Utrecht University

Which aspects of working memory are being measured with the Corsi Block Tapping Test?

Master thesis Neuropsychology

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Date: 22-3-2021

Make public: yes

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Abstract

Impaired spatial working memory is observed in many neurologic and neuropsychiatric conditions. The Corsi Block Tapping Test is a widely used test to asses spatial working memory, nonetheless it is uncertain whether performance on this task reflects spatial working memory capacity or other forms of working memory. The present study tried to gain insight into the cognitive functions that are being measured with the Corsi Block Tapping Test, and test whether there are any differences to be found within performance with increasing age. We conducted an online study where healthy participants (n=80) performed the Corsi Block Tapping Test, a location memory task, a visual *n*-back task to measure visual working memory and a Digit Span task to measure verbal working memory. Regression analysis were carried out to predict whether performance on the Corsi Block Tapping Test was related to other forms of working memory. Correlations were carried out to estimate the relationships between the various types of working memory and to examine whether there were any effects of age to be found on task performance. Results showed that there was no direct relationship between performance on the Corsi Block Tapping Test and location memory, visual working memory or verbal working memory. This could imply that the Corsi Block Tapping Test measures something different than the other tasks that were included. However more extensive research is needed on a broader and more diverse population. Furthermore, the results evidently presented no age-related change of task performance on all of the administered tasks.

Keywords: Spatial working memory, Corsi Block Tapping Test, ageing, location memory, verbal working memory, Digit Span, visual working memory, *n*-back task

Introduction

Spatial working memory refers to the short-term retention and manipulation of (visual) spatial information. When impaired, this may cause issues in storing previously named locations and could lead to repetitive rechecking (Wojciulik et al., 2001). Impaired spatial working memory is observed in many neurologic and neuropsychiatric conditions, such as traumatic brain injury, stroke, schizophrenia and intellectual disability (Klingberg, 2010). Spatial working memory deficits after brain injury are often seen with visuospatial neglect, and are considered one of the core components of the syndrome (Mort et al., 2003). It is, therefore, important to measure spatial working memory properly, which may help in the selection or improvement of future rehabilitation programs for patients with visuospatial neglect. A widely used task to asses spatial working memory is the Corsi Block Tapping Test (Corsi, 1972). However, it is unclear whether performance on the Corsi Block Tapping Test reflects spatial working memory capacity or (also) other forms of working memory. Which could lead to problems when conducting the task, since it is not evident which cognitive function could be affected. The main objective of this study is, therefore, to gain more insight in the cognitive functions that are measured with the Corsi Block Tapping Test. Insight into the cognitive functions that are measured with the Corsi Block Tapping Test will improve interpretation of task performance. This can help in giving the best possible support to patients suffering from deficits in spatial working memory.

The original Corsi Block Tapping Test consists of nine cubes mounted on a board. The examiner taps a sequence of blocks, which the participant has to repeat subsequently in the correct sequential order. By increasing the length of the sequence, the capacity of the (visuo)spatial working memory can be measured (Kessels et al., 2010). The Corsi Block Tapping Test entails a simple measurement that can be administered quick and easily, however, there are several drawbacks. First, the task may measure multiple aspects, namely remembering spatial locations (i.e. the location of the tapped blocks), but also the order of these locations, which might involve visual working memory (i.e. remembering the pattern). In addition, the task cannot be administered to people with a lateralized attention bias (visuospatial neglect), because they might ignore the blocks on one side. In other words, if someone fails on this task, it is not clear why this is the case and which cognitive function is affected.

To assess which mechanism of spatial or visual working memory is affected, it is therefore useful to have a task that measures purely whether people can remember a location, without reference points and without measuring whether they can remember multiple sequences. To make the task suitable for people with neglect as well, locations should be presented on the vertical meridian (i.e. not on the left and right side). Such a task has already been diminished in several studies in people who suffered from a stroke, and showed that remembering locations is reduced in people with visuospatial neglect after stroke, and related with impaired visual search (Fabius et al., 2020; Ferber & Danckert, 2006; Malhotra et al., 2004, 2005; Pisella et al., 2004; Ravizza et al., 2005; Wansard et al., 2014, 2015).

The main objective of this study is to examine whether performance on the Corsi Block Tapping Test is related to pure location memory, visual working memory, and/or verbal working memory. This will be done by conducting an online study where healthy participants will perform the Corsi Block Tapping Test, a location memory task (Fabius et al., 2020), a visual *n*-back task to measure visual working memory (Jaeggi, Buschkuehl, et al., 2010) and a Digit Span task to measure verbal working memory (Woods et al., 2011). Expectations are that performance on the Corsi Block Tapping Test will relate to location memory because these tasks seem to target the same core cognitive aspects (namely remembering locations). Performance on the Corsi Block Tapping Test is also expected to relate to visual working memory since in both tasks participants use the ability of maintaining visual information for a limited time. In order to be able to indicate the specificity of any relations, it is useful to administer a verbal working memory task as well, which is not expected to relate to the spatial and visual working memory tasks (Kessels et al., 2008). Knowing whether performance on the Corsi Block Tapping Test is related to spatial, visual, and/or verbal working memory provides insight into the underlying functions that are measured.

Second, as it is hypothesized that the Corsi Block Tapping Test is not a 'pure' measure of spatial working memory, and because the task is not suited for neglect patients, the aforementioned location memory task (Fabius, 2020) might be more suitable to measure spatial working memory. To gain more insight in the underlying cognitive functions that are measured with this task, performance on the location memory task will be related with visual working memory and verbal working memory performance.

A third aim is to test whether there are any differences to be found between the task performances with increasing age. Fluid cognitive abilities such as (spatial) working memory are vulnerable to age related decline, and have been shown to be subject to linear decline throughout the adult lifespan, possible from the early twenties (Park et al., 2002; Logie & Maylor, 2009; Johnson et al., 2010). It is, therefore, expected that younger participants will perform better on the various tasks than older participants. However, previous research on the topic of age-related decline were mixed (Ellis et al., 1987; Mandler et al., 1977), and results on the Corsi Block Tapping Test showed only a minimal negative correlation between age and performance (Kessels et al., 2008). If spatial, visual, and verbal working memory are independent working memory components, age might differently affect these components. Assessing the effects of age on performance of each of these tasks is, therefore, informative on whether they measure similar constructs or not. Furthermore, assessing the overall effect of aging on performance leads to more variation on task performances and could help in a better understanding of the relationship between the tasks.

The present study contributes to existing literature by extending the theoretical framework of task performances on various cognitive systems, and help choose the right task when measuring spatial working memory, which may help in the selection or improvement of future rehabilitation programs for patients suffering from deficits in spatial working memory. The present study is also among the first to investigate the combination of spatial working memory, location memory, verbal working memory and visual working memory with these specific tasks on healthy participants with increasing age. The present study also gives insight in the do's and don'ts when conducting an online web-based experiment.

Methods

Procedure

Data was collected via the online platform of Prolific, from 13 to 27 November 2020. Participants executed the experiment at home, or wherever they felt comfortable doing the experiment. The experiment consisted of four tasks: the Corsi Block Tapping Test, location memory task (Fabius et al., 2020), Digit Span (Woods et al., 2011), and the visual *n*-back task (Jaeggi, Buschkuehl, et al., 2010). Tasks were performed in the order as described above. The experiment took about ~45 minutes to complete. Participants who completed all study tasks were compensated with £5.63 at the end of the study. The project has obtained Faculty Ethics Approval from the Faculty Ethics Review Board of Utrecht University (protocol 20-058).

Before the start of the experiment, participants were asked to use one monitor with a minimum screen size of 11.6 inch (25.7 x 14.5cm), to sit at a distance of one arm length from their monitor, make sure they could not be distracted during the study, and to close any other programs on their computer. If they indicated that these criteria were met, the participant was asked to provide informed consent. Then, participants were asked their sex, age (in years), level of education (Verhage, 1964), and handedness**.** To control for different monitor sizes between participants, a calibration task was performed (Li et al., 2020). To calculate the number of pixels per cm and the screen size, participants were asked to place a credit card on the screen and adjust a slider until the line on the screen matched the actual credit card.

Participants

To obtain a sample of participants within a wide age range, different age bins were used as inclusion criterion. The age bins chosen were 10 bins of 7 years, from 18 till 81 years old, with every bin having 8 participants (80 in total). Other inclusion criteria were normal or corrected-to-normal vision, being able to use a computer without any assistive software (e.g. programs designed to increase readability for the visually impaired), no self-reported neurological disorders, and having the English language as their primary language.

Tasks

Corsi Block Tapping Test

The digital Corsi Block Tapping Test (Kessels et al., 2008, 2010) is a task which measures visuospatial short term and working memory. Throughout the task, nine blue squares are presented at fixed positions. Per trial, two to nine squares turn yellow for 1000 ms, one by one in a varying sequence. At the end of the sequence, the participant has to recall the sequence by clicking on the squares with their computer mouse (i.e. forward tapping task). In the second part, the participant has to recall the sequence in reversed order (i.e. backwards tapping task). The length of the first sequence is two, and increases to a maximum of nine. Each sequence length is presented twice. The task ends either if the participant is not able to correctly reproduce the sequence in two consecutive trials, or after 16 trials. The outcome measure per part (i.e. forward and backward) is the longest sequence remembered by the participant (i.e. span, range 1 - 9). The task takes approximately 10 minutes to complete.

There are several similarities between the traditional Corsi Block Tapping Test and the digital version, like identical proportions, similar size of the blocks/squares, similar size of the board, and the possibility to customize flash timing to equalize the timings of administration of the digital version with any version of the Corsi Block Tapping Test (Brunetti et al., 2014; Claessen et al., 2015). Differences between the versions include a better control of the Inter-Stimulus presentation timings in the digital version. It is for the examiner particularly difficult to control the temporal accuracy of the manual tapping, who can be slower or faster depending on several factors, such as changing the finger used for tapping, the amplitude of hand and arm movements and the positions of the limbs in the interlapping intervals. Results of the digital versions of the Corsi Block Tapping Test and the traditional version show that these are highly comparable, and is an accessible and user-friendly version of the task (Brunetti et al., 2014; Claessen et al., 2015).

Location Memory Task

This task measures location memory (Fabius et al., 2020). The trial sequence is depicted in Figure 1. A trial starts with a central fixation point that is displayed for 800-1000 ms. Then, a dot (red, 0.3°; Target 1) is presented for 500 ms, in half of the trials above the fixation point and in the other half below. A second dot (blue, 0.3°: Target 2) is presented 2000 ms after the offset of Target 1, and is vertically displaced with respect to the original location of Target 1. The participant has to indicate whether Target 2 is presented above or below the original location of Target 1. The response of the participants is recorded with a keypress of the upwards or downwards arrow keys. The distance between the locations is controlled by a staircase procedure; Accelerated Stochastic Approximation (Kesten, 1958). In the first three trials, the displacement size on the next trial (d_{k+1}) is given by:

$$d_{k+1} = d_k - \frac{3.6}{k}(Z_k - 0.8)$$

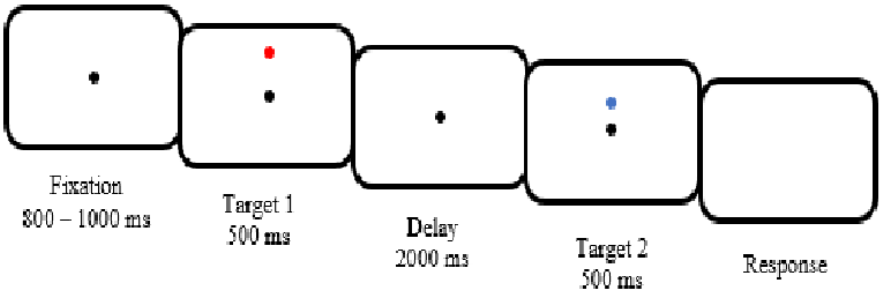
where d_k is the displacement size used in the current trial, 3.6 is the staircase constant, *k* is the trial number, Z_k is 1 when a correct response was provided in the current trial or 0 when an incorrect response is provided, and 0.8 is the desired accuracy level. On the remaining trials, the displacement size is adjusted differently, taking into account the number of switches that had been made, i.e. the switch from a series of correct answers to an incorrect answer or vice versa:

$$d_{k+1} = d_k - \frac{3.6}{2 + m_{switch}}(Z_k - 0.8), k > 3$$

where m_{switch} is the number of switch trials. T1 and T2 are never closer than 1.2° to either the screen edge or the fixation point. The task consists of 32 trials, preceded by 4 practice trials in which a distance of 4.8° is used. The outcome measure in this task is the mean distance of the final 10 trials in visual degrees, assuming a viewing distance of 51 cm (i.e. arm length). The task takes approximately 5 minutes to complete.

Figure 1

Trial Sequence of the Location Memory Task



Note. A trial starts with a fixation point that is presented for 800 – 1000 ms after which Target 1 (red dot) is presented for 500 ms. Target 2 (blue dot) is presented 2000 ms after the offset of Target 1, and is vertically displaced with respect to the original location of Target 1. The participant has to indicate whether Target 2 is presented above or below the original location of Target 1. Responses of the participants are recorded with a keypress of the upwards or downwards arrow keys. The actual background was grey, here portrayed as white.

Digit Span

This task measures (verbal) working memory capacity (Woods et al., 2011). On each trial the participant is presented with a series of digits appearing one at a time for 1000 ms in the centre of the screen (e.g., 4, 5, 2, 6). In the forward task, the participant has to recall the digits in the order they appeared. In the backward task, the participant has to recall the digits in the reversed order. After the digits have been presented, the participant has to enter the answer by clicking on the numbers (these appear on the screen) in the order they were presented. By default, participants have to go through at least 2 practice until a correct response terminates the practice session and advances to the test session. If no correct response is given within 8 practice trials, the task terminates. There are 14 trials in total and 2 digits are presented in the first trial. The number of digits in the next trial increases with one if the response is correct, stays the same if the response is incorrect, and decreases with one if there are two incorrect responses in a row. The outcome measure per part (i.e. forward and backward) is the longest sequence remembered by the participant (i.e. span, range 1 - 15). The task takes approximately 10 minutes to complete.

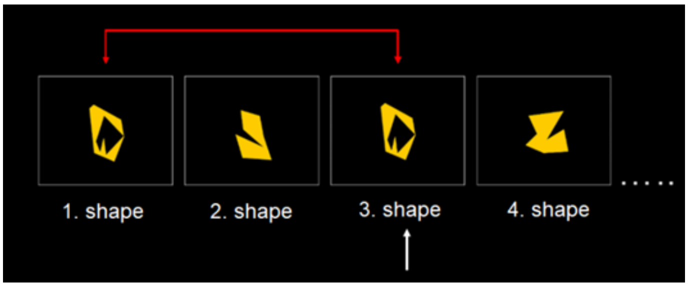
Visual N-Back Task

This task measures visual working memory (Jaeggi, Buschkuehl, et al., 2010). The trial sequence is depicted in Figure 2. The participant is presented with a sequence of ambiguous shapes. Shapes are presented for 500 ms, one by one, separated by 3000 ms. The participant has to decide if the current stimulus is the same as the one presented *n* trials ago. The *n* could be 1 trials, 2 trials, 3 trials, or 4 trials. The higher the number of *n*, the more difficult the task. After instructions, the participant receives 10 trials of practice per level of *n* tested. Each level of *n* is tested in a single block consisting of 20 trials, resulting in four experimental blocks. Eight different shapes are used. Of the 20 experimental trials per block, 6 present a target and 14 do not. The outcome measure is d-prime (d'), computed as the proportion of hits minus the proportion of false alarms averaged over all *n*-back levels. Where the higher the value, the better the targets were overall correctly distinguished from nontargets. The task takes approximately 20 minutes to complete.

Figure 2

Trial Sequence of the Visual N-Back Task

2 - Back



Note. The participant is presented with a sequence of ambiguous shapes. Shapes are presented for 500 ms, one by one, separated by 3000 ms. The participant has to decide if the current stimulus is the same as the one presented *n* trials ago. In this example, the *n* is 2 trials. Figure derived from Jaeggi, Studer-Luethi, et al. (2010).

Statistical Analysis

Demographic Characteristics and Overall Test Results

All analyses were carried out in IBM SPSS Statistics version 26 (IBM Corp., 2019). Descriptive statistics were used to report demographic characteristics and test scores. If the participants ended the experiment prematurely and therefore not completed a task as it was meant to, they were excluded from analyses on that specific task. Data points that were 3 standard deviations above or below the mean on one or more outcome measures were considered outliers and excluded from analyses on that specific task.

Independent Predictors of Performance on the Corsi Block Tapping Test

To estimate which aspects of working memory are measured with the Corsi Block Tapping Test, two linear regression analysis were carried out. One with the forward span as dependent variable, and one with the backward span as dependent variable. The outcome measures of the other three tasks (i.e. mean distance of the final 10 trials of the location memory task, d' over all *n*-back trials, and the forward and backward span of the Digit Span) were entered as independent variables.

Several assumptions have been evaluated prior to interpreting the results of the regression analysis. These include the assumptions of linearity, homoscedasticity, independence, and normality. An a priori power analysis was conducted using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). The statistical test was 'Linear multiple regression: Fixed model, R^2 increase', with an effect size of 0.15, an alpha of 0.05, and a power of 0.80. The total number predictors and the number of tested predicters were set to four (i.e. the outcome of three tests were used in the regression model. A total sample of 77 participants was required.

Relationships between Visual Working Memory, Location Memory, and Verbal Working Memory

To estimate how visual working memory, location memory, and verbal working memory were interrelated, six Spearman correlations were carried out between all possible combinations of the location memory ask, *n*-back task, digit span forward, and digit span backward. The interpretation of the value of Spearman's rho (r_s) were described as followed: .00 -19 "very weak", .20-39 "weak", .40-.59 "moderate", .60-.79 "strong" and .80- 1.0 as "very strong" (Field, 2018). Significant results (alpha level was set to .05) were followed up with Holm-Bonferroni-corrected post-hoc tests.

Relationships between Age and Visual Working Memory, Location Memory, and Verbal Working Memory

To estimate if there were any effects of age on the various types of working memory and if these effects were comparable for the various types of working memory, six Spearman correlations were carried out. Here the results on the Corsi Block Tapping Test, location memory task, Digit Span, and *n*-back task were correlated with the age of the participants. Significant results were followed up with Holm-Bonferroni-corrected post-hoc tests.

For all Spearman correlations, an a priori power analysis was conducted, considering a two-tailed test (i.e. 'Correlation: Bivariate normal model'), with an alpha of 0.05, effect size of 0.30, and a power of 0.80. Results showed that a total sample of 84 participants was required.

Results

Demographic Characteristics and Overall Test Results

Data has been collected from a total of 80 participants, aged 19 to 80 (M = 46.58, SD= 18.13), of which 48 female (60.0%), and an average level of education of 6.33 (SD = 0.93, range = 3 – 7). Of these 80 participants, none have been excluded from all analyses since every participant has completed at least one of the tasks accordingly. Scores on the four tasks, the number of participants who were excluded due to outliers or incompletion of a task are shown in Table 1, and violin plots of all the outcome measure are shown in Figure 3.

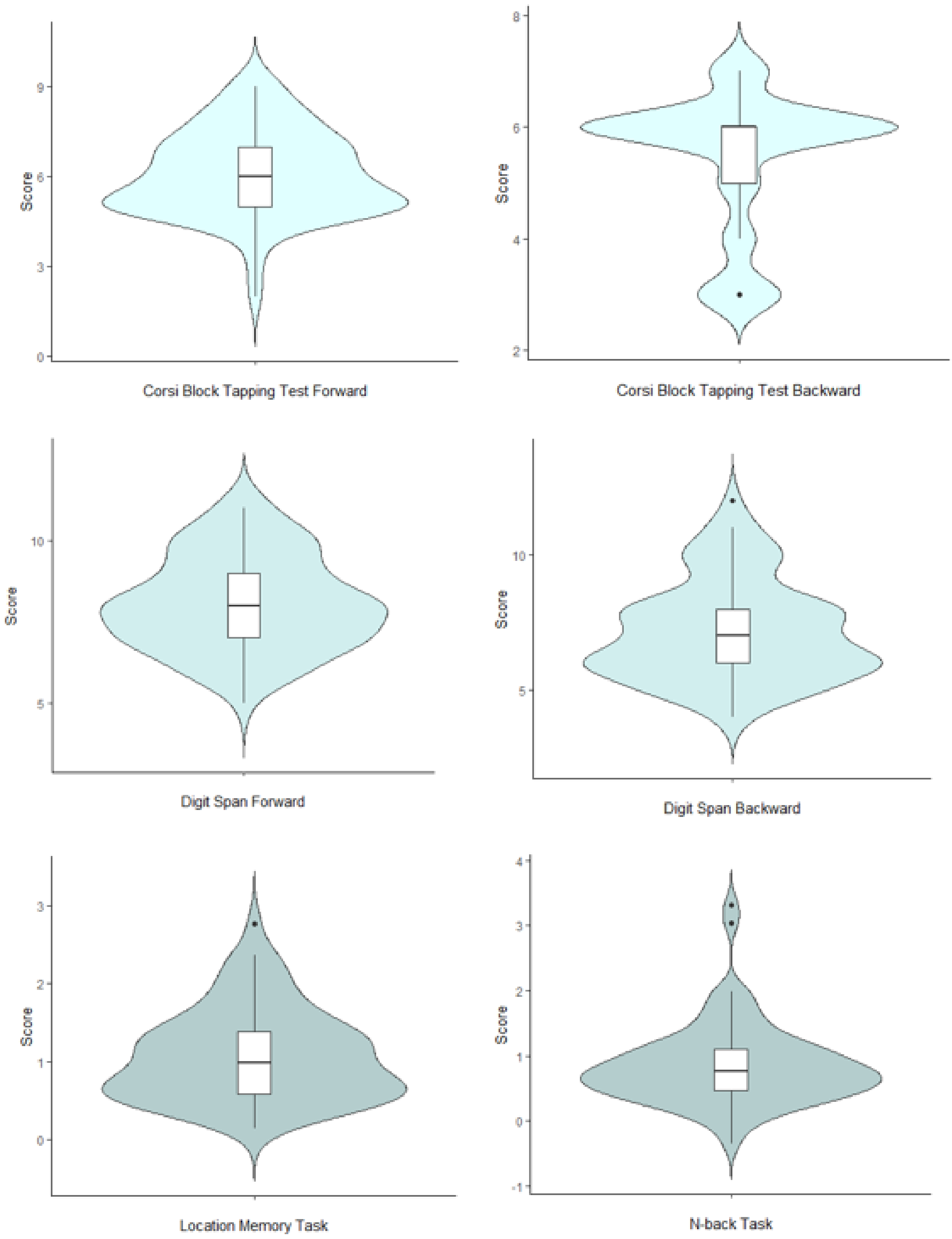
Table 1

Number of Included Participants, Number of Participants that were Outliers or did not complete the Task, Means, Standard Deviations, Minimum and Maximum Scores of the Outcome Measures on the Corsi Block Tapping Test, Location Memory Task, Digit Span and N-Back Task

Outcome	*n*	*n* (outliers)	*n* (incompletion)	Mean (*SD)*	Min	Max
Corsi Block Tapping Test Forward (span)	69	0	11	6.09 (*1.43)*	2	9
Corsi Block Tapping Test Backward (span)	64	0	16	5.44 (*1.25*)	3	7
Location memory task (mean distance in visual degrees of last 10 trials)	72	3	5	1.07 *(0.58*)	0.14	2.77
Digit span forward (span)	74	4	2	8.07 (*1.45*)	5	11
Digit span backward (span)	73	4	3	7.15 (*1.84*)	4	12
n-back task (d')	74	0	6	0.85 (*0.62)*	-0.35	3.31

Figure 3

Violin Plots of all Outcome Measures on the Corsi Block Tapping Test, Location Memory Task, Digit Span and N-Back Task



Independent Predictors of Performance on the Corsi Block Tapping Test

To estimate which aspects of working memory are measured with the Corsi Block Tapping Test Forward, a linear regression analysis was performed. Prior to interpreting the results of the regression analysis, several assumptions were evaluated. First, stem-and-leaf plots and boxplots indicated that each variable in the regression was normally distributed, and free from univariate outliers. Second, inspection of the normal probability plot of standardized residuals as well as the scatterplot of standardized residuals against predicted values indicated that the assumption of normality, linearity and homoscedasticity of residuals were met. Third, Mahalanobis distance did not exceed the critical χ^2 for $df = 3$ (at $\alpha = .05$) of 7.82 for any cases in the data file, indicating that multivariate outliers were not of concern. Fourth relatively high tolerances for all predictors in the regression model indicated that multicollinearity would not interfere with the ability to interpret the outcome of the linear regression analysis.

The regression model in which the Forward span of the Corsi Block Tapping Test was used as a dependent variable, including performance at the Digit Span, location memory task and the *n*-back task as potential predictors, was not significant, $R^2 = .10$, adjusted $R^2 = .03$, $F(4, 57) = 1.49$, $p = .221$ (Table 2).

Table 2

Unstandardized (B) and Standardized (β) Regression Coefficients, and Squared Semi-partial Correlations (sr^2) for Each Predictor in a Regression Model Predicting Corsi Block Tapping Test Forward

Variable	*B* [95% CI]	β	sr^2	*p*
Location memory task (mean of last 10 trials)	0.02[-0.59, 0.62]	0.01	.00	.960
Digit span forward (span)	0.23[-0.03, 0.49]	0.25	.24	.079
Digit span backward (span)	0.07[-0.16, 0.31]	0.10	.08	.537
n-back task (d’)	0.07[-0.53, 0.66]	0.03	.03	.824

Note. $n = 58$. CI = confidence interval.

* $p < .05$.

To estimate which aspects of working memory are measured with the Corsi Block Tapping Test Backward, a linear regression analysis was performed. Prior to interpreting the results of the regression analysis, several assumptions were evaluated. First, stem-and-leaf plots and boxplots indicated that each variable in the regression was normally distributed, and free from univariate outliers. Second, inspection of the normal probability plot of standardized residuals as well as the scatterplot of standardized residuals against predicted values indicated that the assumption of normality, linearity and homoscedasticity of residuals were met. Third, Mahalanobis distance did not exceed the critical χ^2 for $df = 3$ (at $\alpha = .05$) of 7.82 for any cases in the data file, indicating that multivariate outliers were not of concern. Fourth relatively high tolerances for all predictors in the regression model indicated that multicollinearity would not interfere with the ability to interpret the outcome of the linear regression analysis

The regression model accounted for a significant 17% of the variability for the Corsi Block Tapping Test Backward, $R^2 = .17$, adjusted $R^2 = .11$, $F(4, 56) = 2.70$, $p = .040$ (*Table 3*). The individual predictors were examined further and indicated that the *n*-back task was the only significant predictor, There was a negative relationship between the Corsi Block Tapping Test Backward and the *n*-back task, which means that a lower performance on the *n*-back task related to better results on the Corsi Block Tapping Test. Due to this unexpected finding, and because prior expectations were that a positive relationship between the task would occur, another regression analysis was carried out with a different outcome measure used for the *n*-back task, namely the ‘DV’. The ‘DV’ is the total of hits minus the total of false alarms, divided by the number of experimental blocks run in the *n*-back task, this model was non-significant (Appendix A).

Table 3

Unstandardized (B) and Standardized (β) Regression Coefficients, and Squared Semi-partial Correlations (sr^2) for Each Predictor in a Regression Model Predicting Corsi Block Tapping Test Backward

Variable	*B* [95% CI]	β	sr^2	*p*
Location memory task (mean of last 10 trials)	0.03 [-0.50, 0.56]	0.02	.02	.901
Digit span forward (span)	0.01 [-0.25, 0.26]	0.01	.01	.950
Digit span backward (span)	0.07 [-0.15, 0.29]	0.10	.08	.533
n-back task (d’)	-0.85 [-1.40, -0.30]*	-0.46	-.39	.003

Note. $n = 56$. CI = confidence interval.

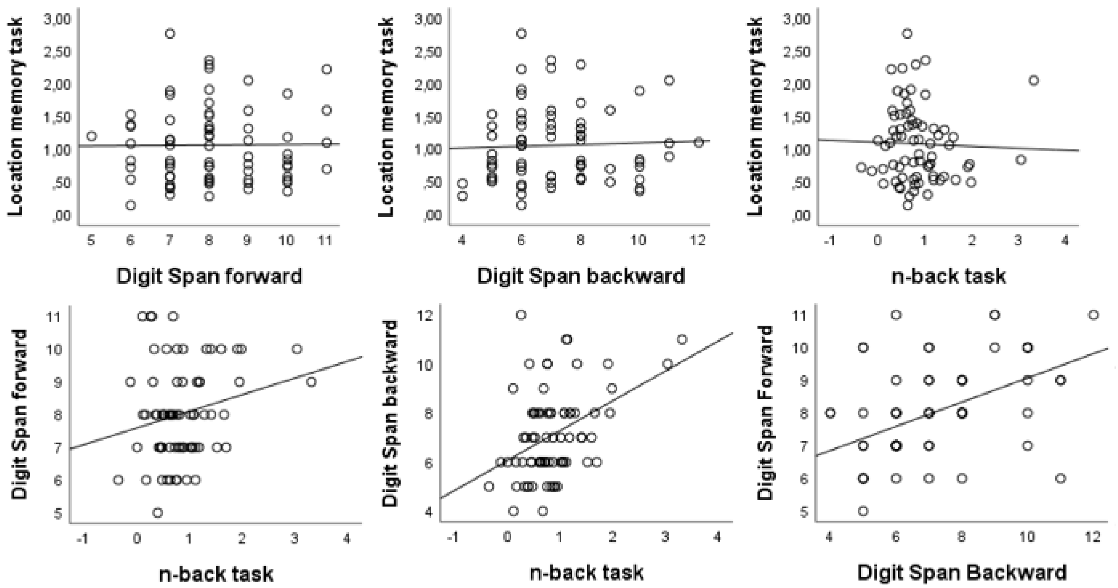
* $p < .05$.

Relationships between Visual Working Memory, Location memory, and Verbal Working Memory

Results of the Spearman correlations between performance at the location memory task, Digit Span and *n*-back task are depicted in Figure 4. There was a moderate positive correlation between performance on the Digit Span forward and the Digit Span backward, r_s = .45, *p* < .001, *n* = 73, indicating that both variables tend to increase in response to each other. There also was a weak positive correlation between performance at the *n*-back task and the Digit Span Backward, r_s = .36, *p* = .002, *n* = 72, indicating that both variables also tend to go up in response to one another, however the relationship is not very strong. There were no significant correlations between the location memory task and *n*-back task, r_s = -.09, *p* = .450, *n* = 71, location memory task and Digit Span Forward, r_s = -.00, *p* = .993, *n* = 70, location memory task and Digit Span (Backward) r_s = .07, *p* = .56,0 *n* = 70, and between the *n*-back task and Digit Span Forward r_s = .15, *p* = .212, *n* = 72.

Figure 4

Scatterplots of all Correlations between the Location Memory Task, Digit Span and N-Back Task



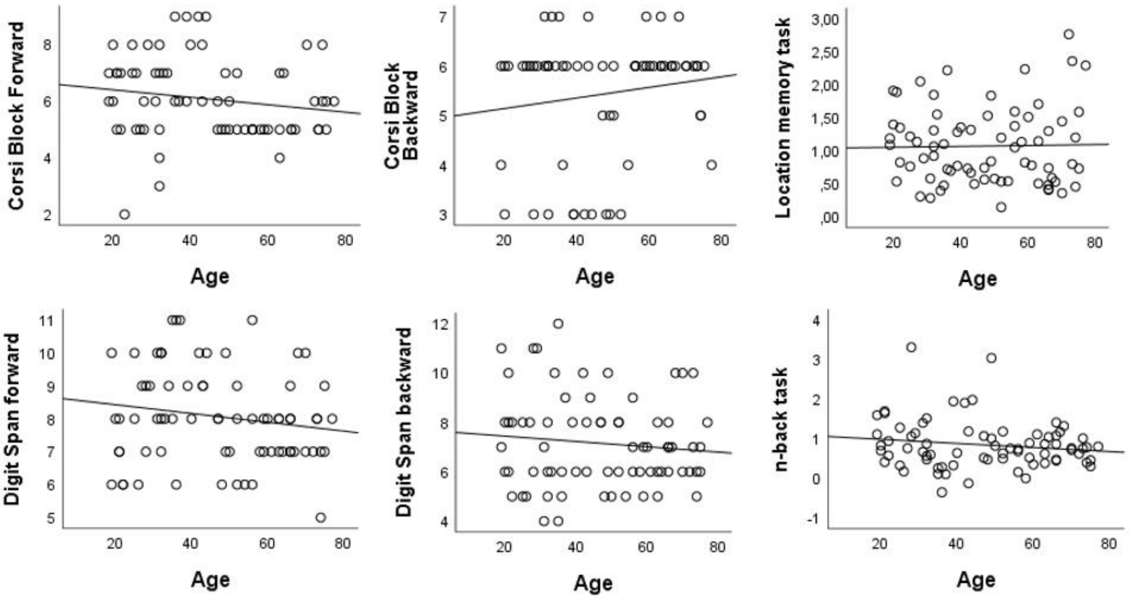
Relationships between Age, Spatial Working Memory, Visual Working Memory, Location Memory, and Verbal Working Memory

There were no significant correlations between age and performance at the Corsi Block Tapping Test Forward, r_s = -.22 , *p* = .070 , *n* = 69, age and the Corsi Block Tapping Test Backward, r_s = .80 , *p* = .528 , *n* = 64, age and the location memory task, r_s = -.05, *p* =

.689 , *n* = 72, age and the Digit Span Forward, r_s = -.14, *p* = .236 , *n* = 74 , age and the Digit Span (Backward), r_s = .-.07, *p* = .553 , *n* = 73, and between age and the *n*-back task r_s = -.12, *p* = .298 , *n* = 74 (Figure 5).

Figure 5

Scatterplots of all Correlations Between Age and Corsi Block Tapping Test, Location Memory Task, Digit Span and N-Back Task



Discussion

The aim of this study was to gain more insight into the cognitive functions that are measured with the Corsi Block Tapping Test, to check if the location memory task (Fabius et al., 2020) was a more suitable task to measure spatial working memory, and test if there were any differences to be found on task performance with increasing age. This has been done by conducting an online study where healthy participants performed the Corsi Block Tapping Test, location memory task, Digit Span, and visual *n*-back task.

Our main results on the independent predictors of performance on the Corsi Block Tapping Test Forward showed no direct relationships between spatial working memory, location memory (as measured with the location memory task), verbal working memory (as measured with the Digit Span), and visual working memory (as measured with the *n*-back task). The Backward span of the Corsi Block Tapping Test showed a negative relationship with visual working memory (as measured with the *n*-back task), which in this case means that a lower performance on the *n*-back task related to better results on the Corsi Block Tapping Test. This finding is contradictory, since it was expected that a better performance on spatial working memory (as measured with the Corsi Block Tapping Test) would be positively related to better performance on location memory (as measured with the location memory task since both tasks seem to target the same core cognitive aspects (namely remembering locations), and would be positively related to visual working memory (as measured with the *n*-back task) because in both tasks participants use the ability of maintaining visual information for a limited time. Since the finding of the negative relationship between the Corsi Block Tapping Test Backward and the *n*-back was unexpected, an extra analysis was carried out with a different outcome measure used for the *n*-back task as suggested by the original study of Jaeggi et al. (2010). Results here showed no relationship between spatial working memory (as measured with the Corsi Block Tapping Test Backward), location memory (as measured with the location memory task), verbal working memory (as measured with the Digit Span), and visual working memory (as measured with the *n*-back task). Possibly, the unexpected negative relationship was a coincidental finding. This could mean that the Corsi Block Tapping Test measures something different than the other tasks that were included. The assumed components of location memory and visual working memory were not related to performance on the Corsi Block Tapping Test, in contradiction with the expectations.

Second, as it was hypothesized that the Corsi Block Tapping Test was not a 'pure measure of spatial working memory, and because this task was not suitable for neglect patients, the location memory task (Fabius et al., 2020) was compared with the Digit Span and *n*-back task to gain more insight in the underlying cognitive functions that are measured with this task. This task is also a possible candidate to measure location memory in patient groups, and is therefore useful to gain more insight into this task. Results showed that performance at the location memory task was not related to performance at a visual working memory and verbal working memory task. There was a moderate positive relationship between the forward and backward span of the Digit Span and a weak positive relationship was found between the *n*-back task and the backward span of the Digit Span. This finding is in line with past reports of a weak association between *n*-back performance and performance on other working memory tasks including reading span, complex span tasks, and the (verbal) Digit Span (Kane et al., 2007; Oberauer, 2005). This is in contrast with the study of Miller et al. (2009) who showed no correlation between *n*-back performance and the Digit Span backward at each of the 0-, 1-, 2- and 3-back loads. It is important to mention that in the latter study a verbal form of the *n*-back was used, were participants had to remember a certain letter for *n* trials, not a sequence of ambiguous shapes as in this study. One potential explanation for the relationship between the *n*-back and Digit Span backward may be that, in the current study, both tasks were presented visually, whereas the Digit Span is normally presented aurally. This could prime participants to use a mental imagery strategy rather than a verbal strategy. To see if a significant correlation still emerges between the *n*-back and the Digit Span, it would be best to conduct the Digit Span aurally.

In terms of the overall effect of aging on task performance, the results clearly showed no age-related decrease of task performance, on all of the administered tasks. This finding is somewhat in line with the findings of Kessels et al. (2008) who observed only a minimal negative correlation between age and performance on the Corsi Tapping Test Backward and no significant correlation between age and performance on the Corsi Tapping Test Forward in their older sample. The same applies for the study of Park et al. (2002) who also observed small age effects in a large sample of participants also including younger adults (ages 20 to 92). In contrast, Moffat et al. (2001) concluded that spatial working memory is markedly impaired by the aging process and Thomas et al. (2012) showed age-related deficits across all visual spatial working memory components. The present results supports the suggestion that task performance on cognitive functions such as spatial working memory, location memory, verbal working memory and visual working memory are not reduced negatively with increasing age. Results showed no sign of a possible ceiling effect, indicating that the tasks were challenging across all ages. Since this study was conducted with only healthy participants it could have led to less variation in the results. It would therefore be interesting to repeat this study again with a population with more variation, for example with patients suffering from deficits in spatial working memory.

When performance of the participants in this present study is compared to that of other (earlier) studies, who conducted (at least) one or multiple of the same tasks, it shows that the participants in this present study performed better on the Corsi Block Tapping Test, Digit Span, and *n*-back task but worse on the location memory task. Performance in this study on the Corsi Block Tapping Test (Forward span: 6.09, Backward span: 5.44) was better compared to performance in the study of Brunetti et al. (2014: Forward span: 5.68, Backward span: 4.99) in which a tablet version of the Corsi Block Tapping Test was used on healthy adults. Participants in this study on the location memory task (mean:1.07) were worse in spatial discrimination compared to that of the original study of Fabius et al. (2020: mean: 0.54) compared to the healthy control group. This could be due to the setting in which the task was conducted, where the present study was conducted fully online in comparison to a controlled setting in the study of Fabius et al. (2020). Participants could suffer from distractions when conducting the task at home, therefore leading to a (possible) decreased performance. Another possibility why these differences in performance were found, could be related to the viewing distance of the participants. One of the most critical issues for web-based online psychophysical experiments is how to control for stimulus geometry given the unknown viewing distance of participants (Li et al., 2020), something which wasn't fully controlled for in this present study. Performance in this study on the Digit Span (forward span: 8.07, backward span: 7.15) was significantly better compared to the visual condition in the study of Olsthoorn et al. (2014: forward span: 6.07, backward span: 5.28) who compared native and non-native Dutch speakers on four digit-span tasks with varying modality (visual/auditory) and direction (forward/backward). Participants in this study on the *n*-back task (mean of d': 0.85) were better in identifying if the current stimulus was presented *n* positions back in the sequence compared to the original study of Jaeggi et al. (2010: mean of d': 0.45) who tested a healthy student population. The results in this present study also support a well-documented effect of direction, with the forward tasks generally resulting in longer spans than the backward tasks (Ramsay & Reynolds, 1995).

Limitations

There are some limitations to this study. Some of these limitations were related to the online component of this study. First, what was most notable from gathering the data online was the fact that not every participant followed all the task instructions accordingly. This was most prominent on the Corsi Block Tapping Test Backward, where 16 participants were excluded because they tried to complete the task as if it were the forward span. This happened despite being given clear instructions and a practice trial with performance feedback. There was no possibility to control for this since participants executed the tasks remotely, with no option to directly communicate with the participant when conducting the experiment, data was received when the participant had 'completed' their experiment.

With the use of prolific, we were able to gather participants from all age groups, but it is never certain that the age someone has chosen on the website is really their age. So this could lead to a false representation of the age groups for the population.

Performance of the tasks could also have been different when this study was conducted in an experimental setting instead of at home. When conducted in a controlled lab setting, participants are more likely to follow all the task instructions accordingly and are able to ask questions when something is unclear about the experiment. There is also no way for the participants to 'cheat' since the examiner is right there. In the current study, some extreme scores (*n* = 4 on forward span, *n* = 4 on backward span) were removed on the Digit Span because they were 3 standard deviations above the mean. It is possible that these participants wrote down the numbers resulting in the maximum score on both of the spans, which seems unimaginable, with an average working memory capacity varying from 2 to 9 for the forward span, and from 2 to 8 for the backward span (Olsthoorn et al., 2014).

Another limitation is the sample size in this study, on average the sample size is relatively small, with an average of *n* = 64 in each condition, thus (possibly) leading to being an underpowered study. The sample used was on average highly educated, with an average of 6.33 on Verhage (1964)'s level of education, this homogeneity is not representative of the general population, but rather results from recruiting a sample on the online platform of prolific. On the other hand, highly educated participants represent a population where frequently used neuropsychological tests are less sensitive in detecting early decline in cognition (Ardila et al., 2000).

Finally, elderly people who are capable of using a computer and performing experiments online may be less affected in terms of cognition compared to elderly people who are no longer capable in doing this. Meaning that the present study could already have a selection of cognitively healthy elderly people, which may not fully represent the current population of elderly.

Conclusion

The present study tried to gain more insight into the cognitive functions that are being measured with the Corsi Block Tapping Test. Results showed that there was no direct relationship between the performance on the Corsi Block Tapping Test and that of tasks for location memory, verbal working memory, and visual working memory. This implies that the Corsi Block Tapping Test measures something different than the other tasks that were included. What this is exactly, should be researched more broadly and with a more diverse population group. This could help in the future development of rehabilitation programs for patients suffering from deficits in spatial working memory, for example a new rehabilitation technique that focuses specifically on spatial working memory for patients suffering from neglect. Other results demonstrated that the location memory task of the original study of Fabius et al. (2020) measures another cognitive function in itself rather than visual working memory or verbal working memory. In terms of the overall effect of aging on task performance, the results evidently presented no age-related change of task performance on all of the administered tasks. When conducting an online study there are multiple factors that could have an impact on the results, but shouldn’t be a reason to believe that the found results aren’t valid. It would therefore be interesting to do this experiment (in some form) again in a clinical setting with healthy participants as a control group, and for example patients suffering from deficits in spatial working memory, to verify the found relationships in a more broad and diverse population group.

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Appendix A

Independent Predictors of Performance on the Corsi Block Tapping Test

Since the finding of the negative relationship between the Corsi Block Tapping Test Backward and the *n*-back was unexpected, an extra analysis was carried out with a different outcome measure used for the *n*-back task as suggested by the original study of Jaeggi et al. (2010). To estimate which aspects of working memory are measured with the Corsi Block Tapping Test Backward, a linear regression analysis was performed. Prior to interpreting the results of the regression analysis, several assumptions were evaluated. First, stem-and-leaf plots and boxplots indicated that each variable in the regression was normally distributed, and free from univariate outliers. Second, inspection of the normal probability plot of standardized residuals as well as the scatterplot of standardized residuals against predicted values indicated that the assumption of normality, linearity and homoscedasticity of residuals were met. Third, Mahalanobis distance did not exceed the critical χ^2 for $df = 3$ (at $\alpha = .05$) of 7.82 for any cases in the data file, indicating that multivariate outliers were not of concern. Fourth relatively high tolerances for all predictors in the regression model indicated that multicollinearity would not interfere with the ability to interpret the outcome of the linear regression analysis.

The regression model in which the Backward span of the Corsi Block Tapping Test was used as a dependent variable, including performance at the Digit Span, location memory task and the *n*-back task as potential predictors, was not significant, $R^2 = .04$, adjusted $R^2 = -.04$, $F(4, 53) = 0.523$, $p = .719$ (Table A1).

Table A1

Unstandardized (B) and Standardized (β) Regression Coefficients, and Squared Semi-partial Correlations (sr^2) for Each Predictor in a Regression Model Predicting Corsi Block Tapping Test Backward

Variable	*B* [95% CI]	β	sr^2	*p*
Location memory task (mean of last 10 trials)	0.19 [-0.38, 0.76]	0.10	.10	.504
Digit span forward (span)	-0.13 [-0.35, 0.10]	-0.18	-.16	.266
Digit span backward (span)	0.07 [-0.15, 0.29]	0.10	.09	.543
n-back task (DV)	0.74 [-0.20, 0.35]	0.08	.07	.590

Note. $n = 53$. CI = confidence interval.

* $p < .05$.