Visuo-spatial construction in patients with frontal and parietal lobe lesions

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Abstract

Visuospatial construction, traditionally viewed as a putative parietal function, also requires sustained attention, planning, organization strategies and error correction, and hence frontal lobe mediation. The relative contributions of the frontal and parietal lobes are poorly understood. To examine the contributions of parietal, frontal lobes, as well as right and left cerebral hemispheres to visuospatial construction. The Stick Construction Test for two-dimensional construction and the Block Construction Test for three-dimensional construction were administered pre-surgically to patients with lesions in the parietal lobe (n = 9) and the frontal lobe (n = 11), along with normal control subjects (n = 20) matched to the patients on age (+/- 3 years), gender, education (+/- 3 years) and handedness. The patients were significantly slower than the controls on both two-dimensional and three-dimensional tests. Patients with parietal lesions were slower than those with frontal lesions on the test of three-dimensional construction. Within each lobe patients with right and left sided lesions did not differ significantly. It appears that tests of three-dimensional construction might be most sensitive to visuospatial construction deficits. Visuospatial construction involves the mediation of both frontal and parietal lobes. The function does not appear to be lateralized. The networks arising from the parieto-occipital areas and projecting to the frontal cortices (e.g., occipito-frontal fasciculus) may be the basis of the mediation of both lobes in visuospatial construction. The present findings need replication from studies with larger sample sizes.

Keywords: Visuospatial construction; Lateralization; Localization; Stick construction; Block construction

1. Introduction

Although an operational definition of constructional abilities is unclear in the literature, visuospatial construction has usually been conceptualized as the ability to assemble objects or produce organized "constructions" (Manning, 2003). Constructions may be either two-dimensional (drawing or constructing simple stick patterns) or three-dimensional (assembling patterns of blocks). A disturbance in producing constructions, termed constructional apraxia, has long been considered a putative indicator of parietal lobe damage (Critchley, 1953; Damasio, Tranel & Rizzo, 2000; Hecaen & Albert, 1978; Joseph, 1995; Manning, 2003).

However, some research has suggested that constructive functions might not be an exclusive parietal lobe function, and that lesions in different cerebral loci might give rise to different kinds of constructional impairments (De Renzi, 1982; Luria & Tvetskova, 1964). While constructional impairments caused by parieto-occipital lesions are primarily visuoperceptual disorders, those arising out of frontal lobe damage are primarily of an executive nature. Pillon (1981) demonstrated that patients with posterior lesions did better on copying tasks when provided with reference points, while those with anterior lesions had better performance with the provision of a copying plan. However, other recent research has not supported the difference in constructional impairments based on lesion foci (Grossi & Trojano, 1999; Kirk & Kertesz, 1989).

Another hypothesis of constructional deficits has been based on the lateralization of lesion. It has been observed that left hemisphere lesions cause more "executive" or organizational impairments, while right hemispheric lesions lead to more specifically "visuoperceptual" deficits (Lang et al., 2006). Left hemisphere lesions are associated with oversimplification of the model with relatively preserved spatial relations due to failure in the organization of actions necessary for construction tasks (also called manipulospatial functions). In contrast, right hemisphere lesions evince over-elaborate, often irrelevant fragments due to failure in the organization of space (spatial-perceptual functions) (Manning, 2003). Nevertheless, many studies also reveal comparable deficits in patients with right- or left-sided lesions (Gainotti, 1985).

In addition, it has been emphasized that drawing, assembling and building cannot be considered equivalent because they rely on various cognitive functions (attention, reasoning, motor, perceptual and visuospatial skills) to differing extents (Grossi & Trojano, 1999). Since the mechanisms involved in two-dimensional and three-dimensional tasks appear to be different, the use of both has been suggested (Benton, 1989). Unfortunately, however, the dominant position in the literature has usually equated drawing with constructional functions, to the exclusion of other measures.

The existing literature does not share a consensus on the relative contributions of different cerebral foci to visuoconstructive functions. It is likely that the anterior and posterior areas, as well as the left and right hemispheres, are associated with specific aspects of constructional abilities. In an attempt to shed some light on this area, therefore, the present study, aims to compare (i) visuospatial construction in frontal- and parietal-lesioned patients, (ii) visuospatial construction in right versus left lateralized lesions. We adopt the null hypotheses that there will be no difference in visuospatial construction between patients with frontal and parietal lesions, or between those with right and left hemisphere lesions.

2. Methodology

2.1. Sample

The sample consisted of patients with lesions in the parietal lobe (n = 9) and the frontal lobe (n = 11). The clinical sample was drawn from the in-patient and out-patient services of the Department of Neurosurgery, National Institute of Mental Health And Neuro Sciences (NIMHANS), Bangalore, India. Lesion localization was determined on the basis of clinico-surgical correlations. In addition, as a reference group, 20 normal control subjects matched to each of the patients on age (+/- 3 years), gender and education (+/- 3 years) were drawn from the community. Only right-handed subjects with no history of psychiatric or other neurological/neurosurgical disorders were included. The mean age of the patients was 34.4 years, while that of normal controls was 34 years; the mean number of years of education was 8.79 for patients and 8.05 for normal controls. There were no significant differences between patients and normal controls on age ($p = 0.35$) or education ($p = 0.87$).

2.2. Tools

Edinburgh Handedness Inventory (Oldfield, 1971): this ten-item inventory has a brief and simple method of assessing handedness on a quantitative scale for use in neurological and other clinical and experimental studies.

Stick Construction Test (Lezak, 1995): this test assesses two-dimensional visuospatial construction. It includes a rotation condition as well as a standard copy condition. This ten-item test is first administered as a copying task. The patient is given four wooden sticks (approximately 5 inch long and 1/4 inch wide with 1/2 inch blackened tip) and asked to copy the examiner's model exactly. After the ten designs are copied, the rotation (or reversal) condition is administered, in which the patient is asked to construct his pattern in the reverse of the examiner's model. Of the ten patterns in the copy condition, only six are used in the rotation condition since the other four look the same as the copy on reversal. The time taken for the construction of each pattern, as well as the number of errors, is noted and totaled, on each condition separately. This generates four variables – time taken for copy condition (Sticks Time C) and the rotation condition (Sticks Time R); as well as number of errors on the copy condition (Sticks Errors C) and the rotation condition (Sticks Errors R).

Test of three-dimensional block construction (Spreen & Strauss, 1988): This test measures visuo-constructional ability by how well constructions in three-dimensional space are copied. The test consists of three block models of increasing complexity using 6, 8 and 15 blocks from an assortment of blocks on a tray. A total of 29 individual blocks of different shapes and sizes are used. The different kinds of errors are noted – Omission (omission of a block), Addition (addition of a block), Substitution (using a different block from the one in the examiner's model) and Displacement (angular deviations greater than 45°, separations, or lack of separations, misplacement). The time taken for the three models (Blocks Time 1, Blocks Time 2 and Blocks Time 3), as well as the total number of errors made on each model (Blocks Errors 1, Blocks Errors 2, Blocks Errors 3) are variables considered for analysis.

3. Results

Statistical analyses were done using the Statistical Package for Social Sciences (SPSS) Version 10.0. Before comparing the two lesion groups, the performance of patients was compared with the reference group of normal subjects. On the Wilcoxon signed rank test (Table 1), patients were significantly slower than the normal controls on Stick Construction Test copy condition as well as on the Block Construction Test Model 2 and Model 3. In addition, patients made significantly more Omission and Substitution errors than normal subjects.

Table 1. Comparison of performance between lesion patients and normal controls

Variable	Mean for patients	Mean for normal controls	Z Value	Significance
Sticks time C	165.45	84.2	-3.006	0.003
Sticks errors C	0.4	0.0	0.000	1.000
Sticks time R	134.35	123.6	-0.75	0.940
Sticks errors R	1.15	1.3	-0.374	0.708
Blocks time 1	39.3	22.9	-1.382	0.167
Blocks errors 1	0.15	0.0	-1.000	0.317
Blocks time 2	120.7	48.15	-2.595	0.009
Blocks errors 2	1.5	0.5	-1.187	0.235
Blocks time 3	124.9	73.15	-2.185	0.029
Blocks errors 3	1.05	0.2	-1.667	0.095
Omission errors	0.4	0.05	-2.121	0.034
Addition errors	0.05	0.0	-1.000	0.317
Substitution errors	1.3	0.55	-1.970	0.049
Displacement errors	0.95	0.00	-0.921	0.357

Note: Sticks Time C = time taken for Stick Construction copy condition; Sticks Time R = time taken for rotation condition; Sticks Errors C = number of errors on the copy condition; Sticks Errors R = number of errors on rotation condition; Blocks Time 1 = time taken for Block construction Model 1; Blocks Time 2 = time taken for Model 2; Blocks Time 3 = time taken for Model 3; Blocks Errors 1 = number of errors on Model 1; Blocks Errors 2 = number of errors on Model 2; Blocks Errors 3 = number of errors on Model 3.

In order to test the significance of the difference between the performance of patients with frontal lesions and those with parietal lesions, a Mann-Whitney Test was done (Table 2). Patients with parietal lesions were significantly slower than those with frontal lesions only on the Block Construction Test Model 3.

Patient groups were collapsed across location of lesion, and divided according to the laterality of the lesion. Another Mann-Whitney Test was done to test the significance of the difference in performance between patients with right sided lesions and left sided lesions (Table 3). No significant differences were found between the two groups of patients on any of the test variables.

Table 2. Comparison of performance between frontal and parietal lesion subjects

Variable	Mean for parietal cases (n = 9)	Mean for frontal cases (n = 11)	Z Value	Significance
Sticks time C	221.22	119.82	-1.521	0.128
Sticks errors C	0.89	0.0	-0.905	0.366
Sticks time R	162.11	111.64	-0.418	0.676
Sticks errors R	1.33	1.0	-0.080	0.936
Blocks time 1	52.22	28.73	-1.408	0.159
Blocks errors 1	0.33	0.0	-1.106	0.269
Blocks time 2	172.89	78.0	-0.950	0.342
Blocks errors 2	2.67	0.55	-1.359	0.174
Blocks time 3	172.56	85.91	-1.976	0.048
Blocks errors 3	1.56	0.64	-0.562	0.574
Omission errors	0.67	0.18	-0.926	0.354
Addition errors	0.11	0.0	-0.707	0.480
Substitution errors	2.33	0.45	-1.056	0.291
Displacement errors	1.44	0.55	-1.291	0.197

Table 3. Comparison of performance between left-sided and right-sided lesions

Variable	Mean for right lesions (n = 13)	Mean for left lesions (n = 7)	Z Value	Significance
Sticks time C	179.62	139.14	-0.040	0.968
Sticks errors C	0.62	0.00	-0.734	0.463
Sticks time R	130.77	141.00	-0.991	0.322
Sticks errors R	1.23	1.0	-0.166	0.868
Blocks time 1	46.08	26.71	-0.238	0.812
Blocks errors 1	0.23	0.00	-0.734	0.463
Blocks time 2	127.00	109.00	-0.198	0.843
Blocks errors 2	2.00	0.57	-1.075	0.282
Blocks time 3	130.54	114.43	-0.040	0.968
Blocks errors 3	1.23	0.71	-0.244	0.807
Omission errors	0.54	0.14	-1.015	0.310
Addition errors	0.07	0.00	-0.707	0.480
Substitution errors	1.69	0.57	-0.506	0.613
Displacement errors	1.15	0.57	0.000	1.000

4. Discussion

As expected, lesion patients were significantly slower than normal controls on several measures – time taken for Stick Construction Test copy condition and for Block Construction Test Model 2 and Model 3. Patients also made significantly more Omission and Substitution errors on the Block Construction Test than normal subjects. This is consistent with other studies, which have showed that patients with brain damage, specifically to the frontal and parietal areas are slower than normal subjects, and make more errors on tasks of visuospatial construction (Critchley, 1953; Hecaen & Albert, 1978; Manning, 2003). Patients and normal controls did not differ on any of the other measures. It is possible that the other measures were not sensitive to visuospatial construction deficits following brain damage. The data presented here was collected during a larger study which established normative data for tests of visuospatial construction and mental rotation (Kashyap, Rao, Kumar & Devi, in press). In that study too, we concluded that the Stick Construction copy and rotation time scores and Block Construction Test time taken to construct Model 3 were the most reliable and valid measures, and that the other variables were not sensitive to lesion-related visuospatial construction deficits.

Patients with parietal lesions were slower than those with frontal lesions on Model 3 of the Block Construction Test. This last model is the most difficult to construct, and hence might be most suitable to elicit visuoconstructive impairments. In the original study of which this paper is a part, cut-off scores were established for each variable (Kashyap et al., in press). Of the nine patients with parietal lesions, six have time scores above the cut-off on Model 3 of the Block Construction Test, indicating impairment. In contrast, only four of the eleven frontal lesion patients have scores in the impaired range. Hence it is possible to suggest that the test of three-dimensional construction is particularly sensitive to parietal visuoconstructive dysfunction. This finding has been supported by other researchers – the Three-Dimensional Block Construction Test has been documented to be more sensitive than a two-dimensional measure such as WAIS Block Design Test, with a higher number of patients falling in the impaired range on the former (Spreen & Strauss, 1988). In addition, the three-dimensional Block Construction Test discriminates between patients with moderate and severe brain impairment which has been attributed to its increased task complexity (Lezak, 1995). This is in keeping with the view originally advocated by Critchley (1953) that patients who respond moderately well to drawing and stick construction tasks display gross abnormalities in three-dimensional construction tasks. It is important to note that analysis of depth, distance and dimension is one of the most important roles of the parietal lobe (Joseph, 1995). This contribution of the parietal lobe to visuospatial construction might distinguish it from frontal visuospatial constructive deficits.

No other differences were evident between patients with frontal and parietal lesions. It is plausible that the frontal and parietal areas do not have strictly delineated or mutually exclusive roles to play in visuospatial construction. Several researchers have hypothesised that the frontal and parietal areas of the brain work in tandem, as a network (Farah, 2003; Goodale & Milner, 1992). Several networks (eg., the superior and inferior longitudinal fasciculi and the occipito-frontal fasciculus) arise from the parieto-occipital areas of the brain and project to the frontal cortices. The occipito-frontal fasciculus in particular has been associated with various aspects of complex visuospatial processing (Petrides & Pandya, 2002) which may be necessary for tasks of construction.

The present study did not find any differences between the performance of patients with right-sided versus left-sided lesions. This could be attributed to the small size of the two groups. In addition, most studies which have found differences in left- versus right-lesioned constructions have reported qualitative differences between the two, such as the approach to the constructions, or over-simplification/over-elaboration of the construction (Grossi & Trojano, 1999; Lang et al., 2006; Manning, 2003). Although the Block Construction Test used in the present study includes an analysis of the different kinds of errors, the Stick Construction Test does not, thus precluding a qualitative analysis of the errors committed by the two groups. Since there is no clear consensus on the nature of differences between left- and right-lesioned constructions, studies usually rely on post-hoc findings, rather than looking for specific features during the task performance (Lang et al., 2006). As Critchley (1953) astutely observed, "… The patient's final design as he offers it at the end of the allotted time may appear good enough, but a record of his manner of carrying out the test may be an eloquent testimony of an abnormal performance".

5. Conclusions

The current study demonstrates significantly greater time taken by parietal lesion patients to construct the last model of the Block Construction Test. No significant differences were evident between patients with right- versus left-sided lesions on visuospatial construction tasks. The strengths of this study are the use of non-graphomotor measures, both two-dimensional and three-dimensional, which has not frequently been done in the past.

The study of normal control subjects matched to the patients on age education, gender and handedness is an added strength. However, the limitations include a small sample size, as well as large variations in age and education of the subjects. In addition, it was not possible to study qualitatively the kinds of errors made on the Stick Construction Test.

To conclude, it appears from the findings of the present study as well as past research that tests of three-dimensional construction might be most sensitive to visuospatial construction deficits. Nevertheless, it is increasingly clear that visuospatial construction might not be exclusively localized to the parietal lobes, but that the frontal and parietal areas might work closely together in producing well-organized constructions. The relative contributions of each area are not yet fully clear, and it is possible that studies with larger samples might help to clarify this question.

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