009). Getting from here to there: spatial anxiety, wayfinding strategies, direction type, and wayfinding efficiency. *Spatial Cognition and Computation, 6*, 179–201.

Iglo, K., Zaoui, M., Berthoz, A., & Rondi-Reig, L. (2009). Sequential egocentric strategy is acquired as early as allocentric strategy: parallel acquisition of these two navigation. *Hippocampus, 19*, 1199–1211.

Kozhevnikov, M., Motes, M. A., Rasch, B., & Blajenkova, O. (2006). Perspective-taking vs. mental rotation transformations and how they predict spatial navigation performance. *Applied Cognitive Psychology, 20,* 397-417.

Kremmyda, O., Hüfner, K., Flanagin, V., Hamilton, D. A., Linn, J., Strupp, M., …Brandt, T. (2016). Beyond dizziness: virtual navigation, spatial anxiety and hippocampal volume in bilateral vestibulopathy. *Frontiers in Human Neuroscience, 10*, 1-12.

Lawton, C. A. (1994). Gender differences in way-finding strategies: relationship to spatial ability and spatial anxiety. *Sex Roles, 30,* 765-779.

Lawton, C. A. (1996). Strategies for indoor wayfinding: the role of orientation. *Journal of Environmental Psychology 16,* 137-145.

Lawton, C. A., & Kallai, J. (2002). Gender differences in wayfinding strategies and anxiety about wayfinding: a cross-cultural comparison. *Sex Roles, 47,* 389-401.

MacMillan, S., Szeszko, P. R., Moore, G. J., Madden, R., Lorch, E., Ivey, J., . . . Rosenberg, D. R. (2003). Increased amygdala: hippocampal volume ratios associated with severity of anxiety in pediatric major depression. *Journal of Child and Adolescent Psychopharmacology, 13,* 65-73.

Maguire, E. A., Spiers, H. J., Good, C. D., Hartley, T., Frackowiak, R. S. J., & Burgess, N. (2003). Navigation Expertise and the human hippocampus: a structural brain imaging analysis. *Hippocampus, 13,* 250-259.

Moffat, S., D. (2009). Aging and spatial navigation: what do we know and where do we go? *Neuropsychology Review,19,* 478-489.

Morris, R. G. M., Garrud, P, Rawlins, J. N. P., & O'Keefe, J. (1982). Place navigation impaired in rats with hippocampal lesions. *Nature, 297,* 681-683.

Nowak, N. T., Murali, A., & Driscoll, I. (2015). Factors related to sex differences in navigating a computerized maze. *Journal of Environmental Psychology, 43,* 136-144.

Oberheim, N., A, Takano, T., Han, X., He, W., Lin, J. H. C., … Nedergaard, M. (2009). Uniquely Hominid Features of Adult Human Astrocytes. *The Journal of Neuroscience, 29,* 3276-3287.

O’Keefe, J. Place units in the hippocampus of the freely moving rat. (1976). *Experimental Neurology, 51,* 78-109.

O'Keefe, J., & Nadel, L. (1979). Précis of O'Keefe & Nadel's the hippocampus as a cognitive map. *Behavioral and Brain Sciences, 2,* 487-494.

Padilla, L. M., Creem-Regehr, S. H., Stefanucci, J. K., & Cashdan, E. A. (2017). Sex differences in virtual navigation influenced by scale and navigation experience. *Psychonomic Bulletin & Review,* 23, 582-590.

Penn, P. R., Rose, F. D., & Brooks, B. M. (2005). Virtual reality in everyday memory assessment and rehabilitation: progress to date and future potential. *Annual Review of CyberTherapy and Telemedicine, 3,* 31-38.

Ramirez, G., Gunderson, E. A., & Beilock, S. L. (2012). Spatial anxiety relates to spatial abilities as a function of working memory in children. *The Quarterly Journal of Experimental Psychology, 65*, 474-487.

Saucier, D. M., Green, S. M., Leason, J., Macfadden, A., Bell, S., & Ellias, L. J. (2002). Are sex differences in navigation caused by sexually dimorphic strategies or by differences in the ability to use the strategies? *Behavioral Neuroscience, 116*, 403-410.

Sneider, J. T., Hamilton, D. A., Cohen-Gilbert, J. E., Crowley, D. J., Rosso, I. M., Silveri, M. M. (2015) .Sex differences in spatial navigation and perception in human adolescents and emerging adults. *Behavioural Processes*, 111, 42-50.

Spiers, H. J., Burgess, N., Hartley, T., Vargha-Khadem, F., & O’Keefe, J. (2001). Bilateral hippocampal pathology impairs topographical and episodic memory but not visual pattern matching. *Hippocampus*, 11, 715-725.

Van der Ham, I. J. M., Kant, N., Postma, A., & Visser-Meily, J. M. A. (2013). Is navigation ability a problem in mild stroke patients? Insights from self-reported navigation measures. *Journal of Rehabilitation Medicine, 45*, 429-433.

Verhage, F. (1964). I*ntelligence and age: Research study in Dutch individuals age twelve to seventy-seven*. Assen: van Gorcum.

Wang, R. F., & Spelke, E. S. (2002). Human spatial representation: insights from animals. *Trends in Cognitive Sciences, 6,* 376-382.

Wolbers, T., & Hegarty, M. (2010). What determines our navigation abilities. *Trends in Cognitive Sciences, 14*, 138-146.