Personal neglect—A disorder of body representation?

Ulrike Baas\textsuperscript{a}, Bianca de Haan\textsuperscript{d}, Tanja Grässli\textsuperscript{a, c}, Hans-Otto Karnath\textsuperscript{d}, René Mueri\textsuperscript{a, c}, Walter J. Perrig\textsuperscript{b}, Pascal Wurtz\textsuperscript{c}, Klemens Gutbrod\textsuperscript{a, c}

\textsuperscript{a} Division of Cognitive and Restorative Neurology, Department of Neurology, Inselspital, Bern University Hospital, and University of Bern, CH-3010 Bern, Switzerland
\textsuperscript{b} Department of Psychology, University of Bern, Switzerland
\textsuperscript{c} Perception and Eye Movement Laboratory, Department of Neurology, Inselspital, Bern University Hospital, and University of Bern, Switzerland
\textsuperscript{d} Division of Neuropsychology, Centre for Neurology, Herite-Institute for Clinical Brain Research, University of Tuebingen, Germany

1. Introduction

Unilateral neglect is defined as a “failure to report, respond, or orient to novel or meaningful stimuli presented to the side opposite the brain lesion when this failure cannot be attributed to either sensory or motor defects” (Heilman, Watson, & Valenstein, 1993, p. 268). It may affect personal space, i.e. one’s own body, as well as extrapersonal space. In personal neglect, the contralesional half of the body is disregarded, less explored or underused by the patient. This means that in activities of daily living, patients with personal neglect seem to “forget” the contralesional side of their body. They tend to groom it to a lesser degree (e.g. they do not shave the left side of their face or forget to lace up their left shoe). They ignore contralesional somatosensory stimuli (e.g. they insert the spectacle’s earpiece incorrectly, or below the contralesional ear), or they do not use the extremities of the contralesional side of their bodies (e.g. they dress using the ipsilesional arm only, despite intact motor functions of the contralesional side).

Personal neglect was first described by Zingerle in 1913 almost as early as extrapersonal neglect (Anton, 1896). At that time, personal neglect was explained as a loss of somatosensory functions (Pierre Marie, 1918 in Babinski, 1918). However, others subsequently suggested that in addition to somatosensory defects, cognitive deficits had to be present (Battersby, Bender, Pollack, & Kahn, 1956). While these authors still considered elementary somatosensory deficits to be a basic prerequisite for personal neglect, researchers later hypothesized that personal neglect represents a higher somatosensory integration defect that can also occur in the absence of somatosensory deficits (Denny-Brown & Banker, 1954; Denny-Brown, Meyer, & Horenstein, 1952). Specifically, they postulated that personal (and extrapersonal) neglect is caused by impairments in integrating afferent input from the contralesional side into a spatial concept.

In the second half of the last century, experimental research almost exclusively focussed on extrapersonal neglect. Due to the common co-occurrence of personal and extrapersonal neglect (Brain, 1941) and the absence of appropriate diagnostic tools to assess personal neglect, personal neglect was subsumed in the concept of unilateral neglect and both phenomena were explained by the same underlying cognitive mechanisms. Unilateral neglect was considered either a unilateral attention disorder (Kinsbourne, 1987,}
a systematic failure in transforming multiple sensory inputs into spatial representations, i.e. into non-retinal egocentric frames of reference (Karnath, 1997), or a dysfunction of the cerebral representation of contralesional body and space (Bisiach & Berti, 1995; Bisiach & Luzzatti, 1978).

Recently, however, diagnostic tools for the assessment of personal neglect such as the Fluff-Test (Cocchini, Beschin, & Jehkonen, 2001) and the Comb-and-Razor-Test (Beschin & Robertson, 1997) have been developed. Interestingly, these tests have shown that personal and extrapersonal neglect dissociate more often than previously assumed: for example, using the Comb-and-Razor-Test McIntosh, Brodie, Beschin, and Robertson (2000) found personal neglect without extrapersonal neglect in six of 44 brain damaged patients, i.e. 13.6%. A similar percentage was discovered by Bowen, Gardener, Cross, Tyrrell, and Graham (2005) with the Fluff-Test: eight of 42 patients with right-sided brain lesions showed personal neglect without extrapersonal neglect, i.e. 19.0%. These dissociations between personal and extrapersonal neglect suggest that different underlying mechanisms and anatomies might be involved.

The current study aims at examining the critical mechanisms and anatomy underlying personal neglect. Specifically, we focus on whether the representational hypothesis put forward by Bisiach and Berti (1995) and Bisiach and Luzzatti (1978) is valid for personal neglect, i.e. if a contralesional body representation defect is the underlying cause.

Body representation is not a unitary concept. It can be divided into various components. For example, Coslett, Safran, and Schwoebel (2002) proposed three main aspects of body representations: the lexical-semantic knowledge of the body and its functions (body image), the knowledge of spatial relationships (body structure description), and a dynamic online-representation of the body in space, which is the result of a computation of multiple afferent somatosensory stimuli (body schema). Thus, according to Coslett et al. (2002) a body schema can be understood as a purely somatosensory representation. Other authors have however additionally emphasized the role of action intention and subsequent motor components of the body schema (Gallagher, 2002). According to Trepel (1999) body representations can also be classified by modalities. Research here suggests that there are elementary motor representations in the precentral gyrus and elementary sensory representations in the postcentral gyrus (e.g. Trepel, 1999), visual representations in the lateral orbitofrontal cortex (the so-called extrastriate body area, Downing, Jiang, Shuman, & Kanwisher, 2001), movement representations in different higher order brain regions (Parsons, Gabrieli, Phelps, & Gazzaniga, 1998), spatial representations in the posterior parietal cortex (Stein, 1992) and conscious-affective representations in the insula (Craig, 2002, 2003; Karnath, Baier, & Nagele, 2005).

The link between personal neglect and defective body representations was first examined by Guariglia and Antonucci (1992). They examined a patient with severe personal – but no extrapersonal – neglect using three tests, measuring different forms of body representations. Their study showed that the patient had more left-than right-sided difficulties in dealing with visuotactile information coming from the body (recognizing touched fingers; indicating parts of the body after verbal, visual or tactile request). Additionally, he had a generally impaired body concept with bilateral difficulties in reconstructing a body and face using pre-cut puzzle pieces, while no visuoconstructive deficits were present. These results indicate that personal neglect can be associated with different body representation deficits.

To operationalize body representation, we decided to focus on a task that assesses proprioceptive and movement representations of the body. In the so-called hand laterality task (Parsons, 1987a, 1987b), subjects have to evaluate if centrally presented pictures of left and right hands presented from the front (prototypical) or back (non-prototypical) view correspond to their covered left or right hand. This task is an elegant method of measuring the proprioceptive and motor imagery of one’s own hand. The reason being that, as Parsons (1987a, 1987b) showed earlier in intensive studies with normal subjects, one has to compare the presented hand picture with the mental (proproioceptive) representation of one’s own hand in order to make an appropriate judgement (see also Shenton, Schwoebel, & Coslett, 2004 for the role of proprioception in motor imagery). Parsons’ experiments demonstrated that subjects mentally moved their hand representation, naturally of their own accord, to bring it into the corresponding orientation with the visual hand stimulus if the orientation of the visual hand stimulus and the hand representation were not identical (1987b). The results from Parsons’ study furthermore showed that it is not the stimulus itself which is mentally rotated, since reaction times increased with implicit awkwardness of stimulus orientation (anatomical constraints: movements to the stimulus orientation). If subjects would have performed a mental rotation on the stimulus itself, reaction times would have increased with the orientation difference (Cooper & Shepard, 1973), which they did not.

Variants of the hand laterality task have also been applied in the context of other body disturbances. For example, it has been shown that arm amputations (Nico, Daprati, Rigal, Parsons, & Sirigu, 2004), focal hand dystonia (Fiorio, Tinazzi, & Aglioti, 2006) or chronic arm pain (Schwoebel, Friedman, Duda, & Coslett, 2001) are linked to impaired body representation, while hemiparesis after stroke was not associated with a deficient representation of the paralyzed arm (Johnson, Sprehn, & Saykin, 2002). The hand laterality task was also used in the context of extrapersonal neglect: Coslett (1998), for example, examined six right-brain-damaged patients, three of whom showed extrapersonal neglect. The latter patients showed significantly more errors with left hand stimuli than with right hand stimuli. The three patients without extrapersonal neglect did not exhibit significant differences. Coslett (1998) therefore concluded that neglect may be associated with a disorder in left body representation.

In the present study we want to find out if personal neglect is linked to defective body representation to a greater extent than extrapersonal neglect. Moreover, we want to know whether these deficits in representation are body-specific (i.e. whether only body representations are affected in personal neglect) or whether there is a dysfunction of the mental representation of the contralesional space in general.

To assess body representations we used an adapted form of the hand laterality task designed by Parsons (Parsons, 1987a, 1987b). To assess extrapersonal representation of visual stimuli, a task comparable to the hand laterality task – termed the mirror laterality task – was developed: imagining the view of a motor-cyclist, participants had to judge photographs of left and right rear-view mirrors of a motor cycle – presented from the front (prototypical view) or back (non-prototypical view) – as left or right. If a general representation deficit is the underlying cause for personal neglect, we expect patients with personal neglect to perform significantly worse with left stimuli than patients without personal neglect, both on the hand laterality task and the mirror laterality task. If personal neglect is due to a specific deficit in body representation, patients with personal neglect should be particularly impaired with left stimuli in the hand laterality task. Furthermore, we were interested in finding patient characteristics that would best predict the occurrence of personal neglect. For this purpose, additional measures were included, such as measures of somatosensory and motor deficits as well as measures of extrapersonal neglect.

So far, few studies have dealt with the neuroanatomical basis of personal neglect. In a post-mortem autopsy of five patients
with personal neglect symptoms, Nielsen (1938) found that all of them showed lesions of thalamoparietal projection fibres. He suggested that in patients with personal neglect these lesions prevent somatosensory stimuli from reaching the supramarginal gyrus in the inferior parietal cortex resulting in diminished consciousness of the left side of the body. In a population of 118 patients with right-sided lesions Hécaen and Angelergues (1961) showed that personal neglect symptoms occurred after parietal lesions in 39%, after parietotemperoparioccipital lesions in 47% and after temporal lesions in 16% of the cases. However, the first and only study exploring the neural bases of personal neglect in eight patients with modern lesion analysis methods stems from Commetti et al. (2007). Their results suggested that the inferior parietal lobe, in particular the supramarginal and the postcentral gyrus as well as the underlying white matter were the critical brain structure for personal neglect.

2. Materials and Methods

2.1. Participants

Twenty-two right-handed patients with subacute right hemisphere stroke (mean time since stroke-onset: 37 days) and without evidence of diffuse or bilateral lesions as well as 13 right-handed healthy control subjects participated in the study. The presence of personal neglect was assessed with a modified version of the Fluff Test (Cocchini et al., 2001). In this test, 24 targets (felt stickers, 22 mm in diameter) were attached to the clothes of the blindfolded subjects by the examiner (six targets to the left and right leg, the left arm, and the trunk). No targets were placed on the right arm, as the task was performed using this arm. The subjects were then asked to the left and right leg, the left arm, and the trunk). No targets were placed on the right arm, as the task was performed using this arm. The subjects were then asked to identify the targets as quickly as possible. The number of targets omitted on the left half of the body after a time limit of 2 min was recorded. Controls never omitted more than three targets on the left side of the body (mean ± SD: 1.15 ± 0.90). Thus, personal neglect was presumed if more than three left targets were omitted. Seven patients showed personal neglect (PN+: 6.57 ± 2.07), while 15 patients presented no left personal neglect (PN−; 0.73 ± 0.88).

To control potentially co-varying or confounding variables (motor and somatosensory impairment as well as extrapersonal neglect) and to investigate the patient characteristics that would best predict the occurrence of personal neglect, an additional test battery was administered. Motor impairment of the upper left limb (hand and arm) was measured with parts of the Chedoke-McMaster Stroke Assessment (Gowland et al., 1993), which consists of 7 levels of motoricity with level 7 representing intact motoricity and level 1 representing absent or minimal motor function. Summing up the scores for arm and hand, the maximum total score attained was 14 (seven for the left arm and hand respectively). Somatosensory deficits of the contralateral arm and hand were evaluated with a clinical screening test used by our occupational therapists for pain perception, touch perception, detection of texture and proprioception. In the test, a maximum score of 12 could be attained for both pain and touch perception, a score of 9 for recognition of texture, and a score of 12 for proprioception. Adding up the scores, the maximum total score attained was 45, indicating intact somatosensory functions. The presence of extrapersonal neglect was assessed by the Line Bisection Test (Schenkenberg, Bradford, & Ajax, 1980) and the Bells Test (Gauthier, Dehaut, & Jeanette, 1989). The dependent variables of the Line Bisection Test were left or right deviations from the centre of the lines. For the Bells Test we calculated the Centre of Cancellation (CoC), using the procedure and software by Rorden and Karnath (2010, www.mricro.com/cancel). This value indicates the centre of mass for all the detected items, so that identifying all the targets would generate a score of zero whereas identifying only the rightmost item would provide a score of one. This measure is sensitive to both the number of omissions and the location of these omissions. CoC scores higher than 0.09 in the Bells Test were regarded as an indication of extrapersonal neglect behaviour (cf. Rorden & Karnath).

Demographic and clinical data are provided in Table 1. As illustrated in the table, patients and healthy controls were comparable with respect to age, sex and educational level. Statistically, PN+ patients and PN− patients were comparable with regard to aetiology, days post-onset of their illness, measures of sensitivity, motoricity, visual field defects, and extrapersonal neglect. MRI scans were available for 20 patients and CT scans for the remaining two patients. In line with the procedure used by Karnath, Fruhmann, Berger, Keller, and Rorden (2004) and Karnath, Himmelbach, and Rorden (2002), diffusion-weighted scans were used when an MRI was conducted within the first 48 h after stroke and T2-weighted scans were used when an MRI was conducted later than 48 h after the stroke. Mapping of lesions was carried out by one of the authors (K.C.) without knowledge of the patients’ test results and clinical features. For the 20 patients with available MRI scans the boundary of the lesions was delineated directly on the individual MRI image for every single transversal slice using MIBcon software (Rorden, Karnath, & Bonilha, 2007; www.mricro.com/mribcon). Both the scan and lesion shape were then mapped into approximate Talairach space using the spatial normalization algorithm provided by SPM5 (http://www.fil.ion.ucl.ac.uk/spm/).

For determination of the transformation parameters, cost-function masking was employed (Brett, Lef, Rorden, & Ashburner, 2001). For the two patients with CT scans, lesions were mapped directly – also using MIBcon – on the T1-weighted MPR single subject template implemented in MIBcon (Rorden & Brett, 2000) with a slice distance of 1 mm using the closest matching transversal slice of each individual.

To identify the anatomical structures commonly damaged in PN+ patients but typically intact in PN− patients subtraction analysis was performed (Rorden & Karnath, 2004). Considering the low number of subjects, a conservative threshold of 50% was employed, highlighting those brain areas that were lesioned at least 50% more frequently in PN+ compared to PN− patients.

### Table 1

Demographic and clinical data for patients with (PN+) and without (PN−) personal neglect and healthy controls (M = means; SD = standard deviation).

<table>
<thead>
<tr>
<th></th>
<th>PN+ (N = 7)</th>
<th>PN− (N = 15)</th>
<th>Controls (N = 13)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>51.47 ± 10.73</td>
<td>61.29 ± 10.42</td>
<td>60.08 ± 7.98</td>
<td>H(2) = 4.13*</td>
</tr>
<tr>
<td>Sex</td>
<td>13.62 ± 6.57</td>
<td>7.89 ± 6.91</td>
<td>6.91 ± 6.57</td>
<td>p = 0.13</td>
</tr>
<tr>
<td>Female</td>
<td>Male</td>
<td>Male</td>
<td>Male</td>
<td>p = 0.15</td>
</tr>
<tr>
<td>Male</td>
<td>4 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>p = 0.56</td>
</tr>
<tr>
<td>Education</td>
<td>12.77 ± 3.11</td>
<td>13.50 ± 3.35</td>
<td>13.58 ± 2.52</td>
<td>H(2) = 4.79*</td>
</tr>
<tr>
<td>MD</td>
<td>3.11 ± 0.64</td>
<td>3.35 ± 0.23</td>
<td>2.52 ± 0.73</td>
<td>p = 0.79</td>
</tr>
<tr>
<td>Aetiology</td>
<td>14 ± 6</td>
<td>14 ± 6</td>
<td>14 ± 6</td>
<td>ch²(1) = 3.84</td>
</tr>
<tr>
<td>Vascular</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>p = 0.33</td>
</tr>
<tr>
<td>Other</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>p = 0.56</td>
</tr>
<tr>
<td>Days post onset</td>
<td>37.73 ± 17.92</td>
<td>35.57 ± 17.92</td>
<td>21.57 ± 17.92</td>
<td>p = 0.14</td>
</tr>
<tr>
<td>Motoricity</td>
<td>5.87 ± 6.71</td>
<td>6.71 ± 6.71</td>
<td>7.12 ± 6.71</td>
<td>p = 0.27</td>
</tr>
<tr>
<td>Sensibility</td>
<td>30.79 ± 28.14</td>
<td>28.14 ± 28.14</td>
<td>17.92 ± 28.14</td>
<td>p = 0.27</td>
</tr>
<tr>
<td>Hemianopia</td>
<td>Yes 4 ± 2</td>
<td>Yes 2 ± 2</td>
<td>Yes 2 ± 2</td>
<td>p = 0.66</td>
</tr>
<tr>
<td>No</td>
<td>12 ± 5</td>
<td>5 ± 5</td>
<td>5 ± 5</td>
<td>p = 0.66</td>
</tr>
<tr>
<td>Extrapersonal neglect: line bisection (omissions)</td>
<td>27 ± 15.7</td>
<td>27 ± 15.7</td>
<td>27 ± 15.7</td>
<td>p = 0.33</td>
</tr>
<tr>
<td>Extrapersonal neglect: line bisection (deviation)</td>
<td>10.47 ± 21.55</td>
<td>10.47 ± 21.55</td>
<td>10.47 ± 21.55</td>
<td>p = 0.28</td>
</tr>
<tr>
<td>Extrapersonal neglect: Bells Test (centre of cancellation)</td>
<td>0.16 ± 0.09</td>
<td>0.16 ± 0.09</td>
<td>0.16 ± 0.09</td>
<td>p = 0.34</td>
</tr>
</tbody>
</table>

* Kruskal–Wallis one-way variance analysis (H-test).
* a-Z-Scores based on Mann–Whitney U tests.
* b-Number of omissions of left-sided lines.
* c-Percentual deviation to the right in left-sided lines.
* d-Cf. Rorden and Karnath (2010) and text.
2.2. Stimuli

For the hand laterality task, photographs of a left or right hand were shown centrally in an upright position from a prototypical (palm-down) or non-prototypical (palm-up) view, resulting in four different stimuli (left prototypical vs. left non-prototypical stimulus, right prototypical vs. right non-prototypical stimulus; see Fig. 1). Palm-down view was considered prototypical because this view was consistent with the position of the participants’ hands during the experiment. The mirror laterality task consisted of centrally presented pictures of left or right rear-view mirrors of a motor cycle, also shown from prototypical (front) or non-prototypical (back) view, thus also resulting in four types of stimuli. Here, the front view was considered prototypical because subjects had to assume the perspective of a motorcyclist during the experiment. In this task, motor cycle rear-view mirrors were used instead of the more common car rear-view mirrors as a preliminary evaluation revealed these stimuli to be more distinctly left or right-sided compared to the rear-view mirrors of a car.

2.3. Procedure

Every hand and mirror stimulus was presented 15 times during the experiment. The 60 (15 × 4) hand and mirror laterality task stimuli were presented centrally on a computer screen in a pseudo-randomized order to prevent an immediate repetition of the same stimulus. Stimuli were separated by a blank screen with a central fixation cross. E-Prime (Psychology Software Tools) was used to program and conduct the experiment and record the response times. A microphone voice key device was used to measure vocal reaction times of participants. Errors were logged by the experimenter. To check for sequence effects, half of the participants performed the hand laterality task first, while the other half started with the mirror laterality task. In the hand laterality task, subjects were asked to determine whether the visually presented hand stimulus corresponded to a left or right hand. In the mirror laterality task, participants had to evaluate rear-view mirrors from the perspective of the cyclist as left or right. Both tasks were preceded by a practice test in which the four stimuli were displayed three times in a pseudo-randomized order without a time restriction. In the practice test of the hand laterality task, participants were allowed to look at their hands while moving them into the required position. Whenever wrong answers were given, the experimenter pointed out the solution (by moving his/her hand into the position of the presented stimulus). In the practice test of the mirror laterality task, photographs of single motor cycle mirrors and photos of the driver’s perspective were shown. This was done to facilitate the subject’s task of mentally assuming the perspective of the motorcyclist. Again, the correct answers were given by the experimenter in the case of wrong answers. Before starting the experiment, participants had to place their hands out of sight palm down in their laps under the computer table. They were instructed to avoid any hand movement and give the answer as quickly as possible by saying “left” or “right” into the microphone to record reaction time (“voice onset”). The stimulus disappeared when a response was given, and a blank screen with a fixation cross appeared. The display of the next stimulus was presented by the experimenter to adapt the experiment to the patient’s individual processing speed.

3. Results

3.1. Group analyses

Since our hypotheses focussed on testing interactions, we used variance analytical procedures. First of all, we tested the assumptions of normal distribution and variance homogeneity, which were partially violated. Therefore, we preliminarily applied non-parametric tests as well as analyses of variance (ANOVA) without and with different variance stabilizing procedures (Winer, 1972) including transformations (Conover & Imam, 1981). Non-parametric tests included Kruskal–Wallis-tests and Mann–Whitney-U-tests to evaluate group differences, and Friedman-tests and Wilcoxon-tests to evaluate differences of the tasks within groups.

As the directions of the results remained the same – indicating the robustness of our data – and one can assume that ANOVA is a robust procedure against violations of normal distribution and variance homogeneity (Bortz, 1989, p. 347), we decided to show non-transformed data using parametric ANOVAs here.

A mixed four-way repeated measures ANOVA with Group (PN+ vs. PN− patients vs. controls) as between subject factor, and Stimulus (hand vs. mirror), View (prototypical vs. non-prototypical) and Side (left vs. right) as within subject factor was performed. The percentages of errors and reaction times (RTs) were analyzed separately. Analyses of RTs only included data for correct responses. With specific hypotheses, significant effects were further analyzed with planned comparisons. Without specific hypotheses, unplanned post hoc comparisons (Newman–Keuls) were performed.

3.1.1. Errors

Mean and standard errors of the mean (SEM) for accuracy data (errors in %) for every stimulus type and group are presented in Table 2.

There was a significant main effect of Group (F(2,32)=5.25; p=.01). Subsequent post hoc comparisons revealed that PN+ patients (25±5) showed significantly more errors than PN− patients (14±3; p=.07). Additionally, the two patient groups committed significantly more errors than controls (5±3; p<.01).

Table 2

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>PN+</th>
<th>PN−</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand prototypical left</td>
<td>23 (6)</td>
<td>7 (4)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>Hand prototypical right</td>
<td>15 (4)</td>
<td>5 (3)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Hand non-prototypical left</td>
<td>19 (6)</td>
<td>9 (4)</td>
<td>7 (4)</td>
</tr>
<tr>
<td>Mirror prototypical left</td>
<td>43 (11)</td>
<td>19 (7)</td>
<td>2 (8)</td>
</tr>
<tr>
<td>Mirror prototypical right</td>
<td>39 (10)</td>
<td>15 (7)</td>
<td>3 (7)</td>
</tr>
<tr>
<td>Mirror non-prototypical left</td>
<td>30 (8)</td>
<td>18 (5)</td>
<td>8 (6)</td>
</tr>
<tr>
<td>Mirror non-prototypical right</td>
<td>18 (7)</td>
<td>25 (5)</td>
<td>7 (5)</td>
</tr>
</tbody>
</table>
There was also a significant main effect of Stimulus ($F(2, 32) = 9.88; p < .01$). Generally, more errors were made in the mirror (19 ± 3) than in the hand laterality task (10 ± 2). Furthermore, the interaction View × Group was significant ($F(2, 32) = 3.31; p < .05$). That is, while PN+ patients made significantly more errors with prototypical stimuli than with non-prototypical stimuli, PN− patients and controls made significantly more errors with non-prototypical than with prototypical stimuli ($PN+: non-prototypical stimuli: 20 ± 5; prototypical stimuli: 30 ± 6; PN−: non-prototypical stimuli: 16 ± 4; prototypical stimuli: 11 ± 4; controls: non-prototypical stimuli: 8 ± 4; prototypical stimuli: 2 ± 4$). More importantly, there was a significant interaction Group × Side ($F(2, 32) = 4.62; p = .02$; see Fig. 2) indicating that PN+ patients made significantly more errors with left stimuli than with right stimuli (left stimuli: 29 ± 6; right stimuli: 21 ± 5; $p < .01$). This was not the case in PN− patients and controls (PN−: left stimuli: 13 ± 4; right stimuli: 15 ± 3; controls: left stimuli: 4 ± 4; right stimuli: 5 ± 4). Additionally, compared to PN− patients PN+ patients made significantly more errors with left stimuli ($p < .03$), while no such difference was found between the two patient groups with respect to the right-sided stimuli. In comparison to healthy controls, the two patient groups made significantly more errors both with the left and the right stimuli ($p < .01$). All other comparisons, in particular the three way interaction Group × Stimulus × Side, did not achieve any significance.

It should be noted that PN+ patients did not differ statistically from PN− patients with regard to extrapersonal neglect. Yet, PN+ patients showed a higher CoC score and/or deviations in measures of extrapersonal neglect, as Table 1 shows. To analyze whether this result was due to a deficit in the representation of the left extrapersonal space significantly predicted personal neglect than in patients without personal neglect. Additionally, there was also a smaller right frontal focus.

3.3. Lesion analyses

The results of the lesion analyses are presented in Fig. 3. The subtraction analysis revealed a centre of lesion location in the temporo-parietal junction and underlying white matter that was damaged at least 50% more frequently in patients with personal neglect than in patients without personal neglect. Additionally, there was a smaller right frontonal focus.

4. Discussion

The aim of the present study was to explore whether personal neglect can best be explained by a specific disorder of contralesional body representation in particular or a dysfunction of the representation of contralesional space in general.

Our results show that patients with left personal neglect made more errors with left stimuli than with right stimuli, regardless of the type of stimulus (hand or mirror, i.e. body or extrapersonal stimulus). Patients without personal neglect and controls did not show any difference in errors between the left and right stimuli. Moreover, errors with left stimuli occurred significantly more often in patients with personal neglect than in patients without personal neglect. Between the patient groups, no significant difference in errors for right stimuli was observed.

![Fig. 2](image_url). Percentage of errors (mean and SEM) for left and right stimuli for patients with (PN+) and without (PN−) personal neglect and healthy controls.
Our results cannot be due to elementary disorders such as somatosensory or motor deficits of the left side of the body, as the respective variables were held constant in both patient groups. Moreover, taking extrapersonal neglect variables as covariates did not affect the results. The results cannot be explained by a general problem of mental imagery either. If this were the case, then not only left stimuli but also right stimuli should have been affected. Furthermore, if the results were solely due to a problem with mental rotation, then the effects should be present particularly with non-prototypical stimuli. The reason for this is that subjects need to make mental rotations with these stimuli in order to compare the visual stimulus with the actual position of their hands. Therefore in prototypical stimuli, where no mental-motor rotations are required, difficulties in evaluation should not have occurred. However, the missing effects of prototypicality show that patients with personal neglect also have difficulties in evaluating the side of prototypical left hands. This means that Parson’s hand laterality task is not only a task of mental rotation, but also a task requiring proprioceptive comparisons with one’s own hand representation.

One might further argue that the left-right effect is due to the position of recognition relevant cues (thumb of the hand and stem of the mirror). Theoretically this could be true for the non-prototypical stimuli, where the hands were presented in palm-up position and the mirrors from the back: here, the recognition relevant cue (thumb or stem) is on the left side of the left stimulus and on the right side of the right stimulus. This could mislead neglect patients into “ignoring” left recognition relevant cues and being more “susceptible” to right recognition relevant cues (which is why an increase in errors with non-prototypical left stimuli and the opposite results for the prototypical stimuli should result). However, as the interactions with the corresponding factor View
If our patients with personal neglect systematically misinterpreted contralesional representations, as postulated in the representational space representation. This suggests a general dysfunction in contralesional representations, as postulated in the representational hypothesis of Bisiach and colleagues (Bisiach & Berti, 1995; Bisiach & Rusconi, 1990; Bisiach & Vallar, 2000). From our results it seems as if our patients with personal neglect systematically misinterpreted left body and left extrapersonal space stimuli as right ones. As a possible explanation for this behaviour, we suggest that patients with personal neglect suffer from a deficit known as “allochiria”. Allotosis is described as a deficit in which stimuli belonging to one side of the body or space are interpreted as occurring on (or belonging to) the other side. This deficit was first described by Obersteiner (1882) for the tactile modality. He had observed this “confusion of sides” (p. 153) in patients with spinal cord injury and hysteria during tactile stimulation: these patients were reason-ably capable of localizing the place where they were touched with the exception of the body side, despite more or less intact tactile sensibility. Later, in the context of hemispatial neglect, allocorhia was interpreted as a unilateral disorder in which contralesional stimuli of different modalities were interpreted as occurring ipsileSIONally (Halligan, Marshall, & Wade, 1992). With regard to this, Joanne and Brouchen (1984) observed that visual stimuli presented in the left hemifield of neglect patients were interpreted as emerging in the right hemifield. Additionally, Bisiach, Capitani, Luzzati, and Perani (1984) noted that some patients describing a visual scene from imagery reported objects on the neglected side as being present on the intact side. Hereby attention was drawn to the occurrence of “these transpositions” in purely “imaginary tasks. The mechanism proposed for this was a defect in neural mechanisms and structures processing incoming sensory stimuli. It was assumed that due to brain damage contralesional stimuli were not processed by the corresponding brain side. Instead they were assigned to the ipsilesional side, resulting in a conscious misconstrue-pretation of a contralesional stimulus as occurring ipsilesionally (Bisiach & Berti, 1995). Or as Brain (1941) wrote: “It appears that severe damage to the body scheme for one half of the body causes events occurring on that half, if perceived at all, to be related in con-sciousness to the surviving scheme representing the normal half” (p. 265). Other authors suggested that not only the contralesional but also the ipsilesional body side is defective (Mijovic, 1991). They proposed that ipsilesonal representations become more “receptive” (p. 1589) to contralesional stimuli, resulting in left stimuli being accepted as fitting the right mental representation (Mijovic, 1991). This could again explain why patients with left personal neglect identify a left hand as a right hand without realizing the mismatch between the perceived left and the mentally represented right hand.

Nevertheless, one might wonder why it is that performance for both body- and non-body stimuli (i.e., hands and rear-view mirrors) is impaired and why the hand task is not more difficult for patients with personal neglect, especially since we assume that a body representation disorder is the underlying cause. There are several possible explanations for these observations: firstly, our results could be attributed to the mirror task being more difficult per se, even in control subjects as the results (main effect of Stimulus combined with absence of significant interaction between Stim-

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(Side × View, Group × Side × View, etc.) were non-significant, this...`
Although personal and extrapersonal neglect are closely related, the results of this study support the view that both forms of neglect are independent disorders that can have distinct underlying causal mechanisms. Personal neglect should therefore be assessed separately from extrapersonal neglect.

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