Touch-screen system for assessing visuo-motor exploratory skills in neuropsychological disorders of spatial cognition

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Abstract—*A new computerised test adopting touch-screen technology has been developed to assess the visuo-motor exploration of extra-personal space. The test was derived from well-known paper-and-pencil cancellation tasks used widely in the diagnosis and quantitative assessment of unilateral spatial neglect (USN), a neuropsychological syndrome that is more frequent and severe after damage to the right cerebral hemisphere. A main component deficit of USN is the defective visuo-motor exploration of the side of space contralateral to the side of the lesion (contralesional), namely, in right-sided brain-damaged patients it occurs on the left side and vice versa. The computer-based paradigm consisted of a visuo-motor spatial exploratory task: the subjects were instructed to touch, in any order they wished, all the targets they detected on a computer touch-screen. This measured the time of occurrence and the spatial co-ordinates of each touch event and forwarded the data to the computer for storage; the computer provided feedback to the subject by 'tagging' the touched target. The paradigm allowed the calculation of accuracy and latency indexes and recorded the exploratory pathway taken by each subject. A pilot study was performed in ten normal subjects and 15 brain-damaged patients, with and without psychometric evidence of USN; the results showed that the equipment was able to provide quantitative indexes related to the spatial–temporal aspects of exploratory ability, which are useful for diagnostic purposes, and revealed significant differences between the controls and patients with USN: the overall average values of latency and crossing indexes increased in patients with USN, compared with the controls (latency from 0.77 to 1.90 s; path crossing index from 7.0% to 59.5%), and the significantly negative USN patient latency gradient (−2.79 against a null control value) evidenced a worsening of performance towards the left side.*

Keywords—*Vision, Extra-personal space, Unilateral spatial neglect, Brain damage, Neuropsychology, Rehabilitation*

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1 Introduction

DAMAGE TO one cerebral hemisphere can disrupt the ability of neurological patients both to explore the side of space contralateral to the side of the lesion and to report stimuli presented in that space. This neuropsychological syndrome, termed unilateral spatial neglect (USN), is more frequent and severe after lesions in the right cerebral hemisphere, involving the contralateral, left, portion of extra-personal and bodily space (BISIACH and VALLAR, 2000; HEILMAN, *et al.*, 1993; VALLAR, 1998). The main pathological mechanisms underlying USN involve a disordered conscious representation of contralesional space, a defective contralesional lateral orientation of spatial attention, or a combination of such pathological mechanisms. Elementary sensory-motor disorders, such as hemi-anopia, hemi-anaesthesia and hemiplegia, are often, but not necessarily, associated with USN, and cannot therefore be regarded as the relevant pathological factor underlying the disorder.

The most widely used exploratory tasks for a quantitative diagnosis of USN involve the manual exploration of near, within hand-reach, extra-personal space. In the vast majority of clinical tasks, subjects are required to cancel or cross out target stimuli that are printed and evenly distributed over the left and right halves of a display, such as an A3 or A4 sheet of paper or a board. The stimuli include lines (ALBERT, 1973), circles (BISIACH *et al.*, 1979), letters (DILLER and WEINBERG, 1977) and meaningful or meaningless drawings (MESULAM, 1985). The display can

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include only targets (BISIACH *et al.*, 1979), or targets interspersed among a variable amount of distracters, e.g. the target is the letter H among other letters (DILLER and WEINBERG, 1977), a black 'bell' silhouette among other meaningful silhouettes (GAUTHIER *et al.*, 1989), a symbol among other symbols (MESULAM, 1985), on a 'small star' among larger stars, words and letters (STONE *et al.*, 1991).

In most versions of the task, the targets remain visible to the subject after being crossed out. In some versions of the paper-and-pencil task, the subject erases the targets using a rubber (Mark *et al.*, 1988). In 'proprioceptive' or 'tactile' versions of the task, patients are blindfolded and asked to search for targets, such as an object, placed in specific positions on a board (DE RENZI *et al.*, 1970; VALLAR *et al.*, 1991).

Patients typically use the arm and hand ipsilateral to the side of the lesion and unaffected by the unilateral cerebral damage (right hand in right-brain-damaged patients, left hand in left-brain-damaged patients). In most versions of the task, the lateral spatial distinctive feature of neglect is assessed by aligning the centre of the display with the mid-sagittal plane of the subject, thus defining the left- and right-hand sides of the display with respect to an egocentric reference frame. However, for specific experimental purposes, the display can be displaced laterally or aligned with other body parts, such as the subject's arm (BISIACH *et al.*, 1985). For instance, it has been shown that USN is reduced when the stimulus is located in the ipsilesional ('non-neglected') portion of egocentric space (see, for example, and HEILMAN and VALENSTEIN (1979) and VALLAR *et al.*, 2000).

The different versions of a visuo-motor exploratory task are able to provide accuracy parameters (e.g. the number of targets crossed out, picked up or omitted correctly, the number of perseverations, repeated cancellation, errors), latency indexes (total time spent to execute the task, computed average time per target) and co-ordinates indicating the exploratory pathway followed by the subject. However, in most current versions of the task, all these measures are recorded manually by the experimenter, who uses a stopwatch and notes, at the same time, the subject's pathway. Such conditions result in reasonably accurate accuracy measures because they can be computed off-line, after the subject has completed the task. On the other hand, the latency index and the pathway description are far from precise, as they are recorded on-line by the experimenter while the subject is performing the task; accordingly, they are usually not recorded.

In an effort to overcome the limitations related to such paper-and-pencil approaches, computer-controlled versions of the paper-and-pencil tasks were developed. In fact, a number of computer-based neuropsychological tests have been reported, and comparison with the corresponding paper-and-pencil test has proved them suitable for diagnostic and rehabilitation purposes (BUTCHER *et al.*, 2000; CURTIS-PRIOR, 1996; KANE and KAY, 1992).

The diagnostic assessment and behavioural rehabilitation of USN in neurological patients is a subject that prompted the development of computer-based tasks (ANTON *et al.*, 1988). One research group, which included some of the present authors, applied an opto-electronic motion capture system to the recording of a paper-and-pencil cancellation test (ABELLO *et al.*, 1995). The pencil tip was marked with reflective film detectable by a set of TV cameras, and the trajectory of the pencil tip was measured; algorithms provided the temporo-spatial dynamics of the subject's test performance.

A computerised version of the target cancellation task was developed, using 12 letter Os as targets, and 12 Xs as distracters, on a graphic tablet interface (DONNELLY *et al.*, 1999), the test performance being recorded in terms of position and latency for each target cancellation event. The subjects' exploratory pathways were also analysed by matching them against a number of stored exploratory patterns that were based on the performance of control subjects. Sixty-eight right-brain-damaged patients and 12 controls were tested; however, the graphic tablet cancellation task proved to be less sensitive than the adopted paper-and-pencil battery (behavioural inattention test (BIT)) (WILSON *et al.*, 1987). The BIT classified 28 of the 68 patients as showing left visual USN, 25 of them also having defective performance for a number of parameters recorded by the graphic tablet task (omissions, latencies and search strategies).

Later, a line bisection task (AXENFELD, 1894; BISIACH and VALLAR, 2000) and a line cancellation task (ALBERT, 1973) were implemented on a graphic tablet (POTTER *et al.*, 2000): Potter examined 38 BIT classified, right-brain-damaged patients with left USN, 57 without left USN and 13 normal control subjects. The BIT-classified left USN patients, after assessment on the graphic tablet versions of the line bisection and line cancellation tasks, were found to exhibit USN also on the computerised versions of the tasks. Furthermore, the graphic tablet test revealed latency differences between patients with and without USN and normal controls. For the left side of the display, the average time lapse between the cancellation of two successive targets was longer for USN patients than for patients without USN, who were, in turn, slower than the normal controls. As no differences were found for the right side of the display, average target cancellation time appears a sensitive index to reveal mild left USN that remains undetected by the accuracy measurements of both BIT and graphic display.

To sum up briefly, the graphic tablet computer-based apparatus appears to be a sensitive and useful tool to detect the presence of left visual USN; however, graphic tablet systems do not allow the implementation of time-evolving and context-dependent test scenarios to test the explorative skills of non-static displays.

Recent technical innovations allow the implementation of test scenarios with a friendly and robust man–machine interface on touch-screens (HUGUENIN, 1997). Such a setting has also proved suitable for experiments in primates (JOUFFRAIS and BOUSSAOUD, 1999). Touch screen-based systems with tests using a relatively simple stimulus array for assessing memory and attention are now available (CROOK *et al.*, 1990; ROBBINS *et al.*, 1994).

In this paper, we present the implementation, on a touch-screen system, of a cancellation test using four settings that differ in stimulus type and spatial arrangement. The implemented setup includes time-evolving and context-dependent displays and feedbacks. Moreover, the results from a pilot study, performed in ten normal subjects and 15 brain-damaged patients, are reported.

2 Materials and methods

The proposed computerised test allows the implementation, on a screen, of the traditional paper-and-pencil cancellation tasks. The main aspects of this approach include

(i) the measurement and recording of the position and timing of each target tagging
(ii) a range of possible types of feedback after contact with the target, e.g. the target can be crossed out or circled, it can disappear or change colour
(iii) the availability of additional test indexes, mainly related to test timing and search strategy
(iv) automatic and real-time evaluation of test outcome
(v) the availability of an animated graphical replica of subject performance.

The computerised test was controlled by three software modules that we set up to manage the test scenario, measure subject performance, and analyse the test outcome.

Mathematical models were used to define the variables and indexes that describe the exploratory capabilities of the subject; such parameters are computed in relation to the whole test screen, as well as to sub-areas that can be defined according to specific experimental or clinical requirements.

2.1 *Experimental setup: hardware*

The measuring device was a monitor* equipped with a touch-screen†. It had all the features of a computer monitor plus the means continuously to detect the position of the subject's contact point (usually tip of the index finger) on the screen surface (Fig. 1).

The touch-screen was based on capacitive sensing technology, two transparent layers being fixed onto the monitor screen: the front layer in contact with the subject was non-conductive and worked as the dielectric in the capacitor; the other layer consisted of conductive material and worked as a capacitor plate. Finger contact with the dielectric layer drained the electric charge, and the intensity of the charge flow was measured at the four screen corners, allowing the computation of the contact point position.

This technology has two important features in terms of safety and operative reliability

(i) it ensures electrical isolation (>25 kV) of the subject from the electronic parts
(ii) only a 'touch' is needed, and there is no need for finger 'pushing', as in touch-screens based on resistive technology; thus the participation of neurological patients with motor weakness becomes possible.

The precision of the touch-screen was 1/1024 of the screen width/height for position measurement, and about 4 ms for the timing measurement (determined by the sampling frequency of 270 Hz).

The touch-screen connection to a standard computer system with a touch-screen is a mouse hardware control connected to the RS232 serial port. Accordingly, the first level signal from the touch-screen is the mouse pointer position in screen co-ordinates.

Fig. 1 *Touch-screen apparatus showing sparse letter display, with subject detecting targets (letter 'H') and touching each one with fingertip*

2.2 *Experimental setup: software*

Fig. 2 shows the overall structure of the computerised test setup. Three main computing modules can be distinguished: the 'test manager' that administers the task of interest; the 'touch manager', a real time touch-event detector; and the 'report manager' that processes subject performance and extracts indexes of interest by applying specific mathematical models. In the current configuration, the software of the three modules had the features described in the following Sections.

2.2.1 *Test manager:* The test manager implements a 'cancellation test' consisting of a number of targets and twice the number of distracters, distributed randomly or aligned in rows on the screen. We used two different sets of targets and distracters (letters or shapes).

The main features of the test manager included

(*a*) an 800 × 600-point screen resolution, with white background
(*b*) a set of items: letters (font Arial, size 24 points, colour black), with the letter H as the target and A–G as the distracters
(*c*) a set of items: shapes (font Monotype Sorts, size 24 points, colour black) with (■) as the target (same ASCII code as 'n'), and (▲), (●), (✖), (◆), (★), (▼) and (◗) (same ASCII codes as s, l, 6, F, H, t and w) as the distracters
(*d*) feedback, determined by touching either a target or distracter among a wide number of alternatives. The feedback can be: a black circle appearing around the target, target disappearance, change in target colour or substitution of the target by a distracter. In our case, there was no feedback on touching a distracter.

'he target/distracter spatial location was defined by a scenario enerator that positioned the items randomly but uniformly ver the screen. Two pattern distributions were set: 'sparse'

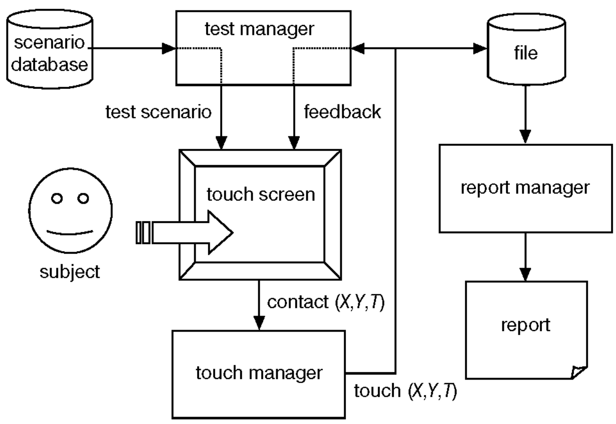

Fig. 2 *Block diagram of touch screen-based system. System included real-time feedback from touch manager to the test manager to provide subjects with visual feedback to their actions. Report manager computed all indexes and delivered measures of interest*

*17″, SVGA graphical resolution, Philips, The Netherlands
†Clear Tek 1000, MicroTouch, USA

and ‘row’. The *sparse distribution* was obtained through two steps: first, a uniform distribution of the targets was generated, ensuring that the minimum distance between any two was 10% of the screen height; then, the distracters were randomly interposed among the targets to fill the area. The shortest distance between any target and distracter was about 7% of the screen height. The *row distribution* consisted of six rows: each included 20 items, arranged randomly, with the constraint that at least one distracter was located between two targets. Each distribution included 120 stimuli (40 targets and 80 distracters), and Fig. 3 shows four test scenarios. Finally, two simplified scenarios were defined to provide practice trials for the target sets; each scenario included four targets and eight distracters.

2.2.2 *Touch manager:* The touch manager consisted of software that ran at the same time as the test manager. Its functions comprised

(i) the detection of subject–screen contact
(ii) the classification of contact as a ‘touch’ associated with a specific item, rejecting sliding; a ‘touch’ was operationally defined as contact within the sensitive circular area associated with the item
(iii) the prompting of the test manager to deliver the defined feedback on the touched item
(iv) the recording of the position and the timing of each touch event in a file.

In fulfilling its functions, the touch manager did not slow down, or in any way affect, the parallel running of the test manager. This was achieved by applying an object-oriented language that avoided unstable screen images, flickering and execution delays. In such a programming approach, all the targets/distracters are ‘objects’, visible from the beginning; feedback is also an ‘object’, not visible at the start of the task, its ‘visibility’ becoming activated by proper run-time controls, e.g. a cross, circle etc., appearing on the item. Alternatively, feedback can be given as a modification of the item, target or distracter, or ‘object’ characteristics, e.g. a change of colour, shape etc.

To avoid erroneous classification through finger sliding on the screen, a refracting phase was introduced: once a touch had been detected by the touch manager, no further touch was detected throughout the refracting phase. A pilot study set the refracting phase as 0.2 s. By adopting this refracting phase, we imposed a ‘touch and go’ exploratory strategy that precluded ‘dragging’, i.e. subjects keeping their fingers on the screen while searching for successive targets. Thus, for our study, we restricted the testing to subjects with appropriate motor ability. In practice, the vast majority of brain-damaged patients with unilateral brain damage could perform the task using the ipsilesional upper limb, where motor skills are usually preserved. Also, the pencil-and paper tests are subject to the same limitation. Only a few patients could perform the exploratory task using either hand, those patients not suffering contralesional motor deficits (frequently associated with unilateral neglect, see, for example, BISIACH *et al.*, (1986)).

In our study, the touch manager applied touch detection for all the items in the scenario (targets, distracters, as well as items already touched), but feedback response was set up only for the targets. Note, however, that it is possible to associate feedback with any touched item.

2.2.3 *Report manager:* The report manager implements the definition of ‘latency’: any touch is associated with latency L_i,

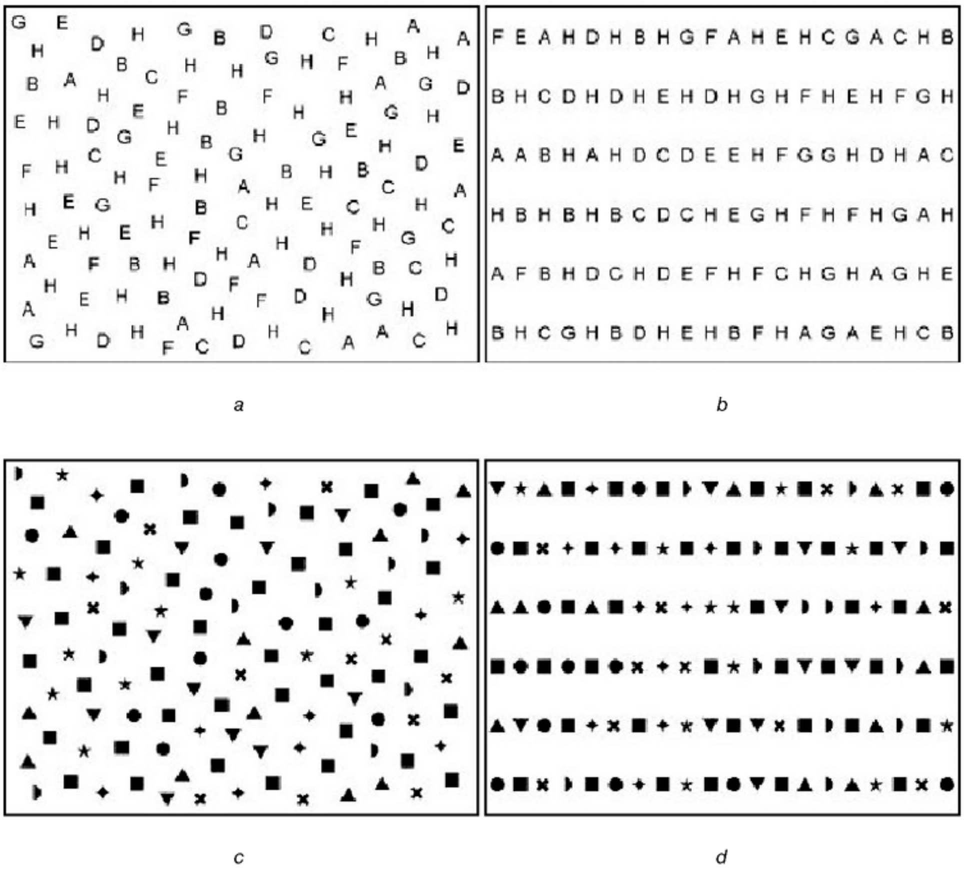

Fig. 3 *Implemented test displays: (a) sparse letter; (b) row letter; (c) sparse shape; and (d) row shape*

which is the time lapse between current touch T_i and previous touch T_{i-1}

$$L_i = T_i - T_{i-1}$$

The above definition of latency does not apply to the first touch: this was computed starting from the test scenario onset and was considered separately from subsequent latencies.

The report manager, after computation of the latencies of all touches, analyses the outcome of the test in the following steps:

(*a*) classification of touches as referred to targets or distracters
(*b*) identification of 'perseverations', defined as repeated touches of a previously touched item; specifically, a 'consecutive perseveration' was the touch of an item, immediately followed by a further touch of the same item, with no other touch being interposed
(*c*) counting the number of targets distracter touches and perseverations and computing the statistical parameters describing the latency distribution (first latency excluded)
(*d*) repetition of the previous analysis for selected sub-areas of the scenario
(*e*) production of a report.

The report manager identified and rejected spurious consecutive perseverations (produced by prolonged contact exceeding the refracting phase duration) that would have been erroneously classified as a series of consecutive touches. In fact, the pilot study showed that finger contact losses greater than 0.2 s from the target contact area were recorded by the touch manager as successive touch sequences. To avoid an inappropriate classification of these sequences as perseverations, the report manager discarded touch sequences where the inter-touch latency was less than the minimum latency measured among non-reiterated touches, which intrinsically consisted of non-spurious touches.

After the rejection of 'spurious' detections and a new computation of latencies, the available data consisted of the following records:

(i) type of touched item: target or distracter
(ii) position of the touched item: *X*, *Y* in normalised screen co-ordinates
(iii) time of the touch: *T* (s) from the beginning of the test
(iv) latency of each touch: *T* (s) from the previous touch.

These data allowed the computation of indexes relating to the outcome and to the modality of the test performance. The following indexes were computed:

(*a*) percentage of omitted targets
(*b*) number of touched distracters
(*c*) number of perseverations on targets
(*d*) 'neglect index': the difference between contralesional and ipsilesional omissions, divided by the total number of targets; a positive value of this percent score indicates a pattern of prevailing contralesional omissions, a negative value indicates ipsilesional omissions
(*e*) 'latency index': the median value of the measured latencies
(*f*) 'crossing index': the total number of search path crossings divided by the total number of touched targets, expressed as a percent score
(*g*) 'latency gradient': the slope coefficient of the regression line of the measured latencies against the lateral screen co-ordinate; this index is negative for latencies increasing towards the left side of the screen and positive for latencies increasing rightwards.

Some indexes can be computed through reference to sub-areas of the test scenario. The report manager is designed so as to identify any number of vertical and horizontal sectors of the screen area.

Table 1 Baseline paper-and-pencil neuropsychological assessments. Mean scores (± standard deviation, range in brackets) in three groups of brain-damaged patients with (+) and without (−) USN

Test	LUSN− (*N* = 5)	RUSN− (*N* = 5)	RUSN+ (*N* = 5)	Cutoff score
MMSE*	26.4 ± 1.7	27.6 ± 1.5	23.2 ± 4.7	≤24
score range = 0–30	(25–29)	(26–30)	(16–29)	
Line cancellation test†	0	0	2.4 ± 3.6	≥1
contro-ipsilesional difference			(0–8)	
Letter cancellation test‡	0	0.4 ± 0.5	21.6 ± 15.2	≥3
contro-ipsilesional difference		(0–1)	(6–42)	
Wundt–Jastrow area illusion test**	0	0	7.8 ± 7.9	≥2
contro-ipsilesional difference			(0–18)	
Sentence reading test††	0	0	3.0 ± 2.2	≥1
score range = 0–6			(0–6)	
Line bisection test‡‡	8.6 ± 0.5	8.6 ± 0.5	3.8 ± 3.1	≤7
score range = 0–9	(8–9)	(8–9)	(0–7)	

**Mini mental state examination* (FOLSTEIN *et al.*, 1975; MEASSO *et al.*, 1993)
†*Line cancellation test* (ALBERT, 1973): patients' task was to cross out 21 slanted lines printed on A3 sheet; score was number of omission errors, in left- and right-hand sides of sheet
‡*Letter cancellation test* (DILLER and WEINBERG 1977; VALLAR *et al.*, 1994): patients' task was to cross out 104 H letters, printed on A3 sheet, interspersed among distracter letters; score was number of omission errors, in left- and right-hand sides of sheet
***Wundt-Jastrow area illusion test* (MASSIRONI *et al.*, 1988): patients' task was to decide which stimulus of a pair appeared longer. Specific stimulus configurations printed on A3 sheet brought about lateralised effect, which normal subjects showed on both left and right sides. Score was number of responses not showing illusory effect ('unexpected'), arising from left (range 0–20), and right (range 0–20) sides of stimulus configuration. Right brain-damaged patients with left USN made errors only on stimulus configurations with left-sided illusory effect
††*Sentence reading test* (ZOCCOLOTTI *et al.*, 1989): patients were asked to read aloud six sentences printed in centre of A4 sheet. USN patients omitted or substituted words or letters on left side of sentences. Score was number of incorrectly read sentences, with left-sided errors
‡‡*Line bisection test* (WILSON *et al.*, 1987): patients were presented with three horizontal black lines (204 mm), in a 'staircase' fashion across page, and received instructions to mark mid-point of each line, using ipsilesional hand. Test was scored by measuring extent to which subject's mark (subjective midpoint) deviated from objective centre of each line

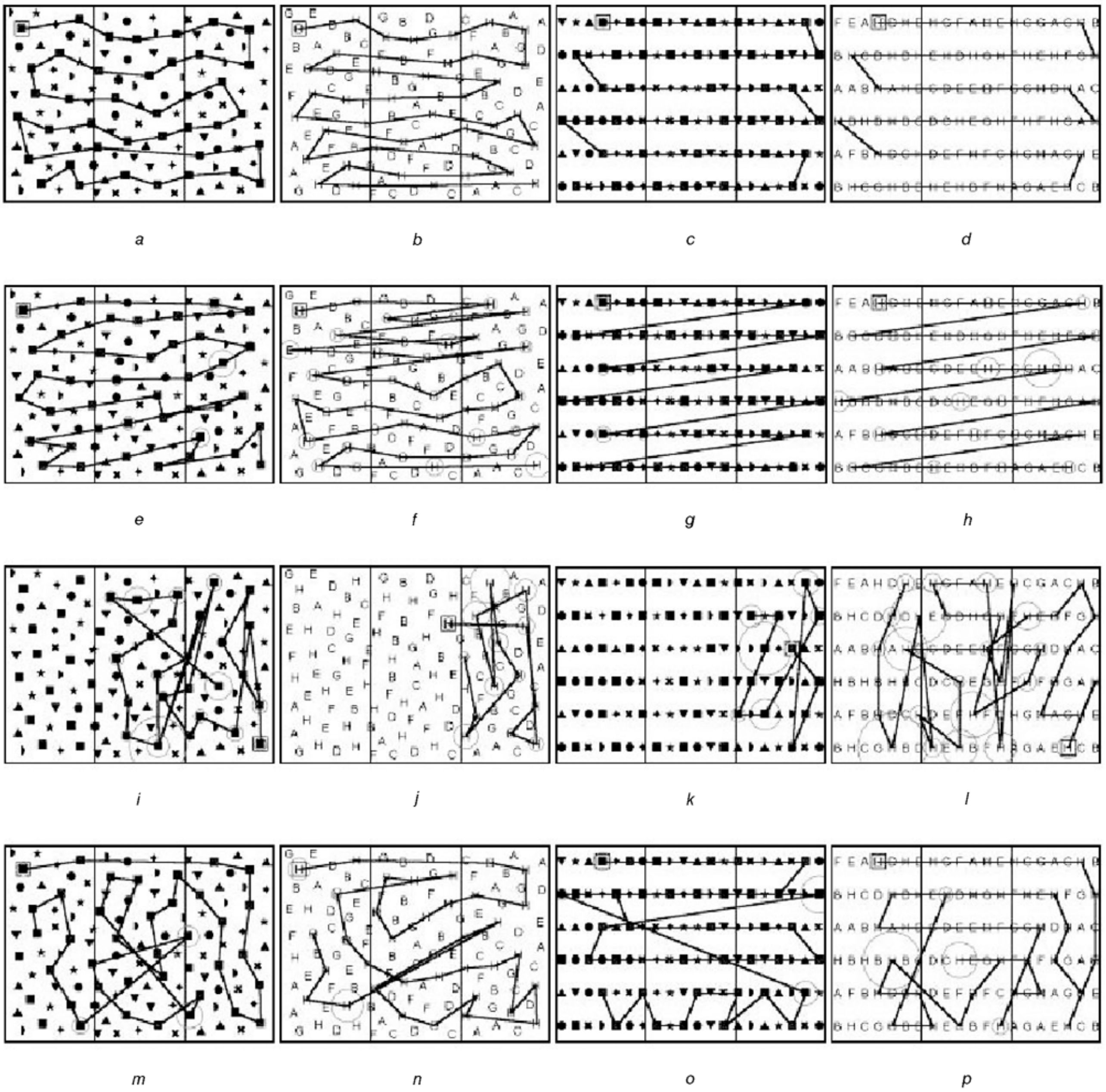

Fig. 4 *Illustrative exploratory pathways. Test displays with sparse and row distributions of letters and shapes are completed with graphical representation of search paths observed in four subjects. In each display, starting point is indicated by a square, and exploratory path is indicated by series of segments, connecting successively touched stimuli. Diameter of circle attached to any touched item is proportional to latency, namely time elapsed from subject's previous touch. (a)-(d) One control subject showed systematic direction of exploration with exploratory pathway organised in rows.(e)-(h) One LUSN− patient exhibited similar pathways, with larger latencies.(i)-(l) One RUSN+ patient made left-sided omissions and showed exploratory pathways characterised by crossings, suggesting less organised strategy.(m)-(p) One RUSN− patient exhibits less definite organisation of exploratory pathways, some crossings, and a few left-sided omissions*

Finally, the report manager produces a report of the test outcome. A replica of the test is presented along with the indexes and a set of demographic and clinical information, both on the computer screen and as a paper print-out. Also available is a graphical animation of subject performance, allowing review by the examiner.

2.3 *Pilot study*

The study included four subject groups:

(i) ten control subjects (four males, six females; mean age 67.1 years, range 60–75; mean educational level 9.4 years, range 5–17), with no history or evidence of neurological or psychiatric disorders or dementia
(ii) five left-brain-damaged patients without neglect (LUSN−) (two males and three females; mean age 64.8 years, range 54–79; mean educational level 12 years, range 5–17), with a mean duration of disease of 22 months (range 1–85)
(iii) five right-brain-damaged patients without neglect (RUSN−) (four males and one female; mean age 60.2 years, range 53–68; mean educational level 11.4 years, range 5–17), with a mean duration of disease of 7 months (range 2–25)
(iv) five right-brain-damaged patients with neglect (RUSN+) (four males and one female; mean age 61.0 years, range 51–75; mean educational level 6.2 years, range 5–8), with a mean duration of disease of 8 months (range 1–18).

All the subjects were right-handed (OLDFIELD, 1971). None of the 15 brain-damaged patients had any history or evidence of

Table 2 Touch-screen computer-based assessment. Mean values of indexes are reported for each group of subjects and for each test modality. Percent omitted targets and latency indexes are shown for three screen sectors (L: left; M: middle; R: right)

Subjects	Test modality	Omitted targets, % (L,M,R)	Touched distracters, *N*	Perseverations on targets, *N*	Neglect index, %	Crossing index, %	Latency index, s (L, M, R)	Latency gradient, s/width
Controls	row letter	1 (1,0,2)	1.6	0	−0.5	6.1	0.78 (0.80,0.80,0.81)	−0.02
(*N* = 10)	sparse letter	3 (4,1,4)	1.0	0.3	−0.5	9.1	0.84 (0.92,0.81,0.89)	−0.04
	row shape	2 (1,1,3)	2.0	0.1	−0.8	4.8	0.74 (0.81,0.73,0.70)	0.05
	sparse shape	1 (1,2,1)	0.7	0.4	0.8	7.9	0.72 (0.73,0.73,0.73)	0.03
LUSN−	row letter	0	3.2	0	0.0	2.5	1.21 (1.37,1.24,1.17)	−0.49
cases	sparse letter	3 (5,0,3)	2.6	0	−0.5	19.1	1.39 (1.47,1.41,1.28)	−0.93
(*N* = 5)	row shape	1 (0,2,0)	2.2	0	0.5	7.0	0.94 (1.01,0.93,0.96)	−0.06
	sparse shape	1 (2,2,0)	1.2	0	−1.0	11.7	1.03 (1.08,1.04,0.98)	−0.16
RUSN−	row letter	3 (7,2,0)	0.6	1.0	2.0	6.1	0.89 (0.98,1.00,0.85)	−0.62
cases	sparse letter	5 (11,2,1)	0.2	0	3.5	9.9	0.88 (0.99,0.88,0.86)	−1.51
(*N* = 5)	row shape	3 (4,2,1)	1.6	0	1.5	8.5	0.82 (0.90,0.80,0.82)	0.23
	sparse shape	3 (6,2,1)	0.2	0.4	2.0	18.3	0.89 (0.94,0.82,0.92)	−0.05
RUSN+	row letter	50 (71,52,26)	2.8	0.8	13.5	79.9	2.00 (−,3.47,1.04)*	−2.98*
cases	sparse letter	56 (94,59,19)	0.8	0.2	31.0	33.7	2.53 (−,1.80,1.12)*	−3.03*
(*N* = 5)	row shape	43 (67,47,16)	1.6	0.6	15.0	58.0	1.81 (−,1.49,0.98)*	−3.01*
	sparse shape	47 (86,43,13)	1.2	1.2	28.5	66.4	1.24 (−,1.80,0.95)*	−2.12*

*Sector latencies are reported for three RUSN+ subjects able to cross out targets in middle sector; latency gradients are reported for four RUSN+ subjects able to touch more than ten targets

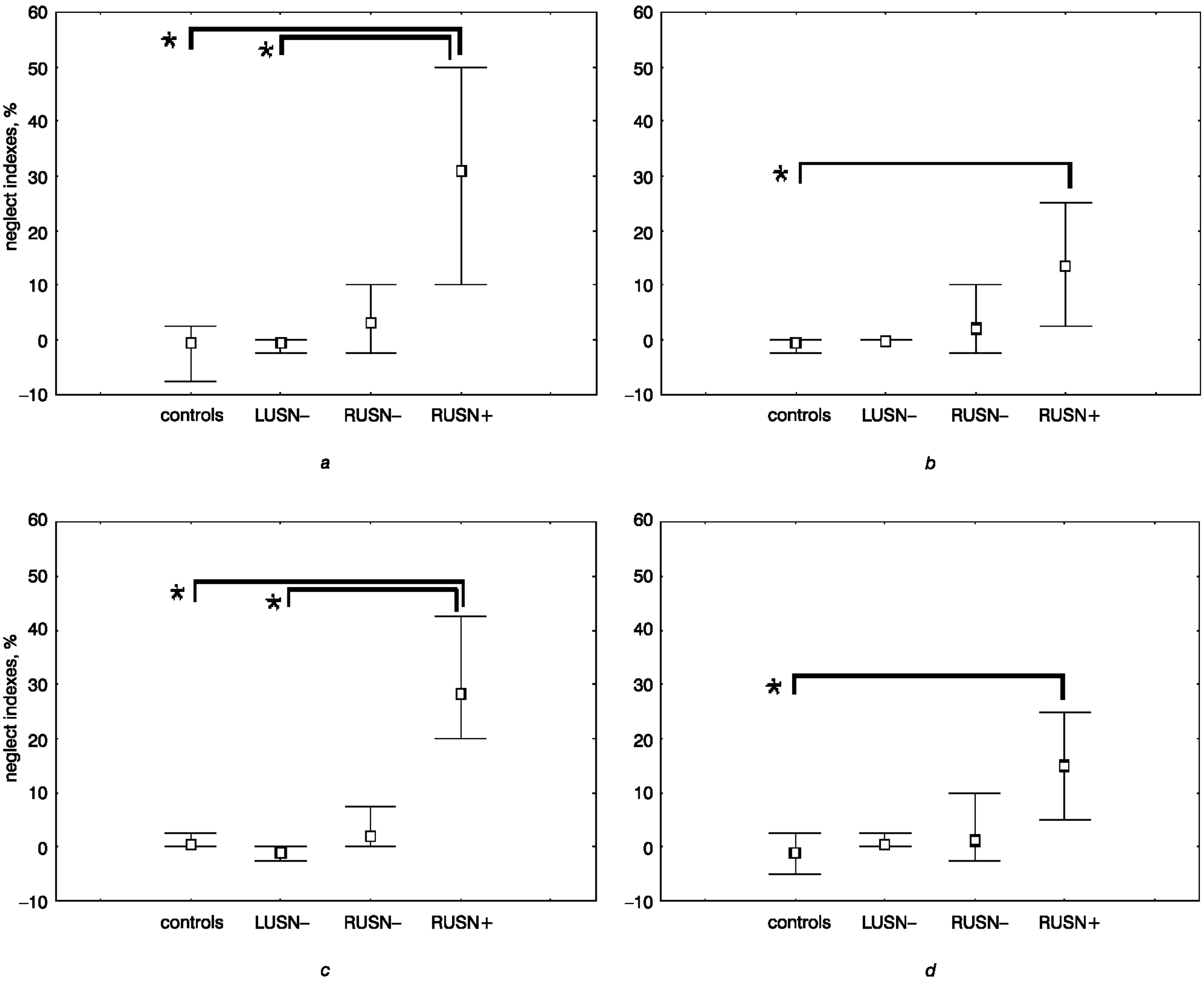

Fig. 5 *Neglect indexes ((□) mean value and min–max range) in four groups, in four test modalities: (a) sparse letter; (b) row letter; (c) sparse shape; (d) row shape. Kruskall–Wallis one way analysis of variance revealed significant difference among groups: (a) $H_{KW}(3,25) = 14.04$, $p = 0.003$; (b) $H_{KW}(3,25) = 14.31$, $p = 0.003$; (c) $H_{KW}(3,25) = 16.53$, $p = 0.001$; (d) $H_{KW}(3,25) = 13.58$, $p = 0.004$. Significant ($p < 0.05$) differences between groups are denoted by horizontal square brackets with an asterisk*

previous neurological or psychiatric disorders or dementia. All of the patients who had suffered a cerebrovascular attack underwent a standard neurological examination (Bisiach *et al.*, 1983). USN was assessed by both a standard paper-and-pencil battery and the mini mental state examination (MMSE), which provides a global overall evaluation of cognitive skills (Table 1). All the subjects were recruited from the rehabilitation services of the Fondazione Don Gnocchi, Milano, and gave informed consent to take part in the study.

2.4. *Test administration*

Each subject was given the four previously described visuo-spatial exploratory tasks, in the following sequence: 'sparse letter' test (Fig. 3*a*); 'row shape' test (Fig. 3*b*); 'row letter' test (Fig. 3*c*); and 'sparse shape' test (Fig. 3*d*). Each test was preceded by a run-in practice test with a simplified scenario of four targets and eight distracters. In all the tests, the subject received, for each touched target, feedback in the form of circles appearing around the target; touched distracters gave no feedback.

The subjects were tested, individually, in a quiet room where they were seated in front of the touch screen with the mid-sagittal plane aligned with the centre of the screen. The subject was then instructed to touch the target with the index finger of the dominant hand. In the case of brain-damaged patients, the hand ipsilateral to the side of the lesion was used (the ipsilesional hand is typically not affected by the motor weakness caused by hemispheric damage). The subjects were free to move their head and eyes and to touch the targets in any order they wished, and they were asked to make a specific declaration of having completed the task. If there was no declaration, but the subject had appeared to stop exploring the touch-screen, the examiner asked him/her whether the task had been completed; if so, no further prompts were given; if not, the subject was asked to proceed until the necessary declaration of having finished the exploration was made.

3 Results

During the practice runs, all the subjects soon became acquainted with the touch-screen setup, and the four tests were completed easily. Fig. 4 shows illustrative examples of the exploratory performance of one subject from each group: the search paths are represented by the segments connecting subsequently touched items in each specific test scenario. Table 2 shows the average scores of the four groups: percent omitted targets, touched distracters, perseverations on targets, neglect, crossing and latency indexes, and latency gradients.

Fig. 5 shows the neglect indexes, Fig. 6 shows the crossing indexes, Fig. 7 shows the latency indexes, and Fig. 8 shows the latency gradients of the four groups.

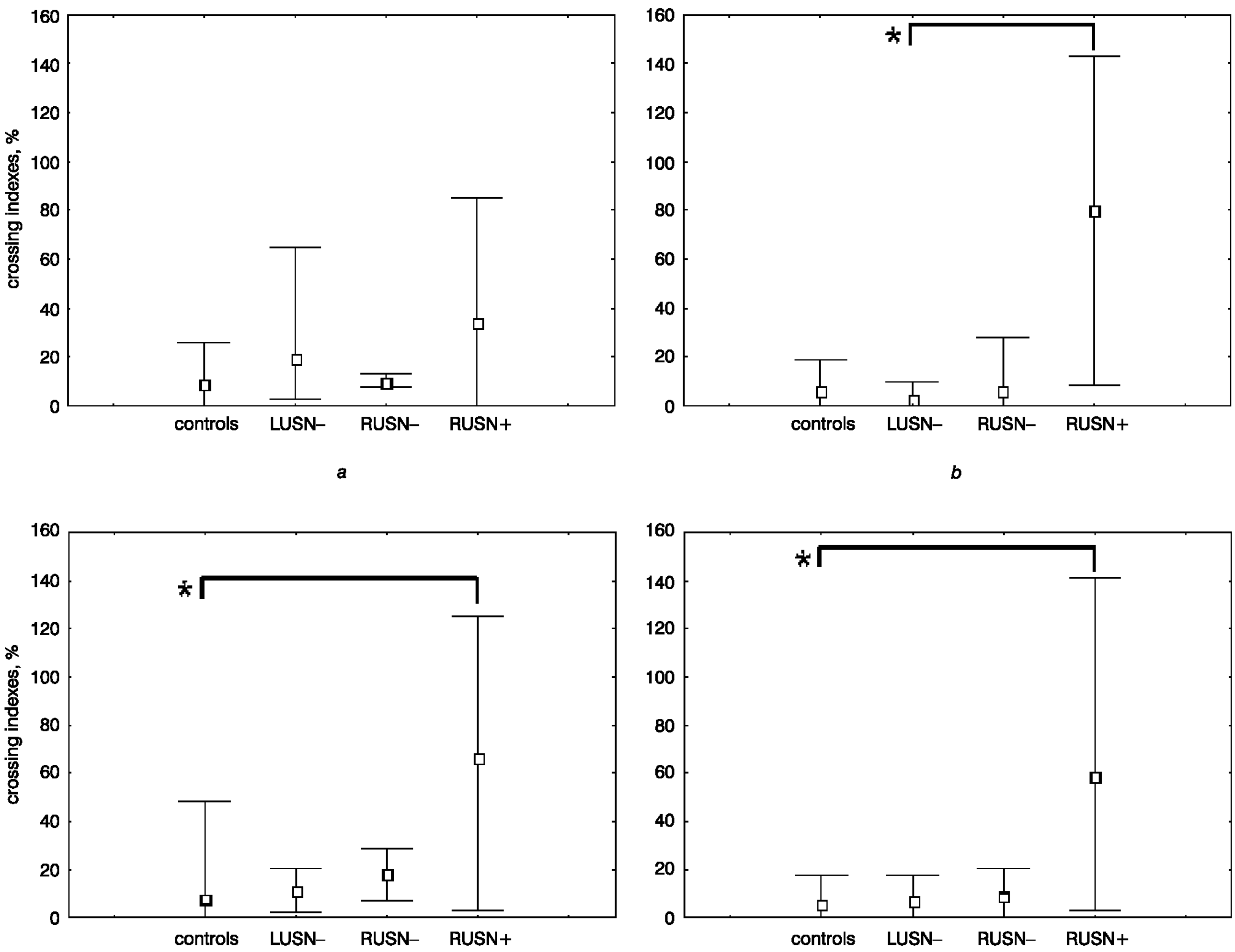

Fig. 6 *Crossing indexes ((□) mean value and min–max range (whisker)) in four groups, in four test modalities; (a) sparse letter; (b) row letter; (c) sparse shape; (d) row shape. Kruskall–Wallis one way analysis of variance revealed significant difference among groups in three test modalities: (b) $H_{KW}(3,25) = 10.61$, $p = 0.014$; (c) $H_{KW}(3,25) = 10.50$, $p = 0.015$; (d) $H_{KW}(3,25) = 8.07$, $p = 0.044$. Significant ($p < 0.05$) differences between groups are denoted by horizontal square brackets with an asterisk*

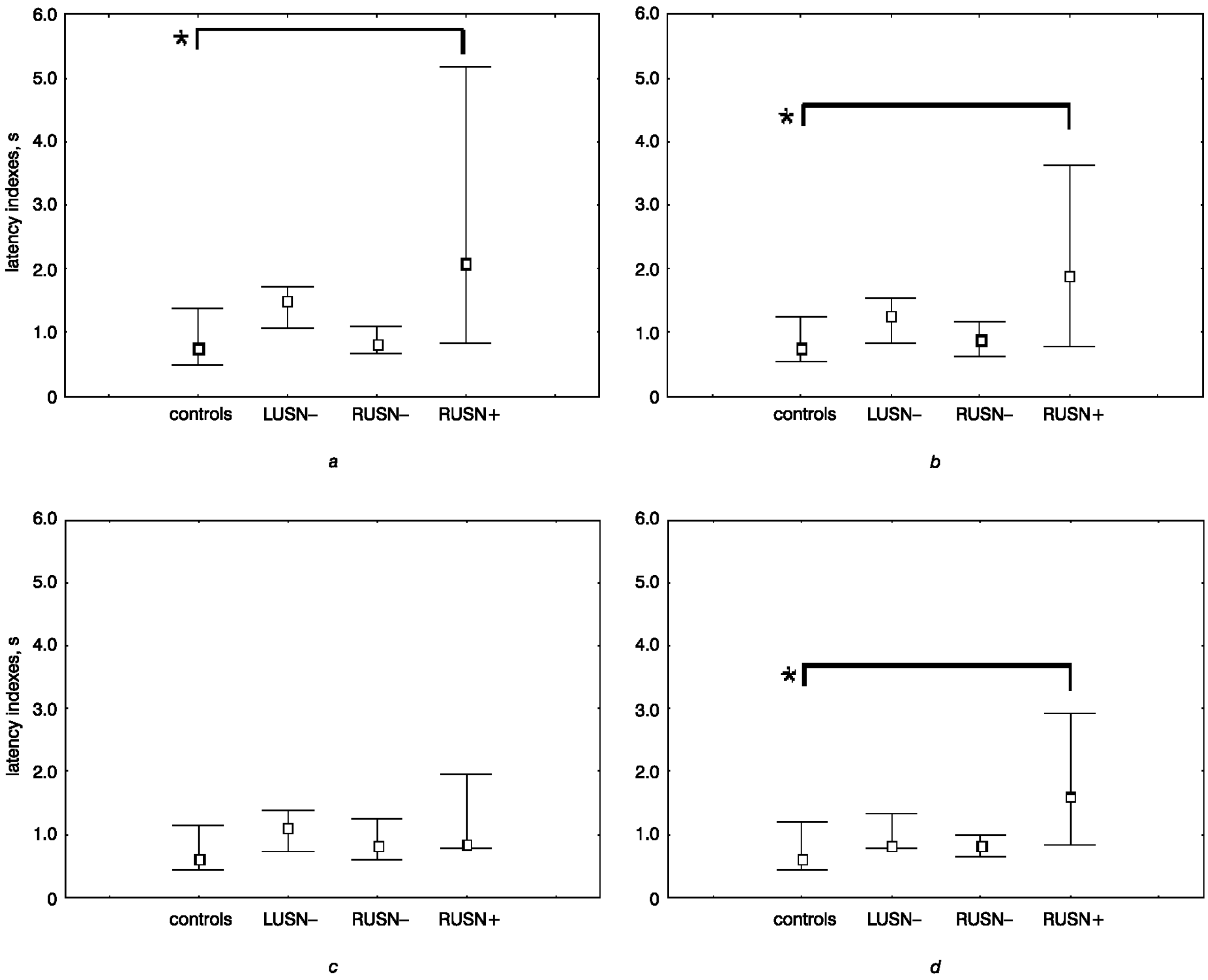

Fig. 7 *Latency indexes ((□) median value and min–max range (whisker)) in four groups, in four test modalities: (a) sparse letter; (b) row letter; (c) sparse shape; (d) row shape. Kruskall–Wallis one way analysis of variance revealed significant difference among groups in three test modalities: (a) $H_{KW}(3,25) = 12.04$, $p = 0.007$; (b) $H_{KW}(3,25) = 9.90$, $p = 0.019$; (d) $H_{KW}(3,25) = 9.87$, $p = 0.020$. Significant ($p < 0.05$) differences between groups are denoted by horizontal square brackets with an asterisk*

It is apparent that the RUSN+ patients have a higher positive neglect index in all four versions of the computer-based exploratory task. In three of the four versions of the task, the RUSN+ patients showed a higher latency index than the control group, as they also do for the crossing index and latency gradient in two versions. In one version of the task, the RUSN + group showed a higher crossing index than the LUSN− group. Overall, the RUSN+ patients have higher positive neglect indexes, indicating a contralesional deficit, and higher crossing indexes, indicating disordered exploratory strategies. As for latency, these patients are slower in most versions of the computer-based task, as revealed by the latency index, and show a latency gradient, the response to target becoming slower towards the contralesional side.

Fig. 9 shows a few examples of individuals: in four subjects, including one control and three patients with different characteristics, the latency of each touched target was plotted against the lateral screen co-ordinate of the target itself, and the regression line was superimposed (see related data using a regression line in cancellation tasks in HALLIGAN *et al.* 1992). The negative slope, the latency gradient, found in the RUSN+ patient appears to be a USN-related index, with performance, as assessed in terms of latency, becoming less and less effective as exploration proceeds leftwards. By contrast, the control subject and the LUSN− patient showed slopes close to zero, even though the LUSN− patient showed larger latencies. Finally, the RUSN− patient showed latencies intermediate to the control and the LUSN− patient, and a negative slope, less steep than that of the RUSN+ patient. These data can be taken as an indication of a minimal rightward bias.

A perusal of the neglect indexes of the individual patients (Fig. 5) revealed that two RUSN− patients had scores within the range of RUSN+ patients (one RUSN- patient in the row shapes test and in both letter tests, the other RUSN− patient in the row letter test only). These preliminary observations suggest that the computer-based touch-screen test may prove to be a more sensitive tool than the equivalent paper-and-pencil version to detect mild neglect.

To investigate the relationships between the visuo-spatial exploratory performances, as assessed by the computer-based paradigm, and the traditional paper-and-pencil H-letter cancellation test, the neglect index was also computed for the latter task. In the 15 brain-damaged patients, a Spearman non-parametric correlation analysis (SIEGEL and CASTELLAN, 1988) was performed with the row letter test, namely the computer-based neglect index of the more comparable task. A Spearman R coefficient of 0.862 was found, indicating a close relationship between the two task modalities (computer-based against paper-and-pencil).

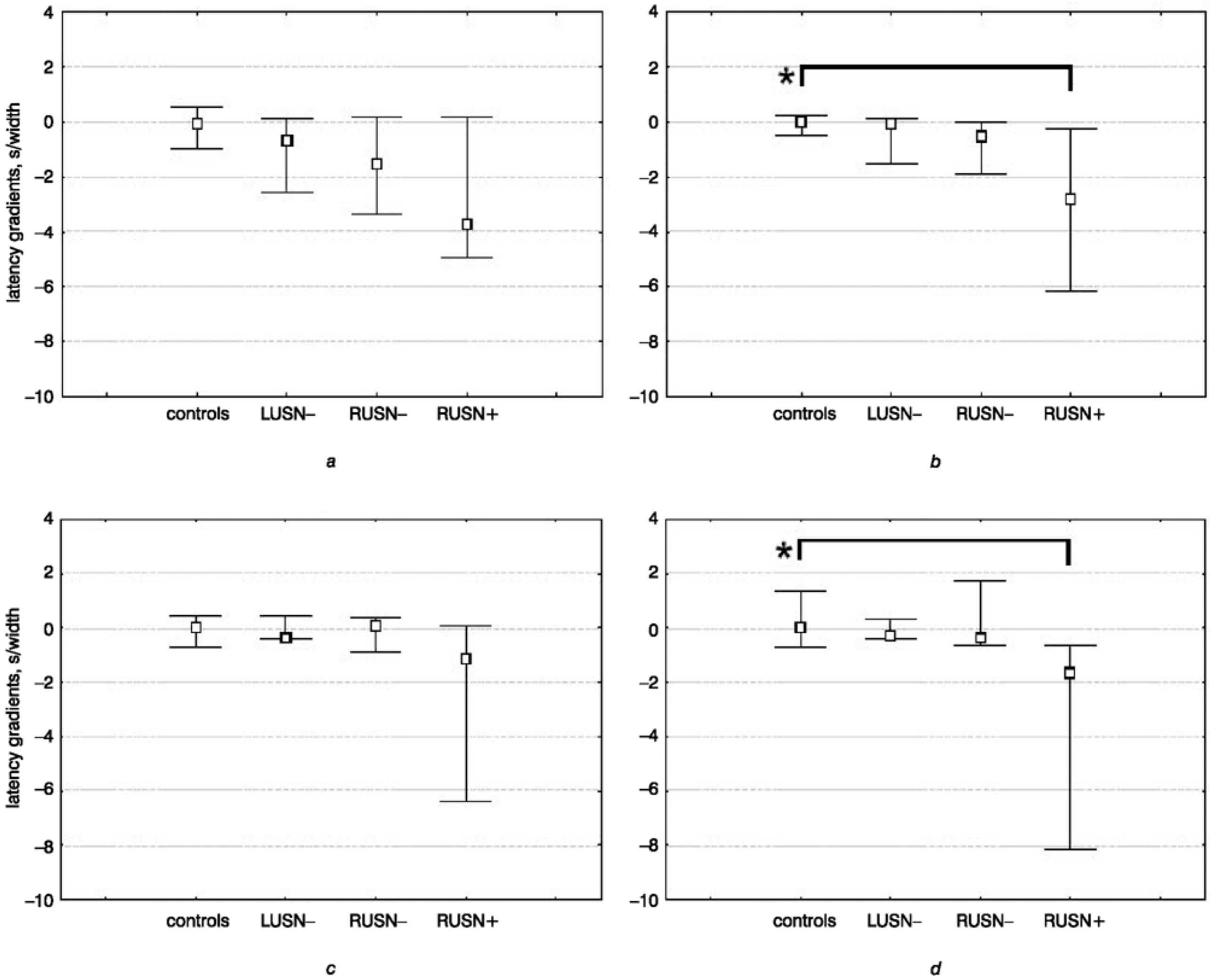

Fig. 8 *Latency gradients ((□) median value and min–max range (whisker)) in four groups, in four test modalities: (a) sparse letter; (b) row letter; (c) sparse shape; (d) row shape. Kruskall–Wallis one way analysis of variance revealed significant difference among groups in two test modalities: (b) $H_{KW}(3,24) = 10.34$, $p = 0.016$; (d) $H_{KW}(3,24) = 8.70$, $p = 0.034$. Significant ($p < 0.05$) differences between groups are denoted by horizontal square brackets with an asterisk*

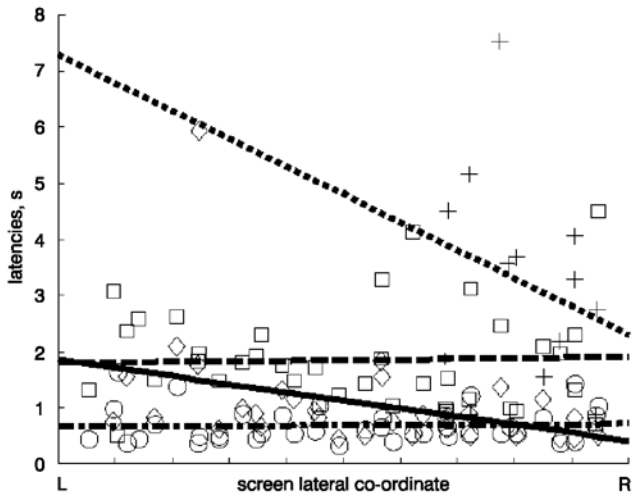

Fig. 9 *Latencies of all touches of four representative subjects (see Fig. 4) in sparse letter test, plotted against lateral screen co-ordinate. Regression lines are shown, with their slope coefficients quantifying latency change from (L) left to (R) right end of screen and providing measure of latency gradients. Measured gradients (s per screen width): (○, –·–) control subject: 0.04; (□, – – –) LUSN– patient: 0.10; (◇, —) RUSN– patient: −1.44; (+, ...) RUSN+ patient: −4.98*

4 Discussion and conclusions

In this pilot study, the touch-screen computer-based apparatus devised to assess visuo-motor exploratory skills proved a useful tool for USN assessment. The touch-screen computer-based test was administered easily, and there were no problems concerning either subject comprehension of the task instructions or subject–computer interaction. The methodological differences between the touch screen-based assessment and the paper-and-pencil test, including the frontal vertical position of the touch-screen, had no negative effect on the sensitivity of the touch-screen tests. Moreover, in addition to the traditional accuracy parameters, the touch-screen computer-based test provided accurate latency and exploratory pathway indexes. It should be noted that, in the paper-and-pencil versions of the task, such measurements are not so easily and accurately recorded.

The findings of this pilot study suggest that the proposed numerical indexes can extend the objective data set on which USN diagnosis is made. Such indexes are sensitive indicators, able to describe the severity and gradient features of USN. From the clinical viewpoint (the task used was visuo-manual exploration), our data support the suggestion that USN is characterised by a contralateral against ipsilateral gradient, with reference to the side of the lesion. Thus it is suggested that the severity of USN diminishes gradually from the contralesional side to the ipsilesional (in right brain-damaged patients, such a contra-ipsilesional gradient of, decreasing severity would be from left to right), with no sharp boundary or divide, such as the mid-sagittal plane, between the neglected and the preserved sides of space (see the discussion in BISIACH and VALLAR (2000)).

Finally, the suggestion that USN is characterised by a contralateral against ipsilateral gradient could lead to a better assessment of neuropsychological disorders of spatial cognition. Moreover, as there is increasing evidence that USN may be a component deficit of dementia (ISHIAI *et al.*, 1989; MENDEZ *et al.*, 1997; VENNERI *et al.*, 1998), patients with diffuse brain damage, as in dementia of the Alzheimer type, could benefit from the touch-screen computer-based test, in that it would be a useful additional tool for monitoring the efficacy of rehabilitation paradigms.

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