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Rey-Osterrieth Complex Figure Test in Differentiating Between Left and Right Lesions Caused by Brain Tumors and Stroke

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Abstract - The aim of this study was to examine whether the ROCF qualitative scoring system developed by Loring, Lee and Meador for differentiating complex partial seizures originating from either the right or left temporal lobe is effective in differentiating left-sided and right-sided brain lesions that are the result of cerebrovascular insult or brain tumours. We were also interested in determining whether this scoring system, which was developed for scoring trials with delayed recall, could be applied to trials with immediate recall and copying. The study consisted of 24 participants with lesions of the left hemisphere and 33 participants with right-sided lesions. Participants with right-sided lesions had a significantly greater number of qualitative errors in copying, immediate and delayed recall, and these three variables are the major contributors in distinguishing between groups. Based on these variables and quantitative results on copying, immediate and delayed recall, we were able to correctly classify 78.3 % of participants with left-sided lesions and 66.7 % of participants with right-sided lesions. Given that more than 90 % of participants with left-sided lesions had two or more errors in delayed recall, it is clear that the criterion of two or more errors which was set by Loring, Lee and Meador for patients with a right-sided focus in epilepsy is not applicable to patients with tumours and strokes. These results do not confirm the usefulness of qualitative errors for distinguishing left-sided and right-sided lesions caused by a tumour or stroke, except, perhaps, in cases of very high results (six or more errors) and when one of these errors is error X in immediate and/or delayed recall.

Key words: Rey-Osterrieth Complex Figure Test; qualitative scoring system; left hemisphere lesions; right hemisphere lesions

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Introduction

The Rey-Osterrieth Complex Figure Test (ROCF) is one of the most widely used tests for measuring visuoperceptual and visuoconstructional functions as well as visual nonverbal memory in patients with brain lesions [1]. Past studies, however, have reported inconsistent results when it comes to distinguishing between left-sided and right-sided lesions. Some research has shown that people with left and right-sided lesions have different results on copying and organizational strategy after a stroke, while the differences have not been confirmed in other studies [2-5].

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Although different studies have shown that immediate and delayed recall scores are significantly associated with organizational strategy that may be more damaged in right-hemisphere patients, in most studies the quantitative results of trials with the immediate and delayed recall of a complex figure did not prove particularly helpful in differentiating between left-sided and right-sided lesions caused by a stroke in adults, a childhood stroke, temporal lobe epilepsy and epilepsy in children [3,6-12]. The reasons for these findings can be very different and related to the lateralization of functions, diaschisis and test characteristics designed to examine nonverbal memory. The absence of differences in samples of children with right-sided and left-sided brain lesions can be understood based on the theoretical viewpoint that lateralization functions are not fully developed in children [13]. In adults, these results may be explained by the fact that these are visuospatial tasks, and research undoubtedly shows bilateral parietal lobe participation in visuospatial processing [14]. In addition, some studies suggest that the lateralization of brain systems and memory processes can be process-specific rather than material-specific [15-17]. Research conducted by Kennepohl, Sziklas, Garver, Wagner and Jones-Gotman on healthy persons studied functional asymmetry in the medial temporal lobe that does not depend on the nature of the material (i.e., verbal or nonverbal) and maybe other characteristics are important, e.g., novelty as well as fundamental differences in processing between the left and right temporal lobes [18]. Some of the studies also revealed the importance of the type of task and that recognition tasks are perhaps more sensitive to right hemisphere lesions than tasks requiring free recall of nonverbal material [19]. In a meta-analytic and narrative review of 24 studies Gillespie, Bowen and Foster report that in 16 studies no differences between left-sided and right-sided lesions caused by a stroke were found in different measures of nonverbal memory [19]. Two studies found differences in some, but not all administered tests. Six studies showed differences between left-sided and right-sided lesions with a medium effect size for nonverbal recognition tasks, while the effect size for nonverbal recall tasks was not significant. The authors explain these results with the possibility that the recognition of nonverbal material lateralized to the right hemisphere and a recall of nonverbal material were determined by processes in both hemispheres. Other studies, however, have not confirmed this finding. Studying patients with intracranial tumours, Goldstein and associates found, for example, that the group with left-sided tumours had a significantly slower mean picture recognition reaction time than the group with right-sided tumours, and they suggest the possibility that picture recognition requires significantly greater involvement of the left hemisphere [20].

With regard to data on atypical language dominance in epilepsy patients associated with an earlier age of seizure onset, it is possible that lateralization for visuospatial stimuli and the memory of persons with long-term epilepsy is atypical [21]. Atypical lateralization, however, cannot explain the lack of differences between left-sided and right-sided lesions in adult stroke patients. The possibility that the effects of transhemispheric diaschisis have contributed to this in some patients cannot be excluded in view of the fact that research has shown that changes in contralateral blood flow after infarction return to normal or near-normal levels several months after a stroke [22]. The average interval between a stroke and testing in research conducted by Lange, Waked, Kirshblum and DeLuca, for example, was 39 days, which means that the effects of diaschisis for these patients cannot be completely disregarded [3]. And, finally, the multifactorial nature of tasks such as the Complex Figure Test, various strategies used by participants and different scoring procedures can influence

results. Even though standardized quantitative scoring methods developed by Osterrieth and elaborated by Meyers and Meyers have proven insensitive to lesion lateralization, these are the methods used in numerous studies [23,24].

In an attempt to eliminate the limitations of quantitative systems in differentiation, Loring, Lee and Meador developed a qualitative scoring system based on the assessment of error types frequently observed in the recall of patients with right temporal lobe epilepsy [1]. They have shown on a small sample of patients with temporal epilepsy that it was effective in determining right-sided lesions (of 18 patients, 15 were correctly classified). This system originally included 11 qualitative errors (diamond on stem, misplacement of diamond, rotation of horizontal lines, distortion of overall configuration, inversion, misplacement or distortion of upper right triangle, additional horizontal lines, additional parallel lines, misplacement of upper left cross or lower cross, major mislocation, additional lines for cross and incorporation of pieces into a larger element). Along with these 11 qualitative errors, Frank and Landeira-Fernandez added a 12th: partial or complete figure rotation [11]. On a sample of 78 epilepsy patients and 34 control group subjects they found that 66 % of the right temporal lobe patients and 38 % of the left temporal lobe patients had two or more errors. These errors were exceptionally rare in healthy persons from the control group (only 15 % had two or more errors). The effectiveness of this system in differentiating between right and left foci in unilateral temporal lobe epilepsy was also confirmed by Piquet and associates on a sample of 26 patients with left temporal lobe epilepsy and 18 patients with right temporal lobe epilepsy [25]. To date, no studies have explored the effectiveness of this qualitative scoring system on patients with strokes or brain tumours.

The aim of this study was to determine whether the qualitative scoring system developed by Loring, Lee and Meador for differentiating partial complex seizures originating from either the right or left temporal lobe is effective in differentiating left-sided and right-sided brain lesions which are the result of cerebrovascular insult or brain tumours [1]. It was also of interest whether this scoring system, which was developed for scoring trials with delayed recall, could be applied to trials with immediate recall and copying. In view of the fact that these are spatial-relational errors, we wanted to reveal whether these are more frequent in copying in persons with right-sided lesions.

Subjects and Methods

1.1 Participants

The study group consisted of 57 right-handed patients (37 males and 20 females) aged 18 to 66 (M = 49.36, SD = 8.57) referred for neuropsychological examination at the Department of Neurology, Psychiatry and Clinical Psychology. Exclusion criteria included the presence of another neurological disorder, psychiatric disorder or substance abuse in their medical history. The average educational level was 10.47 years (SD = 2.90). Of the study group participants, 24 patients had left-sided lesions caused by tumours (N = 7) or a stroke (N = 17), while 33 had right-sided lesions (eight caused by tumours, 25 by a stroke). The groups with left-sided and right-sided lesions did not differ significantly in terms of age, gender, education level, interval from diagnosis to testing, type of lesion, verbal intelligence quotient (VIQ), performance intelligence quotient (PIQ), full scale intelligence quotient (IQ) (Table 1) or lesion localization within the hemisphere ($\chi^2 = 17.11$, NS). The greatest number of participants had temporal lobe lesions that were isolated or included adjacent regions (10 left-sided and 12 right-sided), followed by frontal areas (eight left-sided and 11 right-sided). The basal ganglia were affected in three patients with left-sided lesions and in one patient with a right-sided lesion, while the thalamus was

Table 1. Demographic variables, type of lesion, interval from diagnosis to testing and intelligence test results for left-sided and right-sided lesions

Variables	Left hemisphere	Right hemisphere	Differences
Age	46.98 (8.77)	51.10 (8.12)	F = 3.34, NS
Gender			χ^2 = 0.106, NS
Male	15	22	
Female	9	11	
Years of education	11.25 (1.91)	9.90 (3.36)	F = 3.07, NS
Interval (months)	19.54 (29.01)	31.25 (52.44)	F = 0.89, NS
Type of lesion			χ^2 = 0.174, NS
Tumour	7	8	
Stroke	17	25	
VIQ	99.33 (10.21)	100.09 (13.19)	F = 0.55, NS
PIQ	93.12 (11.04)	89.61 (13.65)	F = 1.05, NS
IQ	96.37 (11.09)	95.19 (13.84)	F = 0.11, NS

VIQ - verbal intelligence quotient, PIQ - performance intelligence quotient, IQ - full scale intelligence quotient

affected in one patient with a left-sided lesion and in four patients with a right-sided lesion. Two patients had lesions of the parietal lobe of the left hemisphere and five of the right.

1.2. Instruments and procedure

The Rey-Osterrieth Complex Figure Test was administered during the regular neuropsychological examination of patients with cerebrovascular insult and brain tumours as part of a comprehensive assessment of cognitive functions. All participants were evaluated by the same psychologist. This study was approved by the Ethics Committee of the General County Hospital.

Rey-Osterrieth Complex Figure Test

The Rey-Osterrieth Complex Figure Test (ROCF) is one of the most frequently used tests for the assessment of visuoperceptual and visuoconstructional functions and nonverbal memory [23]. There are, however, many variations in the administration protocol [26]. The current study used a protocol that included copying, immediate recall and delayed recall. The interval between the immediate and delayed trials was 30 minutes. Colours were used for copying and a single pencil for immediate and delayed recall.

Copying, immediate recall and delayed recall were scored in accordance with guidelines developed by Taylor and revised by Meyers and Meyers [24]. This was followed by the scoring of drawings in accordance with guidelines developed by Loring, Lee and Meador [1].

Data analysis

A one-way analysis of variance (ANOVA) and the chi-square test were used to determine the significance of differences between groups. In order to verify whether the classification of participants according to the ROCF results was correct, a discriminant analysis was carried out which included quantitative and qualitative results from the copying, immediate recall and delayed recall experiments. The statistical significance level was set at $p < 0.05$.

Results

Differences between patients with tumours and strokes

With regard to possible differences in neuropsychological deficits caused by various types of lesions (i.e., brain tumours and strokes), the results of patients with tumours and patients with strokes were compared in order to determine whether these patients could be grouped together. Despite the fact that patients with tumours had a statistically significant higher ($F = 9.50$, $p < 0.01$) quantitative result on delayed recall ($M = 15.03$, $SD = 5.01$) in relation to patients with a stroke ($M = 9.71$, $SD = 5.76$), the two groups had no statistically significant differences in the number of qualitative errors (tumours: $M = 3.33$, $SD = 1.54$ versus stroke: $M = 3.04$, $SD = 1.84$; $F = 0.286$, $p = 0.59$).

Even though this was not the subject of our study, it is interesting to mention that the differences in quantitative results for delayed recall between patients with brain tumours and stroke were not attributed to differences in copying (tumour: $M = 30.20$, $SD = 3.65$ versus stroke: $M = 27.46$, $SD = 6.47$; $F = 2.38$, $p = 0.128$) or immediate recall (tumour: $M = 12.46$, $SD = 5.70$ versus stroke $M = 11.17$, $SD = 5.79$; $F = 0.553$, $p = 0.460$) of the complex figure. Patients with tumours achieved higher results in delayed recall than in immediate recall, which may indicate certain memory characteristics in these participants (e.g., it may take longer to consolidate material), but these considerations fall outside the framework of this study.

Quantitative ROCF for left-sided and right-sided lesions (ANOVA)

The ANOVA was applied in order to determine the existence of significant differences in quantitative results between left-sided and right-sided lesions in trials using copying, immediate recall and delayed recall.

The results show that persons with right-sided lesions achieve statistically significant lower results on copying the complex figure, while there are no statistically significant differences between the two groups in terms of immediate recall and delayed recall (Table 2).

Frequency distribution of qualitative errors for left and right hemisphere patients for copying ≥ 34

In order to answer the question whether it is possible to recognize patients with right-sided lesions based on the criterion of two or more errors as suggested by Loring, Lee and Meador [1], the first step was to separate pa-

Table 2. Quantitative and qualitative ROCF scores of left-sided and right-sided lesions and the significance of differences

	Left hemisphere	Right hemisphere	F
Copy	30.22 (3.67)	26.69 (6.85)	5.25*
Immediate recall	12.43 (6.61)	10.87 (5.07)	0.99
Delayed recall	12.25 (6.90)	10.28 (5.51)	1.42
Qualitative error copy	1.08 (1.01)	2.21 (1.59)	9.24**
Qualitative error immediate	2.08 (1.34)	3.33 (1.65)	8.94**
Qualitative error delayed	2.20 (1.35)	3.78 (1.74)	13.67**

*$p < 0.05$ **$p < 0.01$

Table 3. Frequency distribution of qualitative errors made by patients with left-sided (N = 7) and right-sided lesions (N = 4) and with a copying result ≥ 34

Number of errors	Left hemisphere	Right hemisphere
0	1 (14.3 %)	0
1	2 (28.6 %)	0
2	1 (14.3 %)	3 (75 %)
3	3 (42.9 %)	0
5	0	1 (25 %)

tients who had achieved at least 34 points on the copying task. However, as was to be expected, our sample included more persons with difficulties in copying than was the case with epilepsy patients in the Loring, Lee and Meador study [1]. As Table 3. shows, 34 or more points on the copying task were achieved by seven patients with left-sided lesions and by four patients with right-sided lesions. Table 3. shows that all four patients with right-sided lesions had two or more errors and were correctly classified according to the criterion of two or more errors for right-sided lesions. However, of the seven patients with left-sided lesions, only three were correctly classified. Consequently, we were interested in determining whether these two groups differed according to the type of error. None of the patients had error XI (incorporation of pieces into a larger element). Errors VII (additional parallel lines) and X (additional lines for cross) were present in one patient with a right-sided lesion for each type of error, while the left-sided patients did not make these types of errors. Errors II (misplacement of diamond) and V (inversion, misplacement or distortion of right triangle) were made by one patient with a left-sided lesion for each error and by none of the patients with right-sided lesions. None of the patients made partial or complete rotations of the figure.

Differences in the number, frequency and type of qualitative error between left-sided and right-sided lesions for all patients (ANOVA)

Due to the small number of patients in these subgroups, the results are not of clinical significance and cannot serve as the basis for valid conclusions. Among the type of qualitative errors described by Loring, Lee and Meador [1] were spatial-relational types of errors (e.g., rotation of segments, misplacement, distortions), so it was reasonable to assume that the sample for which copying results were lowered would contain a greater number of these types of errors in copying. For this reason, qualitative errors in copying were scored first, followed by immediate recall for all participants. The results are presented in Table 4. Patients with right-sided lesions had a statistically significant greater number of errors in copying and in immediate and delayed recall (Table 2). We were also interested in the distribution frequency of qualitative errors in copying, immediate recall and delayed recall for left-sided and right-sided lesions and the significance of these differences.

Table 4. shows that 75 % of left hemisphere patients and 39.4 % of right hemisphere patients had less than two errors in copying. Patients with left-sided lesions did not exhibit an extremely high number of errors (five or

Table 4. Frequency distribution of qualitative errors made by patients with left-sided (N = 24) and right-sided lesions (N = 33) in copying, immediate and delayed recall

Number of errors	Copy		Immediate		Delayed	
	Left (%)	Right (%)	Left (%)	Right (%)	Left (%)	Right (%)
0	7 (29.2)	4 (12.1)	3 (12.5)	1 (3.0)	3 (12.5)	
1	11 (45.8)	9 (27.3)	5 (20.8)	3 (9.1)	5 (20.8)	4 (12.1)
2	4 (16.7)	7 (21.2)	6 (25.0)	6 (18.2)	4 (16.7)	5 (15.2)
3	1 (4.2)	7 (21.2)	6 (25.0)	8 (24.2)	9 (37.5)	4 (12.1)
4	1 (4.2)	2 (6.1)	2 (8.3)	9 (27.3)	2 (8.3)	8 (24.2)
5		3 (9.1)	2 (8.3)	3 (9.1)	1 (4.2)	7 (21.2)
6		1 (3.0)		2 (6.1)		4 (12.1)
8				1 (3.0)		1 (3.0)

more in copying and six or more in recall), but 12.1 % of patients with right-sided lesions had five or more errors in copying, while 9.1 % of these participants had six or more errors in immediate recall and 15.1 % in delayed recall. If the criterion of two or more errors for right-sided lesions is applied (as determined by Loring, Lee and Meador) to trials with copying, immediate recall and delayed recall, it becomes evident that 39.4 % of patients with right-sided lesions and 25 % of patients with left-sided lesions would be incorrectly classified. Trials with immediate recall would incorrectly classify 66.6 % of patients with left-sided lesions and only 12.1 % of patients with right-sided lesions. The delayed recall results are similar: 66.5 % of patients with left-sided lesions and 12.1 % of patients with right-sided lesions would be incorrectly classified.

It is interesting to see whether the groups with left-sided and right-sided lesions differ in terms of type of errors.

The copying trial revealed that a statistically significant greater number of persons with right-sided lesions made errors I (diamond on stem), IV (distortion of overall configuration) and IX (major dislocations). It is interesting to note (and perhaps clinically significant, which needs to be examined on larger clinical samples) that persons with left-sided lesions did not make errors III, VI, VII or X and that error XI (incorporation of pieces into a larger element) was not found in present samples. Error II (misplacement of the diamond) was more frequent (but not statistically significant) in persons with left-sided lesions (Table 5).

The immediate recall trial revealed a statistically greater number of persons with right-sided lesions with errors I (diamond on stem), II (misplacement of diamond) and IX (major mislocation). Despite the fact that half of the subjects with left-sided lesions made error IX (major mislocation), it is important to mention that this error was present in over 80 % of the subjects with right-sided lesions. None of the patients with left-sided lesions made error X (Table 5) in both immediate recall and delayed recall.

The delayed recall trial showed that a statistically significant greater number of participants with right-sided lesions made errors II (misplacement of diamond), III (rotation of horizontal lines), IV (distortions of overall configuration) and X (additional lines for cross).

Table 5. Frequency distribution of qualitative errors made by left and right hemisphere patients

Error	Left hemisphere			Right hemisphere			Differences (χ^2)		
	C (%)	Imm (%)	Del (%)	C (%)	Imm (%)	Del (%)	C	Imm	Del
I	1 (4.2)	0	2 (8.3)	8 (24.2)	6 (18.2)	7 (21.2)	4.212*	4.684*	1.733
II	9 (37.5)	4 (16.7)	5 (20.8)	10 (30.3)	16 (48.5)	15 (45.5)	0.324	5.707**	3.69*
III	0	3 (12.5)	3 (12.5)	2 (6.1)	10 (30.3)	12 (36.4)	1.507	2.265	4.081*
IV	3 (12.5)	8 (33.3)	7 (29.2)	13 (39.4)	13 (39.4)	18 (54.5)	4.97*	0.123	3.633*
V	6 (25)	3 (12.5)	4 (16.7)	13 (39.4)	8 (24.2)	10 (30.3)	1.295	1.077	1.394
VI	0	1 (4.2)	3 (12.5)	1 (3.0)	2 (6.1)	4 (12.1)	0.740	0.078	0.002
VII	0	2 (8.3)	2 (8.3)	3 (9.1)	6 (18.2)	6 (18.2)	2.300	0.996	1.117
VIII	4 (16.7)	12 (50)	13 (54.2)	9 (27.3)	18 (54.5)	21(63.6)	0.888	0.031	0.518
IX	2 (8.3)	12 (50)	13 (54.2)	11 (33.3)	26 (81.3)	24 (72.7)	4.93*	3.63*	2.102
X	0	0	0	3 (9.1)	3 (9.1)	7 (21.9)	2.301	2.115	5.056**
XI	0	3 (12.5)	0	0	1 (3.0)	1 (3.1)		2.04	0.637

Note: * $p < 0.05$; **$p < 0.01$. C = copy, Imm = immediate recall, Del = delayed recall

Relationship between qualitative and quantitative errors

We were also interested in the relationship between various quantitative results and qualitative errors. The number of qualitative errors in delayed recall is correlated with the number of qualitative errors in immediate recall ($r = 0.79$, $p < 0.001$). Although lower, the correlation between qualitative errors in delayed recall and quantitative results in copying is also significant ($r = -0.35$, $p < 0.01$), while correlations between qualitative errors in delayed recall and quantitative results for delayed recall ($r = -0.09$) and quantitative results for immediate recall are not significant ($r = -0.20$). In addition to the relationship with qualitative errors in delayed recall, qualitative errors in immediate recall are significantly correlated with qualitative errors in copying ($r = 0.54$, $p < 0.001$) and quantitative results in copying ($r = 0.49$, $p < 0.001$), but not with quantitative results for immediate recall ($r = -0.20$) and delayed recall ($r = -0.09$). Qualitative errors in copying are significantly correlated with all quantitative results: copying ($r = -0.78$, $p < 0.001$), immediate recall ($r = -0.44$, $p < 0.01$) and delayed recall ($r = -0.41$, $p < 0.01$.).

Discriminant analysis

In order to determine the possibilities of discriminating between these groups on the basis of ROCF results, discriminant analysis was conducted. The analyses included all quantitative results and qualitative errors in copying, immediate recall and delayed recall.

The analysis resulted in a statistically significant discriminant function (Table 6). Table 7. shows that the greatest contribution to discriminating between the groups is the number of qualitative errors in delayed recall, followed by the number of qualitative errors in immediate recall and copying, as well as the quantitative results of copying. The contribution of the quantitative results of immediate and delayed recall is relatively modest. The canonical correlation is of medium size.

Table 6. Eigen-value, percentage of variance, canonical correlation, Wilks' lambda, χ^2, degrees of freedom (df) and statistical significance of discriminant function (quantitative and qualitative scores)

Function	Eigen-value	Percentage of variance	Canonical correlation	Wilks' lambda	χ^2	df	p
1	0.334	100	0.501	0.749	14.715	6	0.02

Table 7. Structure matrix

	Function
	1
Qualitative delayed	0.872
Qualitative immediate	0.704
Qualitative copy	0.675
Quantitative copy	-0.500
Quantitative delayed	-0.323
Quantitative immediate	-0.234

Table 8. Group centroids

	Function
	1
Left hemisphere	-0.680
Right hemisphere	0.474

Table 8. shows that persons with right-sided lesions have a greater number of qualitative errors in delayed recall (which is the major contributor to the group differences), copying and immediate recall as well as lower quantitative results on copying, immediate recall and delayed recall. An analysis of variance has, however, shown that the differences between groups are not significant for the quantitative results of immediate recall and delayed recall.

The results for these variables correctly classified 71.4 % of the participants, where the classification was correct for more persons with left-sided lesions (78.3 %) than for persons with right-sided lesions (66.7 %).

Discussion

The results of this study show that the qualitative scoring system for delayed recall developed by Loring, Lee and Meador for differentiating left-sided and right-sided epilepsy has certain limitations and is not entirely applicable to differentiating left-sided and right-sided lesions caused by tumours or a stroke [1]. Due to lower scores on the copying task, a relatively small number of protocols were available for use with this scoring system with delayed recall. It was previously mentioned that the authors set criteria where the copying task was within normal boundaries, i.e., 34 or higher. They noted, however, the possibility that persons with left-sided lesions who perform below 34 on the ROCF copying task may have a large number of "right-sided" qualitative errors on the delayed recall task. This fact was the rationale for studying a sample with more errors in the copying task to determine whether right hemisphere errors are significantly more frequent in persons with right-sided lesions in copying and immediate recall or whether per-

sons with left-sided lesions exhibit a greater number of these errors. It is reasonable to assume that in cases where copying results are lower the borderline values in delayed recall need to be adjusted in order to differentiate persons with left-sided and right-sided lesions based on the number of errors.

This study included 57 persons with lesions caused by tumours or strokes. Anderson, Damasio and Tranel found major differences in the neuropsychological impairment of the two groups (subjects with stroke had more severe deficits), so we studied the differences between the two groups of patients [27]. The only significant difference between these groups was in the quantitative result for delayed recall, while no significant differences were found in the number of qualitative errors in any trials and in the quantitative results for copying or immediate recall, resulting in further joint analyses.

Of the quantitative indicators in right and left hemisphere patients, the only statistically significant result was for copying (lower scores of persons with right-sided lesions), which is in accordance with studies showing greater difficulties with visuoperceptual tasks and copying tasks following a lesion of the right hemisphere, which was not confirmed in all studies [4,28]. More recent studies, however, have shown a bilateral involvement in visuospatial processing, which may explain the fact that quantitative results in copying were lower for all our participants in relation to normative data [14,24]. Hochstenbach, Mulder, Limbeek, Donders and Schonderwaldt noted that at least 40 % of all stroke patients experience difficulties with visuospatial and constructive tasks [29].

The lack of differences between persons with left-sided and right-sided lesions in quantitative results for immediate and delayed recall are in accordance with the findings of the previously mentioned meta-analysis carried out by Gillespie, Bowen and Foster [19]. This study only showed a significant effect size for recognition, not for free recall.

In view of the large number of errors in copying, only 11 of the 57 patients fulfilled the criteria (i.e., a score of at least 34 on the ROCF copy) set by Loring, Lee and Meador for inclusion in the scoring procedure for qualitative errors. Based on criteria set by Loring, Lee and Meador, a relatively high classification accuracy for right-sided lesions (four patients) was achieved by this small subgroup of patients, which was not the case for left-sided lesions, where four of the seven participants had two or three errors (Table 3).

When qualitative errors in delayed recall are viewed independently of the copying results, it is evident that two-thirds of the participants with left-sided lesions have two or more errors (Table 4) and were classified incorrectly, while this was the case in only 12 % of patients with right-sided lesions. These results are in accordance with the warning of Loring, Lee and Meador regarding the possibility that errors may occur on the ROCF copying task for persons with left-sided lesions with results below 34, which are typical for persons with right-sided lesions without difficulties in copying [1]. It should, however, be kept in mind that four of the seven participants with left-sided lesions and results of 34 or higher on the copying task made two or more errors. Apart from this, it should also be mentioned that despite being significant, correlations between qualitative errors in immediate and delayed recall and qualitative copying results are moderate in size. In other words, for the sample of patients with strokes and tumours, the greater number of those making qualitative errors connected with the right hemisphere are of significance, regardless of the lateralization of the lesion and success/failure in copying. It is interesting to note that more than a third of persons with right-sided lesions have five or more qualitative errors in delayed recall, while 95 % of persons with left-sided lesions have

less than five qualitative errors. With regard to the type of error found in persons with left-sided and right-sided lesions in delayed recall, it needs to be mentioned that persons with right-sided lesions show more frequent errors in diamond placement and other figure elements placement, the rotation of the horizontal lines and distortion of the overall configuration. Furthermore, none of the persons with left-sided lesions made error X (additional lines for cross) in any of the experiments, while this error was present in one-fifth of the patients with right-sided lesions in delayed recall (even though it was relatively rare in copying and immediate recall), and it was the greatest contributor to group differences. The misplacement of diamond (error II), rotation of horizontal lines (error III) and distortion of overall configuration (error IV) in delayed recall significantly contributed to the discrimination between groups. Error X could be viewed as a type of perseveration, while errors II, III and IV could be connected with "mistakes" in processing and storing and later recalling of visuospatial information, which is usually associated with the right hemisphere.

In immediate recall, 66.6 % of persons with left-sided lesions and 87.9 % of persons with right-sided lesions had two or more errors (Table 4). Persons with right-sided lesions had a statistically significant higher rate of errors I (diamond on stem), II (misplacement of diamond) and IX (major mislocation). Error X (additional lines for cross) was not found among persons with left-sided lesions (while it was present in three persons with right-sided lesions). Errors I, II and IX significantly contributed to the discrimination between groups. Although significantly more frequent among persons with right-sided lesions, error IX (major mislocation) was among the most frequent errors for persons with left-sided lesions. Error VIII (misplacement of upper left cross or lower cross) was among the most frequent for both groups. These errors can be classified as spatial, but it is obvious that they are not exclusively connected with right hemisphere lesions, and this fact confirms the assumption about bilateral involvement in visuospatial processing.

In copying, errors I, IV, IX and X proved to be discriminative, but it needs to be mentioned that persons with right-sided lesions frequently made errors IV, V and IX, while persons with left-sided lesions made errors II and V. The correlations between qualitative errors in copying and qualitative errors in immediate and delayed recall were significant but moderate (while the correlation between qualitative errors in immediate recall and qualitative errors in delayed recall was high). Apart from this, it is obvious that the type of error in copying (e.g., error V) differs from those in immediate and delayed recall. It is clear that qualitative errors in recall cannot be fully explained by perceptual deficits obvious in the copying phase. Errors II (misplacement of diamond) and V (inversion, misplacement or distortion of upper right triangle) are most frequent in persons with left-sided lesions for copying and it is obvious that these are spatial errors on the right elements of the complex figure (i.e., the right hemifield) since it is well known that the left hemisphere controls attention toward the right hemifield. Poreh and Shye noted that right-sided elements of the ROCF are most useful in differentiating between left-sided and right-sided lesions [30]. However, error V was among the most frequent copying errors in persons with right hemisphere lesions and the groups were not significantly different. Along with this error on the right element of the complex figure, persons with right-sided lesions most frequently display errors IV and IX in copying. Error IV (distortion of overall configuration) can be clearly connected with deficits in global processing, often noted in persons with right-sided lesions, which can also result in error IX, i.e., major mislocation [31]. It is also pos-

sible that the reasons for error V in persons with left-sided and right-sided lesions are different. Along with the previously mentioned possibility that this error is caused by attention problems in persons with left-sided lesions, it needs to be mentioned that some studies relate the upper right triangle where this error occurs with global characteristics, so it is possible that deficits in global processing contribute to the relatively high frequency of this error in persons with right-sided lesions [31]. The frequency of error V, however, decreases in both groups on immediate and delayed recall tasks. The number of persons with left-sided lesions making error II decreases on immediate and delayed recall tasks, while the frequency of this error increases for persons with right-sided lesions in recall tasks (so much so that it significantly contributes to the differentiation between groups). This can further support the assumption that this error is, for persons with left-sided lesions, related to attention problems for the right hemifield on perceptive tasks and thus more obvious in copying than in recall. In persons with right-sided lesions, a higher frequency of this error in recall tasks can be related to problems with positional memory, i.e., the processing of precise, metric information or coordinates. Kessels, Kappelle, Haan and Postma have shown that this aspect of spatial memory is damaged along with lesions of the right hemisphere, while left hemisphere lesions are more frequently associated with object location binding, i.e., the ability to form associations between object identity and positions [32]. A marked increase in error VIII (without significant differences between groups) and IX (significant differences between groups) in recall for both groups in relation to the copying task is, however, unexpected. It is possible that the displacement of the upper left cross or the lower cross (error VIII) can be related to strategies patients use in completing the task and attempts to attribute a recognizable, semantic meaning to the stimulus as is described in cases of mild to moderate dementias [33]. Such conclusions require, however, a more detailed analysis of the figures themselves and additional information from the patient. The possibility that unsuccessful processes of integration between object identity and locations lead to these errors in both groups cannot be excluded. In recall, more than double the number of patients made the major mislocation error (IX) in relation to the copying task in both groups, with a significantly higher frequency in persons with right-sided lesions. It is possible that problems with integration between object identity and locations contribute to these errors, where contributions from both hemispheres are more important than the damage in global processing in persons with right-sided lesions.

The results of this study need to be interpreted with caution, primarily due to the small number of participants. Aside from this, the pathohistological diagnoses or types of therapy were not controlled among persons with tumours. Numerous studies have shown that radiation and chemotherapy have a negative effect on cognitive functions, with damage to functions related to other brain structures independent of the tumour location [34,35]. The results are not unanimous regarding the effect of pathohistological diagnosis, but some studies show that cognitive deficits differ for different pathohistological diagnoses, primarily concerning the speed of tumour growth [36,37]. Data on the degree of hemodynamic damage in the sample of stroke survivors was not available, but could have affected the results.

In conclusion, it can be stated that stroke and tumour patients display a greater number of errors in copying than epilepsy patients and that the criterion of two or more qualitative errors with correct copying introduced by Lee, Loring and Meador for the identification of right hemisphere lesions is not applicable to these groups of patients [1]. It is,

however, clear that qualitative errors in recall are only partially explained by errors in copying. Although these errors are relatively frequent in patients with left hemisphere lesions, especially in immediate and delayed recall, they were more frequently statistically significant in patients with lesions of the right hemisphere in copying, immediate recall and delayed recall, which may be related to deficits in processing and the recall of visuoperceptual and visuospatial information after lesions of the right hemisphere. However, despite a statistically significant difference, the differentiation of left and right lesions on the basis of qualitative errors in clinical judgment is not justified. Perhaps it is justified in the case of an extremely large number of such errors (six or more) or when one of these errors is error X (additional lines for cross) in immediate and/or delayed recall. Error X is not registered in any of the patients with lesions of the left hemisphere. Although errors I, II, III, IV and IX in immediate and/or delayed recall are significantly more frequent in participants with right-sided lesions, these errors were found in a certain number of participants with left-sided lesions, so drawing conclusions regarding the lateralization of brain lesions based on these errors may result in mistakes.

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Conflict of interest

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