Asymmetries of visual attention after circumscribed subcortical vascular lesions

B Fimm, R Zahn, M Mull, S Kemeny, F Buchwald, F Block, M Schwarz

Abstract

Objective—To investigate the role of the basal ganglia and the thalamus for basic processes of visuospatial attention

Methods—Fifteen patients with acute circumscribed vascular lesions (10 with haemorrhage and five with infarction) were included in the study. The lesions were confined exclusively to subcortical structures, such as the basal ganglia, internal capsule, and thalamus, which was confirmed by initial CT on the day of referral and MRI taken 14–28 days after clinical onset. These patients were examined with two computerised attentional tasks (one detection and one search task) measuring spatial visual attention.

Results—There was a clear attentional asymmetry in patients with right hemispheric lesions (RHLs) in the visual search task. Seven out of eight patients with RHLs tended to be slower and/or missed significantly more target stimuli in the left sided part of a stimulus array consisting of 25 small squares than in right sided parts, although none of these patients showed signs of visual hemineglect in the visual detection task presenting visual information simultaneously to the right and left visual hemispace. All but one of these patients showed lesions in the posterior limb of the internal capsule and the putamen. On the other hand, patients with left hemispheric lesions were impaired in the search task with only one patient showing more contralesional omissions of target stimuli than could be expected from the behaviour of normal controls.

Conclusions—The results are in line with previous results showing a dominant role of right hemispheric neuronal structures for spatial attention. Furthermore, the data suggest that even with right hemispheric subcortical lesions without cortical involvement deficits in spatial orienting of attention to the left hemispace can be seen. These asymmetries of visual attention in the absence of neglect symptoms are supposed to be caused (1) by a disruption of the motor corticostriato-pallidothalamo-cortical neuronal circuit or (2) by a (partial) disconnection of relevant parts within the posterior attention network—namely, parietal and thalamic structures.

Ferraro et al12 could show trimodal, visual, or auditory extinction in patients with right striatocapsular infarcts including the caudate and lenticular nuclei and the posterior limb of the internal capsule.

In their comprehensive review of the literature on neuropsychological disorders after subcortical lesions Cappa and Vallar concluded that besides the interoposterior parietal cortex, thalamic nuclei such as the pulvinar nucleus contribute to visuospatial attention.13 The associations between lesions in the basal ganglia and the thalamus as a main source of these deficits suggest an important role for these structures in spatial attention.
Table 1  Clinical and demographic variables of the patients

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<th>Patient</th>
<th>Age</th>
<th>Sex</th>
<th>Aetiology</th>
<th>Side of the lesion</th>
<th>Vol (cm³)</th>
<th>CN</th>
<th>PUT</th>
<th>GB</th>
<th>Thalamus</th>
<th>Int caps</th>
<th>Ext caps</th>
<th>White matter</th>
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<td>73</td>
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<td>H</td>
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<td>L</td>
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<td>H</td>
<td>L</td>
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<td>I</td>
<td>L</td>
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<td>I</td>
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<td>M</td>
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<td>P15</td>
<td>74</td>
<td>M</td>
<td>I</td>
<td>L</td>
<td>12.0</td>
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H=Haemorrhage; I=infarction; L=left; R=right; X=lesion; CN=caudate nucleus; PUT=putamen; GB=globus pallidus; Int caps=internal capsule; Ext caps=external capsule; ant=anterior; post=posterior; paraventr=paraventricular; lat=lateral.

Bold lines represent patients with right sided lesion and visual attentional deficit with respect to the left hemisphere.

ganglia and neglect were suggested to be less close. One criticism of these studies concerns the heavy reliance on CT data as MR is able to show additional cortical lesions in apparently pure subcortical damage as judged by CT.14

Furthermore, the studies mainly focused on the neglect syndrome disregarding symptoms of attentional asymmetries that cannot, with respect to their extent, be conceived as complete inattention of one half of the extrapersonal space but as an impairment or slowing in processing information presented on one side of the extrapersonal space. Such attentional asymmetries, which did not reach the level of impairment such as found in visual hemineglect, have been occasionally reported.15–18

To specify the functional role of the thalamus and the basal ganglia in selective visual attention, we investigated patients with circumscribed subcortical vascular lesions and applied several computerised tasks proved to be sensitive measures of visual attention asymmetries even in cases of recovered or only minor hemineglect.15 19

Methods

Fifteen patients with circumscribed subcortical vascular lesions (10 with haemorrhage—five left sided and five right sided; five with infarction—two left sided and three right sided) were examined 2 to 3 weeks after stroke. The lesions were confined to subcortical structures exclusively, such as the basal ganglia, internal capsule, and thalamus as judged by an initial CT on the day of referral and MRI taken 14–28 days after clinical onset. There was no cortical involvement and no diffuse white matter lesions as judged by MRI. Brain CT was made in axial slice orientation in parallel to the orbitomeatal line with a slice thickness of 8 mm in the supratentorial and 4 mm in the infratentorial parts of the brain. The CT scanner used was a Somatom DRH (Siemens). Brain MRI was performed on a Siemens Magnetom with 1.5 Tesla using axial T1 and T2 weighted images. In addition a T1 coronal three dimensional data set was acquired in six patients. The volume of the lesions was defined by applying the approximative formula

\[
\text{length} \times \text{width}/2 \quad \text{(see Niizuma et al F18 and Kothari et al F17).}
\]

For haemorrhages this was based on the initial CT on the day of referral and for infarctions T2 weighted MRI was used.

Table 1 gives an overview on demographic and clinical data of the patients. None of the patients showed clinically clear signs of visual hemineglect.

NEUROPSYCHOLOGICAL MEASUREMENT

Two computerised subtests of the test for attentional performance were used to measure basic aspects of spatial attention.

Neglect

In this test, subjects have to fixate a central square within which a sequence of randomly changing single letters (zero to two changes/trial) is displayed with the patient having to respond to each change by orally naming the new letter. This task was used to ensure central fixation of the patient at the beginning of each trial. In addition, the display is permanently filled with randomly located three digit numbers that provide simultaneous visual stimulation in both hemifields during the whole task. Within the gaps between these three digit numbers a peripheral three digit target appears in random locations in either left or right visual field within 13 degrees of the central square. During its presentation, the three digit target is randomly changing its value, thus appearing to flicker slightly. The target onset occurs between 1500–6000 ms after trial onset and the target is presented for a maximum of 3 seconds. Twelve targets are presented in each quadrant, giving a total of 48 targets. Subjects have to respond as quickly as possible to the onset of the target by pressing a button with the right hand. Relevant dependent variables were median reaction time for targets in the left or in the right visual field as well as omissions. Furthermore the difference in reaction time between left and right visual hemifield was of special interest. Sturm and Willmes could demonstrate a high sensitivity of this task for neglect symptoms and a high correspondence with cancellation performance in a single case with neglect. Furthermore, the improvement of neglect symptoms as a result of alertness therapy could be similarly measured both with cancellation tasks and with this neglect task.
identities of patients with significant asymmetries between both hemifields are displayed.

Figure 3 Visual scanning task: left-right differences (column 1 minus 5 of the stimulus arrangement) in reaction time and omissions. The space between the two vertical (a and b) and horizontal (c and d) lines respectively denotes the performance of 80% of normal controls. The identities of patients with attentional asymmetries between both hemifields are shown. Two additional patients with RHL missing at least 9 out of 10 target stimuli in the far left column (P04, P15) and one additional patient with LHL with nine omissions in the far right column (P12) are not displayed as a computation of respective times was not possible.

Visual scanning
This task investigates the capacity of active scanning of the visual field. A target pattern, a square opened on the upper side, has to be detected in a 5×5 arrangement of squares with openings on other sides (an example is shown in fig 1). The patients were asked to press the left out of two horizontally arranged buttons with the left hand as soon as they had found the target, and they had to press the right button by using their right hand in cases when no target was present within the 25 squares. They were instructed to use a fixed search strategy—that is, searching line by line, from left to right as if they were reading. Among the 100 trials of the task, 50 contained a target with 10 targets per line and per row of the stimulus arrangement. The time needed to scan the whole stimulus arrangement, the time to find targets in the different columns of the arrangement, the number of omissions in the different columns, and a measure of search strategy (correlation between reaction time and stimulus position after “numbering” the positions line by line from left to right) were obtained. In addition, variables indicating attentional asymmetry were introduced—namely, the difference in reaction time or omissions between the far left and the far right column.

DATA ANALYSIS
The data were analyzed using SPSS for Windows version 8.0. The rationale of the study was to use standardised values. Because the experimental tasks used had been standardised on the basis of 200 normal controls, T scores for the different parameters could be computed for each patient, thus allowing the classification of the patient’s performance as clearly impaired (on the basis of percentile rank 10 or T<37) or not. The distribution of the patients with respect to impairment (yes/no) and lesion side (left/right) was analyzed for several test parameters by using $\chi^2$ statistics. The patients’ lesions documented with CT and MRI were visualised using computer software developed in our functional imaging laboratory; the resulting picture shows a spatial overlay of the lesions superimposed on normalised MRI. Within the overlay darker shades of grey represent an increasing overlap of the individual lesions and identify the commonly affected cerebral structures.

Results
NEGLECT TASK
A clear right-left difference emerged in the neglect task. As illustrated in figure 2, patients with right sided lesions (RHL) showed (1) no difference between the hemifields or (2) lowered performance with respect to stimuli in the left hemifield and patients with left sided lesions (LHL) did the opposite. Patients displayed outside the area between lines a and b in figure 2 showed significant (p<0.05) asymmetries between the hemifields; four patients with left sided lesions (patients P01, P02, P07, and P15) and three patients (P09, P04, and P05) with significant slowing concerning contralesional stimuli. All patients with LHL had exclusive or predominant thalamic lesions; this also held true for two out of the three patients with RHL. These results suggest that the processing of contralesional visual stimuli when there are
no eye movements involved seems to be impaired after thalamic lesions.

VISUAL SCANNING

In this task attentional asymmetries were defined by computing the difference between (a) median reaction times with target stimuli in the far left and the far right column of the stimulus arrangement (Rťleft - Rťright) and (b) the number of omissions (maximum 10) of these two columns (omľeft - omľright). These new parameters are displayed in figure 3.

The space between the two vertical lines denotes the performance of 80% of normal controls concerning Rťavg, the two horizontal stripes show the analogue situation with respect to Omťavg. As can easily be detected, five out of six patients with RHL (P05, P06, P08, P09, and P11) showed attentional asymmetries in the sense of impaired processing of contralesional visual information. Two additional patients with RHL missing at least nine out of 10 target stimuli in the far left column are not displayed as a computation of respective reaction times was not possible (P04, P13). Thus, seven out of eight patients with RHL were impaired in the processing of contralesional visual information. One additional patient with LHL (P12) with four omissions in the far left and nine omissions in the far right column is also not shown in figure 3. Consequently, only two patients with LHL could be considered as having contralesional attentional asymmetries (P07 and P12).

This was not an effect of global impairment in visual scanning, eye movement, or selective attention as a comparison (Mann-Whitney U test) of patients with RHL and those with LHL with respect to their T scores of their total search time of the whole stimulus arrangement and their omissions did not yield any significant differences.

The association between side of lesion and occurrence of contralesional attentional asymmetries (based on the T scores) was highly...
significant (Fisher's exact test: $\chi^2=11.34$; $p<0.01$) and clearly points to the fact that these deficits were predominant in patients with RHL. Seven out of eight patients with RHL showed an attentional asymmetry to the left but only two out of seven patients with LHL were impaired when processing contralesional stimuli. No asymmetry was found in five patients with LHL and one patient with RHL.

**Correlations Between Attentional asymmetries and lesion characteristics**

No clearcut association between the size of the right sided lesion and the amount of attentional asymmetry could be established. Even small lesions within the right frontostriato-pallidothalamic system at different locations provoked the deficiencies in the processing of contralesional stimuli. Remarkably, the putamen was involved in six out of seven and the posterior limb of the internal capsule (PLIC) was lesioned in five out of seven patients (among them two patients with exclusive lesions covering the putamen and PLIC and one patient with thalamic and PLIC lesions without involvement of additional structures). Four patients showed more extensive lesions covering the lentiform nucleus, internal capsule, and/or thalamus or caudate nucleus. A superposition of the individual lesions of the patients with attentional asymmetry (fig 4) shows common areas in the dorsolateral lentiform nucleus, especially the putamen, and (to a lesser degree) the PLIC. The only patient with RHL without attentional asymmetries had an exclusive lesion of the head of the caudate nucleus without any other impaired structures. However, no association between attentional asymmetries and atrophy could be detected.

**Discussion**

In this study we investigated basic attentional functions in patients with circumscribed subcortical haemorrhages and infarctions within the striatopallidothalamic system. Our results demonstrate a clear attentional asymmetry in patients with RHL in visual search. Seven out of eight patients with RHL tended to be slower or missed much more target stimuli in the left sided part of the stimulus array in the visual search task. Patients with LHL performed normally in this task with only two patients showing more contralesional omissions of target stimuli than could be expected from the behaviour of normal controls. This right hemispheric dominance for visual search in the contralesional space. We suppose that the basal ganglia, in particular the putamen, and the thalamus or the caudate nucleus. As none of the patients showed any clinical or psychometric signs of acute visual hemineglect we suppose that no neuronal key structure involved in the shift of visual attention was impaired. In accordance with our results, this association between lesions in the right posterior internal capsule and neglect symptoms has been repeatedly reported.

In summary, circumscribed right subcortical vascular lesions lead to spatial attention deficits of visual search in the contralesional external space. We suppose that the basal ganglia, in particular the putamen, and the posterior limb of the internal capsule form an integral part of the anterior and the posterior attention network being responsible for the orienting of visual attention. The lesion characteristics of the patients lend support to the fact that the subclinical neglect symptoms found in visual search may be caused by a disruption of the functional MRI study. Thus, our results might again demonstrate an important role of right hemispheric basal ganglia or thalamic structures within this network although none of our patients showed signs of visual hemineglect in the visual detection task presenting visual information simultaneously to the right and left visual hemispace. In addition, clinically no signs of acute hemineglect could be found.

There is one limitation in assigning neuropsychological functions to different subcortical structures in our study as the vascular aetiology led to combined lesions of the basal ganglia, thalamus, and internal capsule in most patients. The diversity of lesions within the group with right sided lesions and spatial attention deficits complicates unequivocal statements on the functional role of the basal ganglia and thalamus within the attention network. A superposition of the individual lesions found in these patients disclosed a strong overlap in the dorsolateral lentiform nucleus—namely, the putamen. The structures of the haemorrhages within this group correspond to posterolateral and lateral types of striatocapsular haemorrhage according to Chung et al., although without rupture into the lateral ventricle in our patients. The middle and posterior portions of the putamen are predominantly affected. In primates these parts of the putamen are somatotopically associated with arm and face movements. Accordingly, the putamen is considered to be an integral part of a frontostriato-pallidothalamo frontal circuit being involved in motor control, motor sequencing, and the automatic execution of learned motor plans.

Because five out of seven patients with RHL with spatial attention deficits also had a lesion within the posterior limb of the internal capsule, it is not certain if the basal ganglia or thalamic nuclei themselves are responsible for the spatial attention deficit. Instead, a lesion of the thalamoparietal projections transversing through the posterior limb of the internal capsule via the superior peduncle of the thalamus could lead to a disconnection of functionally relevant structures within the posterior attentional network—namely, the parietal cortex and the pulvinar nucleus. As none of the patients showed any clinical or psychometric signs of acute visual hemineglect we suppose that no neuronal key structure involved in the shift of visual attention was impaired. In accordance with our results, this association between lesions in the right posterior internal capsule and neglect symptoms has been repeatedly reported.
motor frontostriato-pallido-thalamo-frontal neuronal circuit and/or (b) by a (partial) disconnection of relevant parts within the posteriort attention network—namely, parietal and thalamic structures.

29 Damasio AR, Damasio H, Chui HC. Neglect following damage to frontal lobe or basal ganglia. Neuropsychologia 1980;18:123–32.
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