The relation between route order memory and working memory in healthy participants and stroke patients.

Kirsten Richards

Master Thesis Clinical Neuropsychology
Faculty of Behavioural and Social Sciences – Leiden University
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Student number: 1231324
Daily Supervisor: Ineke van der Ham, Department of Health, Medical and Neuropsychology; Leiden University
CNP-co-evaluator: Esther Habers, Health, Medical and Neuropsychology Unit; Leiden University

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Abstract

Route order memory is an important component of navigation, yet it is still an understudied subject. The working memory modality is also necessary to navigate. As navigation goes automatically for healthy people, it can be a profound problem for brain-damaged people. This study focused on the relation between route order memory and working memory in healthy participants and in stroke patients. We hypothesized that the visual- and visuospatial working memory is positively related with route order memory, and the verbal working memory is negatively related. We expected that stroke patients will on average score lower on route order memory than healthy participants. We examined whether the effects of the visual-, visuospatial-, and verbal working memory on route order memory are stronger for stroke patients. Lastly, we hypothesized that stroke patients who are not impaired on route order memory will have a better visual-, visuospatial- and verbal working memory, than impaired stroke patients. A group of 59 healthy participants and 78 stroke patients participated in this study. Comparing these groups, we found that individuals who have a better visual- (p = .018) and verbal working memory (p = .035), have a better route order memory. Healthy participants have a better route order memory than stroke patients (p = .23). Stroke patients that are not impaired in route order memory have a better visuospatial- (p = .013) and verbal working memory (p = .002) than stroke patients that are impaired. In conclusion: visual- and verbal working memory are important for remembering a route, although stroke patients who are not impaired in route order memory have a better visuospatial- and verbal working memory. These results reinforce the general knowledge of the contribution of the working memory modality in route order memory for the purpose of a better comprehension of the complex ability of navigation. This can help further development of treatment for brain-damaged individuals with navigation problems.

Preface

This study was executed in the context of a master thesis as part of the master Clinical Neuropsychology from the University of Leiden. This thesis would not have been possible without the help and tips of my supervisor Ineke van der Ham. This preface is focused on her to say thank you for all the dedication and help. I would like to thank Ineke van der Ham for her excellent guidance and support during this learning process.

Introduction

Navigation is a complex ability that involves various modalities of the working memory. This complex ability is essential because it allows us to move from one place to another, but also to adapt to new surroundings (de Rooij, Claessen, van der Ham, Post, & Visser-Meily, 2017; Wiener, Büchner, & Hölscher, 2009; Wolbers & Hegarty, 2010). This is seen in the amount of daily activities that involve navigation, such as going to the supermarket or even going from the living room to the bathroom. Moreover, navigation is positively correlated to a person's immobility and autonomy (Claessen & van der Ham, 2017; van der Ham, Kant, Postma, & Visser-Meily, 2013). However, for some people this can be more challenging. Research shows that brain damage affects the spatial navigation ability in a negative way (Caglio, Castelli, Cerrato, & Latini- Corazzini, 2011). Navigation problems affect around 30% of brain-damaged individuals (Aguirre & D'Esposito, 1999; Claessen, van der Ham, Jagersma, & Visser-Meily, 2016; de Rooij et al., 2017).

In order to navigate, different methods can be used, such as: remembering the position of landmarks, recognizing the environment, or remembering the sequence of turns (Claessen, Visser-Meily, Jagersma, Braspenning, & van der Ham, 2016). To understand the cognitive construct of navigation, it is necessary to look at various aspects of navigation. One of these aspects is route order memory. It concerns the recollection of the order in which landmarks were encountered in an environment. Conceptually, it is possible that route order memory is connected to a temporal ("when") and spatial ("where") context. Memorizing a route has to do with remembering landmarks at different points in time and space. Therefore, temporal aspects of navigation are referred to as the spatiotemporal context (Claessen et al., 2016; Turk-Browne, Simon, & Sederberg, 2012; van der Ham, Kant, Postma, & Visser-Meily, 2010). Although route order memory is an important aspect of navigation, it is still an understudied aspect; this while it is essential in finding our way (van der Ham, de Zeeuw, & Braspenning, 2016).

Nonetheless, the difference between the temporal and spatial aspects of navigation, can have an influence on navigation impairments. Van der Ham and colleagues (2010) demonstrated the difference between the temporal and spatial aspects of navigation and the effect of having navigation impairment. The case report of patient A. C. illustrates a clear example of problems in route order memory. She had difficulty in acquiring information about the order of decision points along a newly learned virtual route, but she was able to form associations between places (decision points) and actions (turns). However, she lost her way frequently and at random moments, even though she was familiar with the environment. It is possible that A. C. has impaired route ordering, which is often associated with the temporal aspect of navigation. Studies that incorporate route order memory and navigation, use the term ‘temporal aspect’ in order to label route order memory. However, we cannot substantiate this term. As route order memory is about remembering landmarks at different points in time and space, it is questionable if route order memory can be labeled as a ‘temporal aspect’ while the spatial aspect is also applicable (van der Ham, de Zeeuw, & Braspenning, 2016). The case report of W. J. shows that getting lost does not always occur because of route order memory impairment. She reported problems with planning ahead and remembering locations. For her, well-known routes were feasible. This indicates that W. J. was significantly impaired on scene-, object recognition and route continuation, which is associated with the spatial working memory aspect of navigation. This indicates that route order memory is not only associated with the temporal aspect but a double dissociation between the temporal and spatial aspect (van der Ham et al., 2010). This example demonstrates that navigation consists of both spatial and temporal processes (van der Ham et al., 2010). The example of A. C. shows us that it is possible to have route order impairment, while other cognitive aspects of navigation work successfully. This causes immense problems of getting lost. In order to reduce this problem, it is important to understand route order memory (Claessen et al., 2016; van der Ham, Zandvoort, Meilinger, Bosh, Kant, & Postma, 2010). This double dissociation has also been confirmed by the group study of Claessen at al. (2016), which indicates that the information of space and time plays an important role in remembering a route and can be affected in brain-damaged individuals. Little research has been done on the double dissociation of temporal and spatial aspects of navigation, although it is essential in finding our way. (van der Ham, de Zeeuw, & Braspenning, 2016).

As route order memory is an essential modality of navigation, so is the working memory (Claessen, van der Ham, Jagersma, & Visser-Meily, 2016; Wolbers & Hegarty, 2010). This is necessary for people to recall a route or location and is an important factor for environmental learning (Hegarty, Montello, Richardson, Ishikawa, & Lovelave, 2006; Migo et al., 2016). The working memory is the foundation of the retrieval of spatial and temporal context (Claessen et al., 2016). In this study we consider different types of working memory: visual working memory, visuospatial working memory and verbal working memory (Baddeley & Hitch, 1974). Baddeley and Hitch (1974) proposed the original working memory structure, consisting of a visuospatial sketchpad and a phonological loop. The visuospatial sketchpad regulates visual and spatial information, which includes size, shape, speed and location. To navigate with the spatial context, the visuospatial sketchpad is used. The phonological loop regulates verbal-based information. People who navigate using the temporal context will use the phonological loop. If we measure to what extent people use the working memory modality during navigation, we understand more about the contribution of the different types of working memory in route order memory (Baddeley, 2017; Gras, Gyselinck, Perrussel, Orriols, & Piolino, 2012; Knight & Tlauka, 2018; Meilinger, Knauff, & Bülthoff, 2008).

Based on the preceding information, the main aim of this study is to explain route order memory by examining the specific working memory processes: to learn whether these processes account for route order memory performance. We want to understand how people remember the order of a certain route and which different types of working memory contribute to this. Therefore, we examine how different types of working memory contribute to route order memory in healthy individuals and in stroke patients. This way we can study the role of the working memory during navigation.

In this study we hypothesize that the level of visual working memory functioning is positively related with the level of route order memory. Secondly, we hypothesize that the level of visuospatial working memory is also positively related to route order memory. And thirdly, we hypothesize that the level of verbal working memory is negatively related to route order memory. We also expect that stroke patients will on average score lower on route order memory than healthy participants. Lastly, we examine whether the effects of the visual-, visuospatial-, and verbal working memory on route order memory are stronger for stroke patients. Research indicates that most people remember the order of a route by remembering landmarks in space and time, wherefore the visual and visuospatial working memory are important (Knight & Tlauka, 2018).

Some brain-damaged individuals can have an impairment in the route order memory, while other brain-damaged individuals can experience navigation problems without having difficulties remembering a route (van der Ham et al., 2010; van der Ham, de Zeeuw, & Braspenning, 2016). Therefore, we will examine the difference in remembering the route order between stroke patients who have an impaired route order memory and those who are not impaired in route order memory. We hypothesize that stroke patients who do not have an impaired route order memory will on average have a better visual-, visuospatial- and verbal working memory than stroke patients who have an impaired route order. We hypothesize this because visual and visuospatial working memory are important in order to remember a route. So when the route order memory of patients is impaired there is a chance that the visual and visuospatial working memory can be impaired as well (van der Ham, de Zeeuw, & Braspenning, 2016).

In short, our main purpose is to better understand the construct of route order memory. When we understand the role of working memory in route order memory in more depth, we can adjust the techniques or treatment used to remember a route, which will be suitable for stroke patients with navigation problems. When we have gathered this information it will make it easier to predict which problems a patient could experience. Route order memory is a highly understudied concept of navigation, but it is very important in finding our way (van der Ham, de Zeeuw, & Braspenning, 2016). Ergo, to better comprehend the relation between the different types of working memory (visual-, visuospatial- and verbal working memory) and route order memory. We want to know if there is a difference in route order memory and a high or low visual-, visuospatial-, and verbal working memory for both stroke patients and healthy participants. This information is needed to create a treatment for stroke patients with navigation problems, as treatment for navigation problems are scarce. Improving the treatments is important for stroke patients with navigation problems to live an independent life (Claessen et al., 2016).

Methods

Participants

A control group of 59 healthy participants and an experimental group of 78 stroke patients took part in this study. All participants had to meet the following inclusion criteria: can walk independently, have no indications of severe aphasia or neglect, do not suffer from visual, neurological problems, psychiatric disorders as stated in the DSM-5 or mobility problems and do not have a history of substance abuse (American Psychiatric Association, 2013). Demographic and cognitive data (age, gender and education) of all participants are displayed in Table 1.

Design

To study the route order memory we used a between design because we are comparing the control group with the experimental group. To study the route order memory between stroke patients we used a between design, because we are studying the data of the experimental group. This study is part of a larger cross-sectional study which aim is to provide empirical support for the distinction between landmark-based, location-based, and path-based impaired navigation of stroke patients (Claessen et al., 2017). Only the demographic data, working memory data and the navigation tasks would be discussed in the current study.

Measures

The present study entails a series of two neuropsychological tests and one computer task. For this study we will be looking at the following tests:

Virtual Tübingen test

The Virtual Tübingen (VT) test is a computer test, which includes a learning phase and a test phase. In the learning phase the participants watched a video of a route through a realistic virtual town in the German city Tübingen (Claessen, van der Ham, Jagersma, & Visser-Meily, 2016; van der Ham et al., 2010). Prior to watching the video, the participants were instructed to remember as much of the route as possible. There were two different versions of the route to compensate between the participants. However, there are similarities such as; the duration is highly comparable (210 and 253 seconds) and they had an equal distance (400 meters). The speed for both videos was slightly above walking pace and the numbers of decision points (four decision points where the participants had to go straight ahead and seven left and right turns) were equal as well. After the participants watched the video twice, the test battery started and the test phase began. This Test Battery consisted of twelve subtasks; Landmark Recognition (1), Route Continuation (2), Route Sequence (3), Route Order (4), Route Progression (5), Route Distance (6), Pointing to Start (7), Pointing to End (8), Distance Estimation (9), Duration Estimation (10), Route Drawing (11), and Map Recognition (12). All subtasks were paper-and-pencil tasks, except subtask 1, 2, 7, and 8; they were made on a laptop using Presentation software (version 16.3; Neurobehavioral Systems; Claessen et al., 2017).

In this study we are going to focus on the Route Order and the Scene Recognition subtask. In the route order task participants need to recreate the correct order of the route with eleven pictures of decision points that they encountered during the route (Claessen et al., 2016; Claessen et al., 2017). For this test a different approach to scoring was used, which is more sensitive to the actual performance quality. The new scoring system gives a better reflection of the order that the participant gives as an answer. The scoring system operates as followed by converting the answers of the participants into numbers. For each number in the series points are given, except for the last number. One point is given if the number on the right side is bigger than the previous number. If the number is smaller zero points are earned. The score is calculated by adding up all the points from the participant. This way a maximum of ten points could be earned, this indicates that the participant had the entire route correct and could remember the route from the beginning until the end. When participant scored the minimum of three points which indicates that the route is not in the correct order but that three places in the route stand further on in the route than the place before it. This does not mean that the place comes exactly after the place before it, but can also lie much further in the route. With this test we can see how participants score on the Route Order task and see whether or not they are impaired.

As a measure of visual working memory capacity, we use the scores on the Scene recognition subtask. In this task the participants saw twenty-two images one-by-one of different decision points in a random order. Half of these images were shown during the VT video, while the other half of the images were not shown in the VT video. It was the participants' task to indicate whether the decision points were part of the VT video or not. For each correct answer a single point was earned and a total of twenty-two points could be collected (Cleassen et al., 2016; Claessen et al., 2017; de Rooij et al., 2017).

Corsi Block-Tapping Test

To see if participants use the spatial context to remember a route, we will look at the Corsi Block-Tapping Test (Corsi, 1972). The test consists of two conditions, the forward condition, and the backward condition. In the forward condition the participants were asked to tap the blocks in the same order as the examiner presented. In the backward condition the participants were asked to reproduce the block sequence in the reverse order as the examiner presented. To score this test three accuracy measures were noted: the span (the number of blocks in the longest correctly reproduced sequence), the score (the number of correctly repeated sequences) and the product of these two measurements. Because the forward condition is a different task than the backward condition, different cognitive processes are used (Claessen, van der Ham, & van Zandvoort, 2015; Kessels, van Zandvoort, Postma, Kapelle, & de Haan, 2000; Orsini, Simonetta, & Marmorato, 2004). The forward condition measures the visuospatial attention span, while the backward condition measures the visuospatial working memory (Claessen et al., 2016; Claessen et al., 2017; Kessels, van den Berg, Ruis, & Brands, 2008; Kessels et al., 2000). For this study we focus on the score of the backward condition of each participant.

Digit Span test

In order to see if participants use their language to remember the route order, we will use the Digit Span task, a subtask of the WAIS-III (Wechsler, 1997). During this task a sequence of numbers will be presented auditory by the examiner and the participant has to reproduce it. As the Corsi test, the digit Span also consists of a forward and backward condition. In the forward condition the participants had to repeat the digit sequence in the same order as the examiner presented the numbers. In the backward condition participants had to reproduce the digit sequence the examiner presented in the reverse order. There are three accuracy measures to score this test: the span (the number of digits in the longest correctly reproduces sequence), the score (the number of correctly repeated sequences) and the product of these two measurements (Claessen, van der Ham, & van Zandvoort, 2015; Wilde, Strauss, & Tulsky, 2004). The backward condition of the Digit Span test measures the verbal working memory of the participants (Claessen et al., 2016; Claessen et al., 2017; Kessels, van den Berg, Ruis, & Brands, 2008). To analyze this test, we will use the score of the backward condition of the digit span test for each participant.

Procedure

The participants were recruited from the rehabilitation center De Hoogstraat Revalidatie Utrecht and the rehabilitation department of the University Medical Center Utrecht (the Netherlands). In order to participate in the study patients had to be able to walk independently and were not allowed to suffer from severe aphasia or neglect. The healthy controls were not allowed to have any visual, neurological, psychiatric or mobility problems, or have a history of substance abuse. After the nature of this study was explained and participants agreed to cooperate, a written informed consent had to be signed. For participating in this study a financial compensation was given. The medical ethical committee of the University Medical Center Utrecht (the Netherlands) approved this study. The participants were invited to the rehabilitation center De Hoogstraat Revalidatie Utrecht, where the assessment took place. After the inclusion an informed consent was signed before participating in the research. The study started by participants filling out the Wayfinding Questionnaire (WQ; Claessen et al, 2017). After the questionnaire was filled out the participants were asked to participate in a cognitive screening, which was based on four neuropsychological tasks. These tasks consist of; The Dutch version of the Adult Reading Test (Schmand, Lindeboom, & Van Harskamp, 1992), the Corsi Block-Tapping Task (Corsi, 1972), the Trail Making Test (Reitan, 1992), and the Digit Span (Wechsler, 1997), which were assessed in this exact order. Before each task started the examiner explained the instructions to the participant, so the participants understood the intention of the task. When the cognitive screening was finished, the participants could take a short break. The assessment continued with the VT test. Before each subtask of the VT test the instructions were explained verbally and also appeared on the computer screen to make sure the purpose was clear. During the VT test no breaks were allowed to prevent time differences between watching the route and the subtasks between the participants. After this assessment, the research was completed (Claessen et al., 2017).

Statistical analyses

To test the hypotheses, the Statistical Package for the Social Sciences (SPSS) was used. Before testing the hypotheses, the demographic characteristics were compared for both the patients and control group. A Chi-square test for independence was used to control for gender and education level (Pallant, 2006). This way we can see the reason for the difference in performance between patients who are impaired in route order memory and patients who are not impaired in route order memory (Claessen et al., 2017). To compare the age between the stroke patients who are impaired in route order processing and the stroke patients who are not impaired in route order processing a non-parametric t-test was performed. A hierarchical multiple regression was used to test whether there is a positive effect between visual working memory (independent variable) and visuospatial working memory (independent variable) on route order memory (dependent variable) and a negative effect of verbal working memory (independent variable) on route order memory (dependent variable). To test if there is an effect of the group condition (healthy participants/ stroke patients; independent variable) and to test the three interactions between visual-, visuospatial- and verbal working memory on one hand and condition on route order memory on the other hand, the same hierarchical multiple regression was performed.

In the first model we looked at the effect of the three modalities of working memory (visual-, visuospatial– and verbal working memory) on route order memory for both healthy participants and stroke patients. In the second model we examined the effect of the three modalities of working memory on route order memory for the stroke patients only. In the third and last model we looked at the interaction between the three modalities of the working memory and the stroke patients. During this Multiple regression the scores of the Digit Span backwards, Corsi Block-Tapping task backwards and Scene Recognition task of the patients were used as independent variable and route order was used as a dependent variable.

To investigate if stroke patients who are not impaired in route order memory have a better visual-, visuospatial- and verbal working memory and visual working memory than stroke patients who are impaired on route order memory, three Mann-Whitney U Tests were performed (a Bonferonni correction for multiple testing will be applied). The Mann-Whitney U Test is an alternative for an Independent-Samples t-test (Pallant, 2006). We used a non-parametric technique because the two groups (the group of stroke patients who are impaired on route order memory and the group of stroke patients who are not impaired on route order memory) do not have the same sample size. In the Mann-Whitney U Test visual-, visuospatial- and verbal working memory was used as a test variable (dependent variable) and patients who are impaired and not on route order memory were used as the grouping variable (independent variable). As the hypotheses were tested the assumptions were checked. The first assumption about the level of measurement was met; all variables were measured on a continuous scale. The second assumption of normal distribution, which states that the population who is tested should be normally distributed, was met. We used a histogram to check this. The third assumption about linearity was met as well. A scatterplot was used to check that the relations among the variables were linear (Pallant, 2006). To indicate which stroke patients had an impaired route order memory, the scores of the subtests were rescored to Z-scores, which were based on the means and standard deviations of the control groups. As it is commonplace in neuropsychology, we marked the lowest 5% of the scores as impaired, which has a Z-score lower than -1.64*SD* of the mean of the control group (Claessen et al., 2017). In addition to this the p-values were considered significant when the p-value was $\leq .05$.

Results

Demographics

A total of 137 participants took part in this study. The final study consisted of 78 stroke patients (M = 60.12 years, SD = 12.12) and 59 healthy controls (M = 58.69 years, SD = 9.70). Both groups were about the same age ($t(135) = 0.74$, $p = .46$) and the groups in terms of the distribution for gender is comparable ($\chi^2(1) = 1.79$, $p = .18$). There were twelve participants impaired on the route order task, among which three healthy participants and nine stroke patients. For men, the percentage of impaired on route order memory was non-significantly higher (12.2 %) than for women (4.8 %) ($\chi^2(1) = 2.33$, $p = .13$). At last, the average age of the impaired participants (M = 68.67 years, SD = 10.07) was higher ($t(135) = 3.08$, $p = .003$) than the non-impaired participants (M = 58.62 years, SD = 10.87).

Table 1. *Group Characteristics*

		Age	Education	Visual WM	Visuospatial WM	Verbal WM	*N*(total)	*N*(male)
		M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)		
Control	Intact	57.93 (9.05)	5.61 (0.91)	18.02 (2.22)	8.32 (1.60)	6.30 (1.95)	56	26
	Impaired	73.00 (12.49)	5.33 (0.58)	17.33 (1.53)	6.67 (0.58)	4.00 (1.00)	3	2
	Total	58.69 (9.70)	5.59 (0.89)	17.98 (2.18)	8.24 (1.65)	6.19 (1.98)	59	28
Patients	Intact	59.19 (12.18)	5.28 (1.36)	16.65 (2.44)	7.17 (2.32)	5.17 (1.96)	69	39
	Impaired	67.22 (9.54)	4.89 (1.27)	15.33 (2.47)	6.00 (2.00)	3.78 (1.48)	9	7
	Total	60.12 (12.13)	5.23 (1.35)	16.50 (2.50)	7.04 (2.30)	5.01 (1.95)	78	46

Note. The education level is ranged from 1-7; arranged from a low education to a high education (Verhage, 1964). All values represent raw, non-standardized scores.

Relation between visual, verbal and visuospatial working memory with route order memory

Before testing hypothesis assumptions were tested and met. No substantial deviations from linearity and homoscedasticity were found when inspecting the scatterplot showing the standardized residuals versus the predicted values. The residuals follow approximately a normal distribution when looking at the p-p plot. Only one outlier was found with a standardized residual with an absolute value bigger than 3 (Z_{residual}= -3.60).

The hierarchical multiple regression (in three models) was performed to show the relation between the visual-, visuospatial- and verbal working memory (independent variables) and route order memory (dependent variable). Visual-, visuospatial- and verbal working memory were added in model 1, explaining 17.0%, $F(3, 133) = 9.09$, $p < .001$, of the variance in route order memory. The effect visuospatial working memory in this model is positive but non-significant ($b = 0.12$, $t(133) = 1.64$, $p = .10$). However, the effect of visual working memory on route order memory is positive and significant ($b = 0.14$, $t(133) = 2.39$, $p = .018$) which means that people with higher scores on visual working memory are on average associated with higher scores on route order memory. For model 1, the effect of verbal working memory on route order memory is also positive and significant ($b = 0.15$, $t(133) = 2.13$, $p = .035$). In model 2, we added the group of stroke patients to see if the patients scored lower on these tasks than the control groups. The effect of the patients was added and led to a non-significant improvement ($R^2_{\text{change}} = .009$, $F_{\text{change}}(1, 132) = 1.45$, $p = .23$). Within the sample, the stroke patients scored somewhat lower than the healthy participants, but this difference is non-significant ($b = -0.34$, $t(133) = -1.21$, $p = .23$), which means that we cannot conclude that stroke patients in general score lower on route order memory than healthy participants. Adding the three interaction terms to test the moderate effect of stroke patients on the relations between the three focal predictors on route order memory in model 3 didn’t lead to a significant improvement of the model ($R^2_{\text{change}} = .015$, $F_{\text{change}}(3, 129) = 0.78$, $p = .51$) from which we can conclude that effects are not being moderated (no interaction between predictors), see Table 2.

Table 2. *Relation between visual, verbal and visuospatial working memory with route order memory*

	Model 1			Model 2			Model 3		
Predictors	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
Intercept	6.45	0.13	< .001	6.65	0.21	< .001	6.62	0.23	< .001
Visuospatial working memory	0.12	0.07	.103	0.11	0.07	.138	0.11	0.13	.425
Visual working memory	0.14	0.06	. 018	0.12	0.06	.037	0.21	0.09	.025
Verbal working memory	0.15	0.07	. 035	0.14	0.07	.059	0.07	0.11	.539
Stroke patients				-0.34	0.28	.23	-0.32	0.30	.275
Visuo*Patients							0.01	0.16	.975
Visual*Patients							-0.15	0.12	.206
Verbal*Patients							0.14	0.15	.355
	(R^2= .17, $F(3,133) = 9.09$, $p < .001$)			($R^2_{\text{change}} = .009$, *Fchange* $(1, 132) = 1.45$, $p = .23$)			($R^2_{\text{change}} = .015$, *Fchange* $(3, 129) = 0.78$, $p = .51$)		

Relation between impaired and not impaired stroke patients and working memory

To see if patients who are impaired on route order memory have a better visual and visuospatial working memory, we used the Mann-Whitney U test. This test indicates that non-impaired participants have a better visuospatial working memory (M_{rank} = 71.58) than participants that have an impaired route order memory (M_{rank} = 42.13). The difference is significant even when corrected with the Bonferonni correction, (U = 427.5, z = 2.49, p = .013). Participants who are not impaired on route order memory on average have a better visual working memory (M_{rank} = 70.95) than patients who have an impaired route order memory (M_{rank} = 48.71). This difference is not significant (U = 506.5, z = -1.87, p = .062). Participants who are not impaired on route order memory have a better verbal working memory (M_{rank} = 72.20) than participants who have an impaired route order memory (M_{rank} = 35.58). The difference in mean ranking is significant (U = 349.0, z = -3.09, p = .002). This test revealed that there is a significant difference in the working memory of participants that have an impaired route order memory and participants that do not have an impaired route order memory.

Table 3. *Difference between impaired and not impaired stroke patients in route order memory and the modality of the working memory*

Predictors	Mann-Whitney U	z	p	M_{rank}
Visuospatial working memory	427.5	2.49	.013	
Non-impaired patients				71.58
Impaired patients				42.13
Visual working memory	506.5	-1.87	.062	
Non-impaired patients				70.95
Impaired patients				48.71
Verbal working memory	349.0	-3.09	.002	
Non-impaired patients				72.20
Impaired patients				35.58

Discussion

In this study, we assessed route order memory, by examining its relation to three different aspects of working memory. We used visual-, visuospatial- and verbal working memory as the three aspects of working memory for remembering a route (Baddeley & Hitch, 1974; Knight & Tlauka, 2018). The aim of the study was to broaden the knowledge of route order memory. Which can be implemented in creating compensation training for stroke patients with route order memory impairment or by practitioners treating these patients. We wanted to understand how people remembered the order of a route. Therefore, we examined how the three different working memory aspects contributed to route order memory for healthy participants and stroke patients. Firstly, we hypothesized that the level of visual working memory function is positively related to the level of route order memory. Secondly, we hypothesized that the level of visuospatial working memory is also positively related to route order memory and thirdly, we hypothesized that the level of verbal working memory is negatively related to route order memory. We also expected that stroke patients will on average score lower on route order memory than healthy participants. Lastly, we examine whether the effects of the visual-, visuospatial-, and verbal working memory on route order memory are stronger for stroke patients.

Alongside we also wanted to understand the difference in remembering the order of a route between stroke patients who are impaired in route order memory and stroke patients who do not experience route order memory problems. We hypothesized that stroke patients who do not have an impaired route order memory will on average have a better visual-, visuospatial- and verbal working memory, than stroke patients who have an impaired route order memory. Examining our first hypothesis, in line with our expectations, we found that people with a better visual working memory performed better at our route order memory task. This supports the suggestion that, individuals may use the visuospatial sketchpad in order to remember a route (Baddeley & Hitch, 1974). This is consistent with research from van der Ham, de Zeeuw, and Braspenning (2016), which concluded that route order memory is especially based on spatial factors, instead of temporal properties. Furthermore, we found that people with a better verbal working memory also had a better route order memory. Even though we did not expect this, it seems that verbal working memory does play a role in route order memory. This is in line with previous findings of Knight and Tlauka (2018), who report that all components from the working memory contribute in learning a route. Therefore, a good verbal working memory can contribute to remembering a route. As mentioned before

Baddeley and Hitch (1974) proposed a working memory structure, which included a visuospatial sketchpad and a phonological loop, which included three different types of working memory (visual-, visuospatial- and verbal working memory). Research indicates that both spatial and temporal processes are necessary for successfully remembering a route (van der ham et al., 2010; van der Ham, de Zeeuw, & Braspenning, 2016). Our study support the findings of van der Ham and colleagues (2010) as well as the group study of Claessen et al. (2016), that there is a double dissociation between spatial and temporal aspects in route order memory. As we found in this study both the phonological loop as the visuo-spatial sketchpad are used in route order memory (Meilinger, Knauff, & Bulthoff, 2008; Knight & Tlauka, 2018). We found that healthy participants have a better route order memory than stroke patients. This is in line with research that shows brain-damage affect navigation in a negative way (Caglio, Castelli, Cerrato, & Latini-Corazzini, 2011).

As expected, we found that stroke patients who are not impaired in route order memory have a better visuospatial working memory than stroke patients who are impaired. Although against our expectations this relation was also found for the verbal working memory. We examined that people who are not impaired in route order memory have a better verbal working memory than patients who are impaired. Which is in line with earlier studies showing that all components of the working memory contribute to route order memory (Knight & Tlauka, 2018). This shows that both visuospatial- as well as verbal working memory are necessary to remember a route (Knight & Tlauka, 2018; Meilinger, Knauff, & Bulthoff, 2008).

This study may have some limitations. There were only 9 patients with an impaired route order memory. This small sample size makes it debatable if the results are generalizable to the population who experience route order memory problems. Another feasible limitation was that all participants were recruited in the same revalidation center in Utrecht. Environmental factors, such as that those people lived in a city instead of the countryside could influence the way people navigate. Research indicates that there is a slight benefit in navigation for people who grew up in the countryside in contrast to people who grew up in the city (van der Ham, van der Kuil, & Claessen, under review). As all the participants were recruited from the same rehabilitation center in the city Utrecht, it could be possible that those participants have lived in Utrecht their whole life. However more personal information on where the participants grew up is needed to take the environmental influence in to account. Besides these limitations, the research has a number of strengths. One strength was that this study has a large sample size (*N* = 137) that was matched in age, education level and gender, which promoted the external validity. Another strength is that this study incorporated a new approach to score the route order memory test. This new scoring system is more sensitive for the actual performance quality of the participants, because it gives a better reflection of the order that the participant gives as an answer.

In conclusion, the current study showed evidence that individuals who have a better visual and verbal working memory have a better route order memory. This supports the research that implies that all working memory modalities are utilized during remembering a route (Knight & Tlauka, 2018) as well as that stroke patients who are not impaired in route order memory have a better visuospatial- and verbal working memory than stroke patients who are impaired in route order memory. With this study we provided general information of the contribution of the working memory modality in route order memory. This information gives us a better understanding of the working memory modalities of navigation, particularly the contribution of the working memory modalities in route order memory.

For future directions this study can be used by practitioners who treat stroke patients with route order memory problems or who make training schedules for these patients, by proposing to implement verbal working memory strategies in their compensation training. With the expansion of knowledge of the contribution of working memory modality in route order memory, we can help the development of evidence-based treatment for brain-damaged individuals who have problems remembering a route to live a more independent life.

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