Unravelling the role of cognitive mechanisms in visuoconstruction: Rey Osterrieth Complex Figure reconsidered

Master thesis Neuropsychology

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Abstract

Background. Visuoconstruction is the ability to visualize an object or a picture as a set of parts and then to reproduce the original from these parts. It is implied that visuoconstruction is determined by multiple cognitive factors. To gain a more in-depth understanding of visuoconstruction, the Rey-Osterrieth Complex Figure (ROCF) was used. We investigated whether visuoconstruction is a unitary concept or whether it comprises the combination of other cognitive functions. Further, we examined whether drawing strategies of patients are related to performances on other cognitive tasks.

Methods. One hundred and twenty-three neurologic patients were selected from the Neuropsychology database of the University Medical Centre Utrecht (UMCU). Stepwise multiple regression analyses were performed to assess the contribution of visuoperception, visual motor transformation and executive functions in visuoconstruction. Mann-Whitney *U* tests were used to assess whether patients with an impaired performance in proposed underlying components of drawing used a less efficient drawing strategy than patients with unimpaired performance.

Results. Performances on executive functioning tasks did not impact ROCF performance, while performances on a visuoperception task and visual motor transformation task modestly impacted ROCF performance. Less efficient drawing strategies in the copy condition of the ROCF were related to impaired performances on working memory, inhibition and visual motor transformation measures. When drawing from memory no relationship was found.

Conclusion. Our results suggest that visuoconstruction is a unitary concept. When copying the ROCF, we found the drawing strategy to be related to performance on working memory, inhibition and visual motor transformation tasks.

Keywords: Cognition, visuoconstruction, Rey Osterrieth Complex Figure, cognitive mechanisms, drawing strategy

Introduction

Visuoconstruction can be described as the ability to visualize an object or picture as a set of parts and then to reproduce the original from these parts (Mervis, Robinson, & Pani, 1999). It is a key cognitive function in everyday life such as making a bed, buttoning shirts and drawing (Mervis et al., 1999). An impaired visuoconstruction ability is associated with a decline in the performance of instrumental activities of daily living, such as driving (Gallo, Rebok, & Lesikar, 1999). Patients with diverse neurological disorders including Alzheimer's disease (Berry, Allen, & Schmitt, 1991), Mild Cognitive Impairment (Kasai et al., 2006), Parkinson's disease (Grossman et al., 1993), vascular dementia (Cherrier, Mendez, Dave, & Perryman, 1999) and mild head injury (Leininger, Gramling, Farell, Kreutzer, & Peck, 1990) often present with impaired visuoconstructional skills.

Visuoconstruction as a concept was first described by Kleist in 1934 and called constructional apraxia (CA). Kleist defined CA as the inability of patients to integrate perceptual information and motor processes. As a consequence, patients with CA are unable to make purposeful actions even though their senses and motor capacity are intact (Benton, 2000, p.117). The term visuoconstruction is now used more loosely and is often applied to describe patients who have difficulty with copying or constructing objects regardless of the presence or absence of underlying cognitive deficits (Walsh, 1987, p.227). Since multiple cognitive functions are involved in visuoconstruction, it is suggested that visuoconstruction is not unitary in nature (Carlesimo, Fadda, & Caltagirone, 1993; Possin, Laluz, Alcantar, Miller, & Kramer, 2011). For instance, Grossman et al. (1993) found that visuoconstruction in patients with Parkinson's disease is multifactorial, including executive functioning, visual perception and motor functioning. Another study by Ávila et al. (2015) showed that working memory and cognitive flexibility (components of executive functioning) are crucial for good performance on visuoconstructional tasks, demonstrating that these functions are intricately linked to planning and visuoconstruction. Adequate visuoconstruction seems to be the result of multiple cognitive functions, making it difficult for clinicians to decide to which cognitive concept poor performance should be attributed.

There are numerous tests that can be used to assess visuoconstruction in patients. The Rey-Osterrieth Complex Figure (ROCF) (Osterrieth, 1944) is a commonly used test in clinical practice (Spreen & Strauss, 1998). In this test, patients are asked to copy a complex geometric figure (copy condition). Depending on the administration procedure, patients can then be asked to immediately recall the figure and/or recall the figure from memory after a delay (often 20 minutes). In the delayed condition, incidental visual memory is measured because patients are not forewarned. Visuoconstruction tasks such as the ROCF require diverse cognitive processes including attention, concentration, visual perception, fine motor skills and components of executive functioning (Freeman et al., 2000; Schreiber, Javorsky, Robinson, & Stern, 1999; Shin, Park, Park, Seol, & Kwon, 2006; Somerville, Tremont, & Stern, 2000). This makes the ROCF a very sensitive, but non-specific test. One way of trying to improve clinicians' understanding of a patient's behaviour, therefore, has been to use quantitative as well as qualitative methods. The most frequently used quantitative method is the Meyers and Meyers scoring system (MQSS) (Meyers & Meyers, 1995). This system divides the figure into 18 elements and looks at the presence and accuracy of each element. In a study of left-brain damaged stroke patients using a piecemeal drawing approach, Binder (1982) showed that they sometimes manage to perform adequately. This suggests that the quantitative scoring system might not be comprehensive enough to evaluate patients' performances thoroughly as the disorganized drawing approach, possibly caused by an impairment, is not captured by the quantitative scoring system. This suggests that studying qualitative aspects might be valuable. Preliminary work done by Osterrieth in 1944 (Corwin & Bylsma, 1993), further developed by Boelema, Ruis and Van Zandvoort (2015), indicates that the same seven drawing strategies are used when copying or drawing the ROCF from memory. They found drawing strategy 1 to be the most efficient and strategy number 7 the least efficient (Table 1).

Table 1. *Efficient and inefficient drawing strategies used during copying or recalling the ROCF* (Boelema et al., 2015; Osterrieth, 1944)

Drawing strategies	
Efficient	**Not efficient**
1. Starting with the central rectangle, adds details in relation to the whole figure	4. Specific subcomponents are copied without clear organisation
2. Starting with a detail or subcomponent, finishes rectangle and adds details	5. Details are copied without an organisational structure
3. Starting with the contour of the figure, then adds internal details/ draws from left to right or top to bottom	6. Draws a similar object (boat or house)
	7. Scribbling

To be able to copy a complex figure, different steps need to be performed (Figure 1). First, the person needs to look at the complex figure. By making automatic as well as voluntary eye movements, the figure and spatial relationships are analysed. In order to adequately explore the figure, cognitive control is required to direct voluntary eye movements. The Frontal Eye Field (FEF) in the cortical region and the superior colliculus (subcortical) control voluntary eye movements (Paus, 1995; Schiller, True, & Conway, 1980). Then the person needs to prepare the drawing plan (for which the representation of visual information is needed). This plan is made by segmenting the figure into parts (production strategy), followed by selecting and ranking the parts to enable reproduction in a logical sequence (contingent planning) (Van Sommers, 1989). When performing these steps, short term memory (visuospatial sketchpad) is used. The visuospatial sketchpad, a part of the working memory, holds and manipulates visuospatial information (Baddeley & Hitch, 1994). The drawing is then transformed into a motor program. While executing the drawing plan, the person needs to check the accuracy of the drawing (Grossi & Trojano, 1999, pp.441-450). When drawing from memory, the semantic system is activated after hearing the verbal instruction. The person then retrieves the visual representation from the long-term visual memory instead of looking at the figure (Guérin, Ska, & Belleville, 1999). Thereafter, the drawing process involves the same cognitive components (Figure 1). During drawing, bottom-up and top-down processes can be used (Kosslyn & Koenig, 1992). Bottom-up processes are used for spatial properties, which include categorical relations (the spatial relationship between objects), coordinate relations (the metric relationship between objects) and spatiotopic mapping. Spatiotopic mapping enables the person to locate objects in space and within a reference frame (Guérin et al., 1999). Top-down processes (involve controlled as well as automatic processes) can be used for the properties of a stimulus and for directing attention to different parts of a stimulus (Kosslyn & Koenig, 1992). On a neural basis, adequate drawing requires the activation of a wide neural network. A symptom-lesion study by Biesbroek et al. (2014) found the superior temporal, frontal, posterior parietal and middle occipital cortices of the right hemisphere to be involved in ROCF performance. Another study with focal brain-damaged patients, found both hemispheres to be involved in ROCF performance (Chechlacz et al., 2014).

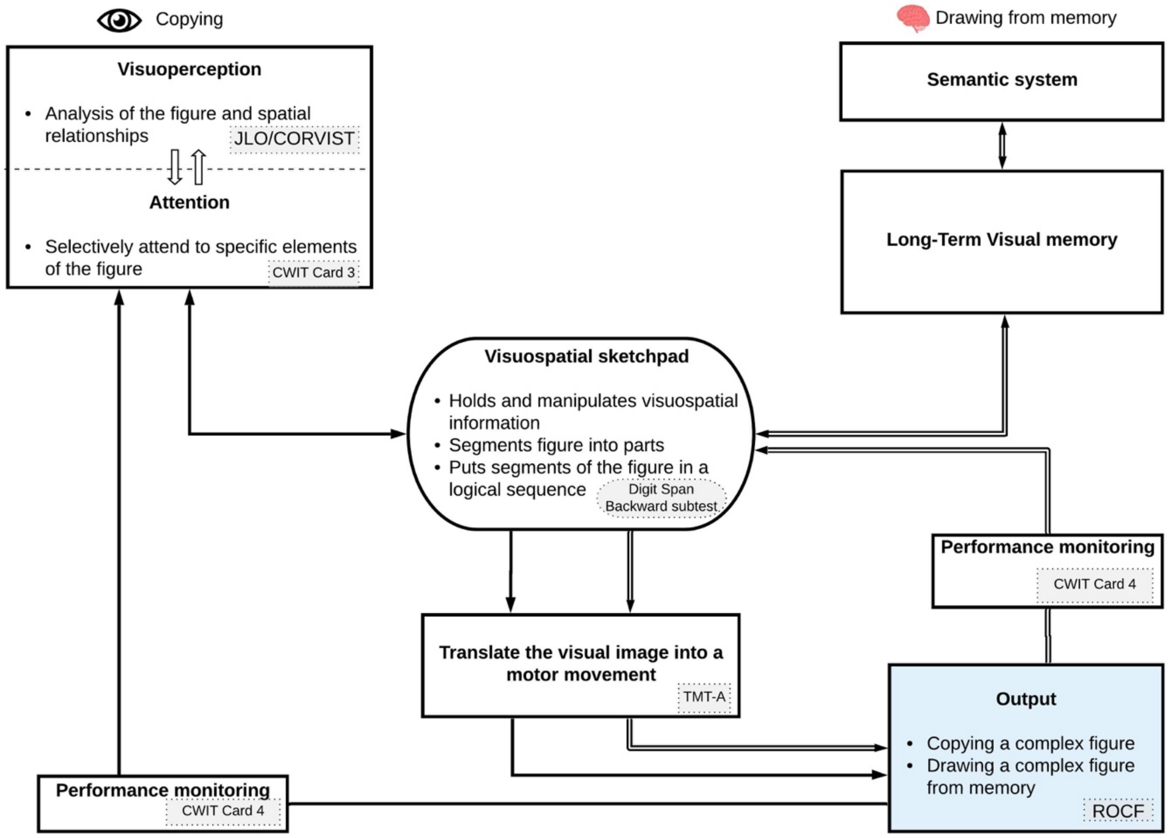

Figure 1. A simplified cognitive model of copying and drawing complex figures from memory. The figure is created based on elements of Van Sommers' (1989), Roncato, Sartori, Masterson, & Rumiati's (1987), Kosslyn and Koenig's (1992), Guerin et al.'s (1999) model. It is a simplified model representing the cognitive processes involved in copying and drawing complex figures from memory. Single arrows are the steps involved in copying. Double arrows are the steps involved in drawing from memory. Performance monitoring during copying involves visual feedback and shifting attention. Performance monitoring during drawing from memory is internal, checking whether the output is in accordance with the original goal. The grey boxes with the name of neuropsychological tests are measures that represent and assess the main cognitive components of copying and drawing from memory. JLO; Judgement of Line Orientation; CORVIST, Cortical Vision Screening Test; CWIT, Colour Word Interference Test; TMT- A, Trail Making Test- Part A; ROCF, Rey Osterrieth Complex Figure.

Based on the above review, it implies that visuoconstruction is determined by multiple factors. The main aim of the study is, therefore, to gain a more in-depth understanding of visuoconstruction using the ROCF. We investigated whether visuoconstruction can be used as a unitary concept or whether it (just) comprises the combination of multiple cognitive functions. We expected that visuoconstruction as a construct is a combination of different cognitive functions. Accordingly, we expected that poor visuoperception, poor executive functions and visual motor transformation difficulties will negatively impact ROCF performance. The second aim of the study was to investigate whether evaluating the drawing strategy could provide additional diagnostic information. Since drawing appears to involve multiple cognitive components, we wanted to know whether the drawing strategies identified by Boelema et al. (2015) and Osterrieth (1944) reflect cognitive impairments in the different underlying cognitive components. We expected patients with cognitive deficits in visuoperception, executive functions or visual motor transformation to use a less efficient drawing strategy than patients without cognitive impairments in these cognitive functions.

Methods

Participants

Patients for the study were drawn from the Neuropsychology database of the Department of Neurology and Neurosurgery at the University Medical Centre Utrecht (UMCU). This database holds records of neurologic patients who were referred for a neuropsychological assessment at the hospital's outpatient clinic. The database was established in 2010 and is constantly updated since. Only the data from 2015 was taken into account since this is the moment neuropsychologists began to evaluate patients on their drawing strategy when performing the ROCF. Inclusion criteria included: (a) complete data on the ROCF (outcome score and drawing strategy), (b) no indication for underperformance (malingering) and (c) no missing data on specific neuropsychological tasks (see measures). If eligible patients had undergone a cognitive- re-examination, only the data of the first neuropsychological report was taken into account, so only first-ever assessments were included.

Measures

The Judgement of Line Orientation (JLO) and/or Cortical Vision Screening Test (CORVIST), Digit Span Backward test (subtest of the WAIS-IV), Trail Making Test- Part A (TMT-A) and Colour Word Interference Test (CWIT) were used to represent and assess the cognitive functions that are involved in executing the individual steps of copying and drawing a complex figure from memory (ROCF) (Figure 1). To measure patients' ability to perceive stimuli and to analyse spatial relationships the JLO and/or CORVIST were used. The third stimulus card of the CWIT was used to measure the ability to selectively attend to specific information of a stimulus while ignoring irrelevant information. The Digit Span Backward test was used to study patients' ability to manipulate information (put segmented parts in a logical sequence). Being able to transform a visual image into a motor movement was measured by using the TMT-A. Card four of the CWIT was used to examine the ability to constantly switch the attention between different stimuli.

Visuoperception tasks (JLO (Benton, Hamsher, Varney, & Spreen, 1983) / *CORVIST* (James, Plant, & Warrington, 2001)). A short form of the JLO was used to measure visuospatial perception. Before starting the test, patients got five practice items. The mistakes made during the practice items were corrected by a neuropsychologist. No further feedback was given during the test. Patients indicated which two lines from the array had the same spatial orientation as the two presented lines above the array. There was no time limit. One point was given for every correct trial (i.e. both lines were identified correctly). No point was given for one or no correct answer. The score on the short form was converted to the long form score by multiplying the total score by two. The maximum possible score was 30 points. The higher the score, the better the performance. The CORVIST, a screening task, was also used to assess visuoperception. Nine of the ten subtasks were administered. Visual acuity (symbol acuity) was assessed first. Thereafter higher-order visual problems were assessed.

Visual motor transformation task (*TMT-A*; Reitan, 1955). Patients were given a piece of paper with twenty-five circles. A line between the circles had to be drawn as fast as possible in ascending order. It was not allowed to let go of the paper with a pencil. The total time (in seconds) that was needed to complete the task was noted. If a mistake was made, patients were immediately corrected by a neuropsychologist. Errors indirectly contributed to the performance on the task because they cost extra time to correct. The more time needed, the worse the performance.

Executive functioning is a broad cognitive function. In the current study, the findings of Miyake et al. (2000) were used to operationalize executive functioning. They say that executive functioning is composed of three related, yet distinct, executive functions including inhibition (inhibiting dominant responses), shifting (switching between tasks or mental sets/cognitive flexibility) and updating (updating and monitoring working memory contents). Three tasks were used to measure these components of executive functioning.

Inhibition task (*CWIT – stimulus* card; Delis, Kaplan, & Kramer, 2001). Patients were given a stimulus card containing the words “red”, “green” and “blue” which were printed incongruently in red, green or blue ink. They named the colour of the ink as fast as possible and tried to make no mistakes. The completion time was noted. A longer time needed to complete the task indicated a worse performance.

Cognitive flexibility task (*CWIT – stimulus card* 4; Delis et al., 2001). Patients got a stimulus card with the name of colours (“red”, “green” and “blue”) that again were printed incongruently. Some of the words were presented in a box. They were asked to name the colour of the ink in which the words were printed (like in the third condition). Whenever a word was presented in a box, patients needed to read the word aloud. They completed the task as quickly as possible without trying to make mistakes. The more time needed, the worse the performance.

Working memory task (*Digit Span Backward* test *(WAIS-IV)*; Wechsler, 2008). Digit series were read to the patients after which they were asked to repeat the number sequences backwards. The number sequences increased in length. Each item consisted of two trials (two sequences of the same length). If patients correctly repeated one or two same length digit series the next item was administered by the neuropsychologist. The number sequence of every following item was extended by one digit. If both trials (same digit span length) were repeated incorrectly the task was stopped. Every item was scored, and a sum score was calculated. A higher score indicates better performance.

The ability to copy and draw a complex figure from memory was assessed with the ROCF. In the copy condition, patients were asked to copy a complex line figure as accurately as possible on a blank piece of paper. In the delayed condition, patients were asked to draw the same figure once again but from memory. A 20-minute delay was used. There was no time limit. Performance on the task was evaluated by dividing the figure into 18 elements and assessing the presence and accuracy of every unit. A maximum score of 36 points could be obtained. The higher the outcome score on the ROCF the better the performance (Osterrieth, 1944). The used drawing method was observed by a neuropsychologist and classified according to the different drawing strategies identified by Osterrieth (1944) and Boelema et al. (2015).

Design

For the current study a cross-sectional observational design was used.

Procedure

All patients were referred by a neurologist or neurosurgeon for a neuropsychological assessment. The neuropsychological assessment was done by a neuropsychologist in the setting of standard clinical care; therefore, no informed consent was needed. During the assessment, the above-mentioned tests were administered as part of a larger test battery. The total test administration time took approximately two hours. The neuropsychological assessment procedures described by Lezak et al. (2004, pp. 100-132) were followed.

Analysis

Data preparation. Prior to the statistical analyses, the raw neuropsychological test scores were corrected (for age, sex and education) when normative data was available. Depending on the scoring procedure of the test, the adjusted scores were subsequently converted into percentiles or scaled scores (except for the dependent variable). The independent variables were dichotomized, being scored as "unimpaired" for patients with unimpaired performance on a cognitive task and "impaired" for patients with impaired performance. "Impaired" was defined as a performance of 1 or more standard deviation(s) (*SD*) below the mean of the normative sample. Performances ≥ -1 *SD* the mean of the normative sample were defined as "unimpaired". In the case of percentile scores, the 16th percentile (-1 *SD*) marked the cut-off point. Patients with a performance below the 16th percentile were assigned to the impaired group and patients with a performance ≥ 16th percentile were assigned to the unimpaired group. In the case of the scaled scores ($M = 10$, $SD = 3$), a scale score of 7 (-1 *SD*), marked the cut-off point. Patients with a performance ≤ 7 were assigned to the impaired group and patients with a scale score > 7 were assigned to the unimpaired group.

ROCF. The raw test scores in the copy and delayed condition were adjusted for age and education level. Normative values by Caffara et al. (2000) were used to calculate the adjusted scores. The adjusted scores were used in the analyses.

Visuoperception *(JLO/CORVIST)*. Exploratory analyses revealed that excluding patients that did not complete the JLO would reduce the sample size considerably. As a smaller sample size reduces the statistical power, we decided to create a composite score for visuoperception. By making a composite score, we were able to get a general measure of the impact of visuoperception on ROCF performance. Patients were divided into two groups based on their performance on the JLO/CORVIST or their performance on both tasks. For the JLO the normative values of Benton (1983) were used to correct the raw scores for age and gender and to transform the scores into percentile scores. The CORVIST has no normative values (normal healthy subjects are expected to show a 100% correct performance). In clinical practice, a 95% correct performance is accepted. In the present study patients' neuropsychological reports, as stored in the electronic patient database of the hospital, were read if the CORVIST was a part the patients' test battery and more than 1 mistake was made. The neuropsychological reports were consulted to see if the mistakes were made on one subtest or on multiple subtests. If more than one mistake was made on one of the subtests, the neuropsychologists' evaluation was read to see whether visuoperception was evaluated as impaired or unimpaired. Based on their evaluation patients were assigned to the unimpaired group or the impaired group in the current study.

Visual motor transformation *(TMT-A)*. Raw scores were adjusted for age and education level using the normative values of Schmand, Houx and de Koning (2012). The scores were converted into percentiles.

Inhibition and cognitive flexibility *(CWIT stimulus card 3 and stimulus card 4)*. Raw scores on the CWIT were transformed into scaled scores based on the normative values of the D-KEFS Colour Word Interference Test. The scaled contrast score inhibition/switching *vs* combined colour naming and word naming and scaled contrast score inhibition/switching *vs* inhibition were used in the current study.

Working memory *(Digit Span Backward test)*. Normative scores of the WAIS-IV were used to correct the raw scores for age and to transform the scores into scaled scores. The scaled scores were converted to percentiles.

Statistical analyses. All statistical analyses were performed using IBM SPSS Statistics 25 (IBM Corp, 2017). Pearson correlations were computed (one-tailed) to explore the relationships between the dependent and predictor variables and to check for multicollinearity between the predictor variables (correlation coefficient > .80; Field, 2015, p.325). Thereafter, a stepwise multiple regression analysis was performed to investigate the amount of variance in ROCF performance (copy condition) that can be explained by executive functions, visuoperception and the ability to transform visual information into motor movements. The three components of executive functioning (inhibition, cognitive flexibility and working memory) were used as unique predictors of visuoconstruction. All predictors were made categorical by creating dichotomous variables (unimpaired *vs* impaired). The unimpaired group served as a reference group. The minimum sample size required was assessed using the rule of thumb of Tabachnick and Fidell (2007), (104 + the number of predictor variables). Before performing the multiple regression analysis, the continuous dependent variable (adjusted scores on the ROCF) was checked for normality. The adjusted scores on the ROCF were nonnormally distributed (negatively skewed distribution, tested with the Shapiro-Wilk test). Therefore, the adjusted scores on the ROCF were reversed and then normalized with log transformation. Pre-conditions for applying the linear model were assessed. The assumptions of linearity, multicollinearity, independent errors and normally distributed errors were met. As multiple regression is very sensitive to outliers, the data was checked for outliers by looking at the standardized residuals. One patient had a standard residual above three. The original neuropsychological report in the electronic patient database was consulted and performance under the cut-off score of a symptom validity test (Rey Fifteen-Item test) was found. This indicated that the performances of this patient were biased. Based on these findings, it was decided to exclude the patient from the analyses. Another stepwise multiple regression analysis was performed to investigate the amount of explained variance in ROCF performance (delayed condition) by executive functions, visuoperception and the ability to transform visual information into a motor movement. The adjusted outcome score on the ROCF (continuous dependent variable) was checked for normality (Shapiro-Wilk test) and the assumption of normality was met. Assumptions (linearity, multicollinearity, independent errors and normally distributed errors) were checked and met. One outlier was found yet not removed from the analysis as there was no apparent reason for doing this.

Mann-Whitney *U* tests were used to determine whether deficits in visuoperception, visual motor transformation and/or executive functions influence the drawing process when copying and drawing from memory. The drawing strategy was the dependent variable and the cognitive functions (translating visual information into motor movements, visuoperception, executive functions) were the independent variables (dichotomous variables). The assumptions of a Mann-Whitney *U* test were checked. Not all the distributions of data had the same shape. Nonetheless, the test was still used as this is the best method to preserve the ordinal nature of the drawing strategies. In the current study, there were no patients that used drawing strategies 6 and 7. So only drawing strategies 1 to 5 were taken into account. Group differences were assessed with left-sided one-tailed tests, since we didn't expect patients with a cognitive deficit to use a more efficient drawing strategy than patients without a cognitive deficit in visuoperception, visual motor transformation and executive functioning. For the statistical tests, the alpha level was set at 0.05.

Results

Patient characteristics. This study included 123 patients out of the population of 358 as shown in Figure 2. These patients visited the outpatient clinic between January 2015 and February 2018. Only the first neuropsychological assessment of every patient was kept, resulting in the exclusion of 160 duplicate cases. As indicated, one patient was excluded from the analyses due to performance below the cut-off score of a symptom validity test. Demographic and clinical characteristics of the study sample are presented in Table 2.

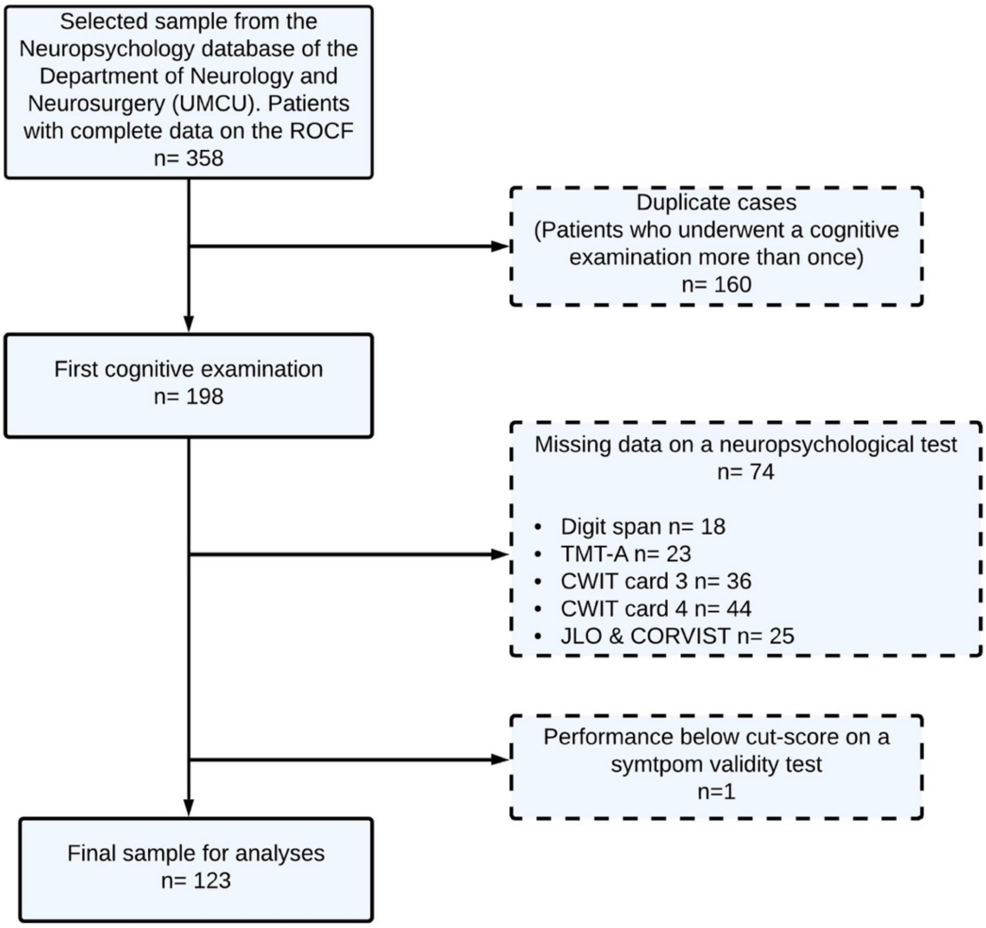

Figure 2. Flow diagram inclusion procedure participants

Table 2. *Demographic characteristics of the study sample (N=123)*

Descriptive statistics of demographic variables and clinical diagnosis	
Demographic variables	
Age in years (M ± SD) [a]	51.6 ± 15.6
Range	18-81
Sex, n (%) male [b]	66 (54%)
Education level, n (%) [c]	
Lower (1-5)	64 (52%)
Higher (6-7)	59 (48%)
Clinical diagnosis [d]	
Brain tumour, n (%)	30 (24.4%)
Left hemisphere, n (%)	13 (43.3%), vermis: 1
Epilepsy, n (%)	19 (15.5%)
Left hemisphere, n (%)	6 (31.6%)
Neurodegenerative disease, n (%)	18 (14.6%)
Cognitive disorders, etiology unknown, n (%)	11 (8.9%)
Mental health problems, n (%)	10 (8.1%)
Cerebrovascular disease, n (%) [e]	8 (6.5%)
Left hemisphere stroke, n (%)	1 (33.3%)
Autoimmune disease, n (%)	6 (4.9%)

Traumatic brain injury, n (%)	4 (3.3%)
Left hemisphere, n (%)	0 (0%)
No cognitive disorders, n (%)	8 (6.5%)
Other, n (%)	9 (7.3%)

[a] M= mean and SD= standard deviation are reported for continuous data. [b] n= number of individuals and %= percentage are reported for categorical data. [c] Education level was based on Verhage's classification system (1 = less than primary school, 7= university degree). [d] Diagnosis was made after the neuropsychological assessment by a neurologist. [e] Cerebrovascular disease included small vessel disease (SVD), cerebral autosomal dominant arteriopathy (CADASIL), ischemic stroke and haemorrhagic stroke.

Copying the ROCF. Pearson correlation analyses were performed to explore the relationships between performance on the cognitive tasks (visuoperception task, executive functioning tasks, visual motor transformation task) and ROCF performance. One-tailed Pearson correlations were used because we expected impaired executive functions, visuoperception and visual motor transformation abilities, to be related to poorer ROCF performance. In Table 3, the correlations between the five predictors and ROCF performance are depicted. ROCF performance was moderately related to visuoperception r (121) = .304, p <.001. Impaired visuoperception performance (as opposed to unimpaired visuoperception) was related to a poorer ROCF performance. Visual motor transformation performance was weakly related to ROCF performance r (121) = .180, p = .023. Inhibition abilities were also weakly related to ROCF performance r (121) = .186, p = .040. Impaired performance on the visual motor transformation task and inhibition task were related to poorer ROCF performance. Working memory r (121) = .038, *ns,* and cognitive flexibility r (121) = .059, *ns,* were not related to ROCF performance.

Table 3. *Correlation analyses between ROCF performance in the copy condition and the five predictor variables*

	Visuo-construction ROCF	Working memory Digit Span test	Visuoperception JLO and/or CORVIST	Visual motor transformation TMT-A	Inhibition CWIT card 3	Cognitive flexibility CWIT card 4
Visuoconstruction ROCF[a]	-					
Working memory Digit span test[b]	.038	-				
Visuoperception JLO and/or CORVIST[b]	.304**	.073	-			
Visual motor transformation TMT-A[b]	.180*	.148	-.083	-		
Inhibition CWIT card 3[b]	.186*	.220**	.100	.021	-	
Cognitive flexibility CWIT card 4[b]	.059	-.090	-.033	-.060	-.158*	-

**p* <.05, ***p* <.01. One-tailed significance tests were used. [a] The adjusted scores on the dependent variable ROCF were reversed and log transformed. A higher score on the dependent variable (ROCF performance), therefore, indicates a worse performance. [b] Categorical variable (unimpaired vs impaired). The unimpaired group served as reference group.

A stepwise multiple regression analysis was used to assess the amount of variance in ROCF performance that is explained by performance on executive functioning tasks, a visuoperception task and a task that measures the ability to transform visual information into motor movements. Visuoperception was a significant predictor, t (120) = 3.774, p <.001 and accounted for 9.3% of the variance in visuoconstruction, R^2= .093, F (1, 121) = 12.35, p = .001. Being able to transform visual information into motor movements was also a significant predictor, t (120) = 2.429, p = .009 and accounted for an additional 4.2% of the variance in visuoconstruction, ΔR^2= .042, ΔF (1, 120) = 5.90, p = .017. In combination, visual motor transformation and visuoperception explained 13.5% of the variance in visuoconstruction, R^2 = .135, adjusted R^2= .121, F (2, 120) = 9.38, p < .001. The effect size was medium (f^2=.16) (Cohen, 1988). The three components of executive functioning were excluded from the final regression model. The regression coefficients and probability value (*p)* for each predictor on each step of the stepwise multiple regression analysis are shown in Table 4.

Table 4. *Linear model of predictors of visuoconstruction measured using ROCF (copy condition)*

	B	*SE B*	*ß*	*p*
Step 1				
Constant	.662	.025		p<.001
Visuoperception[a]	.204	.058	.304	p<.001
Step 2				
Constant	.628	.028		p<.001
Visuoperception[a]	.215	.057	.322	p<.001
Visual motor transformation[a]	.121	.050	.207	p=.009

R^2= .093 for Step 1 (*p* <.05); ΔR^2= .042 for Step 2 (*p* <.05). Adjusted ROCF scores in the copy condition. The adjusted ROCF scores were reversed and log transformed (base 10). High scores indicate a poorer performance. [a] Categorical variable (unimpaired vs impaired). Unimpaired group served as reference group.

One-tailed Mann-Whitney *U* tests were performed to test whether patients with cognitive deficits in visuoperception, executive functions and visual motor transformation differ in the copying drawing strategy from patients without these cognitive deficits. Analysis indicated that there was a significant difference in the drawing process between patients with an impaired performance on the working memory task (*n* = 36) and patients with an unimpaired performance on the working memory task (*n* = 87), *U* = 1217, *z* = -2.038, *p* = .021, *r* = -.18. Patients with impaired performance on the working memory task used a less efficient drawing strategy (*Mdn (median)* = 3) than patients with an unimpaired performance on the working memory task (*Mdn* = 2). There was also a difference in the used drawing strategy between patients with impaired performance on the visual motor transformation task (*n* = 32) and patients with an unimpaired performance (*n* = 91), *U* = 1099.50, *z* = -2.159, *p* = .016, *r* = -.19. Patients with an impaired performance on the visual motor transformation task used a less efficient drawing strategy (*Mdn* = 3) than patients with an unimpaired performance (*Mdn* = 2). A difference in drawing strategy between patients with an impaired performance on the inhibition task ($n = 14$) and patients with unimpaired inhibition abilities ($n = 109$) was found, $U = 533.50$, $z = -1.920$, $p = .028$, $r = -.17$. The unimpaired patient group used a more efficient drawing strategy (*Mdn* = 2) than the impaired patient group (*Mdn* = 3). No significant difference was found between patients with visuoperceptual difficulties (*Mdn* = 2.50 $n = 22$) and patients without visuoperceptual difficulties (*Mdn* = 2, $n = 101$) in the way they copied the complex geometric figure, $U = 920.50$, $z = -1.320$, $p = .094$, $r = -.12$. No difference was found between patients with an impaired performance on the cognitive flexibility task (*Mdn* = 2, $n = 20$) and patients with an unimpaired performance on the cognitive flexibility task (*Mdn* =2, $n = 103$) in the copying process, $U = 988.50$, $z = -.299$, $p = .383$, $r = -.03$.

Drawing from memory. Relationships between ROCF performance in the delayed condition and performance on the cognitive tasks (visuoperception, executive functions, visual motor transformation) were studied using Pearson correlation analyses. A weak relationship was found between visuoperception performance and ROCF performance, r (121) = -.165, $p = .034$. Impaired visuoperceptual abilities were related to poorer ROCF performance. The ability to transform visual information into motor movements was also weakly to moderately related to ROCF performance, r (121) = -.218, $p = .008$. An impaired performance on the visual motor transformation task was related to poorer ROCF performance. Performance on the working memory task r (121) = -.084, *ns*, inhibition task r (121) = -.145, *ns*, and cognitive flexibility task r (121) = .073, *ns*, were not significantly related to ROCF performance. The correlation coefficients between the five predictor variables and ROCF performance in the delayed condition are shown in Table 5.

Table 5. *Correlation analyses between ROCF performance in the delayed condition and the five predictor variables*

	Visuo-construction ROCF	Working memory Digit Span test	Visuo-perception JLO and/or CORVIST	Visual motor transformation TMT-A	Inhibition CWIT card 3	Cognitive flexibility CWIT card 4
Visuoconstruction ROCF[a]	-					
Working memory Digit span test[b]	-.084	-				
Visuoperception JLO and/or CORVIST[b]	-.165*	.073	-			
Visual motor transformation TMT-A[b]	-.218**	.148	-.083	-		
Inhibition CWIT card 3[b]	-.145	.220**	.100	.021	-	

Cognitive flexibility[b] CWIT card 4	.073	-.090	-.033	-.060	-.158*	-

*p <.05, **p <.01. One-tailed significance tests were used. [a] Adjusted scores on the ROCF in the delayed condition. A higher score indicates a better performance on the ROCF. [b] Categorical variable (unimpaired vs impaired). The unimpaired group served as reference group.

To assess the amount of variance in ROCF performance- delayed condition that is explained by performance on executive functioning tasks, a visuoperception task and a task that measures the ability to transform visual information into motor movements, a stepwise multiple regression analysis was performed. The ability to transform visual information into motor movements was a significant predictor, t (120) = -2.659, p = .005 and accounted for 4.8% of the variance in drawing from memory, R^2 = .048, F (1, 121) = 6.05, p = .015. Visuoperception was also a significant predictor, t (120) = -2.100, p =.019 and accounted for an additional 3.3% of the variance in visuoconstruction, ΔR^2=.033, ΔF (1, 120) = 4.41, p = .038. In combination, the two predictors explained 8.1% of the variance in visuoconstruction, R^2=.081, adjusted R^2= .066, F (2, 120) = 5.31, p=.006, f^2=.09. The effect size was small to medium (Cohen, 1988). The three components of executive functioning were excluded from the final model. Coefficients of the regression model are depicted in Table 6.

Table 6. *Multiple linear regression model, ROCF performance in the delayed condition*

	B	*SE B*	*ß*	*p*
Step 1				
Constant	16.484	.611		p<.001
Visual motor transformation[a]	-2.944	1.198	-.218	p=.015
Step 2				
Constant	17.047	.659		p<.001
Visual motor transformation[a]	-3.152	1.185	-.234	p=.005
Visuoperception[a]	-2.849	1.357	-.184	p=.019

R^2= .048 for Step 1 (p <.05); ΔR^2= .033 for Step 2 (p <.05). The dependent variable is a continuous variable (scores on the ROCF were adjusted for age and education level). High scores indicate a better performance. Adjusted ROCF scores in the delayed condition. [a] Categorical variable (unimpaired vs impaired). Unimpaired group served as reference group.

Mann-Whitney *U* tests (one-tailed tests) were performed to investigate whether cognitive deficits in visuoperception, executive functions and visual motor transformation influence the used drawing when drawing from memory. The analyses indicated that there was no difference in drawing strategy between patients with impaired performance on the visuoperception task(s), executive functioning tasks and visual motor transformation task and patients with an unimpaired performance on these tasks. No significant difference in drawing strategy was found between patients with an unimpaired performance on the working memory task (*Mdn* = 1, *n* = 87) and patients with an impaired performance on the working memory task (*Mdn* = 2, *n* = 36), *U* = 1429, *z* = -.823, *p* = .206, *r* = -.07. There was no significant difference between patients with an impaired performance on the visual motor transformation task (*Mdn* = 2, *n* = 32), and patients with an unimpaired performance on the visual motor transformation task (*Mdn* = 1, *n* = 91), *U* = 1212, *z* = -1.520, *p* = .064, *r* = -.14. No difference was found between patients with visuoperceptual difficulties (*Mdn* = 2.50, *n* = 22) and patients without visuoperceptual difficulties (*Mdn* = 1, *n* = 101) in their used drawing strategy, *U* = 1015, *z* = -.685, *p* = .247, *r* = -.06. There was no difference between patients with impaired inhibition abilities (*Mdn* = 2.50, *n* = 14) and patients with unimpaired inhibition abilities (*Mdn* = 1, *n* = 109), *U* = 612.50, *z* = -1.295, *p* = .098, *r* = -.12. No difference in drawing strategy between patients with cognitive flexibility difficulties (*Mdn* = 2, *n* = 20) and patients without cognitive flexibility difficulties (*Mdn* = 1, *n* = 103) was found, *U* = 933, *z* = -.718, *p* = .236, *r* = -.06.

Discussion

The main aim of the present study was to gain a more profound understanding of visuoconstruction as a construct, using the ROCF. We investigated whether visuoconstruction can be used as a unitary concept or whether it is a concept that (just) comprises the combination of multiple cognitive functions. The second aim of the study was to investigate whether cognitive deficits in executive functions, visuoperception or visual motor transformation influence the drawing process (drawing strategy). We wanted to know whether evaluating the drawing strategy could yield additional diagnostic information.

Main findings

When assessing the contribution of visuoperception, visual motor transformation and executive functions in visuoconstruction, we found that performance on the visuoperception task and performance on the visual motor transformation task had marginal influence on patients' ability to copy and draw a complex figure from memory. The three assessed executive functions did not influence the patients' drawing skills. Since ROCF performance, to a small extent, was predicted by performance on a visuoperception task and a visual motor transformation task, these results suggest that visuoconstruction as a concept is more unique than we expected. The finding that visuoperception influences visuoconstruction skills is in line with a number of studies demonstrating that patients with focal brain damage in the left or right hemisphere have difficulty copying a complex figure due to visuospatial and representational disturbances (Serra et al., 2013; Trojano et al., 2004). The finding that visual motor transformation plays a role in visuoconstruction was also congruent with a previous study done by Ogawa and Nagai (2010). They found copying deficits in patients with Williams Syndrome to be correlated with activity in the posterior parietal cortex (especially in the V6 region), suggesting that adequate visual motor transformation skills are required in successful copying. Contrary to our expectations, executive functions as assessed in our study, did not contribute to ROCF performance. This is not in line with previous studies showing intact executive functions to be crucial for adequate visuoconstructional skills (Grossman et al., 1993; Somerville et al., 2000). Executive functioning deficits in patients with Parkinson's disease were found to negatively impact the ability to copy and draw from memory (Grossman et al., 1993). A possible reason for the discrepancy between our study and this one might be the way in which executive functioning was assessed. Grossman et al. (1993) examined executive functioning by using a pen and paper task, asking patients to draw as many different designs as possible, (design fluency). It is imaginable that due to the similar nature of the tasks (task impurity; Miyake et al., 2000), executive functioning was found to largely impact drawing performance in this study. Another study showed poor drawing skills in patients with dementia to be influenced by working memory (weak relationship) and inconsistent results between inhibition (measured using a graphical sequence test) and drawing skills (Freeman et al., 2000). While Somerville and colleagues (2000) found the type of errors and accuracy of drawings to be weakly correlated with executive functioning measures. Freeman et al. (2000) and Somerville et al. (2000) used the Boston Qualitative Scoring system (BQSS) (Stern et al., 1994), a qualitative scoring system, to assess the relationship between ROCF performance and executive functions. This scoring system evaluates the accuracy of the figure and the type of errors made. The fact that these studies used a qualitative scoring system to assess the relationship between executive functions and ROCF performance, might account for the difference in findings. For instance, Schreiber and colleagues (1999) found in adults with Attention Deficit Hyperactivity Disorder (ADHD) different results between using the 36-point scoring system and the BQSS. They found the qualitative scoring system in comparison to the 36-point scoring system to be more sensitive for cognitive deficits (i.e. executive functioning) associated with ADHD.

The other aspect of the study explored whether there was a difference in drawing strategy between patients with a cognitive deficit in visuoperception, executive functions and visual motor transformation and patients without these cognitive deficits. Our results indicated that in the ROCF- copy condition drawing strategy was related to working memory, inhibition and visual motor transformation performances. Patients with an intact performance used a more efficient drawing strategy. Contrary to our expectations, patients with poor perceptual abilities and poor cognitive flexibility did not use a less efficient drawing strategy. The relationship between executive deficits and the drawing process was consistent with the findings of Scarpina et al. (2016) who found planning ability (such as the order in which the copied elements were drawn) and neatness (how neatly the figure was copied) in PD patients to be related to executive difficulties, specifically planning and impulsivity. Unexpectedly performances on the visuoperception, executive functions and visual motor transformation tasks were not related to drawing strategy in the ROCF- delayed condition. To our knowledge, previous studies have not investigated the relationship between the drawing approach and cognitive functions.

Limitations and Strengths

The current study has several limitations and strengths. A limitation may have been the little variance in performance on the neuropsychological tests. Within our sample, there were only a few patients with a distorted performance on the neuropsychological tests. No standardised neuropsychological test battery was used to assess the cognitive functions, which makes it likely that patients who appeared to have much difficulty with one or more or of our criterion tests subsequently got easier tests, and as a result, did not meet the inclusion criteria of the current study. This could also have been the reason that none of the patients used drawing strategy 6 or 7. As small variance can impact results (decrease predictive ability), the levels within the variables were, reduced to increase the variance in the current study (Field, 2015). The levels within the variable were reduced by assigning both patients, with a cut-off score of 1 SD and patients with 2 SD's below average, to the impaired group. By doing this, no distinction was made between patients with mild cognitive deficits and severe cognitive deficits. Qualitative information on the ROCF performance was collected by observing the drawing strategies identified by Osterrieth (1944) and further developed by Boelema et al. (2015). Although this is a time efficient way and easy method to collect qualitative information, unfortunately, no study has researched the inter-rater reliability. Over the years, the ROCF was administered by different psychologists at the outpatient clinic. To maximize the consistency in the evaluation of the drawing strategy psychologists deliberated with their colleagues in ambiguous situations. A methodological limitation could have been the presence of an outlier in the ROCF- delayed condition. When re-running the analysis without the outlier, we found that the outlier did not have a big impact on the final regression model (same significant predictors and an explained variance $R^2 = .101$). Finally, the use of a cross-sectional study design may have been a potential limitation. Since the cognitive examinations were done in the setting of clinical care, we were limited in our choice selection of neuropsychological tests (to represent and assess the proposed cognitive components involved in drawing) in order to retain a sample size with sufficient power. For example, based on the proposed cognitive models of drawing, we would have wanted to assess visuospatial working memory in patients instead of verbal working memory.

A strength of the study is the way in which the contribution of executive functions in visuoconstruction was assessed. Even though cognitive tasks are supposed to measure specific cognitive functions, many tests assess multiple cognitive functions (Miyake et al., 2000). As more complex tasks (e.g. planning tasks) often involve multiple cognitive mechanisms (Goel & Grafman, 1995), we tried to reduce the task impurity problem by selecting components of executive functioning. Another strength is that the current study assessed the relationship between cognitive deficits and the drawing strategy used when copying and drawing from memory. To our knowledge, previous research has mainly focused on qualitative measures used in the ROCF- copy condition.

Future directions

For future research it would be interesting to investigate whether using a larger sample with a greater range in cognitive performances would replicate the current findings. The present study looked at the role of visuoperception, executive functions and visual motor transformation in ROCF performance. It may be interesting to investigate whether the cognitive functions language and memory contribute to performance on the ROCF as this has not been adequately dealt with in the literature. Since visuoconstruction starts with eye movements, it would also be interesting to assess the role of spatial attention, spatial working memory and spatial planning in ROCF performance by using an eye-tracker, for example. The present study used the ROCF to gain a more profound understanding of visuoconstruction as a construct. Future studies could look at other frequently used visuoconstruction tasks (i.e. the Mini Mental State Examination pentagon) to investigate whether this leads to the same or divergent findings.

Implications

Our study has some important implications for clinical practice. When clinicians want to assess patients' visuoconstructional skills by using the ROCF, they should take into account that visuoperception and visual motor transformation performances can impact the performance on the ROCF. So, if clinicians want to assess visuoconstructional skills in patients, it is recommended to interpret patients' ROCF performances along with performances on visuoperception and visual motor transformation measures to assess whether these cognitive functions may have contributed to the ROCF performance.

When taking the used drawing strategy into account, this can provide additional diagnostic information during the copy condition of the ROCF. Patients with impaired working memory, impaired inhibition skills and a poor ability to transform visual information into a motor movement tend to use a less efficient drawing strategy than patients without these cognitive difficulties. No relation was found between cognitive deficits in visuoperception, executive functions, visual motor transformation and drawing strategy. Suggesting that copying and drawing from memory might tap on different cognitive mechanisms.

Conclusion

Our results showed that ROCF performance was modestly impacted by visuoperception and visual motor transformation performance. Executive functions did not contribute to explaining variance in ROCF performance. Based on these findings, the current study suggests that visuoconstruction can be used as a (unitary) concept. Less efficient drawing strategies in the copy condition of the ROCF were related to impaired performances on working memory, inhibition and visual motor transformation measures. When drawing from memory, drawing strategies were not related to performances on visuoperception, visual motor transformation and executive functions measures. More research is needed to gain a better knowledge of the cognitive mechanisms in drawing. A better understanding of the cognitive mechanisms involved in drawing, will improve our understanding of visuoconstruction as a concept.

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