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Influence of Visuospatial Working Memory on Navigational Strategy Training Outcome

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Abstract

Aim: The aim was to study whether high visuospatial working memory is linked to higher navigation performance. Multiple studies have found that the visuospatial working memory is involved in navigation and that a bigger capacity is related to better performance. Furthermore, navigational strategy also influences navigational performance. A strategy that is more targeted at the environment (allocentric) is also hypothesized to lead to better navigational performance than a strategy targeted at the position of the person in the environment (egocentric). In the current study, allocentric and egocentric participants were tested on navigational performance to determine if their level of visuospatial working memory capacity and/or preferred navigational strategy had any influence on navigational performance. Participants were also given a navigational training (allocentric or egocentric) and were tested on navigational performance after training to determine if the training had effects on their performance and if these effects differed for the different kind of groups (high and low visuospatial working memory capacity, egocentric and allocentric preferred navigational strategy).

Methods: Preferred navigational strategy (egocentric or allocentric), level of visuospatial working memory, and performance on a navigational task were assessed for 86 healthy participants in the first session. After the first session, participants did two weeks of navigational training, which consisted of short, computerised exercises on navigational skills such as using maps or remembering turns in a route. In the second session, preferred navigational strategy and performance on a navigational task were assessed again.

Results: The results showed that participants with high visuospatial working memory capacity did not show better performance on the navigational tasks than participants with low visuospatial working memory capacity at baseline. After two weeks of navigational training. participants with an allocentric preferred navigational strategy did not show more improvement on the navigational tasks than those with an egocentric preferred navigational strategy. In addition, 19 participants switched their preferred navigational strategy with the majority switching from an allocentric navigational strategy to an egocentric navigational strategy.

Conclusion: Level of visuospatial working memory capacity did not have any impact on navigational performance. Preferred navigational strategy also did not have any effect on navigational performance. These findings can possibly indicate that difference in level and preferred strategy do not influence the ability to benefit from the navigational training, which means that the navigational training is very accessible. Being able to change preferred navigational strategy also turned out to be possible, but not for all participants.

Introduction

Finding your way in your environment, also known as spatial navigation, is a very fundamental cognitive function, which involves basic memory and perception processes. Due to the integration of multiple sensory processes, e.g. visual cues, perceptions of self-motion, and cues from the environment, navigation is extremely complex (Wolbers & Hegarty, 2010). Because of this complexity, there are large interpersonal differences in navigational abilities. According to Baldwin and Reagan (2009), Gender, age, experience and navigational strategies all influence these interpersonal differences in navigational performance. Another influence on the interpersonal differences in navigational performance and an important component of navigation is sense of direction (SOD). SOD can be defined as the awareness of location or orientation, or as the knowledge of one's position in space (Prestopnik & Roskos-Ewoldsen, 2000). So, someone with a good SOD has a high awareness of where they are and how they are oriented in an environment. SOD can usually be self-rated, based on knowledge of one's navigational skills. This idea even dates to 1977, when Kozlowksi, Bryant, and Posner found that students with a positive self-rating of SOD showed more improvement in a pointing accuracy test in an unknown environment.

Another factor that influences the interpersonal differences in navigational performance is working memory ability. The working memory provides temporary storage to verbal and visuospatial information (Baddeley, 1986). The visuospatial information enters the visuospatial sketchpad, also known as the visuospatial working memory (Mammarella, Borella, Pastore, & Pazzaglia, 2013). The visual part of the visuospatial working memory (VSWM) is concerned with environmental qualities (e.g. colours and shapes) and the spatial part is concerned with movement and relations between objects in space (Meneghetti, Labate, Pazzaglia, Hamilton, & Gyselinck, 2017). The VSWM allows information about movement and locations to be stored and manipulated and therefore it plays an important role in wayfinding, as Hund (2016) describes. In her experiment, some of her participants performed a concurring visuospatial task during wayfinding, some a verbal task during wayfinding, and some were in a control condition without a dual task. In the visuospatial dual task group, participants' accuracy of directions that they had to give was significantly lower compared to that of the verbal and control condition. This indicates that the VSWM is involved in wayfinding, because burdening the VSWM with a visuospatial task while wayfinding disturbed wayfinding performance (as measured by the accuracy of the directions given by the participants). Meilinger, Knauff and Bülthoff (2008) also found similar results. In their study, participants had to memorize two routes through a virtual version of the German town of Tübingen. During the memorising, participants performed an extra visual or spatial task. After memorising, participants were tested on route memorization. Both the visual and spatial extra tasks had a negative impact on route memorization, and that the spatial task had the most negative impact. The researchers concluded that visuospatial skills play a role in wayfinding.

To summarize, the size of the capacity of the VSWM determines a person's ability to manipulate environmental information, with an increasing size leading to better performances. Not everyone has the same VSWM capacity (Xu, Adam, Fang, & Vogel, 2017), so interpersonal differences in navigational performance can arise. Xu, Adam, Fang, and Vogel (2017) also confirmed that interpersonal differences in VSWM capacity are stable over time. An important note is that it is important to keep in mind that there are more factors of influence on these interpersonal differences (Baldwin & Reagan, 2009). However, considering the importance of the VSWM in wayfinding (Hund, 2016; Meilinger, Knauff, & Bülthoff, 2008; Nori, Grandicelli, & Giusberti, 2009), it can be expected that participants with a higher VSWM capacity perform better on navigation.

There is also a relationship between sense of direction and VSWM capacity. A good sense of direction makes people more able to imagine spatial relationships that go beyond their own current position (Cornell, Sorenson, & Mio, 2003). This requires a great amount of effort and skill from the visuospatial working memory. Baldwin and Reagan (2009) found that people with a good SOD use their VSWM more efficiently than participants with a poor SOD. People with a poor SOD relied more on verbal working memory and less on spatial working memory, failing to create knowledge of their orientation (Wen, Ishikawa, & Sato, 2013). A good SOD is an important part of navigation, since multiple researchers have found that a good SOD is related to a more extensive use of the VSWM (Garden, Cornoldi, & and Logie, 2002; Gras, Gyselinck, Perrussel, Orriols, & Piolino, 2013). Nori, Grandicelli, and Giusberti (2009) also found that people with a good VSWM performed better on tasks of wayfinding, making less mistakes and working faster than people with a poor VSWM. They operationalised good and poor VSWM as scoring above or below the mean of four different visuospatial tests (Mental rotation task, Corsi Block Tapping Test, Copying Task, and the Spatial Problem Task). In this study, VSWM capacity was measured using the backward and forward version of the Corsi Block Tapping Test (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; Vecchi & Richardson, 2001) which correlates with test of working memory and spatial ability (Mitolo et al., 2015). Another article that states the importance of the VSWM in navigational tasks is that of Labate, Pazzaglia, and Hegarty (2014). They found that for every measure of survey knowledge that they used, the interference that a secondary spatial task produced was larger than the interference produced by a secondary verbal task. To summarize, the VSWM is an important part of wayfinding, as a bigger VSWM capacity allows a person to use the information about the environment more efficiently.

This information about the environment is better known as survey knowledge. It refers to a kind of knowledge about the orientation and distance between landmarks, and it is comparable to the term “allocentric” that will be used in this study. Most people prefer a certain style of navigation (egocentric or allocentric) but most of the time these strategies are used together (Klaztky, 1998; Zhong & Kozhevnikov, 2016). An allocentric navigational style is harder to adopt, because it involves more complex processes. These complex processes are correlated to activation in the hippocampus, one of the parts of the brain which is also involved in the VSWM by storing spatial information and mental representations for short periods of time (van Asselen et al., 2005). In contrast, the parahippocampal cortex plays a more important role in another kind of navigational style (Weniger et al., 2010), namely egocentric. This strategy seems to be less related to the VSWM. An example of an egocentric style is when someone tries to remember a certain route by remembering the turns someone must take. This is not very flexible, because it can only be applied to one certain route. It is extremely dependent on orientation of one’s body in space. In contrast, an allocentric navigational style uses maps (mental, but also physical). With this style, it is not so much about the position of the individual, but about the position of landmarks in relation to each other. To summarize, one might expect that people with allocentric preferred strategies would be better at wayfinding than people with egocentric preferred strategies, because of the closer involvement of VSWM capacity in people with allocentric preferred strategies.

Two expectations are thus far created, one is that people with a higher VSWM capacity will perform better at navigation, and the other one is that people with an allocentric preferred strategy will also perform better at navigation. To operationalise VSWM capacity, navigation performance, and preferred navigational strategy, the current study employs multiple measures. The forward and backward Corsi Block Tapping Test will be used to measure visuospatial memory (Kessels et al., 2000; Vecchi & Richardson, 2001) and The Point to Start and Point to End task of the Virtual Tübingen (Claessen, van der Ham, Jagersma, & Visser-Meily, 2016; van Veen, Distler, Braun, & Bülthoff, 1998) will be used to measure navigational performance (sense of direction) at one point in time and over time. These specific tasks test the ability to remember a route correctly in the best possible way, and they require a good sense of direction. A number of participants will also be completing a navigational training, allocentric or egocentric. Their preferred navigational strategy will be determined via the Starmaze task (Iglói, Zaoui, Berthoz, & Rondi-Reig, 2009).

The main aims of this study are to examine if participants with high visuospatial working memory capacity have an advantage in performance over participants with low visuospatial working memory capacity on a navigational task and to test if the navigational training has any effect on performance. Because this study measures performance at two points in time, it is also possible to examine and compare the high and low VSWM capacity groups at baseline, where it is expected that the high VSWM capacity will perform better than the low VSWM capacity. What is also a possibility is to examine change in performances of the different groups after the navigational training. It is expected that the high VSWM capacity group and the low VSWM capacity group will show improvement over time, due to the navigational training.

Similar expectations can be formulated for the preferred navigational strategies: Participants with an allocentric preferred navigational strategy will have an advantage in performance over participants with an egocentric preferred navigational strategy on a navigational task. A comparison at baseline is also possible, participants with an allocentric preferred navigational strategy will perform better at baseline than the participants with an egocentric preferred strategy. Lastly, Any changes in preferred navigational strategy can also be examined. It is expected that there will be participants who change their navigational strategy after the training, and most participants will switch from an allocentric to an egocentric strategy. This expectation is based upon the idea that the navigational training immerses participants in the navigational training that they do not use a lot. Training might make them aware of other ways of navigating, and they might implement some of the newly learned ways of navigating. The expectation that most participants will switch to an egocentric strategy is based upon the idea that an egocentric navigational strategy might be less cognitively demanding and thus easier to adopt (Fricke & Bock, 2018).

If there is an advantage for participants with high visuospatial working memory capacity or a kind of navigational strategy, this could have consequences for the navigational strategy training. This would mean that some people either benefit more from the training or are better at baseline at the given task. However, this does not imply that the people who benefit less from the training are not improving. When it is known what type of people this training works best for, attempts can be made to examine what makes these people benefit more from the training.

Methods

Design

This current study is part of a larger study at Leiden University. It has been approved by the Ethical Commission Psychology of Leiden University and the seventh version of the Declaration of Helsinki (World Medical Association, 2013) was applied. The study had an experimental design. Participants were divided into four conditions, mainly based on order of assessment. The participants in the control condition received no additional tasks or information between the first and second session. The participants in the psychoeducation condition received psychoeducation about navigation after the first session. The rest of the participants were put into either an allocentric or an egocentric training condition, based on their performance on a navigation strategy screening task. This screening task was the Starmaze task (Iglói et al., 2009), and participants were assigned to the training that was the opposite of their preferred navigational strategy. Men and women were evenly distributed over the four different conditions.

Participants

The overall sample of participants consisted of 86 healthy Dutch speaking participants (35 male, 51 female) aged 18 to 30 (M = 21.94 years, SD = 3.65 years) took part in this study. Education level was ranked according to Verhage's (1964) classification system. Mean education level was 6.6, the education levels ranged from 5 to 7. Participants were notified about this study via recruitment flyers which were spread around the Faculty of Behavioural and Social Sciences at Leiden University. Participants needed to have access to a PC or Mac and Internet and fall in the age range (18 to 35 years). They could not participate if they had any psychiatric disorders or problems (e.g. ADHD, depression).

Measures

A HP notebook with Windows 7 Professional (64-bit) operating system, an Intel Core i7-3840QM CPU @ 2.80 GHz processor, and a Nvidia Quadro K4000M graphics card was used. The screen measured 42 by 32 cm and its resolution was 1920 by 1080 pixels. The navigation training game was made with Unity3D (5.3.4fl) 64-bit software.

A general questionnaire was used to collect information about the gender of the participants, age, level of education, handedness, experience with gaming, and if they had ever been treated for any psychological problems, and if so, what kind of problems.

In the Virtual Tübingen test (VT) participants were instructed to carefully watch a film of a route through a virtual version of the German town of Tübingen. There were four different routes and two different viewpoints: allocentric or egocentric (bird's eye view or first-person view). Afterwards, participants had to do six tasks (Arrow task, Route continuation, Distance estimation, Point to Start (PTS), Point to End (PTE), and map reading). To measure sense of direction, only the data from Point to Start and Point to End tasks was used for answering the research question. In both tasks, participants had to point with a metal rod on a 360 degrees protractor at either the starting point or the end point of their route, as seen from their own location in the virtual town. The average deviation in degrees from the correct answers was used as an indicator of sense of direction, with a higher deviation average representing a poorer sense of direction. This test is based on earlier versions of the VT, with added conditions (Claessen, van der Ham, Jagersma, & Visser-Meily, 2016; van Veen, Distler, Braun, & Bülthoff, 1998).

In the Corsi Block Tapping Test (Kessels et al., 2000) the total score of the backward and forward version was used to represent visuospatial working memory capacity (Meneghetti et al., 2016). The total score forward had a range of 0 – 144 and the total score backward had a range of 0 – 112. The backward CBTT has slightly more discriminative power when it comes to differentiating participants with a good VSWM from participants who do not have a good VSWM (Cornoldi & Mammarella, 2008). However, the backwards version is not more difficult than the forwards version, so both versions are combined in this study (Kessels, van den Berg, Ruis, & Brands, 2008).

The Starmaze task (Iglói et al., 2009) was used to determine preferred navigational strategy. It represents a maze with ten alleys, five of them forming a pentagon and the other five radiating outwards from the corners of this pentagon. At the end of the outer alleys, visual landmarks were placed (consisting of two antennae, different mountains and two different forests). Participants were instructed to walk towards a finish at the end of one of the alleys that only showed up on the screen once they walked over it. Participants were also told that the starting locations never changed (but it secretly did in the last trial). If participants payed more attention to the landmarks, they would figure out that the last trial was different. If they figured this out and proceeded to the correct side of the maze, they had an allocentric navigational style. This is because they were not only paying attention to the route, but also to the surrounding environment and the relations between certain objects in that environment. Participants who kept on walking the same route shape had an egocentric style, because they had focussed more on the turns of their 'body', and not on the environment.

Procedure

Pre-training. Participants were screened on psychiatric complaints and age (18-35 years). They were also asked to sign an informed consent form. During the two-hour first session, the participants completed a general questionnaire, a wayfinding questionnaire (Van der Ham, Kant, Postma, & Visser-Meily, 2013), the Starmaze task, and the Virtual Tübingen test with the following subtasks: Arrow task, Route continuation, Distance estimation, Point to Start, Point to End, and map reading. They also completed the Corsi Block Tapping test, Perspective taking test (also used by Hegarty and Waller, 2004), Mental rotation task (48 items, based on Peters & Battista, 2008) and the Digit span task of the WAIS-IV (forwards and backwards versions). After the tests, the participants received psychoeducation about navigational strategies.

After this first session, participants had to train the navigational strategy that they were the least proficient at, so either an allocentric or egocentric training. The outcome of the Starmaze task was used as a guide to determine to what training participants would be assigned. This was a computerized task, so the computer interpreted the way the participant would navigate through the Starmaze and this interpretation could be mixed, egocentric or allocentric. For example, if a participant showed an egocentric way of navigating, they received the allocentric training. They did their assigned training for one hour in total over the course of two weeks, with sessions of at least 15 minutes. Participants in the psychoeducation group received only psychoeducation and no training. Participants in the control group did not receive psychoeducation and did not have to train.

Training. Over the course of two weeks, participants had to practice the navigation training game at least four times, 60 minutes in total. Participants were reminded via email on days that they had to train. The participants trained for 46 minutes on average. Both the allocentric training and the egocentric training consisted of three minigames.

Allocentric games. **"**Local landmarks" was the first minigame of the allocentric training. A map of a desert environment was shown to the participants with an invisible target, and three differently coloured pillars (the local landmarks). Participants also were given two golden coins before they were dropped (without a map) in this desert environment. The goal of this game was to find the invisible target by orienting yourself with the help of the coloured pillars. If a participant took to many steps, they would lose a coin. There was a total of five levels.

The second minigame was “Distant landmarks”. Here, participants were shown a map of a circular island, but with large structures (the distant landmarks) at each compass point. Again, participants had to find an invisible target by orienting themselves by looking at the structures in the distance. Too many steps meant a loss of gold coins, and there were five levels in total.

The third minigame was “Use a map”. Here, participants were put into a room with a wall painting. This room was connected to other rooms via a system of tunnels. Some rooms had to be avoided. A map was also shown on the screen, indicating a starting point and an ending point. The goal here was to get to the ending point without taking too many steps or walking into a room that had to be avoided. Too many steps or entering a forbidden room meant a loss of gold coins, and there were five levels in total.

Egocentric training. “Remember the route” was the first minigame of the egocentric training. Participants were shown a route in a maze, consisting of only Y-junctions. They had to remember this route by remembering each turn made at each Y-junction. For each correct turn they then made when they had to walk the route themselves, they received a gold coin. A wrong turn meant a loss of one gold coin, and there were five levels in total.

The second minigame was “Sense of direction”. Participants had to walk a certain route through a set of walled hallways. The starting point was marked with a noticeable stone. Every now and then, participants were stopped and instructed to point with the mouse to the point where they had started their route. They could not see the stone because of the walls. They closer they pointed to the stone, the more coins they could receive. There were five levels in total.

The third minigame was “Landmarks”. A route in a maze consisting of only Y-junctions was shown. Each junction also had a different painting on the wall. Participants had to remember what turns they made at which painting and then walk the route themselves. A gold coin could be received for every correct turn, and for every wrong turn, participants would lose a gold coin. There were five levels in total.

Post-training. In the second session, after about two weeks, participants had to complete the wayfinding questionnaire, a general questionnaire, the Starmaze task and the Virtual Tübingen test. No neuropsychological assessments were done in the second session. After participants had completed the second session, they were debriefed and rewarded with credits via SONA or they received a monetary reward.

Statistical analysis

SPSS 23.0 was used for the statistical analysis. A statistical significance level of .05 was used. To examine the low and high scores of the forward and backward versions of the Corsi Block Tapping Test, a median split was performed. The median score on the forward CBTT was 60 and the median score on the backward CBTT was 70. So, each participant with a score below 60 on the forward CBTT and score below 70 on the backward CBTT can be classified as having low VSWM abilities. Each participant with a score above 60 on the forward CBTT and a score above 70 on the backward CBTT can be classified as having high VSWM abilities. A new variable was created: *CorsiLevel*. Participants who had a low score on both the forward and backward CBTT were coded as group zero, participants who had a high score on both the forward and backward CBTT were coded as group one, and the remaining participants were coded as group two. Outliers on the CBTT scores were detected and removed via SPSS boxplots.

In order to check differences in Virtual Tübingen tests over time, differences scores were created. In the first session, each participant completed four pointing tasks: allocentric Point to Start and Point to End, and egocentric Point to Start and End. In the second session, participants completed these pointing tasks again. A difference score in percentages was calculated for each of these tasks. The following formula was applied: ((Score on session 2 – Score on session 1) / Score on session 1) * 100%. These variables were labelled: *DPerc_A_PTS*, *DPerc_A_PTE*, *DPerc_E_PTS*, and *DPerc_E_PTE*, were A and E stood for allocentric and egocentric respectively, and PTS and PTE stood for Point to Start and Point to End respectively. Furthermore, outliers based on raw scores of the Virtual Tübingen tasks were deleted. These outliers were found by creating boxplots. Outliers based on difference score in percentages were also deleted and found in the same manner.

To examine the expectation that participants with high VSWM abilities perform better on the Virtual Tübingen Point to Start and Point to End tasks than participants with low VSWM abilities over time, an independent samples t-test was used. This test is used to determine if there are any differences between independent groups (participants with a high CBTT score and participants with a low CBTT score) on more than one continuous dependent variable (the Virtual Tübingen Point to Start and Point to End tasks difference scores in percentages). The test variables were the difference scores in percentages on the Virtual Tübingen Point to Start and Point to End tasks, the grouping variable was set to *CorsiLevel* (levels zero and one were chosen, zero represented the low VSWM capacity group, and one represented the high VSWM capacity group).

To examine the expectation that participants with high VSWM abilities perform better on the Virtual Tübingen Point to Start and Point to End tasks than participants with low VSWM abilities, an independent samples t-test was used. This test is used to determine if there are any differences between independent groups (participants with a high CBTT score and participants with a low CBTT score) on more than one continuous dependent variable (the Virtual Tübingen Point to Start and Point to End tasks scores at session one). The test variables were the scores on the Virtual Tübingen Point to Start and Point to End tasks at session one, the grouping variable was set to *CorsiLevel* (levels zero and one were chosen, zero represented the low VSWM capacity group, and one represented the high VSWM capacity group).

To examine the expectation that the high VSWM capacity group and the low VSWM capacity will show improvement over time on the navigational task, a paired samples t-test was performed. Scores on the Point to Start and Point to end tasks at session one were paired with the corresponding scores on the Point to Start and Point to End tasks at session two.

To examine the expectation that the participants with an allocentric preferred navigational strategy will perform better on the Virtual Tübingen Point to Start and Point to End tasks over time, an independent samples t-test was performed. The test variables were the difference scores in percentages, the grouping variable was set to *Starmaze_1* (zero represented a preference for the egocentric navigational strategy, one represented a preference for the allocentric navigational strategy).

To examine the expectation that participants with an allocentric preferred navigational strategy should perform better on the Virtual Tübingen Point to End and Point to start tasks at session one than participants with an egocentric preferred navigational strategy, an independent samples t-test was performed. This test is used to determine if there are any differences between independent groups (participants with an allocentric preferred navigational strategy and participants with an egocentric preferred navigational strategy) on more than one continuous dependent variable (the Virtual Tübingen Point to Start and Point to End tasks scores at session one). The test variables were the scores on the Virtual Tübingen Point to Start and Point to End tasks at session one, the grouping variable was set to *Condition* (three represented the participants who completed the egocentric training, and four represented the participants who completed the allocentric training.

To examine the expectation that some participants will change their navigational strategy over time, the variable *Strat_change* was made, based on the variables *Starmaze_1* and *Starmaze_2*. *Strat_change* was labelled with either a one (change), or a zero (no change). *Starmaze_1* and *Starmaze_2* were labelled with either a one (allocentric strategy) or a zero (egocentric strategy). To check which switch of strategy occurred the most, a simple method of counting was applied.

Results

One participant was an outlier on the forward CBTT, so this participant will be removed from the sample. The outlier was calculated via a boxplot: the 25th percentile = 54, the 75th percentile = 77, median = 60, interquartile range = 77 – 54 = 23, the maximum therefore is 77 + (1.5*23) = 111.5, and participant seven scored 112 on the forward CBTT. The complete sample consisted of 85 healthy participants with 35 males and 50 females. Education level in this table is based on the classification made by Verhage (1964).

Next, a median split was performed to classify the low and high CBTT scoring groups. On the forward CBTT, the median was 60. On the backward CBTT, the median was 70. Participants with a score below these medians could be considered as having a low overall CBTT score. Participants with a score above these medians could be considered as having a high overall CBTT score. This median split created a sample of 42 participants, of which 21 had a low overall CBTT score and the other 21 participants had a high overall CBTT score. The control condition consisted of 9 participants, the psycho-education condition consisted of 11 participants, the egocentric training condition consisted of 10 participants, and the allocentric training condition consisted of 12 participants. The correlation between forward and backward CBTT scores was found to be $r = .320$, $p < .05$. This is a weak, positive correlation.

Table 1. *Descriptive statistics of different groups and total*

		N	Mean	Std. Deviation
Low VSWM group	Age in years	21	21.57	2.44
	Education level	21	6.62	.50
High VSWM group	Age in years	21	21.57	2.23
	Education level	21	6.43	.60
Total	Age in years	85	21.96	3.66
	Education level	85	6.58	.54

Additional outliers based on raw scores of the Virtual Tübingen tasks were deleted. These outliers were found by creating boxplots. Outliers based on difference score in percentages were also deleted and found in the same manner.

Next, difference scores in performance on the Virtual Tübingen tasks over time were calculated in percentages. This was done by subtracting the score on the different subtests completed in session one from the score on the different tasks completed in session two, then dividing this score by the score on the different tasks completed in session one, and then multiplied by 100%. This yielded differences scores in percentages. For example, to find the difference score for the allocentric point to end task, one would subtract the score at session one on this subtest from the score at session two on this subtest, divide this by the score at session one, and then multiply this by 100%. These scores were labelled as *D PTS A*, *D PTE A*, *D PTS E, and D PTE E*, were *D* stood for difference score, *PTS/E* for point to start/end, *A* for allocentric and *E* for egocentric.

No statistically significant difference in scores on the allocentric point to start, egocentric point to start and egocentric point to end navigational tasks over time were found between participants with a high visuospatial working memory capacity and participants with a low visuospatial working memory capacity. Statistics were respectively $t(34) = -.529$, $p = .600$, $t(39) = -1.528$, $p = .134$, and $t(40) = -.004$, $p = .997$. Opposite to what was expected, participants with a high visuospatial working memory capacity did show significantly less improvement in percentages on the allocentric point to end task, $t(38) = 2.074$, $p = .045$. Means and standard deviations can be found in Table 2, where D stands for difference, PTS/E stands for Point to start/end and A/E stands for allocentric or egocentric.

Table 2. *Means and standard deviations of difference scores – VSWM capacity*

	High	Low
Difference score	Mean (Std.deviation)	Mean (Std.deviation)
D PTS A	24.94 (79.74)	12.63 (59.33)
D PTE A*	35.16 (93.98)	105.92 (121.25)
D PTS E	25.96 (113.58)	-15.37 (42.39)
D PTE E	43.39 (82.43)	43.26 (140.00)

* $p < .05$

At baseline, there was a statistically significant difference in scores on the egocentric point to end task, $t(40) = 3.311$, $p = .002$. The high visuospatial working memory capacity group scored significantly lower than the low visuospatial working memory capacity group on the egocentric point to end task. There was no statistically significant difference in scores on the egocentric point to start ($t(40) = 1.460$, $p = .152$) and allocentric point to start($t(37) = 1.224$, $p = .229$) tasks. For the allocentric point to end task, a trend level was found, $t(38) = 1.899$, $p = 0.65$. This trend level was in favour of the high visuospatial working memory capacity group, who scored lower than the low visuospatial working memory capacity on this task. Means and standard deviations can be found in Table 3, where PTS/E stands for Point to start/end and A/E stands for allocentric or egocentric.

Table 3. *Means and standard deviations at session one – VSWM capacity*

	High	Low
VT Task	Mean (Std.deviation)	Mean (Std.deviation)
PTS A	17.92 (10.52)	22.27 (11.62)
PTE A	20.57 (8.85)	25.84 (8.66)
PTS E	43.95 (18.08)	51.65 (16.07)
PTE E**	37.61 (17.95)	59.11(23.73)

**$p < .01$

When examining within the low visuospatial working memory capacity group, a statistically significant difference was found between the allocentric point to end task scores at session one and two ($t(18) = -3.537$, $p = .002$). There was also a statistically significant difference between the egocentric point to start task scores at session one and two ($t(19) = 2.545$, $p = .020$). No statistically significant difference was found between the allocentric point to start tasks scores at session one and two ($t(18) = .028$, $p = .978$). No statistically significant difference was found between the egocentric point to end tasks scores at session one and two ($t(20) = -.558$, $p = .583$).

When examining within the high visuospatial working memory capacity group, no statistically significant difference was found between the allocentric point to start task scores at session one and two ($t(16) = -.150$, $p = .882$). No statistically significant difference was found between the allocentric point to end task scores at session one and two ($t(20) = -1.366$, $p = .187$). No statistically significant difference was found between the egocentric point to start tasks scores at session one and two ($t(20) = .815$, $p = .425$). For the egocentric point to end task, a trend level was found, ($t(20) = -1.985$, $p = .061$). Participants with a high visuospatial working memory capacity seemed to score higher on this task at session 2. Means and standard deviations for both the high and low visuospatial working memory capacity groups can be found in Table 4, where VT stands for Virtual Tübingen, PTS/E stands for Point to start/end and A/E stands for allocentric or egocentric.

Table 4. *Means and standard deviations VSWM groups session one compared to session two*

VT Task	Session	High Mean (Std.deviation)	Low Mean (Std.deviation)
PTS A	1	18.98 (10.64)	21.44 (11.31)
	2	19.37 (9.75)	21.36 (10.63)
PTE A	1	20.57 (8.85)	25.84 (8.66)**
	2	25.36 (17.83)	49.67 (31.28)**
PTS E	1	43.95 (18.08)	52.53 (16.26)*
	2	39.90 (13.69)	40.87 (17.68)*
PTE E	1	37.61 (17.95)	59.11 (32.73)
	2	48.01 (26.56)	64.26 (28.73)

*$p < .05$, **$p < .01$

No statistically significant difference in difference scores in percentages was found between participants with an allocentric preferred navigational strategy and participants with an egocentric preferred navigational strategy. For the allocentric point to start and point to end tasks, statistics were respectively: $t(73) = 1.412$, $p = .162$, and $t(77) = -.985$, $p = .328$. For the egocentric point to start and point to end tasks, statistics were respectively: $t(78) = -.814$, $p = .418$, and $t(82) = -.849$, $p = .398$. Means and standard deviations can be found in Table 5, where D stands for difference, PTS/E stands for Point to start/end and A/E stands for allocentric or egocentric.

Table 5. *Means and standard deviations of difference scores – Preferred navigational strategy*

Difference score	Allocentric Mean (Std.deviation)	Egocentric Mean (Std.deviation)
D PTS A	7.35 (69.13)	36.94 (98.47)
D PTE A	64.92 (113.92)	42.77 (85.10)
D PTS E	20.29 (88.86)	6.10 (66.55)
D PTE E	50.46 (124.76)	31.87 (76.00)

At baseline, no statistically significant difference on performance on all the navigational tasks was found between the participants with an allocentric or egocentric preferred navigational strategy. Statistics for the allocentric point to start and end tasks and the egocentric point to start and end tasks were respectively: $t(79) = -.569$, $p = .571$, $t(79) = .594$, $p = .554$, $t(81) = .985$, $p = .328$, $t(82) = 1.581$, $p = .118$. Means and standard deviations can be found in Table 6, where PTS/E stands for Point to start/end and A/E stands for allocentric or egocentric.

Table 6. *Means and standard deviations at session one - Preferred navigational strategy*

	Allocentric	Egocentric
VT Task	Mean (Std.deviation)	Mean (Std.deviation)
PTS A	20.83 (10.25)	19.36 (11.92)
PTE A	23.81 (10.05)	25.23 (10.75)
PTS E	43.81 (18.66)	47.58 (15.83)
PTE E	44.85 (20.75)	52.57 (22.52)

Lastly, nineteen participants had changed their preferred navigational strategy. Most of the participants who had switched strategy switched from an allocentric to an egocentric strategy (13 out of 19). Most of these participants who switched strategy had completed the egocentric navigational training, nine out of 19 switched participants. Out of the participants who had completed the egocentric navigational training, eight switched to an egocentric strategy.

Discussion

A good sense of direction (SOD) is part of successful navigation, because it is related to a more extensive use of the visuospatial working memory (VSWM) (Garden et al., 2002; Gras et al., 2013). The VSWM is concerned with qualities of the environment (colours and shapes), and with movement and relations between objects in space (Meneghetti et al., 2017). The VSWM also plays in important part in wayfinding (Hund, 2016). An increasing size of VSWM capacity leads to a better performance in wayfinding, but not everyone has the same size of VSWM capacity (Xu et al., 2017). In this current study, SOD was measured by using the allocentric and egocentric versions of the Virtual Tübingen point to start and end task (Claessen et al., 2016: van Veen et al., 1998). VSWM capacity was measured by the forward and backward version of the Corsi Block Tapping Test (Kessels et al., 2000; Vecchi & Richardson, 2001). The main aims of this study were to test the influence of level of VSWM capacity on navigational performance (at baseline and after navigational training) and to test the influence of preferred navigational strategy on navigational performance (at baseline and after navigational training).

Following from the literature, it was expected that the high VSWM capacity group would have an advantage (i.e. perform better) in performance over the low VSWM capacity group on the used navigational tasks over time. A difference was indeed found on the allocentric point to end task. On this task, the low VSWM capacity group showed statistically significantly more improvement than the high VSWM capacity group. No statistically significant differences between the high VSWM capacity group and the low VSWM capacity group on remaining tasks was found. In other words, level of visuospatial working memory capacity seemed not to matter when it came to navigational performance over time, which contrasts with what was expected at first. Nori and colleagues (2011) however did find statistically significant differences between high and low VSWM capacity groups, showing that the high VSWM capacity group was better at wayfinding. However, they based high and low VSWM capacity on more tests than just the Corsi Block Tapping Test.

The high and low VSWM capacity groups have also been compared at baseline. There were no statistically significant differences between both groups on the allocentric and egocentric point to start tasks. On the egocentric point to end task, the high VSWM capacity group does score significantly better. On the allocentric point to end task, a trend toward significance was found, where the high VSWM capacity group does score better. This result might point to something going on in specifically the point to start tasks. It might be the case that pointing to where one came from originally is more difficult than pointing to where one ended up, simply because backtracking a route could be harder than following a route in the right order. This could possibly be researched by having the allocentric and egocentric groups back track several routes and then compare the two groups on performance.

Another important factor in interpersonal wayfinding differences is the use of different navigational strategies. The allocentric (environment-based) strategy has a closer involvement with the VSWM (van Asselen et al., 2005), so it was expected that participants with this preferred strategy would perform better on the Virtual Tübingen tasks (over time and at baseline). There were no statistically significant differences found over time between the allocentric and egocentric preferred navigational strategy groups on any of the navigational tasks. in addition to this, no statistically significant differences at baseline were found between the allocentric and egocentric preferred navigational strategy groups. This could implicate that preferred navigational strategy has no influence on the performance of the navigational tasks. This also means that no preferred navigational strategy has an advantage over the other, which creates equal chances for everyone using the navigational strategy training and makes the training more accessible for different people. Another explanation for the nonsignificant differences is that egocentric and allocentric strategies are usually used together in healthy subjects (Klaztky, 1998; Zhong & Kozhevnikov, 2016). Participants might have a preferred strategy, but subconsciously use both strategies, which could explain why no significant differences have been found.

The high and low VSWM capacity groups have also been examined on improvements within the groups. In the low VSWM capacity group, a statistically significant difference was found between the scores on the allocentric point to end task for session one and session two. There is a deterioration in performance on this task. There also was a statistically significant difference between the scores on the egocentric point to start task for session one and session two. There is an improvement in performance on this task. This difference between the allocentric and egocentric versions of the same task might be explained by the fact that the egocentric version of this task might be easier for these participants, as they possibly do not use their VSWM in the most efficient way (Wen, Ishikawa, & Sato, 2013).

What was also found is that some participants had changed their initial strategy, which was expected. Most of these participants switched from an allocentric strategy to an egocentric strategy. Most of the participants who switched had completed the egocentric training as well. This might possibly suggest that an egocentric strategy is easier to obtain, which could be a valid explanation for this found phenomenon. According to Fricke & Bock, (2018), this could hypothetically be the case, as they stated that an egocentric navigational strategy might be cognitively less demanding. Claessen, van der Ham, Jagersma, & Visser-Meily, (2016) also found that some chronic stroke patients also had changed strategies after navigational training. The fact that change was found in some of the participants in this study does confirm that navigational strategies can be changed, so it is still relevant to research navigational training.

Some critical notes on this study need to be made. First, the Corsi Block Tapping Test forward and backward scores were combined to determine if a participant had a high level of visuospatial working memory or not, but the scores on the forward and backward versions did not have a very strong correlation. It is therefore questionable to combine these two separate scores. However, Kessels, van den Berg, Ruis, & Brands, (2008) did find that there was no difference in difficulty between the forward or backward version, but it is still surprising that these two scores in our sample did not correlate that strongly. Replication with both versions separately is advised for future research, as Cornoldi & Mammarella (2008) did find that the backward version was slightly more predictive of navigational performance. The second limitation is that measuring navigational performance with a virtual task, e.g. the Virtual Tübingen test, might not be realistic enough. This is feedback received from current participants, who felt like the VT was not approximating real-life navigation. Van der Ham, Faber, Venselaar, van Kreveld, & Löffler (2015) found in their research that performance relying on survey knowledge (which is related to allocentric navigational strategy) was better in real-life environments than in virtual conditions. A third limitation might be that this study only used young and healthy participants. Many researchers have found that allocentric navigation deteriorates as people become older (Gazova et al., 2013; Jansen, Schmelter, & Heil, 2010; Moffat & Resnick, 2002). The allocentric training might be more beneficial for older people, because of this deterioration over time (Fricke & Bock, 2018).

As for suggestions for further research, it might be useful to include more variables. Perspective taking test and mental rotation were also measured in this study, and these two factors might also influence participants' performance. Apart from these two measures, age, experience and gender can also be responsible for the interpersonal differences in navigation (Wolbers & Hegarty, 2010). All these different variables should be considered in future research.

To summarize, level of visuospatial working memory capacity did not have a major impact on navigational performance over time. At baseline, differences were slightly more distinct. Here, the high VSWM capacity group did score better. Preferred navigational strategy did not have any effect on performance over time and at baseline. The results look promising towards the navigational training because the results suggest that it is accessible to people with different VSWM capacities and preferred navigational strategies. However, further research on this topic is needed, as navigational training could be very beneficial for people who have navigational impairments. A promising finding is that some participants in this study were able to adopt another navigational strategy, which makes the training even more promising for future use.

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