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Clarifying individual differences in navigational ability

The role of spatial anxiety, verbal and visuospatial working memory

Gada Swadi

Master Thesis (Clinical Neuropsychology)
Faculty of Behavioural and Social Sciences – Leiden University
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Studentnumber: s1589725
Daily Supervisor: Ineke van der Ham
CNP-co-evaluator: Esther Habers

Abstract

This study meant to contribute to the understanding of individual differences that exists in navigational ability. In order to reach this, our first aim was to investigate the role of individual differences in working memory in the relationship between spatial anxiety and navigational ability. Our second aim was to investigate the relationship between visuospatial memory and navigation performance. Navigation ability was assessed by means of a self-report questionnaire and a virtual reality based navigation task battery. Visuospatial and verbal working memory were assessed using neuropsychological tests and spatial anxiety was measured by means of a self-report questionnaire. Eighty-seven participants were included in this study. First, it was expected that participants who scored higher on spatial anxiety would perform worse on navigational ability tasks than participants who reported lower spatial anxiety. Second, it was expected that verbal working memory moderates the relationship between spatial anxiety and navigation performance. Third, it was expected that participants who scored higher on the visuospatial task would perform better on navigational ability tasks than participants who scored lower on the visuospatial task. The first two hypotheses were analyzed by means of a hierarchical regression analysis and the third hypothesis was analyzed by means of a multivariate regression analysis. According to our results verbal working memory did not significantly moderate the relationship between spatial anxiety and navigation performance and visuospatial working memory was not significantly related to navigation ability. However, we did find support for the hypothesis that spatial anxiety was significantly related to navigation performance. It is important to continue investigating significant effectors of navigational ability in order to contribute to the understanding of individual differences that exist in navigational ability and facilitate clinical interventions designed to target navigation impairments associated with (spatial) anxiety. Future directions are provided for studies who wish to contribute to identifying the cognitive processes and the emotion-cognition interactions that underlie navigation behavior.

Introduction

In order to travel successfully, navigation is required. Navigational ability relies on a variety of cognitive processes such as attention, memory, perception and decision-making skills (Berthoz & Viaud-Delmon, 1999; Burgess, 2006; Corbetta, Kincade, & Shulman, 2002; Lepsien & Nobre, 2006). The proper function of all these cognitive processes together can make individuals become familiar with the environment using several strategies for navigation (Iaria, Bogod, Fox, & Barton, 2009; Wolbers & Hegarty, 2010). Due to its complexity, navigation behavior differs substantially among healthy individuals (Chrastil, 2013; Farr, Kleinschmidt, Johnson, Yarlagadda, & Mengersen, 2014; Walkowiak, Foulsham, & Eardley, 2015; Wiener, Büchner, & Hölscher, 2009; Wolbers & Hegarty, 2010). A part of these differences has been explained by factors such as gender, age, computer experience, early wayfinding experience and spatial skills (Lawton & Kallai, 2002; Montello & Sas, 2006; Taillade, N'Kaoua, & Sauzéon, 2015). However, a large percentage of these differences found in navigation performance are still unexplained (Montello & Sas, 2006; Wolbers & Hegarty, 2010). This is partly due the fact that not all aspects that underlie navigation are known yet. One way of clarifying these aspects is by studying the differences in brain activation between good and bad navigators. In this way, a part of the complexity of navigational ability can be unraveled by understanding what cognitive processes underlie navigation behavior (Baumann, Chan, & Mattingley, 2010; Wolbers & Hegarty, 2010). Another way is to consider emotion-cognition interaction that can also explain the differences found in navigation performance (Schmitz, 1997; Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013).

The outline of the present study will be as followed. First the role of verbal and spatial working memory in navigation will be discussed. Also, individual differences in reliance on these different working memory systems and their effect on navigation performance will be discussed. Then, the relationship between anxiety and cognitive task performance will be explained. After that, spatial specific anxiety effects on navigation performance will be discussed. The effects of working memory performance and anxiety are relevant to this study because they are thought to explain a part of the individual differences found in navigation performance. In the end, the specific research goals along with the hypotheses will be presented.

Cognition and navigation

Navigational ability depends strongly on the storage and updating of information, which are functions that are strongly associated with working memory (e.g. Montello, 1993).

Accordingly, previous studies have shown that both verbal and spatial working memory are involved in navigation behavior (Baumann, Skilleter, & Mattingley, 2011; Garden, Cornoldi, & Logie, 2002; Meilinger, Knauff, & Bülthoff, 2008; Montello, 1993). Information from the environment can be retained two formats: in verbal working memory as a sequence of route directions, or in spatial working memory as a configuration (e.g. Allen, Kirasic, Dobson, Long, & Beck, 1996). Individual differences in reliance on these different working memory formats could explain a part of the variance found in navigation performance. For example, Baumann, Chan and Mattingley (2010) did an fMRI study in which they examined patterns of neural activity associated with encoding and retrieval processes during a navigation task. They found that good navigators show significantly stronger memory-related activation in striatal brain regions, whereas poor navigators show significantly higher activity in the left hippocampus. Baumann and colleagues (2010) also suggest that the stronger striatal activity in good navigators might reflect a non-verbal component of the memory process, while the stronger left hippocampal activity in poor navigators reflects a predominantly verbal code to remember the target object's location (Garden et al., 2002). Another study conducted by Baumann, Skilleter and Mattingley (2011) used a different approach to investigate individual differences in navigation performance by using a dual-task paradigm (Baumann et al., 2011). Their findings suggest that poor navigators rely on a combination of both visuospatial and verbal working memory and good navigators depend strongly on a non-verbal, visuospatial working memory process during navigation in a virtual environment. Accordingly, previous research has shown this positive significant relationship between visuospatial working memory and navigation tasks several times (e.g. Garden et al., 2002; Labate, Pazzaglia, & Hegarty, 2014; Miyake, Rettinger, Friedman, Shah, & hegarty, 2001; Muffato, Meneghetti, & De Beni, 2016; Pazzaglia & Cornoldi, 1999; Shah & Miyake, 1996; Taillade, N'Kaoua, & Sauzéon, 2015).

So a part of the individual differences found in navigation performance can be explained by differences in reliance on visuospatial and/or verbal working memory. However, there are also other factors that can influence navigation performance. For example, anxiety has been often associated with adverse effects on cognitive task performance (Eysenck, Derakshan, Santos, & Calvo, 2007; Vytal, Arkin, Overstreet, Lieberman, & Grillon, 2016).

Anxiety and cognition

Anxiety can express itself in several ways. One way is by anxious arousal, which is characterized by physiological changes in heart rate variability, sweat production, increased vigilance and other automatic preparatory responses that prime defense mechanisms. Another way is by anxious apprehension, which is characterized by awareness of physiological changes, worry and rumination (Vytal, Cornwell, Letkiewicz, Arkin & Grillon, 2013). The processing efficiency theory described in Eysenck et al. (2007) provides several explanations concerning how anxiety is associated with cognition, based exclusively on the anxious apprehension component of anxiety. The first explanation states that anxiety induced by stressful situations can create worry, which has two effects. One effect is that worry creates cognitive interference by depleting the temporary storage capacity for working memory. This results in less available resources for the concurrent task and therefore a lower task performance. The greater the worry and the more difficult the task, the greater the disruption. The other effect is that worry increases the motivation to minimize the experienced anxiety and its detrimental effects. This is achieved by promoting enhanced effort and the use of other resources and compensatory strategies. If these resources are available, the potential performance impairments are compensated for and thus less likely to occur.

A second explanation for the adverse effects of anxiety on cognition concerns the mechanisms and components of working memory. This explanation is based on the first working memory model created by Baddeley (1986). According to this theory, worrisome thoughts interfere with the processing- and storage of information by the central executive. This notion has been supported by much evidence (e.g. Derakshan & Eysenck, 1998; Eysenck et. al, 2005; MacLeod & Donnellan, 1993). Additionally, anxiety places a burden on self-regulatory functions and compensatory strategies that are needed in case of working memory resource depletion. It is also expected that the detrimental effects of anxiety are rather expected in the phonological loop than on the visuospatial sketchpad because worry contains a verbal component rather than imagery representations. This notion has also been supported by much evidence (e.g. Beilock & DeCaro, 2007; Eysenck et al., 2007; Ramirez, Gunderson, Levine, & Beilock, 2012); Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013). Finally, pathological anxiety can create an attentional bias towards threat, which can alter perception, perhaps even at the expense of goal-directed behavior (Vytal et al., 2016; Vytal et al., 2013).

Thus far effects of anxiety on several aspects of cognition have been discussed. In the following section a more specified type of anxiety will be introduced. The focus point will be to explain the effect of this type of anxiety on a more specialized cognitive function, namely navigation ability.

Spatial anxiety and navigation

Ramirez et al. (2012) conducted an experiment in which they found that spatial ability is influenced by worrisome thoughts, but only in students who scored high on a verbal working memory task. Worrisome thoughts caused by spatial anxiety lowered the efficiency of a spatial skill called mental rotation by causing the individual to switch strategy to a less working memory intensive one (Hund & Minarik, 2006; Ramirez et al., 2012). In this case, spatial anxiety has led to performance decrements on a spatial task. Ramirez et al, (2012) defined spatial anxiety as “anxiety about performing spatial tasks in an evaluative context”. However, spatial anxiety can also relate to finding the way through an unfamiliar environment (Hund & Minarik, 2006). The difference between spatial anxiety and other types of anxieties, such as general anxiety, is that spatial anxiety is a form of state anxiety while general anxiety is a form of trait anxiety. State anxiety is defined as an individual's anxiety in a particular situation, while trait anxiety is the tendency to become anxious in many situations. The latter represents a personality dimension of that individual (Eysenck et al., 2007).

Spatial anxiety has been known to have several negative influences on navigation behavior. For example, spatial anxiety negatively influences self-esteem and the motivation to explore unfamiliar environments (Cohen & Cohen, 2013). Lawton (1996) stated that heightened spatial anxiety consumes cognitive resources, which in turn negatively influence navigation behavior. This idea strongly resembles the notion that anxiety depletes the temporary storage capacity for working memory and lowers cognitive performance, as stated in the processing efficiency theory. However, other studies found that spatial anxiety was unrelated to navigation efficiency (Mckeen, 2007; Saucier et al., 2002).

According to this literature review, a part of the individual differences found in navigation performance can be explained by differences in reliance on visuospatial and/or verbal working memory. Good navigators seem to depend more strongly on a non-verbal, visuospatial working memory process during active navigation than poor navigators. This stresses the importance of visuospatial working memory function in efficient navigation. Also, emotion-cognition interactions seem to explain a part of the individual differences in navigation performance. Accordingly, there is much support for the existence of a significant relationship between spatial anxiety and navigation ability, even though results were mixed. Explanations for individual differences in this relation are provided by the processing efficiency theory, which states that subjects who rely more on verbal working memory strategies than visuospatial working memory appear to be more susceptible for spatial anxiety related decrements in navigation performance. Altogether, previous research has shown that cognitive and spatial skills, but especially spatial anxiety, have a great influence on effective wayfinding. These factors could explain a big part of the individual differences found in navigational ability (Farr et al., 2014; Hund & Minarik, 2006; Ramirez et al., 2012; Walkowiak, Foulsham, & Eardley, 2015). Clarification about the relationship between spatial anxiety and navigation performance may facilitate interventions designed to target navigation impairments associated with spatial anxiety. In order to clarify the individual differences in navigational ability, large-scale experimental studies have to be performed that include the most important effectors of navigational ability.

This study meant to contribute to the understanding of individual differences that exists in navigational ability. In order to reach this, our first aim was to investigate the role of individual differences in working memory in the relationship between spatial anxiety and navigational ability. Our second aim was to investigate the relationship between visuospatial memory and navigation performance. In our study navigation performance was assessed by means of a self-report questionnaire and a virtual reality task that measured certain navigation skills important for navigational ability (Van der Ham, Kant, Postma, & Visser-Meily, 2013; Van der Ham et al., 2010). Visuospatial and verbal working memory were assessed using neuropsychological tests and spatial anxiety was measured by means of a self-report questionnaire. First, it was expected that participants who scored higher on spatial anxiety would perform worse on navigational ability tasks than participants who reported lower spatial anxiety. Second, it was expected that verbal working memory moderates the relationship between spatial anxiety and navigation performance. Third, it was expected that participants who scored higher on the visuospatial task would perform better on navigational ability tasks than participants who scored lower on the visuospatial task.

Methods

Participants

Since older adults show compromised spatial navigation abilities, and children's cognitive functions are still in development, only participants between 18 and 30 years old were included in the experiment (Fair et al., 2009; Head & Isom, 2010). Also, participants who suffered from neurological or neurodevelopmental disease were excluded from participation, because neurological damage or alteration could also influence navigational ability (Iaria et al., 2009; Van der Ham et al., 2010). Finally, participants who have been in the German city Tübingen were also excluded from participation, as familiarity with this city could affect their performance. Due to technical problems seven participants were excluded from the study. Also, one participant was excluded because the fire alarm went off and one because the age limit was exceeded. Consequently, this left us with 78 participants (17 male) in the data analysis. Participants ranged in age from 18 to 30 years old (M= 21.38, SD = 3.176).

Design and procedure

This study was part of a larger study. All participants completed two neuropsychological working memory tasks, four navigation skills tasks and in total four questionnaires of which two are relevant to this study. The participants were instructed to provide informed consent at the beginning of the experiment and were presented a written debriefing at the end of the experiment. This protocol was approved by the local ethical committee (Leiden University, Institute for Psychological Research).

Neuropsychological tasks

Corsi block-tapping task. The Corsi block-tapping task was used as a measure of visuospatial working memory capacity (e.g. Vandierendonck, Kemps, Fastame, & Szmalec, 2004). In this task, participants were asked to repeat the pointing pattern of the examiner in a series of blocks that were arranged in an irregular order on a board based on the original standard display developed by Corsi (1972). For a detailed description of the protocol we refer to Corsi (1972). Higher total Corsi span scores represented better spatial working memory function. Scoring: Number of correctly repeated patterns, range: 0–30.

Digit span. The Digit Span is a subtest of the Wechsler Intelligence Scale for Adults–Fourth Edition (Wechsler, 2008). The total digit score, which is a composite of the child's forward and backward spans, is a measure of working memory. The forward digit span task is a commonly used measure of immediate verbal short-term memory, whereas the backward digit span task is often used as a measure of executive attention (Ramirez et al., 2012).). For a detailed description of the protocol we refer to Wechsler (2008). Scoring: Number of correctly repeated number sequences responses, range: 0–30.

Navigation task battery

The Virtual Tübingen Tasks (VTT) are a virtual reality environment of the town Tübingen in Germany, which assess navigation skills designed by Van der Ham et al. (2010). The task consisted of several elements: the study phase, a scene recognition test, a route continuation test, a route ordering test and a map selection test. First, the participant was shown a short movie (302 seconds) of a route through the virtual environment, whereby the set speed equals walking speed. Afterwards, different aspects of knowledge about the learned route were systematically assessed by means of four tasks.

Scene recognition. This test showed 21 snapshots, of which 11 were snapshots from the movie and the other 10 were distractors, which were not shown in the movie. The participant had to reply whether he/she saw the picture in the movie or not. The total score was the percentage of correctly answered responses.

Route continuation. In this test, the participant was shown an image of the route, after which they were asked whether the route was continued with a left turn, straight ahead or a right turn. In total 11 images were shown. The total score was the percentage of correctly answered responses.

Map selection. Four closely resembling maps were shown to the participants, which were supposed to represent the route that they saw in the short movie shown in the beginning. They were allowed to only choose one map. The map of choice was scores as either correct or incorrect. The final test was route ordering. In this task a total of 21 images were shown to the participants, which were all present in the short movie. Their task was to put the images in the same order as they appeared in the short movie. Each correctly ranked image was given two points; whereas one point was given for each image that was put one position too early or too late in the order. A combined test score was derived of all four tests. In order to obtain one combined test score from all the test scores with different metrics, a weighted composite score was made. In order to obtain this, first the raw test scores had to be converted into z-scores. Subsequently, these z-scores had to be added up in order to obtain the composite score, which could be used in the statistical analysis as a score representative for navigational ability. A higher score represented better navigation performance.

Questionnaires

Wayfinding Questionnaire Spatial Anxiety subscale. In order to assess wayfinding, an extensive questionnaire constructed by Van der Ham et al. (2013) was administered. In this questionnaire questions were presented, which represent the different cognitive components involved in successful wayfinding. The subscales represented spatial ability and spatial anxiety. In total the questionnaire contained 22 questions. The spatial anxiety subscale in this questionnaire indicated the level of anxiety experienced when navigating on one's own in an unknown environment. Only the subscale score representing spatial anxiety (WQ-SA) was used for further statistical analysis, in which higher scores indicated higher anxiety.

Santa barbara sense of direction scale. The Santa Barbara Sense Of Direction (SBSOD) scale (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002) is a self-report scale consisting of 15 statements designed to measure a person's judgment of his or her own spatial orientation ability. Participants responded by circling a number from one (strongly disagree) to seven (strongly agree) to indicate their level of agreement with each statement. A higher scoring rate indicated a better self-report sense of direction. The internal reliability of the scale is .88.

Statistical analysis

Our first two hypotheses were investigated by performing a hierarchical regression analysis. Moderator analysis was conducted using the procedure described by Baron and Kenny (1986). They asserted that moderation should be established by assessing the direct effects of a predictor (in this case WQ-SA or Digit Span), a potential moderator (Digit Span), and the interaction product of the predictor and moderator (WQ-SA x Digit Span). The dependent variable is represented by either SBSOD or VTT. The first hypothesis is supported if the main effect of WQ-SA in the prediction of SBSOD and VTT is significant. The moderator hypothesis is supported if the prediction of SBSOD and VTT by the interaction term is significant. The hierarchical regression analysis will be performed twice using each of the dependent variables separately with the same main and interaction effects. Our third hypothesis was tested by conducting a multivariate regression analysis with the VTT composite score and SBSOD score as continuous dependent variables and the Corsi score as a continuous independent variable.

Of special importance in (multiple) univariate and multivariate linear regression analysis are the assumptions of normality, linearity, homoscedasticity and the absence of extreme outliers. If one or more of these assumptions are violated, the statistical results may become biased or distorted. To achieve multivariate normality, three conditions have to be met: univariate normality, linear combinations of the variables should be normally distributed and all pairwise combinations of the variables should also be normally distributed. To test whether each variable is normally distributed, Meyers, Gamst and Guarino (2006) recommend a thorough univariate normality examination coupled with bivariate scatterplot examination of key pairs of variables. Univariate normality was graphically assessed by looking at the Q-Q plot of each variable. Normality was assumed if the data points fall on or very near the diagonal line. Another way of assessing univariate normality was done by looking at the kurtosis and skewness values of each variable. Kurtosis and skewness values were judged following the criteria of Meyers, Gamst and Guarino (2006), who accept values between +1.0 and -1.0. In addition, a statistical test was used that assessed univariate normality, called the Kolmogorov-Smirnov test. This test is recommended for samples greater than 25 and performs an aggregate test of skewness and kurtosis in the univariate case. Significant results indicate that the data significantly deviate from a normal distribution. To determine if the variables were linearly related to each other, bivariate scatterplots for key variables were examined. If the scatterplots were elliptical or oval shaped, linearity between two variables was indicated. To assess homoscedasticity Box's M test for equality of variance-covariance matrices was used. Box's M tests the statistical hypothesis that the variance-covariance matrices are equal. Significant results indicate the absence of homoscedasticity. Extreme outliers were checked by inspecting box-plots of all used variables. The extreme outliers are any score more than 3*IQR (IQR stands for Interquartile range, which is the middle 50% of the scores.

We used a significance level of $p < .05$ for all statistical tests. Data analysis was performed using the Statistical Package for the Social Science (SPSS) for Windows, Version 21.0 (SPSS Inc., Chicago, IL, USA).

Results

Descriptive statistics

The procedures for checking the assumptions related to multivariate regression yielded the following results. No extreme outliers were found in the data of all variables. Q-Q plots of all variables appeared to show data points that fall on or very near the diagonal line, which indicates normality. The kurtosis value of SBSOD scores indicated a flat distribution (Kurtosis > 1). Also, Digit Span scores showed a kurtosis value between -0.5 and -1.0, which also indicates a flat distribution. However, when adhering to the criteria of Meyers, Gamst and Guarino (2006) the Digit Span kurtosis value falls within acceptable limits (between +1.0 and -1.0). Kurtosis and skewness values of remaining variables showed values between -0.5-0.5, which indicate that these distributions are not far away from a normal distribution that is bell-shaped and not too peaked or flat. Results of the Kolmogorov-Smirnov test showed statistical significance for WQ-SA ($p < .05$). The Kolmogorov-Smirnov test also showed statistical significance for Digit Span scores ($p < .05$), indicating a non –normal distribution (Burdenski, 2000). Therefore a log transformation has been applied on WQ-SA scores and Digit Span scores. The resulted Kolmogorov-Smirnov value after transformation of the WQ-SA distribution was not significant anymore, which indicated a normal distribution. However, the resulted Kolmogorov-Smirnov value after transformation of the Digit Span distribution still showed statistical significance ($p < .05$). When looking at bivariate scatterplots with SBSOD and VTT as dependent variables and WQ-SA and Corsi as independent variables, the Corsi data points showed least linearity with the dependent variables because of the missing oval/elliptic shape and seemingly random scattering of data points. Even though the scatterplots between the dependent variables and WQ-SA scores did not show perfect ovals, they appeared to show enough linearity in the relationships of the variables to proceed with the analysis. Also, the bivariate scatterplot between Digit Span scores and WQ-SA scores were examined. These also showed a lack of oval/elliptic shape indicating non-linearity. The Box’s M test for equality of variance-covariance matrices showed non-significant results for the dependent variables VTT and SBSOD. This indicates equal levels of variability across the range of the independent variables WQ-SA and Corsi, which assumes homoscedasticity. The means and standard deviations for the measures (including the transformed data) are included in Table 1.

Table 1

Means and standard deviations for the SBSOD (range 1-7), the VTT (range -7.84-7.84), the WQ-SA, (range 0-0.85), Digit Span scores (range 0-1.48), Corsi scores (range 0-30)

Variables	Mean (SD)
SBSOD	4.14 (0.98)
VTT	0.04 (2.68)
WQ-SA	0.48 (0.18)
Digit Span	1.21 (0.07)
Corsi	20.01 (2.82)

SBSOD: Santa Barbara Sense Of Direction scale; VTT: composite score of the Virtual Tubingen tasks; WQ-SA: the spatial anxiety subscale of the Wayfinding Questionnaire; Digit span: Digit Span scores; Corsi: Corsi scores.

Hypotheses

Given our hypotheses, it was predicted that higher WQ-SA scores are associated with lower SBSOD or VTT scores. Secondly, it was predicted that Digit Span scores can moderate the relationship between WQ-SA and SBSOD or VTT. Following the Baron and Kenny (1986) approach, a hierarchical regression analysis which consisted of three sets of regressions was performed twice: WQ-SA was used as independent variable, Digit Span as the moderating variable, WQ-SA x Digit Span was the interaction term. SBSOD represented the dependent variable in the first regression analysis while VTT represented the dependent variable in the second regression analysis. In predicting SBSOD scores, only a significant main effect for WQ-SA was obtained ($\beta = -.407$, $p < .05$, $R = .407$), which signifies that participants who had higher WQ-SA scores yielded lower SBSOD scores. This result was in accordance with our expectations. In contrast to our expectations, no significant interaction effect was found, which signifies that Digit Span scores did not significantly moderate the relationship between WQ-SA and SBSOD scores. In predicting VTT scores, only a significant main effect for WQ-SA scores was obtained ($\beta = -.271$, $p < .05$, $R = .271$), which signifies that individuals who had higher WQ-SA scores yielded lower VTT scores. This result was in accordance with our expectations. However, no significant interaction effect was found, which means that Digit Span scores did not significantly moderate the relationship between WQ-SA and VTT scores.

It was also hypothesized that higher Corsi scores were associated with higher VTT and SBSOD scores. To test this hypothesis a multivariate regression analysis was run. Results of this analysis indicated that there was no significant relationship between the Corsi scores and SBSOD scores nor VTT scores (Table 2).

Table 2

Summary of Multiple Regression Analysis for Corsi scores

Dependent Variable	B	Std. Error	t	*p*
SBSOD	0.02	0.04	0.59	0.56
VTT	0.09	0.11	0.87	0.39

$R^2 = .005$

SBSOD: Santa Barbara Sense Of Direction scale; VTT: composite score of the Virtual Tubingen tasks.

Discussion

This study meant to contribute to the understanding of individual differences that exists in navigational ability. The first goal of this study was to investigate the role of individual differences in verbal working memory in the relationship between spatial anxiety and navigational ability. This goal was based on a part of the processing efficiency theory which states that individuals who rely more on verbal working memory solving strategies are more vulnerable to the detrimental effects caused by anxiety, because working memory strategies and anxiety compete for the same limited amount of cognitive resources (Beilock & DeCaro, 2007; Eysenck et al., 2007; Ramirez et al., 2012). The second goal was to investigate the relationship between navigational ability and visuospatial memory. This was based on the notion that visuospatial working memory is crucial for efficient navigation, because it can form a spatial configuration from the sequence of viewpoints that an individual encounters during a walk, which can be used for navigation (Baumann et al., 2011; Conte et al., 1995; Garden et al., 2002; Pazzaglia & Sanavio,1995). By identifying the cognitive processes and the emotion-cognition interactions that underlie navigation behavior, we hope to contribute to the understanding of the unexplained individual differences in navigational ability found in literature (Farr et al., 2014; Hund & Minarik, 2006; Ramirez et al., 2012; Walkowiak, Foulsham, & Eardley, 2015). This in turn can facilitate interventions designed to target navigation impairments and/or spatial anxiety.

Based on the first goal we expected that spatial anxiety and navigational ability were related and that the relationship between spatial anxiety and navigational ability was moderated by individual differences in verbal working memory. More specifically, we expected that participants who scored higher on a verbal working memory task were more susceptible to navigation performance decrements under the influence of higher spatial anxiety than participants who scored lower on a verbal working memory task. Based on the second goal we expected that visuospatial working memory was significantly related to navigational ability. To be more specific, we expected that participants who scored higher on the visuospatial task performed better on the navigation tasks. However, our results did not meet two of our expectations: verbal working memory did not significantly moderate the relationship between spatial anxiety and navigation performance, visuospatial working memory was not significantly related to navigation ability. But our results did show that spatial anxiety was significantly related to navigation performance.

The results in this study indicated that spatial anxiety and navigational ability were significantly related. More specifically, more spatial anxiety subjectively rated by the participant lead to worse navigation performance, which is in accordance with earlier research (e.g. Farr et al., 2014; Hund & Minarik, 2006; Ramirez et al., 2012; Walkowiak et al., 2015). However, we found no evidence to confirm the hypothesis that the relationship between spatial anxiety and navigational ability was moderated by individual differences in verbal working memory. This is inconsistent with research showing that individuals with high working memory scores switch to less effective problem solving strategies under the burden of anxiety, leading to anxiety-related performance decrements (Ashcraft & Krause, 2007; Beilock & DeCaro, 2007; Eysenck et al., 2007; Ramirez et al., 2012). One explanation for this result can be found in the processing efficiency theory described in Eysenck et al. (2007). In this theory, a part describes that heightened anxiety creates worry that can increase the motivation to put in extra effort which in turn can lead to compensation for performance impairments caused by spatial anxiety. This could mean that the participants who scored high on verbal working memory did switch to less effective problem solving strategies during navigation tasks, but this did not lead to lower navigation performance because they put in extra effort by using compensatory strategies that lead to less performance decrements. Another explanation is provided by Vytal, Cornwell, Arkin, and Grillon (2012), who demonstrated that anxiety (induced by shocks) impaired verbal working memory task performance under low load, but not under high load. In line with the processing efficiency theory, their findings suggest that anxiety-related performance decrements are driven by competition for executive resources under low cognitive load in healthy individuals. However, they also found that high task demands are least vulnerable for anxiety-related performance disruptions, while the processing efficiency theory states the opposite. According to Vytal et al. (2012) this can be explained by the existence of an inflection point between moderate and high cognitive load where cognitive resources shift from divided attention between anxiety and the task under low-moderate load to a full focus on the task under high load. The full focus requires all resources which eliminates the workspace of anxiety to operate in. So, when attentional demands are high, task performance takes precedence over anxiety-related cognitive processing. This “distraction” from anxiety has also been used in therapeutic techniques, such as Eye Movement Desensitization and Reprocessing (EMDR) and has proven its efficacy in reducing anxiety in patients with anxiety disorders (e.g. Coubard, 2016). For our results, this could mean that our navigation tasks loaded heavily on verbal working memory which depleted resources that anxiety could act upon. This could have led to a non-significant relationship between spatial anxiety and navigation performance among individuals who relied more on verbal problem solving strategies. This could serve as an explanation for why we did not find a significant moderating role for verbal working memory scores on the relationship between spatial anxiety and navigation performance.

We also found a non-significant relationship between scores on a visuospatial task and navigation performance, even though there is evidence that good navigators depend strongly on a spatial short-term memory process during active navigation (e.g. Baumann et al., 2011; Conte et al., 1995; Hegarty, 2006; Nori, Grandicelli, & Giusberti, 2009). One possible explanation for the absence of a significant relationship between our spatial working memory measure and navigation performance measures is that our used measures of navigation ability require little or no configurational knowledge or inference from the memory of the learned route (Hegarty, 2006). This could mean that there was a low load on spatial working memory in the navigation tasks which lead to the found non-significant contribution of spatial working memory function to navigation performance. Based on this notion, one could speculate that spatial working memory function is not crucial for efficient navigation, or that our used navigation measures are not representative for real-world navigation. However, the former possibility seems more plausible given that our navigation tasks have proven to be a valid alternative to navigation tests that rely on real-world route exposure (Claessen, Visser-Meily, de Rooij, Postma, & van der Ham, 2015). But this would contradict evidence that shows that the inference of information from spatial memories is essential to many large-scale tasks (Hegarty et al., 2006). Taking this evidence into account, there is also the possibility that our measure of visuospatial working memory is not a good representation for the inference of information from spatial memories that occurs in real-world navigation. This problem relates to the question whether standard neuropsychological tests, such as our measure for visuospatial working memory, are effective in predicting real-world ability. Several studies have shown that this does not seem to be the case (e.g. Nadolne & Stringer, 2001; Van der Ham et al., 2013). According to their findings, our used measure for visuospatial ability is not suitable for the prediction of navigation ability. One reason why standard neuropsychological tests are not effective in predicting everyday performance is the difference in the amount of space they involve. Standard neuropsychological tasks are small-scale tasks that include object space, while large-scale tasks include environmental space. Previous studies have shown that the processing of spatial information is different for both of these scales and that they involve different brain structures and mechanisms (Kosslyn & Thompson, 2003; Morris & Parslow, 2004). If the processing of spatial information at different scales involves processes that are not related, then performance on the small-scale tasks are not likely to influence large-scale task performance. This supports the idea that small-scale spatial tasks are not/weakly predictive of large-scale navigation performance, which is in line with previous literature (e.g. Allen et al., 1996, Bryant, 1982, Juan-Espinosa et al., 2000, Kirasic, 2000). Other reasons why standard neuropsychological tests are not effective in predicting real-world ability can be found in the article written by Farley, Higginson, Sherman, and MacDougall (2011).

A number of limitations were involved in this study. As explained above, the use of small-scale tasks is a limitation involved in our study because it is not or only weakly predictive of large scale task performance. Future studies should assess spatial and verbal working memory in large-scale tasks that are strongly predictive of real-world navigation. A second limitation in our study concerns the internal and external validity of the obtained results. External validity of our study is questioned because our results do not seem to be generalizable beyond the selected sample. This remark is based on the fact that this study population mostly consists of Leiden University students. Because most of the participants were undergraduate Leiden University students, it could be stated that due to such a select study sample the results cannot generalize to groups other than undergraduate students that are scientifically schooled. This means that the sample we have used does not provide good estimates of the general population characteristics and therefore is not representative (Kukull & Ganguli, 2012). Next to external validity, also internal validity in our study is questioned due to the lack of variability and normality of certain measures. For example verbal working memory scores showed little variability (SD = .07) and non-normality. Also, the distribution of self-reported navigation ability indicated a flat distribution, which deviates from a normal distribution. Because of these statistical shortcomings, variability in verbal working memory levels cannot be used to explain differences in navigation measures and therefore not provide reliable results to answer our first research question. In future studies, this can be prevented by using a more representative sample for the general population, which could increase the chances in providing more spread and normality in verbal working memory and navigation ability measures. Third, it is important to highlight the use of a virtual environment. It serves as a limitation to our study due to the limited input it provides. Navigational ability includes, among other factors, the use of locomotion: successfully moving towards the intended direction without injuring ourselves. This requires a coordinated response to our immediate surroundings accessible through our sensory and motor systems (Bohil, Alicea, & Biocca, 2011; Montello & Sas, 2006). During our virtual navigation task, subjects do not receive direct proprioceptive or vestibular feedback to act upon, which is why subjects do not experience physical locomotion (Bohil et al., 2011; Ruddle, Payne, & Jones, 1997). The senses of the vestibular system which is present in real life contribute to spatial updating and learning of spatial layout (e.g. Chance, Gaunet, Beall, & Loomis, 1998; Klatzky, Loomis, Beall, Chance, & Golledge, 1998). The absence of these senses in the virtual environment can lead to difficulties in staying oriented by impeding the process of inferring spatial information that is obtained during the encoding process (Bohil et al., 2011; McNamara & Shelton, 2003; Montello, Waller, Hegarty, & Richardson, 2004). This makes the participants rely on more effortful updating. Another drawback associated with the use of a virtual environment is that the field of view in the virtual environment lacks peripheral vision. This leads to the faster removal of a visual feature from the visual field than in real life. Also, the subjects are not able to rotate their heads to notice what they are walking past, which places more demand on the working memory system to maintain an internal representation of the environmental information (Sholl, 1996). Finally, there is also the disadvantage concerning the lack of psychological sensation of being in the virtual environment. Instead, the participant senses being in a physical environment interacting with a computer screen. This can also influence task performance, because it leads to the (feeling of) uncoupling of head and body movements in real life with the body and head movements in the virtual environment (Bohil et al., 2011; Lombard & Ditton, 1997). In relation to the drawbacks involved in the use of a virtual environment, several interesting options are worth considering for future research. The first one includes the use of hybrid virtual environments. In these hybrid environments movement of the body and the sensory flow of the virtual environment are coupled. This creates a visual experience that corresponds to real world head and body movements. Also, a sense of presence in the virtual environment is created by the multimodal stimulus inputs that trick the user's sensorimotor system into the illusion of being present in the virtual environment (Biocca & Levy, 2013; Bohil et al., 2011). The incorporation of these virtual and/or physical interface elements overcome limitations of virtual or real life navigation alone and still provide a high degree of ecological validity and control (e.g. Bohil et al., 2011; Wang & Lindeman, 2015). Fourth, a limitation of this study is that we did not assess other types of anxiety than spatial anxiety. A possibility exists that the found significant relationship between spatial anxiety and navigational ability is not only related to the spatial domain, but involves anxiety that is general in nature (Ramirez et al., 2012). Hypothetically, the relationship between spatial anxiety and general anxiety can be described in three possible ways. The first way is that spatial anxiety is fully encapsulated by general anxiety. The second is that spatial anxiety and general anxiety both measure overlapping as well as separate traits. The third is that spatial anxiety and general anxiety do not share any overlap whatsoever in the measurement of traits. A study conducted by Mckeen (2011) showed evidence for the hypothesis that spatial anxiety and general anxiety have a partial overlap in their measurement of variables, ruling out the two other possibilities (Mckeen, 2011). Given that trait anxiety (such as general anxiety) significantly decreases cognitive function regardless of state anxiety (such as spatial anxiety), it is important for future research to assess the presence of general anxiety too in order to make sure the effects of spatial anxiety on navigation are not attributed to non-spatial specific fears.

Next to the suggestions for future research that have already been mentioned above, there are some additional suggestions worth mentioning. The first additional suggestion concerns the measurement of spatial anxiety. Spatial anxiety can be expressed through anxious arousal and/or anxious apprehension, which rely on distinct neural systems and can disrupt verbal and/or spatial working memory differentially (Vytal et al., 2013). Future studies should therefore consider adding continuous measures of heart rate variations, such as electrocardiography (ECG) (Appelhans & Luecken, 2006). Also, a more direct measure of anxious apprehension is advised, in order to make sure that worrisome thoughts are related to the observed disruptions evoked by the navigation tasks in the experimental setting (Vytal et al., 2012). The second additional suggestion for future research concerns the addition of variable levels of cognitive load of the navigation tasks. Vytal et al. (2012) has shown that anxious apprehension was reduced by high cognitive load. They proposed that verbal working memory and anxious apprehension share neural resources and that under high load all the resources are allocated to verbal working memory, leaving no resources for anxious apprehension to act upon. By adding variable cognitive loads in the navigation tasks this theory could be tested and perhaps contribute to a part of the individual differences found in the relationship between spatial anxiety and navigation performance. The third additional suggestion for future research involves the assessment of used verbal or/and spatial strategies that participants used to solve the navigation tasks. In this way it can be determined that the tasks successfully tapped verbal and spatial working memory. Also, it can elucidate the nature of emotion-cognition interaction involved, as the different types of anxiety (anxious apprehension versus anxious arousal) affect verbal and spatial working memory function differently. Fourth, future studies should consider using fMRI, because it can inform about the activity of brain regions such as spatial and verbal working memory (e.g. Baumann et al., 2010). In this way it can be checked whether the navigation tasks specifically tap spatial and/or verbal working memory successfully. Instead of only gaining information about strategy use on a behavioral level, it will also be possible to gain information about the activity of the involved brain region on a neural level. This could give more insight about the mechanisms of anxiety-related navigation task impairments. Fifth, future studies should include patients with anxiety disorders next to healthy participants in order to see if the mechanisms of anxiety-related impairments are manifested differently in anxious individuals. This could provide more insight into the nature of disruption and improve treatments for different anxiety disorders. Additionally, it could be of significance for the evaluation of navigation impairment as a potential risk factor for pathology (Vytal et al., 2013).

This study did not provide support for the hypothesis that verbal working memory moderates the relationship between spatial anxiety and navigation performance. Neither did we find support for the hypothesis that visuospatial working memory significantly related to navigation ability. However, our results did support the hypothesis that spatial anxiety significantly related to navigation performance. In order to explain the nature of this relationship, future studies should include assessment of the nature of the involved spatial anxiety by controlling for the presence of general anxiety, provide more direct measures of worrisome thoughts and include a valid measure of anxious arousal (such as ECG). In order to explain the individual differences in navigation ability, future studies should use hybrid environments with variable cognitive loads and preferentially include functional neuroimaging such as fMRI. It is important to continue investigating significant effectors of navigational ability in order to contribute to the understanding of individual differences in navigational ability and facilitate clinical interventions designed to target navigation impairments associated with (spatial) anxiety.

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