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Abstract

Spatial cognition deficits can be caused by various factors including aging, neurodegenerative disease, stroke, or TBI and have thus far received inadequate attention in the literature. This study aims to further our understanding of spatial cognition in order to progress the field and assist in the assessment and diagnostics of associated deficits in affected populations. Research has outlined the practicality of VR in assessing cognitive complaints. VR can provide ecological validity to navigation assessments and can be used alongside neuropsychological tools to further understand cognitive deficits. Therefore, the objectives of this study were to investigate the relationships of presence and subjective navigation ability with objective navigation performance in VR, and to further examine the effect of gender on navigation performance. The van der Ham et al. (2020) online task battery was used to assess spatial navigation ability by requiring participants to complete five tasks testing landmark, location and path knowledge. The experiment was conducted online on a computer or phone screen. Sense of presence in the virtual environment and subjective navigation ability were measured using the IPQ (Schubert, Friedmann, and Regenbrecht, 2001) and the WQ (Claessen et al., 2016). A test-retest design was employed to investigate the gender differences in performance over time. The results of this study indicate that presence is not a significant predictor of navigation performance in the VR task. However, subjective navigation ability did predict objective navigation performance. Additionally, gender differences were found in performance over time, with males consistently performing better than females. These findings suggest a need to further investigate the different navigation mechanisms used by males and females, and the effect that stereotypical beliefs have on performance. In conclusion, this study determined that assessment of navigation abilities is not affected by experienced presence, and thus can be made accessible in an online format. The findings for gender differences and the relationship between subjective navigation ability and objective navigation performance also have the potential to contribute evidence-based improvements in assessments, diagnostics and rehabilitation interventions. Further research is required to investigate the effect of different levels of immersion on sense of presence and performance as this could affect VR assessment of navigation.

Keywords: spatial cognition, navigation, virtual reality, presence

Layman's Abstract

This study was conducted to examine spatial navigation performance in healthy individuals. While deficits of the spatial cognition nature tend to be most prevalent in aging populations and in those who have a stroke, TBI or neurodegenerative diseases, this study examined a young, healthy population as there is insufficient information on optimal spatial navigation performance. 77 participants were recruited with ages ranging from 18-35. By examining this cohort, we obtained valuable data which can be used as a norm score comparison to help improve diagnostics, assessments, and interventions for those experiencing navigation deficits.

An online virtual environment (van der Ham et al., 2020) was used to assess spatial navigation. It required participants to watch a video which gave the impression that they themselves were navigating an alien planet. After the video, five tasks were completed to test participants landmark, location and path route knowledge. Additionally, the participants sense of presence in the virtual environment and subjective assessment of navigation ability were assessed in order to examine the impact these variables may have on objective navigation performance. Finally, gender differences in performance were examined to provide further evidence for previous work.

The results outlined a significant effect of self-reports of navigation ability and gender on objective navigation performance, with males consistently performing better than females. This finding highlights the need to further examine the effect of stereotypical male/female navigation abilities, and to investigate testing mechanisms to avoid gender bias. Sense of presence in the virtual environment was expected to play a significant role in performance. However, our findings show that this was not the case in the online virtual task used. This finding is important as it indicates that simple online tasks can be used to assess navigation in affected populations from a computer or phone screen at home. This will save time and money as it does not require the clinician to conduct immersive virtual reality testing in their office or lab.

Overall, this study succeeded in combining navigation mechanisms with neuropsychological correlates and also provides evidence of norm scores for navigation performance. This will be beneficial in improving future diagnostics, assessments and interventions for affected populations. Additionally, our findings highlight the need to further examine the gender discrepancy in performance and investigate navigation assessments which may be more suited to female navigation processes.

Spatial Navigation in Virtual Environments: the Role of Presence and Subjective Ability in Navigation Performance

Navigating the world around us is something humans do all day every day. When we get off the train in a new city we consciously navigate ourselves towards where we need to go depending on our current needs, be it hunger, a business meeting, or a sports event. But we also navigate in unconscious ways, like finding our way to the bathroom in the dark when we are still half asleep, or driving to work in the morning on autopilot because the route is so familiar. Navigation ability and spatial cognition are important aspects of daily life and skills required for normal everyday functioning. The ability to actively explore the world around us is often taken for granted and before the current technological era where one has constant access to satellite navigation in their pocket, navigation skills were an essential part of human evolution and survival (Ekstrom et al., 2018).

Spatial navigation is a cognitive function which uses memory and executive function processes to plan, initiate, and remember where to go and how to get there (Brodbeck & Tanninen, 2012; Brown and Chrastil, 2019). It shows large individual differences and has been found to change across the lifespan, declining in older adulthood, especially with pathological aging (Gazova et al., 2013; Klencklen, Després, & Dufour, 2012; Lester et al., 2017; Moffat, 2009). This cognitive function is a common complaint and impairment found in traumatic brain injury (TBI) and stroke survivors in particular, who often report difficulties in spatial navigation after their injuries (van der Ham et al., 2013). However, as of yet, there is insufficient research in this domain for those who suffer from spatial navigation deficits.

Much research has investigated the neurological aspects of navigation including the neurocognitive architecture of navigation ability (Maguire, 2001) and the neurological processes used in navigation such as path route and survey knowledge (Mellet et al., 2000), and allocentric/egocentric processing (Burgess, 2006; Klatzky, 1998). These spatial coding systems define navigating and locating mechanisms depending on the point of reference. Allocentric navigation is an object-to-object reference system where one encodes location information of an object or landmark with respect to another object or landmark. Egocentric navigation is a representation of objects in space with reference to oneself, thus a self-to-object reference system (Burgess, 2006; Martinez-Martin et al., 2014). Determining the navigation strategies used by individuals affected by deficits related to acquired brain injury or neurodegenerative disorders can be helpful in assessing the extent of their impairments and for guiding appropriate treatment plans (Caglio et al., 2012; Claessen et al., 2016; Lithfous, Dufour, & Després, 2013). Yet the neuropsychological correlates of these navigation mechanisms have been neglected. In order to improve assessment, diagnostics, intervention strategies and rehabilitation for those experiencing spatial cognition deficits it is necessary to further explore navigation mechanisms in both healthy and clinical populations. By including healthy populations in this research area we can form norm based data and also explore the efficacy of new findings before treating vulnerable populations.

Recently many researchers have used VR paradigms to stimulate experiences in the real world while testing the domains of spatial cognition and navigation (Diersch, & Wolbers, 2019; Ijaz et al., 2019). To measure navigation performance, van der Ham et al. (2013) designed an online navigation task battery for clinical and experimental use in spatial navigation ability research. This online navigation task has successfully been used as on objective measure of spatial navigation alongside self-reported subjective measures from the Wayfinding Questionnaire (WQ; Claessen et al., 2016; Rooij et al., 2019; van der Ham et al., 2020). Additionally, van der Ham et al. (2020) used this task battery to demonstrate the effect of age and gender on self-reported spatial navigation and performance across all age groups. In this study it was found that males had higher self-reports and performed better in the navigation tasks than females. This is in keeping with findings by Sanchis-Segura and colleagues (2018) that females are often stereotyped to have poorer spatial abilities than males. Further research in this area is necessary to explore the findings for gender differences in navigation.

The van der Ham et al. (2013) navigation task battery can be useful to objectively assess spatial navigation via an accessible VR platform and it can be used in conjunction with other neuropsychological measures. It has also been shown that it is effective on both computer and mobile phone screens (van der Ham et al., 2020). Therefore, the present study aims to assess the spatial navigation abilities of a health population via this virtual reality platform in order to compare objective navigation ability with neuropsychological assessment tools, and to further investigate the effect of gender on navigation task performance. The findings should provide information which can contribute towards assessment tools for navigation deficits and the formulation of norm based data. Thus, it will be useful in clinical environments for comparing patient population scores.

Virtual Reality

VR has become one of the most rapidly developing technologies since the turn of the 21st century. The term 'virtual reality' can be used to describe a range of non-immersive (2-D presentations, interacting with computer etc.) and immersive applications in which one feels integrated in the display through devices such as head mounted displays (HMDs) or body tracking sensors (Krohn et al., 2020). According to Krohn et al. (2020) a steep upward trend of 'virtual reality' and 'virtual reality + cognition' search results in the Pubmed database can be seen from 1995-2018. They also found that the proportion of 'virtual reality + cognition' hits in Pubmed accounts for 20% of all virtual reality hits. This is indicative of the value of VR in cognitive research in recent years and the importance of further investigation into the possibilities of VR in neuropsychological assessment, intervention, and rehabilitation.

VR can provide ecological validity to standard neuropsychological tests that are often effected by the environment in which they are tested. Parsons (2015) noted VR as a solution to the scientific debate about the importance of ecological validity vs. experimental control. As VR systems advance, so too does the real life experience felt by the user, their ability to interact with dynamic stimuli in the environment, and the opportunity for the experimenter to control and manipulate this environment. Kourtesis and colleagues (2021) concluded that VR scenarios can provide real time measurements of data from participants everyday functioning, in a controlled and safe environment, which is also beneficial for ecological validity. Additionally, the benefits of using immersive VR for spatial navigation memory in particular in dementia screening was outlined by Ijaz and colleagues (2019).

Feasibility of VR, especially in 3-D, is often a limiting factor in its implementation. Technical, training and user feasibility, performance quantification and immersive capacities are but a number of potential limiting factors outlined by Krohn et al. (2020) in the evaluation of VR paradigms. More recently, worldwide restrictions on movement due to the COVID-19 pandemic have highlighted the importance of accessibility and the use of online virtual environments vs. 3-D VR which can be difficult to use in some instances as it requires patients to come into the clinicians office or lab. In order to address accessibility limitations, we must investigate the efficacy of online virtual environments in a number of different domains. One such domain worth investigating may be the level of presence experienced by a user in an online virtual environment versus an embodied 3D VR environment when assessing spatial cognition.

Presence

Immersion has been investigated in many VR studies and recently Parong et al. (2020) and Kuhrt et al. (2020) found evidence to suggest that technologies with higher immersion led to better spatial learning and a higher sense of presence in the online world. This sense of presence in turn was associated with better spatial learning and mediated the relationship of immersion with survey knowledge. Presence has been succumbed to many different definitions and operationalizations by researchers over the past number of decades. In recent years there has been a consensus that it describes a sense of 'being there' in a virtual environment. Witmer and Singer (1998) explained this as "the subjective experience of being in one place or environment, even when one is physically situated in another". The importance of presence in VR and online environments has been stressed across academic literature, where its relevance in an individual's experience and performance in a range of areas such as medicine, training, education, and entertainment has been explored (Hartmann et al., 2015; Hein et al., 2018; Riva et al., 2003; Usoh et al., 2000). Navigation impairments are often qualitatively assessed by asking patients about the frequency with which they get lost. This method is flawed and could be improved by assessing actual navigation performance. Therefore, this study aims to address this gap in the literature and investigate the effect of presence in VR on spatial navigation performance.

To measure presence in research several different subjective questionnaires have been proposed. One of the most used questionnaires is the Igroup Presence Questionnaire (IPQ; Schubert, Friedmann, and Regenbrecht, 2001). The IPQ is designed to quantify one's sense of presence in a virtual environment along three subscales: involvement, realness, spatial presence, as well as a general question on the user's sense of 'being there'. Its reliability has been proven and it has been used successfully in many recent studies to quantify users experience of presence in VR (Hruby et al., 2020; Schubert, 2003; Schwind et al., 2019).

Present Study

The purpose of this study is to investigate spatial navigation performance in healthy participants by assessing the effect of presence and subjective navigation ability on navigation performance in an online virtual task and investigate whether gender can also affect navigation performance over time. As previously outlined, much research has been carried out on the various factors that can influence spatial navigation in both healthy and clinical populations (Diersch, & Wolbers, 2019; Ijaz et al., 2019; Parong et al., 2020). However, there are still gaps evident in the literature in merging neuropsychological tools with objective navigation assessment procedures. This study will address these gaps in our current understanding of the topic by investigating the relationships between presence or 'being there' in VR, subjective navigation ability measured via the WQ, and objective navigation performance in VR. It will make use of the van der Ham et al. (2013) online navigation task in a test-retest design and investigate gender differences in performance which will expand on previous work.

The first hypothesis for this study is that higher reports of presence in the virtual world will predict better objective navigation performance in the task. From the literature investigating presence as a variable in virtual environments, it is evident that those who report a higher sense of presence in the environment perform better in tests of navigation ability (Parong et al., 2020; Schubert et al., 2001). This may be due to several factors which are covered in the IPQ: the sense of being physically present in the environment; the amount of attention one devotes to the virtual environment and feels involved; and the subjective experience of realism such that one is in a 'real-life' environment. Therefore, I will use the IPQ as a measure of presence to investigate its effect on objective navigation performance. The WQ will be used alongside the navigation task, as per previous work by De Rooij et al. (2019). This will provide a measure of subjective navigation ability and provide evidence for our second hypothesis: higher reports of subjective navigation ability will predict better objective navigation performance.

From previous findings it is also hypothesised that participants who experience more presence in the online environment will have higher self-reports of subjective navigation ability. Therefore, we hypothesise that subjective navigation ability will be a moderator in the relationship between presence and objective performance. The final hypothesis of this study is that effect of gender differences in navigation performance will be consisted over time. From the study by van der Ham et al., (2020) which found that age and gender effect quality of self-reports in a between group design, this study will expand on this information to investigate the reliability of this finding within-subjects over time in a test-retest design.

Methods

Design

A within subject's test-retest design was employed for this study. Participants visited similar versions of a virtual environment twice, with a parallel version that was slightly different to avoid recognition interference. The experimental design was longitudinal and consisted of two measurements taken 2-4 weeks apart. Participants were randomly assigned into either of the two versions of the virtual environment (original vs parallel) in the first measurement and were assigned to the alternative virtual environment for the second measurement.

Participants

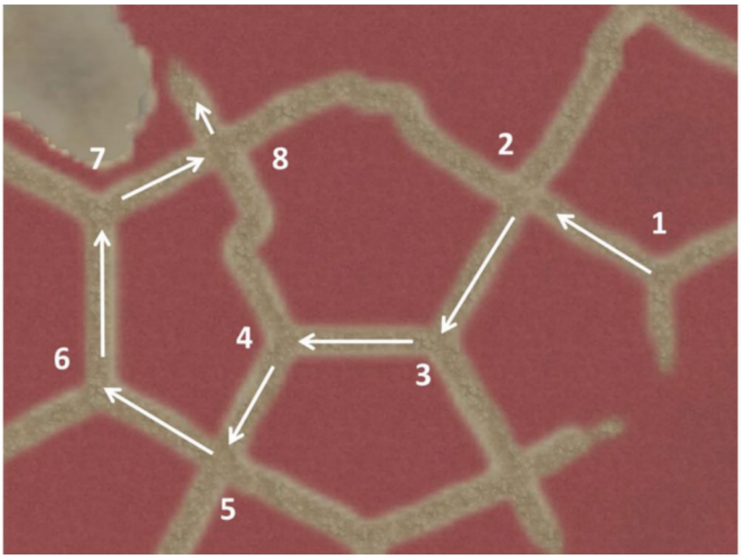
Participants were both male and female, recruited through convenience sampling by the researchers and via online university platforms. The requirements were that they be between the ages 18-35, have good command of the English language and not be suffering from any major mental or physical illness or disability. In the experiment information letter and informed consent form participants were explicitly asked to exclude themselves from participation if they suffer from any psychiatric or neurological condition or have any major physical impairments. 77 participants were included in part one of the experiment, consisting of 33 who identified as male and 44 who identified as female, with ages ranging from 19 to 31 years old ($M = 23.47$, SD = 2.16). Participants were randomly assigned to version 1 ($n = 39$) or version 2 ($n = 38$) of the online virtual world. 60 participants additionally took part in part 2 of the experiment 2-4 weeks later, in which they completed the alternative version of the experiment (version 1: $n = 30$; version 2: $n = 30$). The study was approved by the local ethical committee at Leiden University, and each participant provided informed consent prior to the experiment in accordance with the declaration of Helsinki (2013).

Measures

This experiment made use of the navigation task battery described by van der Ham et al. (2020). This online 3D navigation experiment was set up on Qualtrics software (Qualtrics XM, 2021), along with demographic questions concerning age and gender before the task, and the WQ and IPQ after the task. The navigation experiment consisted of a short video exploring an unknown environment containing eight distinguishable landmarks (oil drums, a shield, a crate, a boat, a car, a shipping container, a gemstone, and a buoy). The video explained that the participant had landed on an unknown planet and must find their way back to their spaceship to return home. They were instructed to remember as many elements of the route they take as possible. An overview of the route layout is shown in Fig. 1.

Figure 1

The layout of the route, where each number represents an object at an intersection.



Following the short video, the participant completed five different tasks to measure cognitive navigation abilities: landmark knowledge, egocentric location, allocentric location, path-route, and path-survey knowledge. As the landmark task contained four items present in the video and four items as distractors, it was always shown first. The other four tasks were assigned at random. For the egocentric location task, participants were shown a landmark and asked which of the six provided arrows indicate the direction of the spaceship at the end of the route. This was measured over four trials. The allocentric location task was measured by showing participants a birds-eye-view map of the environment, like that shown in Fig.1, and a specific landmark. They were required to decide at which location A, B, C, or D, the landmark was on the map. This task was measured over four trials. The path-route task required the participant to decide in which direction the path continued after a specific landmark with two or three possible options provided depending on the landmark. This task was measured over four trials. Finally, the path-survey task consisted of 3 landmarks being presented at once, of which the participant decided which two landmarks were closest together. They were requested to measure this distance from a bird's eye perspective of the map, thus assessing their mental representation of the environment. This task was also measured over four trials.

The first independent variable of interest was experienced presence in the virtual environment, measured using the IPQ (Schubert, Friedmann, and Regenbrecht, 2001). The IPQ is a 13 item Likert scale questionnaire which contains 1 item assessing the general sense of "being there" along with subscales measuring spatial presence (5items), involvement (4 items), and sense of realness in a virtual environment (3 items). For this study, the general sense of "being there" item was used in our analysis to quantify presence. The second independent variable was subjective ratings of navigation ability which was measured by the WQ (Claessen et al., 2016; de Rooij et al., 2017; van der Ham et al., 2013).

The WQ consists of 22 items measuring spatial navigation in the domains of Navigation and Orientation (11 items), Distance Estimation (3 item), and Spatial Anxiety (8 items). Scores are reported on a Likert scale ranging from 1 to 7. The scores for each subscale can be totaled individually with lower scores indicating more complaints in navigation ability and higher scores indicating better perceived navigation ability. For this study we used the total score from the Navigation and Orientation subscale as it most accurately reflects subjective opinions on one's own spatial abilities. The dependent variable was objective navigation performance which was measured via performance in the online navigation task (van der Ham et al., 2013). As each task had various levels of difficulty, scores for each subtask were standardized and summed together to calculate the total performance score.

Figure 2

An example of objects seen in the virtual environment

A B C

Note. A = oil drums, B = the shield, C = the crate.

Procedure

The experiment was carried out online via Qualtrics (Qualtrics XM, 2021) on a computer or phone screen that was convenient to the participant. Previous research with the navigation task confirmed that the use of either a computer or phone screen does not affect participants performance in the task (van der Ham et al., 2020). The layout remained largely identical for both devises aside from vertical instead of horizontal Likert scale options to fit the narrower phone screen layout. Participants were provided with information on the purpose of and aims of the study as well as information about compensation, confidentiality, the right to withdraw etc. There was information regarding the storage of email addresses separately to experimental data as providing a personal email address is essential to contact the participant in order to complete the second measurement of the experiment at a later date. They were then asked to give consent for the use and storage of their data by clicking a button stating they accept the conditions outlined.

The first measure began with participants being asked demographic questions on their age and gender, as well as a question about their spatial abilities: how good do you think your spatial abilities are in comparison to your peers? Responses for this question were inputted via a slider with ‘very bad’ on the left and ‘very good’ on the right. Specific scoring was not visible to the participant but for analysis reasons the slider was calculated between 0 – 100. Participants were randomly assigned into either the original or parallel version of the navigation task for the first measurement, and were assigned to the remaining one for the second measurement. There was a pseudorandom distribution of males and females across the two versions of the experiment. Before the virtual world video began, participants were instructed to pay attention and remember as much information about the environment as possible. When the video finished, the five associated tasks became available. The landmark knowledge task always appeared first as it contained recognition information, and the remaining four task were provided at random.

After the spatial navigation task, participants were asked how good they thought they did in the task and then were requested to fill out the IPQ and the WQ. Finally, an additional question was asked which addressed stereotypical beliefs: in your opinion, who has better spatial abilities? Again, this response modality included a slider from 0-100, with ‘female’ on the left and ‘male’ on the right. Some elements will not be discussed further as they were used for other research.

Two weeks after the completion of the first measure, participants were contacted via email to complete the second part of the experiment as soon as possible but no later than two weeks after receipt of the email (2-to-4 week time interval). They were provided with a link to access the experiment. For the second measure participants were first asked how good they think their spatial abilities are in comparison to their peers. Following this, a similar parallel version of the virtual task they completed previously was shown and they were requested to follow the instructions to complete the same five associated tasks. The IPQ and the WQ were completed again after the navigation task.

After completion of the second measure of the experiment, participants were thanked for their participation, debriefed on the experiment, and offered the opportunity to ask questions or add comments for the research team.

Analysis

Descriptive statistics were first carried out to investigate frequency and normality of the data collected. To determine the effect of presence and subjective navigation ability on objective navigation performance a multiple regression analysis was be used, with objective navigation performance as the dependent variable, and experienced presence and subjective ratings of navigation ability as the independent variables.

Moderation analysis was to be carried out to investigate the moderating effect subjective ratings of performance have on the relationship between presence and objective navigation performance. Moderation was tested with presence as the independent variable, objective navigation performance in the navigation task as dependent variable, and subjective navigation ratings from the WQ as the moderating variable.

Finally, to investigate the differing effects of gender on objective navigation performance a repeated measures ANCOVA was carried out with time as the within-subjects factor, gender as the between-subjects factor, and experienced presence as the covariate. Analysis and findings will be discussed further in the results section.

Results

Descriptive statistics were carried out on each navigation subtask, sense of presence and subjective navigation ability for experiment part 1 and 2 to determine the mean and standard deviation distributions, as can be seen in Table 1.

Table 1

Descriptive stats

	Exp. 1		**Exp. 2**	
	Mean	SD	Mean	SD
Landmark recognition	7.12	1.10	7.40	.84
Egocentric	1.35	.94	1.24	.96
Allocentric	1.94	1.09	2.24	1.14
Path Route	3.00	.73	2.66	1.02
Path Survey	1.97	1.08	2.05	.96
Sense of Presence	2.82	1.75	2.78	1.49
Subjective Navigation Ability	48.45	13.95	43.47	12.86

A two-step hierarchical linear regression was conducted to determine if experienced presence and subjective navigation ability contributed to performance in the navigation task. The dependent variable was overall performance in the navigation task measured during the first experiment. For step 1 in the regression, presence was entered as a predictor variable into the null model. Subjective navigation ability was added as a predictor variable in step 2. All assumptions of multiple regression were met by the data. The hierarchical regression analysis found that presence did not significantly predict performance in the first step, $F(1, 76) = .43$, $p = .513$, $\Delta R^2 = -.01$. This model thus indicates that adding presence did not account for a significant amount of additional variation in performance on the navigation task. For step 2, subjective navigation ability did significantly predict performance, $F(2, 76) = 10.09$, $p < .001$, $\Delta R^2 = .193$. This model indicates that adding subjecting navigation ability explained an additional 19.3% of the variation in overall navigation performance. The results for each regression are shown in Table 2.

Table 2

Regression Coefficients

	B	Std. Error	β
Model 1			
Constant	-.38	.59	
Presence	.12	.18	.08
Model 2			
Constant	-4.73	1.11	
Presence	.14	.16	.09
Subj. Nav. Ability	.09	.02	.46***

Note. * = sig. at the .05 level; ** = sig. at the .01 level; *** = sig. at the .001 level

In order for moderation to be supported, two conditions must be met. First, the causal predictor variable, presence, must significantly predict navigation task performance. Secondly, the interaction model of presence*subjective ability, must explain significantly more variance of performance than the non-interaction model. As presence did not significantly predict performance, B = .12, t(76) = 0.66, p = .513, the first condition was not met. Therefore, moderation was not supported.

Table 3

Repeated Measures ANCOVA Results

Source	*df*	*MS*	*F*	*p*	η_p^2
Between-Subjects					
Presence	1	24.69	2.90	.094	.05
Gender	1	48.14	5.66	.021*	.09
Residuals	55	8.51			
Within-Subjects					
Obj. Performance	1	.03	.00	.948	.00
Presence*Obj. Performance	1	.15	.02	.878	.00
Gender*Obj. Performance	1	.20	.03	.859	.01
Residuals	55	6.18			

Note. * = sig. at the .05 level; ** = sig. at the .01 level; *** = sig. at the .001 level

A repeated measures ANCOVA with one within subjects factor (time) was conducted to determine the effect of gender on objective navigation performance at time 1 and time 2, with presence as a covariate. All assumptions for a repeated measures ANCOVA were satisfied. The covariate, presence, was not significantly related to navigation task performance at time 1 and time 2, $F(1, 55) = 2.90$, $p = .09$. However, the between-subjects factor, gender, was significantly related to performance at time 1 and time 2, $F(1, 55) = 5.66$, $p < .05$, with the standardized score for males ($M = .185$, $SD = .098$) being higher overall than that for females ($M = -.114$, $SD = .068$). The main effect for performance was not significant, $F(1, 55) = .004$, $p = .95$, indicating the scores at time 1 and time 2 were all similar for navigation task performance in version 1 and version 2. Finally, a Pearson correlation coefficient was computed to assess the test-retest reliability of performance at time 1 and time 2 which found a weak positive correlation, $r(55) = .275$, $p < .05$. Table 3 presents the ANCOVA results.

Discussion

Spatial cognition deficits obtained from pathological aging, stroke, TBI, or neurodegenerative disease have thus far received inadequate attention in the literature. This study aimed to further our understanding of healthy human spatial navigation abilities in order to progress the field and assist in the assessment and diagnostics of spatial cognition deficits in affected populations. The van der Ham et al. (2020) online task battery was used to assess spatial navigation ability by requiring participants to complete five tasks testing landmark, location and path knowledge. Additionally, gender differences in navigation performance were examined by way of a test-retest design. The results of this study provide evidence that subjective navigation ability is a significant predictor of objective navigation performance. However, this study has not found evidence to show that presence is a significant predictor of navigation performance in a virtual reality environment. Additionally, moderation analysis was not supported as presence was not a significant variable in the model. Therefore, the hypothesised moderation analysis could not be carried out. Nonetheless, with the test-retest design, this study has demonstrated that gender has an effect on navigation performance over time, in keeping with findings from the study by van der ham et al. (2020), with males consistently performing better than females.

While we expected to see some contribution of presence on navigation performance, the results achieved indicate that there is no predictive relationship present between the variables in this sample. As can be seen from the results for our first hypothesis we failed to reject the null hypothesis. Therefore, in contrast to the literature, experienced presence in a virtual environment may not be an important factor in assessing navigation ability. Much of the research investigating presence in VR is not centred around spatial navigation or cognitive function. Instead, the focus lies mainly in education, training, and entertainment (Grassini et al., 2020; Riva et al., 2003). I did, however, expect the findings of previous work on education, training, and entertainment VR to be transferable to assessing spatial navigation due to the construction of the experiment in a game-like fashion. This was not the case, so as this study did not find significant results for presence, we can conclude that experienced presence in a 2-D VR environment does not specifically influence navigation performance. However, this unexpected finding is worth discussing and further investigating presence in relation to immersion.

According to Parong et al. (2020) immersion is an important factor in the effect of presence on spatial learning. The 2020 study also found evidence to suggest that higher immersion leads to better spatial learning. As most studies investigating the effects of presence and immersion make use of head-mounted displays and embodied experiences (Ijaz et al., 2019; Kuhrt et al., 2021), the results of the present study could be affected by the fact that the experiment had to be made available in an accessible online format due to COVID-19 restrictions. For this reason, the virtual world was only presented to participants in 2-D format and on a computer or phone screen. This experience was technically ‘non-immersive’. According to Schubert et al., (2001), the conscious sense of presence in VR was due to the representation of bodily actions in the virtual world. Had it been possible, it would have been beneficial to manipulate the level of virtual reality immersion in this study. This would require participants to come into the lab to use VR headsets which was not feasible during the pandemic. Future research could explore this hypothesis further to investigate if there is a difference in results based on presence experienced in immersive vs non-immersive VR. This may be a reason for the results achieved, but one of the aims of this study was to investigate whether accessible home assessments for navigation performance would be useful for patient populations. If presence is not a contributing variable then we can conclude that providing at-home 2-D assessment of spatial navigation is a viable option for people with complaints in this domain. Additionally, further research may indicate if presence is solely a factor in an immersive environment, as per the literature discussed.

As can be seen from the results, subjective navigation ability was a significant predictor in the regression model for objective navigation performance, therefore we can reject the second null hypothesis. This leads to the conclusion that one’s own perception of navigation ability can cause an individual to perform worse on a navigation task. A possible reason for this could be due to spatial anxiety, however this would require further research. As the literature suggests that women generally perceive their navigation abilities to be worse than men do (Sanchis-Segura et al., 2018; Vander Heyden et al., 2016), this could have an impact on objective performance and explain the gender discrepancies found. In terms of forming norm based data, the findings from this study suggest that subjective navigation ability should be taken into account when assessing performance. However, correlation does not imply causation. From the results we can see that lower subjective ability results in worse objective performance, but it may be necessary to delve further into these findings in future research to determine if this is a causal effect or potentially due to factors such as higher spatial anxiety and stereotypical expectation. Further research should also investigate whether the effect of subjective ability on navigation performance is viable in populations with spatial navigation complaints, as they may have an altered opinion on their abilities post-injury.

This study employed a test-retest design to further investigate the discrepancy in navigation performance between males and females found in the van der Ham et al. (2020) study. Our findings confirm this discrepancy. The results achieved demonstrate that males consistently perform better than females in the online navigation task. This is in keeping with the literature that suggests that there is a stereotypical belief that males have better spatial abilities than females, which may in turn affect performance (Sanchis-Segura et al., 2018; Vander Heyden et al., 2016). Evidence from this study and other research indicates a possible gender differences in information processing, as well as a female preference for landmark cues (Rosenthal et al., 2012). This consistent finding is cause for further research into why females underperform in navigation tasks and whether the standard navigation task model should be altered to support female's intrinsic navigation mechanisms. Additionally, as the correlation analysis conducted on the time 1 and time 2 performance achieved low reliability, it is necessary to further examine this online task battery and improve reliability.

Although limitations existed in this study which were already discussed such as conducting the navigation task in an online format and a lack of varying levels of immersion, there are also strengths which provide valuable insight to navigation processing in healthy populations. This study gathered subjective and objective navigation data simultaneously in the study design. This was valuable in assessing the predictive value of subjective navigation ability on objective performance, and investigating neuropsychological correlates of navigation mechanisms. While presence was not a significant predictor of objective navigation performance, this data led to the conclusion that immersion may not be a significant variable in assessing the navigation abilities of healthy populations, thus assessments can be conducted online from a computer or home screen. This will be beneficial to clinicians and patients alike in making navigation assessment more accessible. Additionally, the test-retest design was significant in confirming the effect of gender on navigation performance. This finding provides evidence for the need to address stereotypical beliefs of navigation ability in future research and to formulate assessment platforms that can be tailored towards female navigation processing preferences. While the data gathered on healthy participants provides us with valuable insight, a weakness of this study is that it does not include patients from a clinical population. Had this study included survivors of stroke or TBI, it would have gathered much more comparative data. However, the information gathered from the norm groups still provides sufficient insight from which we can base future research on spatial navigation deficits.

Conclusion

Research into navigation deficits experienced during aging or by stroke or TBI survivors is limited. The value of this study lies in its unique exploration of the contribution of subjective navigation ability and sense of presence in a virtual environment to objective navigation performance in VR. This study was carried out on healthy individuals with no navigation complaints, thus the results can be used as a norm-score from which assessments for individuals with spatial navigation complaints can be compared. Subjective navigation ability was found to be a significant predictor of objective navigation performance. Additionally, the study found an effect for gender on navigation performance, with males consistently performing better than females. These are valuable findings and should be taken into consideration when testing navigation abilities.

As there was no significant relationship between experienced presence in the virtual world and objective navigation performance, we can conclude that presence is not an essential variable in navigation, and thus assessments can be carried out remotely without the need for immersive VR headsets. However, as this study did not manipulate the level of immersion, future research may investigate whether different levels of immersion in VR can effect sense of presence and navigation performance. While limitations to this study have been addressed, the finding that sense of presence is not a significant predictor in objective navigation performance is of vital importance in clinical settings. Navigation deficits can thus be assessed remotely. This will make the process more affordable and accessible to patients. The findings for gender differences and the relationship between subjective navigation ability and objective navigation performance also have the potential to contribute evidence-based improvements in assessments, diagnostics and rehabilitation interventions. This will provide the population who suffer from spatial navigation deficits with the opportunity to address their difficulties and may provide significant improvement in coping mechanisms and recovery times, thus leading to enhanced independence, quality of life and psychological wellbeing in their future. Future research in this area is still essential to perfect the mechanisms through which VR is used to assess spatial cognition across age groups and genders.

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