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Task-dependent differences in the exploratory behaviour of patients with spatial neglect

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Abstract

The present study analysed task-dependent effects on the exploratory behaviour of neglect patients during their spontaneous search of the surroundings. We were asking whether different tasks would be associated with different structuring of the visual display and, therefore, would result in different forms of neglect in one and the same brain-damaged subjects. Neglect patients' eye and head movements were recorded when they searched for a target within a homogeneous stimulus array surrounding the subjects. Subsequently, they explored the same array which was now segmented into different areas. When the patients' attention was allocated to the whole surrounding space, all patients completely neglected the left hemispace and spontaneously attended to the right hemispace. No significant left–right asymmetry was detected in a selected segment located in the periphery of the attended, right hemispace. However, all patients completely ignored the left part of this segment when they had to concentrate visual search on this segment alone. The results suggest an important influence of task-dependent effects on the exploratory behaviour of neglect patients. They show that one and the same physical stimulus at one and the same location in a scene might be attended or, in another situation, neglected, just depending on the behavioural goal of the subject. The findings support the idea that the brain organises and reorganises continuously the representation of the same physical input according to the changing task requirements.

Keywords: Neglect; Brain-damage; Egocentric; Object-centred; Reference frame; Space; Human

1. Introduction

Patients with spatial neglect show a disturbed ability to find target stimuli located on the contralesional side in the surroundings [2,11,21]. This spatio-behavioural deficit was assumed to be based on a disturbed cortical representation of the presented scenery (e.g. [3]). Given such a representation that guides behaviour, an economical implementation would be a flexible neural matrix that encodes stimuli depending on the task that the subject is currently dealing with. The notion that the brain uses context-dependent representations of the stimulus displays is supported by single-unit studies recording from the parietal and the temporal cortex in monkey. These studies found neurons that differentially responded to identical visual stimuli merely depending on the task-related significance of the stimuli [5,8]. Consequently, if a disruption of such representations is the agent of neglect, one should expect that the behaviour in neglect patients is influenced by the respective task the subject is dealing with.

Indeed, it is known that various kinds of manipulations can modulate neglect behaviour. For example, cues directing the patients' attention to the contralesional side can temporarily reduce the severity of neglect symptoms [6,17]. However, it is not clear whether such cues have a *direct* impact on the supposed disturbed representation or influence the patients' performance *indirectly*, e.g. via an additional compensation effect relying on mechanisms independent from the defect causing spatial neglect.

Marshall and Halligan [14] used explicit verbal instructions to bias a neglect patient's figure-ground perception of ambiguous figures. Depending on these instructions, the patient either perceived or neglected a contour in the stimulus display. But this effect might be restricted to situations where ambiguous figure-ground perception supports switching between different ways to perceptually structure the visual image. However, it might not occur with less ambiguous stimulus arrays allowing perception to converge on one robust 'interpretation' of the visual scene. Explicit verbal task instructions requesting either to mentally rotate the stimulus material or to ignore the display's orientation also have been shown to determine the spatial distribution of detected stimuli in neglect [4]. However, it might be that the cognitive processes exogeneously driven by such instructions do not adequately match the strategies a subject would employ when spontaneously performing the task.

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The goal of the present study was to analyse task-dependent effects on the exploratory behaviour of neglect patients during their spontaneous search of the surroundings. We were asking whether different tasks would be associated with different structuring of the visual display and, therefore, would result in different forms of neglect in one and the same brain-damaged subjects. To test this hypothesis, we employed a visual search task in a random stimulus array and manipulated the subjects' task by instructing them to either focus on the whole surrounding space or only on a certain part of it. During the tasks we recorded the subjects' exploratory eye movements. Since eye movements and attentional mechanisms are closely related (e.g. [12,13,20]), this method provides a spatially fine grained mean to estimate the spatial pattern of salience distribution across space and also has been shown to reflect neglect related deficits in tests other than visual search [9].

2. Methods

2.1. Subjects

Exploratory gaze movements of three unselected, consecutively admitted patients with an acute right hemispheric lesion and severe neglect were recorded. Demographic and clinical data are given in Table 1; lesion location in Fig. 1. For control, we studied gaze movements in four neurological patients without brain lesions (one woman, three men, aged from 53 to 71 years, median = 64 years). All subjects gave informed consent to participate in the study. None of the subjects had oculomotor palsies as assessed by standard neurological examination. In all subjects, we confirmed intact colour discrimination with a probe of those colours used in the present experiment.

2.2. Apparatus and procedure

Eye position in space (gaze) was recorded using the magnetic field-search coil technique [18]. Three orthogonal alternating magnetic fields were generated by three pairs of Helmholtz coils mounted in a cube-like configuration on the outer surface of the spherical part of a light bulb-shaped cabin. To measure horizontal and vertical gaze positions, the subjects wore a 2D search coil embedded in a silicone rubber ring, which adhered to the sclera by suction (Skalar Medical, Delft, The Netherlands). The sampling rate was 100 Hz. Data were stored on a computer for off-line analysis.

Subjects were seated in the cabin which was dimly illuminated with 2 day light bulbs for enhanced colour discrimination. The subjects' head was located in the centre of the upper spherical part of the cabin and could be freely moved while the trunk was immobilised by belts and shoulder straps. On the inner surface of the sphere a dense random array of letters ($n = 1960$, each 2° high) was presented within a range of $\pm 140^\circ$ to the left and right of the mid-sagittal trunk plane in the horizontal dimension and $\pm 30^\circ$ in the vertical dimension. We used such a large array to cut down any influence of borders of the display in the horizontal dimension on the subjects' spontaneous exploratory behaviour during visual search especially for the two first search conditions.

We studied the exploratory gaze movements of our subjects in four conditions of the visual search task. The conditions varied by giving different instructions and presenting the letters in different colours. The first condition, the 'global' test condition, served as a baseline. In this condition, all letters in the array were presented with grey colour so that the array appeared as a homogeneous field of scattered characters. Fig. 2A provides a schematic view of the set-up. The subjects were instructed to search for a single grey target letter 'A' located 'somewhere in the whole sphere'. In fact, no target letter was presented during data registration. This was done to avoid systematic effects of target detection on the distribution of eye movements that are not directly related to the process of visual search [11]. All subjects were required to conduct two trials of this condition of the visual search task, each lasting 60 s.

The second condition, termed the 'global segmented' condition, was employed to sort out the possible neglect effects that were caused by 'bottom-up' segmentation processes due to visual features of the surrounding stimuli but that were independent of task-dependent search strategies. For

Table 1
Demographic and clinical data of the right-brain-damaged patients with neglect (NEG)

	Sex	Age (years)	Etiology	Days post onset	Hemianopia	Letter cancellation		Bells test		Copying	
						Left	Right	Left	Right	Left	Right
NEG1	W	79	Infarct	6	Yes	0	10	0	8	–	(−)
NEG2	M	58	Infarct	34	No	0	15	0	10	–	(−)
NEG3	W	64	Infarct	16	Yes	0	11	0	5	–	(+)

Letter cancellation [23]: the number of correct target letters on each half of the test sheet is $n_{\max} = 30$ on either side. Bells test [7]: the number of correct targets on each half of the test sheet is $n_{\max} = 15$ on either side. The five targets of the central column were not regarded. Copying task: the multi-object scene consisted of four elements (a fence, a car, a house and a tree) two in each half of a DIN A4 sheet of paper: – omission of at least one whole object; (−) omission of at least one left-sided feature of a figure; (+) copying without omissions.

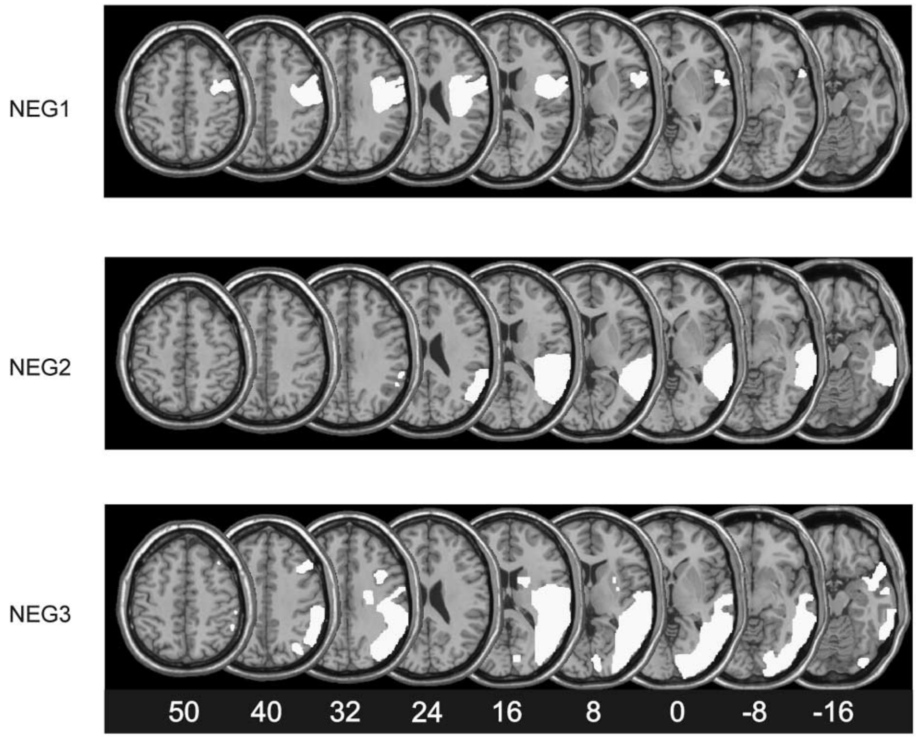

Fig. 1. Infarcted areas of the patients with spatial neglect. Brain lesions were identified by computed tomography or magnetic resonance imaging. Using MRIcro software [19] (www.psychology.nottingham.ac.uk/staff/cr1/mricro.html), the lesions were mapped on slices of a template MRI scan from the Montreal Neurological Institute (www.bic.mni.mcgill.ca/cgi/icbm_view) normalized to Talairach space [22]. The z-coordinates of each transverse section are given.

this condition, the subjects saw the same letters presented at the same positions as in the first condition. However, as is illustrated in Fig. 2B, the colour of the letters was changed. On the left side, in a sector extending from -80 to -40° (horizontal dimension), the colour of the letters was changed to blue, from -40 to 0° all letters were purple, from 0 to $+40^{\circ}$ on the right side the letters were green, and in the area from $+40$ to $+80^{\circ}$, the letters were orange. The letters on the extreme left (-140 to -80°) and extreme right ($+80$ to $+140^{\circ}$) were coloured grey as in the first experimental condition. Thus, the array of letters appeared segmented into six different areas (Fig. 2B). The four more central segments (blue, purple, green, and orange) each contained 280 letters, while the grey segments on the far left and right side contained 420 letters, respectively. Equi-luminance of the five colours was controlled by a Lunasix 3 light meter. The subjects were shown five different target letters 'A', each in one of the five colours. They were informed that one of the five 'A's would be presented somewhere 'in the whole sphere', but within the segment of the same colour. Hence, if the blue 'A' was chosen as the target letter, it would appear in the blue segment; if it was the purple 'A', it would appear in the purple segment, and so forth. We did not tell the subjects which colour the target letter 'A' would be or in which segment to search. Consequently, the array was visually segmented into areas of different colours but this feature was not informative and, hence, independent from the task. So, again the subjects had to search for the 'A' in the whole sphere. However, as in the first condition, no target 'A' was present during data recording. We registered the subjects' movements during two search trials each lasting 60 s.

For the third condition, termed the 'focus' condition, the same coloured letter array was used as before. The subjects attention was now drawn to the orange segment within $+40$ to $+80^{\circ}$ on the right side (Fig. 2C). At the beginning of this condition, the subjects were shown an orange target letter 'A' and were instructed that this target would be presented 'somewhere in the orange segment'. Thus, for this third condition, the colours of the segmented stimulus array were informative restricting visual search to the segment of orange letters. As in the conditions before, the target was not presented during recording exploratory movements. Each subject performed two trials searching for the (non-existent) target each lasting 40 s.

To further enhance the visual contrast of the orange segment with respect to the rest of the letter array, a fourth condition was conducted that may be referred to as the 'focus and frame' condition. For this condition, the same coloured letter array was presented as before and the subjects had again to search for the (non-existent) orange target letter 'A' only within the orange segment of the array. In order

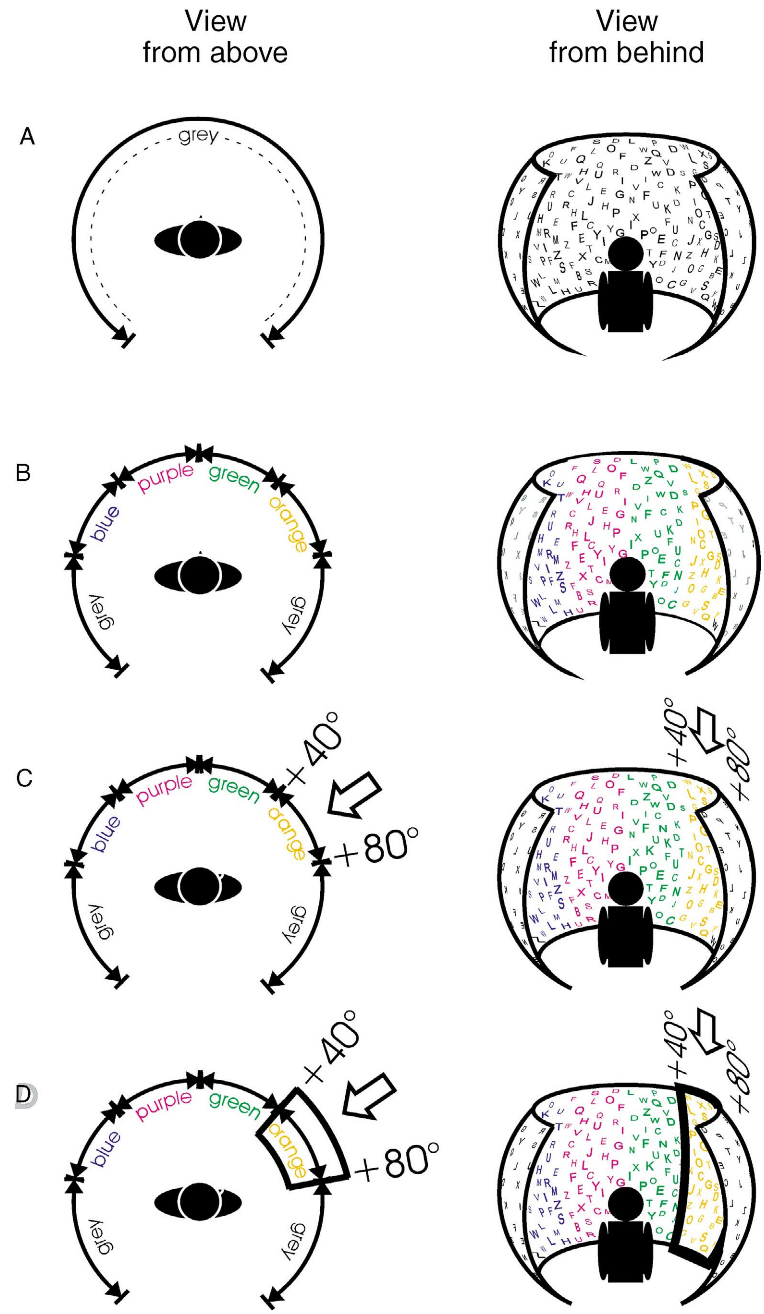

Fig. 2. The four experimental search conditions (A–D). The subjects were seated in a light bulb-shaped cabin. On the inner surface of the spherical part of the cabin, an array of randomly scattered letters was presented (horizontal extension: ±140°, vertical extension: ±30°). The subjects were asked to search for a single (non-existent) target letter 'A' during four different conditions. (A) 'Global' condition. All letters were presented with grey colour. The subjects were asked to search in the whole letter array. (B) 'Global segmented' condition. The letter array was segmented into six different areas that differed in the colour of their stimuli. Again, the subjects were instructed to search in the whole array. (C) 'Focus' condition. The same segmented letter array was used but the subjects now were required to search for an orange 'A' only in the orange segment (+40 to +80° on the right, ipsilesional side). (D) 'Focus and frame' condition. Once more, the subjects were asked to confine visual search to the orange segment. In addition to the former task, the segment was surrounded by a black frame.

to increase the salience of the orange segment (Fig. 2D), it was surrounded by a thick black frame (height: 60°, width: 40°, width of the bars: 1.5°). The instruction was as in the preceeding condition, namely that the orange target letter 'A' would be located only in the framed orange segment. Each subject was required to perform two trials, each lasting 40 s. Again, the target was not presented during the two trials.

In order to maintain the subjects motivation, the four experimental conditions were supplemented by additional trials with a target being presented but without recording exploratory movements.

3. Results

Fig. 3 illustrates the frequency distribution of horizontal gaze positions during the four conditions of the visual search task. During the 'global' and the 'global segmented' conditions, the control subjects showed a flat, symmetrical distribution of exploratory movements, covering a broad part of space up to about 140° on the left and the right side of the body's mid-sagittal trunk plane with only a slight increase for the more central parts of the letter array. These data confirm previous results of broad distributions of exploratory movements in control subjects [11]. When exploring only

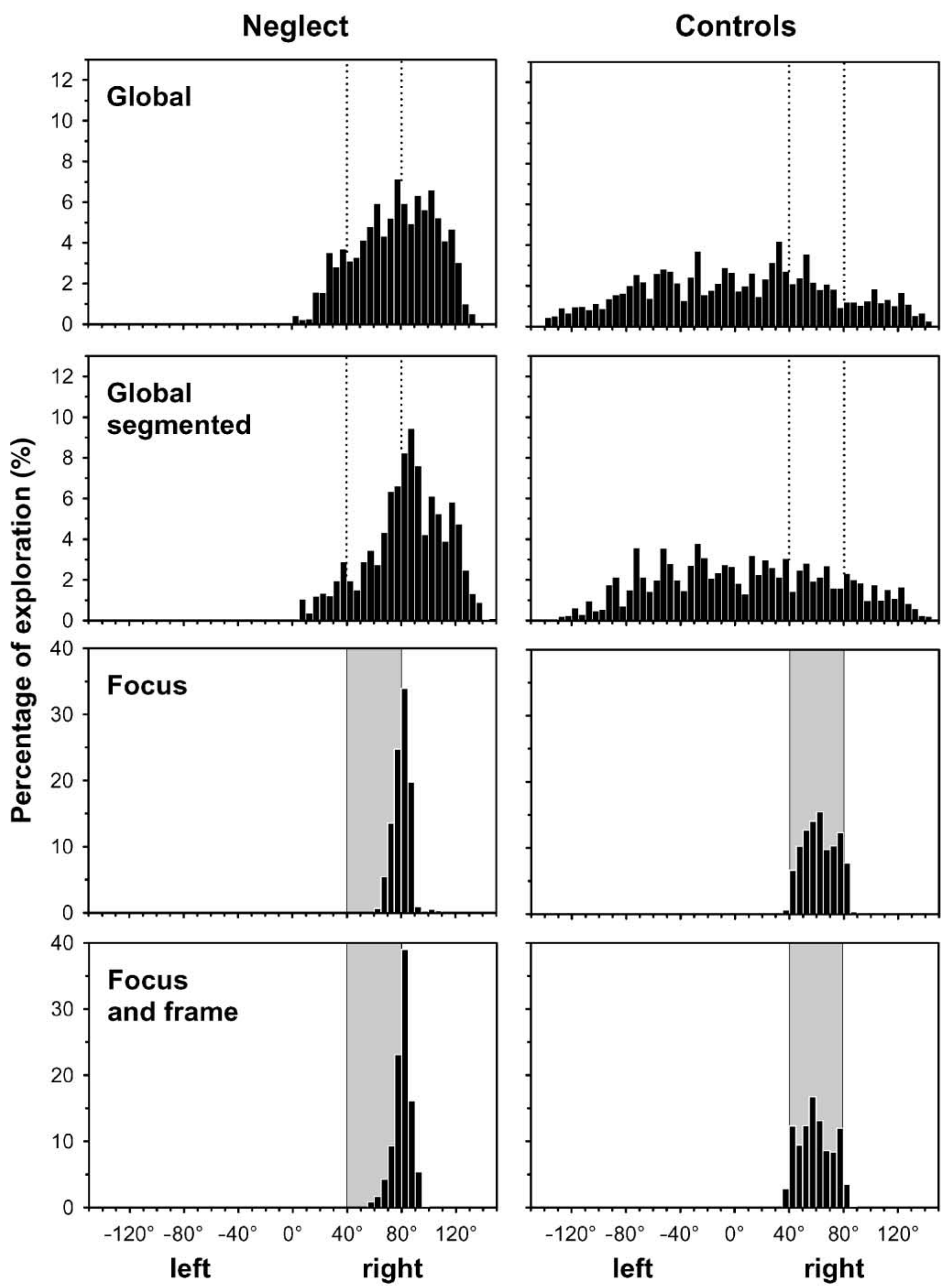

Fig. 3. Frequency distribution of exploration time recorded for the neglect patients and the control subjects during the four search conditions. Exploration time is plotted in discrete 5° sectors along the horizontal dimension. Negative eye positions indicate locations on the left side of the subject's mid-sagittal trunk plane, positive values locations on its right side. The vertical dotted lines and grey fields mark the part of the letter array ranging from +40 to +80° on the right side where the letters were coloured orange in three of the four test conditions.

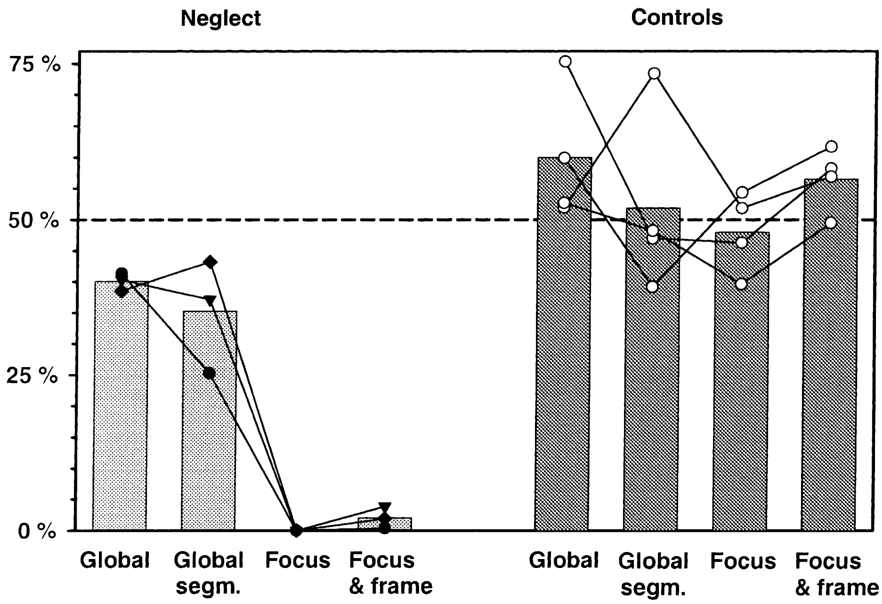

Fig. 4. Percentage of search time spent in the left half (+40 to +60°) of the area where the letters were coloured orange in three of the four test conditions, relative to the time searched in this whole segment (+40 to +80°). The individual performance of each control subject is plotted as open circles; the individual data of each neglect patient as black symbols. The underlying light and dark grey bars represent the mean values for each condition. Data points above the dashed horizontal line indicate a preference for the left half of the segment, data points below that line a preference for its right side. Global segm. 'global segmented'.

the orange segment (the area between +40 and +80°) during the 'focus' and the 'focus and frame' conditions, the control subjects restricted eye movements to that area showing nearly equal frequencies of visual search along the horizontal extension of the segment. Only few gaze movements exceeded its borders on the left and right side.

While searching in the whole letter array ('global' and 'global segmented' conditions), the neglect patients ignored the left part of the letter array completely (Fig. 3). The mean gaze position was shifted +76.4° during the 'global' condition and +83.6° during the 'global segmented' condition to the right of the mid-sagittal trunk plane. Again, these findings confirm previous results demonstrating this bias in neglect patients [11]. A two-way ANOVA for average gaze position revealed a significant factor 'patient group' ($F\ (1,\ 5) = 56.84$, $P = 0.001$) that could be attributed to the rightward bias in the neglect patients in contrast to controls. Neither the factor 'search condition' ('global' versus 'global segmented') nor the interaction yielded significance suggesting that presenting the distractor letters as a homogeneous array or segmented into different areas had no effect on the spontaneous orientation of the neglect patients' exploratory behaviour in space.

The question now arised whether the neglect patients' exploratory deficit would vary with the respective tasks. The dotted vertical lines in Fig. 3 mark the part of the sphere from +40 to +80° where the orange letters were presented. In both the 'global' and the 'global segmented' condition, the neglect patients showed a left–right increase of exploration within this area. Nevertheless, their eye movements covered the whole area from +40 to +80°. In contrast to these two conditions, in the subsequent 'focus' and 'focus and frame' conditions, the patients almost completely neglected the left side of that same segment. To analyse this effect quantitatively, we calculated the ratio of exploration time spent in the left half of that segment relative to the time spent in the whole segment (i.e. percentage of gaze movements within +40 to +60° by percentage of gaze movements within +40 to +80°). In Fig. 4, these data are given for each subject separately as well as for the respective group. We conducted a multivariate repeated measures ANOVA for this ratio with 'patient group' as between factor and 'condition' ('global', 'global segmented', 'focus', 'focus and frame') as a within factor, finding a significant interaction ($F\ (3,\ 15) = 40.38$, $P = 0.006$). Post hoc, this result could be attributed to a significant effect of search condition in the neglect patients ($F\ (3,\ 6) = 59.76$, $P < 0.001$) but not in the control subjects ($F\ (3,\ 9) = 1.04$, $P = 0.420$). In the neglect patients, additional planned t-tests revealed significant differences between the 'global' condition on the one hand and the 'focus' and the 'focus and frame' conditions on the other hand ('global' versus 'focus': $t\ (2) = 48.94$, $P < 0.001$; 'global' versus 'focus and frame': $t\ (2) = 25.70$, $P = 0.002$). We also found differences between the 'global segmented' and the 'focus' and 'focus and frame' conditions ('global segmented' versus 'focus': $t\ (2) = 6.68$, $P < 0.022$; 'global segmented' versus 'focus and frame': $t\ (2) = 7.01$, $P = 0.020$). No significant differences were found between the 'global' and the 'global segmented' conditions, or between the 'focus' and the 'focus and frame' conditions

($t\,(2) = 0.80$, $P = 0.506$ and $t\,(2) = -2.04$, $P = 0.179$, respectively). Thus, the same part of space was attended or neglected depending on whether it was perceived as part of the 'whole surroundings' or as left half of the target for the current task (i.e. the segment of orange letters). Fig. 4 shows that this pattern of distribution of neglect behaviour occurred in each of the three consecutively admitted neglect patients.

An additional aspect of the patients' exploratory behaviour was that they spent a substantial part of time searching outside the orange segment on the right side although the instruction required that they confine exploration to that segment. We compared the percentage of exceeding eye movements in the 'focus' and the 'focus and frame' conditions and found no difference ($t\,(2) = 0.17$, $P = 0.878$). Thus, this behaviour could not be attributed to e.g. a visual deficit in recognising the borders of the orange segment.

4. Discussion

The goal of the present study was to analyse task-dependent effects on the exploratory behaviour of neglect patients. Exploration was recorded when their attention was directed to the whole surrounding space and was compared with conditions when it was drawn to a certain, well-defined segment of space. As in previous studies [10,11], the first condition revealed contralesional neglect with respect to the body in all patients. When they had to attend to the whole surrounding environment, the patients' gaze positions were deviated towards the ipsilesional right with the centre of exploration around $+80^\circ$ right of the mid-sagittal trunk plane. With respect to this maximum, neglect patients oriented gaze with decreasing frequencies up to 0° to the left and up to $+120^\circ$ to the right. In other words, when the patients' attention was allocated to the whole surrounding space, they completely neglected the left hemispace and spontaneously attended the area between 0 and $+120^\circ$ on the right.

The area from $+40$ to $+80^\circ$, thus was positioned right within the patients' spontaneously attended part of space. Exploratory movements completely covered this area irrespective of whether this area could be visually distinguished from the rest of the surrounding scenery as a segmented, coloured *gestalt* (in the 'global segmented' test condition) or whether this was not possible because it was just one piece of the homogeneously coloured environment ('global' test condition). However, their behaviour changed dramatically when this same area became a specific region of interest in the 'focus' and the 'focus and frame' conditions. When the patients were instructed that the target letter could only be located in that segment, they almost completely neglected the left side of this coloured segment. Thus, the same part of space, namely the area from $+40$ to $+60^\circ$, that had been attended spontaneously when the subjects' attention was directed to the whole surrounding space, now was completely neglected when it became (by instruction) the 'left side' of a circumscribed segment to which their attention was allocated. (This effect was found though for the two focus tasks the search time relative to the area that should be explored was 4.7 times longer during the focus conditions than during the global conditions (40 s for 280 letters or 40° versus 60 s for 1960 letters or 280°, respectively)). This effect even was so dominating that the neglect patients spent a substantial part of time searching outside the orange segment on the right side although instructed to confine exploration to that segment only.

The present findings explain the apparent contrasting results reported by Behrmann et al. [2] on the one hand and Karnath et al. [11] on the other. Both studies recorded eye movements of neglect patients during visual search in an array of randomly presented letters. Behrmann et al. found a steep gradient in the patients' eye movement pattern. From the left to the right of the search field, the patients made more fixations and spent more time searching. Their observation argued for a lateral gradient of attention in these patients. In contrast, Karnath et al. found the exploratory movements of neglect patients symmetrically distributed around a deviated centre located right of the patients' mid-sagittal trunk plane. Different from Behrmann et al. findings, the patients did not orient predominantly towards the extreme ipsilesional side but rather oriented attention symmetrically to the left and right of this deviated exploration centre.

The crucial difference between these two previous studies concerns the area to which the experimenters allocated the attention of their subjects. While Behrmann et al. [2] presented a small search area with a horizontal extent of $\pm 22.5^\circ$ right and left of the body's mid-sagittal plane, Karnath et al. [11] used a large stimulus array of $\pm 140^\circ$ that almost completely surrounded the patients. The latter study required subjects to allocate attention to the 'whole surrounding space', whereas in the study of Behrmann et al. the subjects had to concentrate their attention to only a small part of it. The present study compared very similar test conditions but now within the same individuals. In fact, we observed the differing exploratory behaviour intraindividually. We found decreasing exploration frequencies to both sides of a deviated centre in the global test conditions and a left–right gradient in the focussed test conditions. The previous studies of Behrmann et al. [2] and Karnath et al. [11], thus, did not report contrasting but rather complementing results. When the subjects' attention is directed to the whole surrounding space, a large part of the contralesional space is neglected. The patients spontaneously attend the ipsilesional space and perform exploratory movements that are symmetrically distributed around an ipsilesionally deviated exploration centre. However, when attention is restricted to only a certain segment of that spontaneously attended area, the same part of space is neglected when it (by instruction) becomes the 'left side' of a circumscribed *gestalt* to which their attention is allocated. In the latter case, we found the same left–right asymmetry of exploration as reported by Behrmann et al. [2]. Such search patterns seem to occur not only in patients with rather severe neglect as in the present study but also in patients with less marked neglect symptoms [16].

However, the present findings are in certain contrast to the more recent observations of Behrmann and Tipper [1]. The authors searched for support for spatial- and object-based frames of reference in selective attention mechanisms by asking whether both spatial- and object-centred neglect might occur simultaneously in the same task in patients suffering from spatial neglect. The authors compared detection of targets in two squares presented stationary on the left and right side of a computer monitor with the detection of targets in the simultaneously presented left and right circles of a barbell that could either be static or moving. While the static square stimuli provided a stable background, demarcating the left and right of an egocentric, space-based frame of reference, the circles of the barbell constituted the left and right side of a static or moving object. The results argued for simultaneous, object- and space-based neglect. Targets that appeared on the left of the static square stimuli were responded slower than targets in the circle on the right of the rotating barbell whose final locus was on the left, just adjacent to the static left-sided square stimulus. Vice versa, the detection of targets on the right-sided static square was quicker than the detection of targets in the left circle of the rotating object whose final resting locus was also on the right side of the PC monitor.

Alternative concepts to explain these results are attentional tracking effects or the splitting of the attentional focus (e.g. [15]). Also the present results suggest an explanation different form the one given by Behrmann and Tipper [1]. The results suggest that 'object'- and space-based neglect may not occur in two spatially distinct, adjacent loci but that one and the same physical stimulus presented at one and the same location in space can either be attended or neglected just depending on whether the task defines this part as a piece of the surrounding space or as part of a particular 'object' of interest. Solely presenting the orange segment (the area from $+40$ to $+80^{\circ}$) without drawing the subjects' attention to it (in the 'global segmented' test condition), did not result in neglect for the left side of this part of the letter array. In this test condition, the different colours were irrelevant for the patients' behavioural goal to find the target that was (by instruction) located 'somewhere in the whole sphere'. This behaviour changed at once when the colour of the same segment became an important discriminative feature for their search (in the 'focus' and 'focus and frame' test conditions), although the same physical stimuli were present at exactly the same spatial locations as before in the 'global segmented' test condition.

In conclusion, the results of the present study suggest an important influence of task-dependent effects on the exploratory behaviour of neglect patients. They show that one and the same physical stimulus at one and the same location in a scene might be attended or, in another situation, neglected, just depending on the behavioural goal of the subject. Thus, instead of a static model of stimulus representation in multiple frames of reference, our findings rather favour a dynamic view. The idea is that the brain organises and reorganises continuously the representation of the same physical input according to the changing task requirements.

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References

[1] Behrmann M, Tipper SP. Attention accesses multiple reference frames: evidence from visual neglect. Journal of Experimental Psychology: Human Perception and Performance 1999;25: 83–101.
[2] Behrmann M, Watt S, Black SE, Barton JJS. Impaired visual search in patients with unilateral neglect: an oculographic analysis. Neuropsychologia 1997;35:1445–58.
[3] Bisiach E. The spatial features of unilateral neglect. In: Thier P, Karnath H-O, editors. Parietal lobe contributions to orientation in 3D space. Heidelberg: Springer, 1997. p. 465–95.
[4] Buxbaum LJ, Coslett HB, Montgomery MW, Farah MJ. Mental rotation may underlie apparent object-based neglect. Neuropsychologia 1996;34:113–26.
[5] Chelazzi L, Miller EK, Duncan J, Desimone R. A neural basis for visual search in inferior temporal cortex. Nature 1993;363:345–7.
[6] Dunai J, Bennett K, Fotiades A, Kritikos A, Castiello U. Modulation of unilateral neglect as a function of direction of object motion. NeuroReport 1999;10:1041–7.
[7] Gauthier L, Dehaut F, Joanette Y. The bells test: a quantitative and qualitative test for visual neglect. International Journal of Clinical Neuropsychology 1989;11:49–54.
[8] Gottlieb JP, Kusunoki M, Goldberg ME. The representation of visual salience in monkey parietal cortex. Nature 1998;29:481–4.
[9] Johnston CW, Diller L. Exploratory eye movements and visual hemi-neglect. Journal of Clinical and Experimental Neuropsychology 1986;8:93–101.
[10] Karnath H-O. Spatial limitation of eye movements during ocular exploration of simple line drawings in neglect syndrome. Cortex 1994;30:319–30.
[11] Karnath H-O, Niemeier M, Dichgans J. Space exploration in neglect. Brain 1998;121:2357–67.
[12] Kowler E, Anderson E, Dosher B, Blaser E. The role of attention in the programming of saccades. Vision Research 1995;35:1897–916.
[13] Kustov AA, Robinson DL. Shared neural control of attentional shifts and eye movements. Nature 1996;384:74–7.
[14] Marshall JC, Halligan PW. The yin and the yang of visuo-spatial neglect: a case study. Neuropsychologia 1994;32:1037–57.
[15] Mozer MC. Explaining object-based deficits in unilateral neglect without object-based frames of references. In: Reggia JA, Glanzman D, editors. Progress in Brain Research, vol. 121. Amsterdam: Elsevier; 1999. pp. 99–119.
[16] Niemeier M, Karnath H-O. Stimulating and testing visual exploration in spatial neglect based on a new model for cortical coordinate transformation. [submitted for publication].
[17] Riddoch MJ, Humphreys GW. The effect of cueing on unilateral neglect. Neuropsychologia 1983;21:589–99.

[18] Robinson DA. A method of measuring eye movement using a scleral search coil in a magnetic field. IEEE Transactions of Biomedical Electronics 1963;10:137–45.
[19] Rorden C, Brett M. Stereotaxic display of brain lesions. Behavioral Neurology 2001;12:191–200.
[20] Schneider WX, Deubel H. Visual attention and saccadic eye movements: evidence for obligatory and selective spatial coupling. In: Findlay JM, Walker R, Kentridge RW, editors. Eye Movement Research. Amsterdam: Elesevier, 1995. pp. 315–24.
[21] Smania N, Martini MC, Gambina G, Tomelleri G, Palamara A, Natale E. The spatial distribution of visual attention in hemineglect and extinction patients. Brain 1998;121:1759–70.
[22] Talairach J, Tournoux P. Co-planar stereotaxic atlas of the human brain: three-dimensional proportional system: an approach to cerebral imaging. New York: Thieme, 1988.
[23] Weintraub S, Mesulam M-M. Mental state assessment of young and elderly adults in behavioral neurology. In: Mesulam M-M, editor. Principles of behavioral neurology. Philadelphia: F.A. Davis Company, 1985. pp. 71–123.