

ORIGINAL REPORT

TACTILE SPATIAL RESOLUTION IN UNILATERAL BRAIN LESIONS AND ITS CORRELATION WITH DIGITAL DEXTERITY

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Objective: To test the tactile spatial resolution in chronic unilateral brain lesions. Additionally, since sensory deficits are thought to have an impact on motor deficits, this study investigated the correlation between tactile spatial resolution and finger dexterity.

Design: Descriptive cross-sectional study.

Patients: Twenty-two patients with unilateral brain lesions (12 children with congenital hemiplegia and 10 patients after stroke).

Methods: Tactile spatial resolution was measured with a grating orientation task, and finger dexterity with the Purdue Pegboard Test.

Results: Major tactile spatial resolution deficits were measured on the paretic hand and preserved abilities on the non-paretic hand, both in children with congenital hemiplegia and in patients after stroke. No correlation was found between the deficits of tactile spatial resolution and digital dexterity in the paretic hand ($r=0.126$; $p=0.572$).

Conclusion: The specific location of tactile spatial resolution deficits on the hand contralateral to the lesion was surprising when one considers the left hemispheric dominance of tactile spatial resolution in healthy subjects. The absence of correlation between tactile spatial resolution and dexterity deficits suggest that these abilities are not related, suggesting that they should be considered separately and equally integrated into the rehabilitation of unilateral brain lesions.

Key words: sensory impairments; hemiplegia; tactile spatial resolution; dexterity; rehabilitation.

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INTRODUCTION

Central neurological impairments arising either early or late in life are characterized by motor deficits and also frequently by sensory impairments (1–6). The measurement of sensory deficits is considered to be a good predictor of outcome following intervention strategies (7). The multimodal aspect of tactile perception requires the investigation of different modalities, of which light touch, proprioception and tactile discrimination are the most frequently investigated (5, 8–10). Light touch and

proprioception have been investigated extensively in unilateral brain lesions (5, 8–10). Tactile spatial discrimination/resolution is currently tested using 2-point discrimination (1, 10–12). However, this test has been described as incorrect to measure spatial resolution, as non-spatial cues are not controlled (13–16). Our study was designed to test the tactile spatial resolution in chronic unilateral brain lesions, i.e. congenital hemiplegic (CH) children and stroke patients, using a Grating Orientation Task (GOT). This test has been described as reliable and valid (15, 16). Furthermore, a tactile spatial resolution test similar to GOT, based on the principle of discrimination of differences in finely graded plastic ridged surfaces, has been described as a “quantitative, standardized measure appropriate for testing patients after stroke in clinical settings” (9).

In healthy subjects, grating orientation discrimination has shown a left hemispheric dominance (intraparietal sulcus activation) independent of the hand stimulated (17). Therefore, in patients after stroke, one could hypothesize that patients with a left lesion are likely to present deficits in both hands and patients with right lesions should be less affected. In CH children, we expected that the early cortical reorganization would induce highly variable recovery.

In addition, this study investigates the correlation between tactile spatial resolution and digital dexterity. This relationship is of particular interest since it is common to start rehabilitation by using sensory stimulations to enhance both sensory and motor recovery based on the generally accepted idea that good sensory abilities are needed to perform skilled hand movements (18, 19) and could be useful to motor recovery (20–26). Results from acute patients after stroke in tactile spatial resolution support this concept: in pure motor syndromes, sensory performances would be increased to compensate for the motor deficits (27). These statements may encourage therapists to use sensory rehabilitation preferentially over motor rehabilitation, especially in patients with large motor deficits where sensory rehabilitation could be considered useful to enhance motor function. A correlation between sensory and motor abilities at a chronic stage would support this concept. In contrast, the absence of a link between these 2 abilities would suggest a quite independent recovery and thus enhance interest in using equal motor and sensory rehabilitation.

The aims of this study were: (i) to investigate tactile spatial resolution deficits in chronic unilateral brain lesions; (ii) to study whether the neonatal or adult occurrence of the lesion influences recovery, and especially the impact on the non-

paretic hand; and (iii) to test for a correlation between tactile spatial resolution and digital dexterity.

MATERIALS AND METHODS

Subjects

This study was authorized by the ethics committee of the Université catholique de Louvain, School of Medicine in Brussels, Belgium. Subjects and parents gave their written informed consent.

Twelve children with congenital hemiplegia (2 girls) age range 10–16 years participated in the study (mean age 12.5 years; standard deviation (SD) 2.1). The 10 patients after stroke, including 3 women, were in the age range 36–81 years (mean age 59 years). All of them were initially right-handed and none of them presented aphasia, hemineglect or hemianopsia.

For children, a normal school level, implying no cognitive deficits, was a selection criterion to participate in the study. For adults, a minimum score of 26 on the mini-mental state evaluation (MMSE) was required. A brief description of each patient is given in Table I.

Test description

The tactile spatial resolution threshold of the patients was measured with the Grating Orientation Task using the JVP Domes (JVP Domes, Stoelting Co., Wood Dale, IL, USA). Subjects sat in a quiet room with their forearm in a supine position and the index finger stuck to the table using double-sided adhesive tape applied to the nail (28). The test was first demonstrated and explained to each subject. The paretic hand was tested first, followed by the non-paretic hand.

A classical set of 8 hemispherical JVP domes presenting gratings with equidistant bar and groove widths (0.35, 0.50, 0.75, 1.00, 1.20, 1.50, 2.00, 3.00 mm) was used for CH children. An extended set of 3 additional domes (3.5, 4 and 4.5 mm) designed for older adults was used for the patients after stroke.

The domes were normally applied on the subjects' index finger, resulting in 1–2 s in a skin deformation of approximately 2 mm (29–31). Subjects were required to determine the grating orientation before removal of the stimulus (30). Starting with the largest grating, the bars and grooves were randomly presented longitudinally or transversely to the long axis of the finger for 10 trials. Subsequently, the next smallest grating was used following the same experimental

Table I. Clinical description and lesion description

Patient (sex)	Age, years	Hemiparesis	Lesion description (MRI)	GFMC level	Time since lesion, months	SIAS, /76
1 (M)	10.1	Left	R encephalomalacy in superficial sylvian area, R cerebral peduncle atrophy.	1		
2 (M)	10.5	Left	R widespread micropolygyria (frontal lobe, insula and part of temporal lobe). Ventricular, thalamic and peduncular asymmetry (L>R).	2		
3 (M)	10.9	Right	L subcortical malacical lesions (ovale centrum, periventricular white matter), caudate nucleus L thalamic and peduncular atrophy.	1		
4 (M)	11.1	Right	L periventricular leucomalacy (white matter, caudate nucleus), L moderate ventricular widening, relative thalamic atrophy.	1		
5 (M)	11.6	Left	Widespread macrocystic leucomalacy, R parietal and frontal lobe, L discrete parietal lesion.	1		
6 (F)	11.9	Left	R sylvian artery stroke with micro and macrocystic gliosis in the ovale centrum (white matter atrophy), R ventricular widening, R caudate nucleus lesion.	2		
7 (F)	12.6	Left	Very discrete periventricular leucomalacy, parietal bilateral, frontal R.	1		
8 (M)	13.3	Right	Bilateral periventricular leucomalacy, with L predominance, thalamic asymmetry (R>L).	1		
9 (M)	13.9	Right	Large L macrocystic gliosis in the left hemisphere (ant. temporal pole, middle and superior temporal gyrus, inf and middle frontal gyrus, insula, parietal lobe, part of occipital lobe, lenticular nucleus, caudate nucleus body, major part of thalamus). Large L peduncular, corticospinal and bulbar atrophy, L ventricular widening.	1		
10 (M)	15.1	Left	Drained hydrocephaly, bilateral periventricular leucomalacy in posterior regions, predominant in R ovale centrum, corpus callosum atrophy.	2		
11 (M)	15.6	Left	Large R macrocystic lesion in deep and superficial sylvian territory; hemispheric, thalamic and peduncular atrophy; discrete L cerebellar atrophy.	2		
12 (M)	15.9	Left	R large macrocystic gliosis in ovale centrum, associated with R peduncular and corpus callosum atrophy, consistent with vascular prenatal cerebral lesion. L discrete internal frontal closed schizencephaly.	1		
13 (F)	36.0	Right	L sylvian CVA.		64	64
14 (F)	48.0	Left	Ablation of R frontal angioma in premotor area.		125	60
15 (F)	49.0	Left	R deep sylvian ischemia.		53	60
16 (M)	49.0	Left	R deep and superficial sylvian CVA, extended to frontal inferior area, insular, temporal and lenticular R areas.		17	66
17 (M)	57.0	Left	N/A		63	48
18 (M)	60.0	Right	L deep sylvian ischemia (<i>lenticular nucleus, insula, corona radiata, caudate nucleus</i>).		33	69
19 (M)	67.0	Right	L ischemia in the posterior part of putamen and corona radiata.		6	72
20 (M)	69.0	Left	R large sylvian CVA with Wallerian dysgenesis of CST, peduncular atrophy and bulbar olive dysgenesis.		113	70
21 (M)	74.0	Right	L capsulo-lenticulo-striated ischemic CVA.		37	67
22 (M)	81.0	Left	R ischemia in the pons, leucoaraiosis in supratentorial white matter.		9	61

MRI: magnetic resonance imaging; R: right; L: left; M: male; F: female; CST: corticospinal tract; CVA: cerebral vascular accident; GFMC: gross motor function classification; SIAS: stroke impairment assessment scale.

method, and so forth. The evaluation was terminated when the probability of a correct answer for 1 dome reached 50% of the 10 trials (32). The tactile acuity grating (TAG) score, which is a simple linear interpolation estimate of the 75% correct grating width, was then calculated (33). The tactile spatial resolution performance improves as TAG score decreases.

Digital dexterity was measured using a subtest of the Purdue Peg-board test. This test consists of a board containing 2 rows of holes and 2 cups containing pins. The subjects had to pick up, 1 at a time, as many pins as possible and place them into the holes in the board within 30 s. Before starting, they were allowed to practice with 3 or 4 pins. The test was performed 3 times with each hand, alternating the non-paretic and the paretic hand. The score was the mean number of pins placed during the 3 trials for each hand (34). This subtest of the Purdue pegboard has been described as a test measuring finger dexterity, which is the "ability to make rapid, skilful, controlled manipulative movements of small objects, where the fingers are primarily involved" (35). Therefore it can be considered as a test of fine dexterity.

Data analysis

Age effects have been demonstrated through the lifespan in tactile spatial resolution (32, 36) and digital dexterity (37–40). Our data were Z-transformed according to the norms provided in these papers. For tactile spatial resolution in adults, norms provided by the sighted group of Van Boven et al. (29) were used. The Z-score allowed each subject to be compared with values of normal people of his/her age acquired from the literature. The paretic hand was compared with the non-paretic hand using a *t*-paired test or a Wilcoxon test in non-parametric conditions. The tactile spatial resolution and digital dexterity results of CH children in the paretic and non-paretic hands were compared with those of patients after stroke using a *t*-test or a Mann–Whitney test in non-parametric conditions. Spearman's correlations were used to study the correlation between tactile spatial discrimination and digital dexterity in the paretic and non-paretic hand.

RESULTS

Tactile spatial resolution in unilateral brain lesions

Table II reports the rough score and Z-score of each subject for tactile spatial resolution. CH children and patients after stroke showed major impairments in the paretic hand. All but 2 of the CH children had a Z-score lower than -2 in the paretic hand, which is considered to be the lower limit of normality. In patients after stroke, it was also found that only 2 participants had Z-scores in the normal range for the paretic hand. Surprisingly, the non-paretic hand showed Z-scores similar to the normal values. All CH children had Z-scores between $+2$ and -2 . Only 1 patient after stroke had a Z-score slightly lower than normal values (-2.9). The comparison of tactile spatial resolution between the paretic and non-paretic side thus showed a significant difference (Wilcoxon test, $W=247$, $p<0.001$) both for CH children and patients after stroke.

The results of paretic hand performance in CH children were not significantly different from those of patients after stroke (Mann–Whitney test, $T=104$, $p=0.489$). In the non-paretic hand, there were also no differences observed between the CH and stroke groups (*t*-test, $t=0.106$, $p=0.971$).

Digital dexterity in unilateral brain lesions

The rough score and Z-score of each subject for digital dexterity are presented in Table III. Both CH children and patients

Table II. Tactile spatial resolution: rough and Z-scores

Patient	Age, years	Tactile spatial resolution			
		Paretic		Non-paretic	
		Score, mm	Z-score	Score, mm	Z-score
1	10.1	3.21	-3.90	1.41	-0.55
2	10.5	2.58	-2.70	1.69	-1.07
3	10.9	2.50	-2.60	1.45	-0.62
4	11.1	2.25	-2.13	0.97	0.28
5	11.6	4.50	-6.30	1.63	-0.95
6	11.9	2.58	-2.80	1.17	-0.09
7	12.6	5.63	-8.50	0.91	0.40
8	13.3	0.66	0.87	0.59	0.99
9	13.9	7.50	-12.00	1.18	-0.10
10	15.1	1.92	-1.50	1.75	-1.19
11	15.6	5.63	-8.50	0.71	0.78
12	15.9	2.88	-3.31	1.47	-0.66
13	36.0	4.18	-5.90	0.81	1.40
14	48.0	5.63	-9.05	1.17	0.64
15	49.0	4.08	-5.70	2.83	-2.98
16	49.0	3.43	-4.28	0.94	1.13
17	57.0	11.25	-14.25	2.83	-0.22
18	60.0	3.19	-0.82	2.83	-0.22
19	67.0	3.75	-1.75	2.38	0.54
20	69.0	4.08	-2.30	3.45	-1.25
21	74.0	5.63	-5.56	3.63	-0.56
22	81.0	11.25	-19.63	3.91	-1.28

after stroke had impairments in the paretic hand, since only 1 child and 1 adult had a Z-score included in the normal range. The non-paretic hand showed Z-scores in the normal range for most CH children, and only 1 patient after stroke had a Z-score slightly lower than normal values (-2.9). Therefore,

Table III. Digital dexterity: rough and Z-scores

Patient	Age, years	Digital dexterity			
		Paretic		Non-paretic	
		Score, <i>n</i>	Z-score	Score, <i>n</i>	Z-score
1	10.1	0.00	-12.37	12.00	-3.28
2	10.5	0.00	-12.37	12.00	-3.28
3	10.9	3.33	-9.55	16.00	-0.03
4	11.1	9.66	-3.41	14.00	-1.37
5	11.6	0.00	-9.90	14.66	-0.93
6	11.9	10.33	-3.27	15.66	-0.59
7	12.6	14.33	-0.54	15.66	-0.68
8	13.3	7.33	-5.44	14.00	-1.88
9	13.9	0.00	-10.57	15.33	-0.37
10	15.1	0.66	-12.55	13.66	-2.14
11	15.6	0.00	-13.11	15.33	-0.88
12	15.9	0.00	-13.11	14.66	-1.38
13	36.0	9.33	-4.31	15.66	-1.06
14	48.0	1.33	-9.13	16.00	-0.89
15	49.0	5.00	-6.92	12.00	-2.91
16	49.0	1.00	-8.42	13.33	-1.72
17	57.0	1.66	-8.05	13.66	-1.85
18	60.0	11.00	-1.13	12.33	-0.25
19	67.0	8.00	-3.13	9.66	-2.03
20	69.0	1.00	-7.80	10.33	-1.58
21	74.0	2.00	-4.14	10.00	-0.63
22	81.0	3.66	-3.61	8.00	-1.05

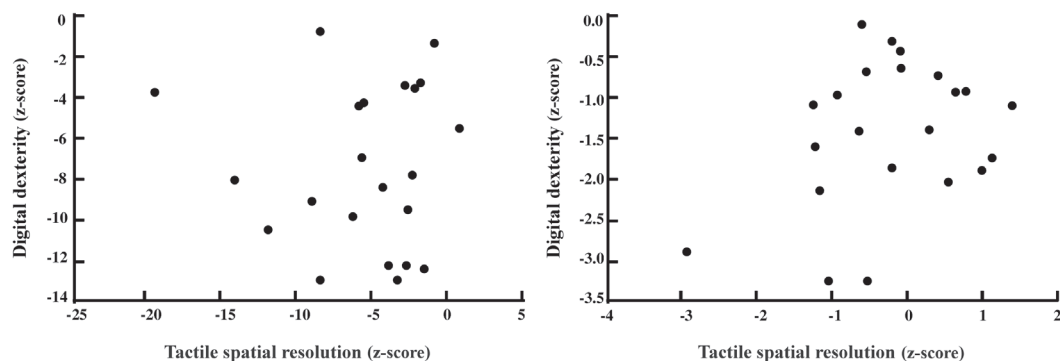


Fig. 1. No correlation was observed between the performance of tactile spatial resolution and the digital dexterity in the whole sample. Each plot represents 1 patient. Left panel shows the paretic hand performance, right panel, the non-paretic hand performance.

the digital dexterities of the paretic and non-paretic sides were significantly different (t -paired test, $t=-7.6$, $p<0.001$). The results for CH children were not significantly different from the results for patients after stroke for both the paretic and non-paretic hand (t -test, all $p>0.05$).

Correlation between tactile spatial resolution and digital dexterity

No correlation was found between tactile spatial resolution measured with the GOT and digital dexterity measured with the Purdue Pegboard in our patients (Spearman's correlation; $r=0.126$, $p=0.572$ and $r=0.195$, $p=0.377$; for paretic and non-paretic hand, respectively; Fig. 1). This suggests that the deficits in both abilities are not linked.

We further investigated whether a relationship was present specifically in left or right lesions. In right lesions ($n=14$) no significant correlation was observed in the paretic or in the non-paretic hand (all $p>0.09$).

In left lesions ($n=8$), no significant correlation between tactile spatial resolution and digital dexterity was observed in the paretic hand ($p=0.160$). However, on the non-paretic hand a negative correlation was observed ($r=-0.762$; $p=0.021$; Fig. 2).

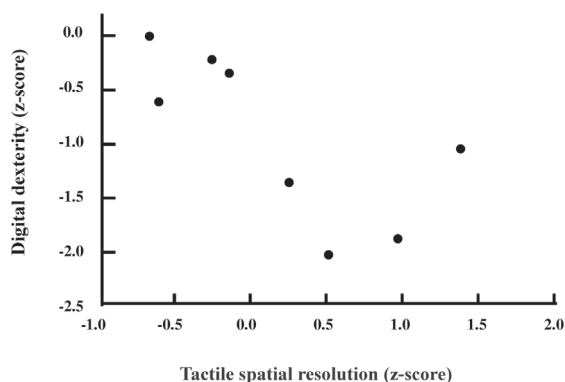


Fig. 2. Correlation between digital dexterity and tactile spatial resolution in the non-paretic hand of patients with left lesion. Each plot represents 1 patient.

DISCUSSION

This study was designed: (i) to investigate tactile spatial resolution deficits in chronic unilateral brain lesions; (ii) to determine whether the occurrence of the lesion during a neonatal period in children or later in adult patients after stroke influences the extent of tactile spatial resolution deficits, especially in the non-paretic hand; and (iii) to test for a correlation between tactile spatial resolution and digital dexterity.

Tactile spatial resolution

The results show major impairments in tactile spatial resolution in the paretic hands of both CH children and patients after stroke. In contrast, the non-paretic hands were preserved. We expected to find, at least in adult patients after stroke, great differences with respect to the side of the central damage and the location of the lesion. Since tactile spatial resolution has been described as being a function presenting a left-hemisphere advantage for processing independent of the side stimulated (17), one could hypothesize that patients with left lesion are likely to present deficits in both hands. In contrast, patients with right lesions should be less affected. Our results are quite surprising regarding this hypothesis. The systematic deficit in the paretic hand and preservation of the non-paretic hand independent of the side of the lesion contradicted our hypothesis that patients with central lesions would have a systematic left dominance advantage in tactile spatial resolution independent of the hand tested. Furthermore, the major deficits in paretic hands with many different insults suggest that tactile spatial resolution requires the integrity of many structures beyond the left intraparietal sulcus, considered until now as the cradle of tactile spatial resolution.

The absence of differences observed between the performances of CH children and adult patients after stroke in both the paretic and non-paretic hands clearly shows that neonatal or adult occurrence of the lesion does not influence the extent of the deficit.

Digital dexterity

Results regarding digital dexterity presented in this study clearly match the results of previous studies showing impair-

ments in paretic hands and preserved abilities in non-paretic hands (4, 41).

Correlation between tactile spatial resolution and digital dexterity

The neurorehabilitation of patients presenting with a unilateral brain lesion is based on many concepts supported mainly by observations and clinical trials. The widespread idea that sensory recovery is needed and/or useful for motor recovery (20–26) promotes the use of sensory training, especially at the beginning of rehabilitation, as useful for both sensory and motor recovery. In a previous article, it was shown that neither tactile pressure detection nor proprioception were related to manual ability (4), but the authors suggested that it would be more interesting to investigate tactile spatial resolution since tactile spatial resolution involves the cortical representation of peripheral impulses. This hypothesis is congruent with articles showing a correlation between tactile spatial resolution and digital dexterity in normal adult and ageing subjects (42, 36).

In this study, no correlation was shown between tactile spatial resolution and fine dexterity deficits in unilateral brain lesions at a chronic stage when considering the whole sample. Therefore, we suggest that these 2 abilities may be not related. This is further supported by our recent results in healthy children, showing no relationship between tactile spatial resolution and digital dexterity (43). Tactile spatial resolution deficits do not automatically imply poor digital dexterity and vice versa. Thus, we further suggest that these abilities should be considered separately and equally integrated into the rehabilitation of unilateral brain lesions. This is further supported by the negative correlation found in left lesions in the non-paretic hand of our patients. This negative correlation between tactile spatial resolution and digital dexterity suggests that, at least following a left lesion, tactile spatial resolution and digital dexterity, instead of evolving in parallel, are likely to be submitted to a competition between both systems. This is in line with the findings of Doh et al. (27) showing that the tactile spatial resolution of hemiplegic patients significantly and inversely correlated with the severity of their initial motor deficit in the non-dominant side. Since both systems seem to compete in some conditions, rather than evolving in parallel, this reinforces our suggestion that motor and sensory function should be considered separately and integrated equally into the neurorehabilitation of unilateral brain lesions.

Limitations of the study

Instead of questioning the relationship between tactile spatial resolution and digital dexterity, the surprising results of this study could rather question the validity of the Grating Orientation Test. There may, in fact, be a link between tactile perception and motor abilities, but tactile spatial resolution may be a poor measurement of the tactile modality linked to the motor function of the patient.

Since we intended to determine whether the occurrence of the lesion during a neonatal period in children or later in adult

patients after stroke influences the extent of tactile spatial resolution deficits, our sample included both patients after stroke and children with congenital hemiplegia. Due to the small sample of each of these 2 populations, one must remain cautious not to overstate the results. Furthermore, the heterogeneous aspect of the populations that make up this sample could also influence the results. It would therefore be interesting to conduct large sample studies both on tactile spatial resolution and on the relationship between sensory and motor performance in patients with unilateral brain lesions.

In conclusion, the specific location of tactile spatial resolution deficits on the hand contralateral to the lesion was surprising when one considers the left hemispheric dominance of tactile spatial resolution in healthy subjects (17). Furthermore, the absence of correlation between tactile spatial resolution and dexterity deficits suggests that these 2 abilities are not related. Therefore, we suggest that they should be considered separately and integrated equally into the rehabilitation of unilateral brain lesions, both in congenital and acquired lesions. Further large-scale investigations are needed to confirm these results.

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