

# A disengagement deficit in representational space

Tobias Loetscher\*, Peter Brugger

*Department of Neurology, Unit of Neuropsychology, University Hospital Zurich, CH-8091 Zurich, Switzerland*

Received 13 April 2006; received in revised form 26 September 2006; accepted 27 September 2006

Available online 3 November 2006

## Abstract

Some patients with hemispatial neglect show a deficit of “disengagement”, i.e., their left-sided inattention is largely a consequence of an inability to move the spotlight of attention away from right-sided stimuli. We report a neglect patient with a failure of disengagement in imagined space, a feature not previously described. The patient was repeatedly moved along a hallway and had to memorize 20 objects placed alongside the walls (alternating starting points). Each learning run was followed by a recall run, in which objects had to be named in their correct sequence from one imaginary starting point. Initially, when performance was still poor, only right-sided items were named, a response pattern mimicking a neglect of representational space. However, as recall improved over successive runs, left-sided objects were as well memorized as right-sided, but the latter were named before the former. By contrast, if photographs of single objects were presented in the center of a screen for laterality decisions, neither accuracy nor latency of the patient’s decisions differentiated between left-sided and right-sided items. We interpret the sticking to the right side during initial periods of free recall, in the absence of side-differences during cued recognition, as a failure to disengage from the right side of a mental image. In view of the extensive cortical and subcortical lesions in our patient the current debate about the functional neuroanatomy of this deficit cannot be resolved. However, the present report adds to our understanding of the heterogeneous nature of deficiencies in the representation of space.

© 2006 Elsevier Ltd. All rights reserved.

*Keywords:* Spatial learning; Neglect; Mental imagery; Single case; Visuo-spatial randomization

## 1. Introduction

Perceptual, motor and attentional functions are affected to varying degrees in individuals with hemispatial neglect (see Kerkhoff, 2001 for a review). Posner, Walker, Friedrich, and Rafal (1984) suggested that patients with right-sided parietal lesions have a specific deficit in disengaging attention from ipsilesional (right-sided) stimuli, once directed to the right side. This hypothesis derived from a simple visual orienting paradigm that required the detection of a lateralized target after a centrally presented spatial cue. This cue was an arrow, pointing either in the direction of the upcoming target (valid cueing) or in the opposite direction (invalid cueing). Patients’ reaction times (RTs) were markedly prolonged in one particular condition, i.e., to left-sided targets after a right-pointing arrow. Thus, after their attention was directed to the right side, it seemed to stick to that side. The authors argued that the failure to switch attention

from the ipsilesional to the contralesional side would be crucially mediated by the parietal lobes, and later studies indicated a causal relationship between the magnitude of this disengagement deficit and the severity of hemispatial neglect (Bartolomeo, Sieroff, Decaix, & Chokron, 2001; Morrow & Ratcliff, 1988).

A simple clock drawing task may serve to demonstrate a disengagement deficit in clinical settings. Di Pellegrino (1995) reported a patient with a severe visuo-spatial neglect, who drew a clock face with left-sided numbers transposed to the right side of the dial. However, when the numbers 1–12 had to be drawn each on separate outlines of a clock face, number location was precise, and there was no transposition. Thus, as long as no right-sided visual stimuli were capturing the patient’s attention, he could well orient toward the left side of the clockface. A similar observation was communicated by Mark, Kooistra, and Heilman (1988), who used a particularly clever design to monitor the process of disengagement. These authors administered two versions of a cancellation task to patients with left hemispatial neglect. The first version was a traditional cancellation test in which the patients had to mark each stimulus line on a

\* Corresponding author. Tel.: +41 1255 5579; fax: +41 1255 4429.  
E-mail address: tobias.loetscher@usz.ch (T. Loetscher).

sheet with a pencil. In the second version they had to erase the stimuli instead of highlighting them with a mark. Performance was significantly better in the line erasing compared to the line marking task, indicating that the mere presence of right-sided visual stimuli appeared to induce, or at least exaggerate, left-sided neglect. Disengagement effects have been documented by still other research groups and by a variety of different methods (Losier & Klein, 2001; Robertson & North, 1993), all confined, however, to uncover disengagement from visual stimuli in physical space. We report here a patient with neglect in physical and imaginal space, who evidenced a disengagement deficit in both spatial exploration and representation.

## 2. Methods

The patient was evaluated within the first days after stroke (acute phase) and once again 5 months after (retest). We designed two tasks to test for a disengagement deficit in physical and representational, respectively, space. A third task tested the patient's left/right decisions to centrally presented photographs of the previously lateralized objects. The patient was highly motivated and provided written informed consent to be further tested outside a clinical framework.

### 2.1. Patient history

A.S. is a 63-year-old right-handed general practitioner, who was hospitalized after sudden weakness on the left side of the body. On admission, neurological signs included a left-sided sensorimotor hemisyndrome (NIHSS Score of 12; Brott et al., 1989) with extinction and an initial anosognosia for the paresis of the left hand. There was a homonymous hemianopia to the left. MRI showed multiple extensive, right hemispheric ischemias in the areas subserved by the internal carotid artery, the posterior cerebral artery, the posterior inferior cerebellar artery, and the anterior inferior cerebellar artery. Neuropsychological examination 3 days after admission revealed normal orientation to time, place, person and situation including full insight into his motor deficit. Most dominant was a left-sided hemispatial neglect. Spontaneous orientation of head and gaze was constantly deviated to the right; only on command did the patient orient to the left side. There was a tactile, auditory, and visual extinction on bilateral stimulation in the respective modalities. A.S. showed a moderate personal neglect (Bisiach, Perani, Vallar, & Berti, 1986) with closed, but not with open eyes. Lines of 16 cm were bisected far to the right of the true center (mean bisection at 13.6 cm from the left). Line bisection in far space (Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) was as much impaired as that in near space. When copying a simple multi-object scene (adapted from Ogden, 1985), the patient neglected objects on the left half of the sheet as well as the left part of most objects on the right side of the sheet. When he had to imagine walking through a street of his hometown from two opposite vantage points he named more right-sided than left-sided objects (27 versus 18). A repetition of this task with a different street gave similar results (32 right versus 25 left). Mental imagery without spatial components (e.g., descriptions of objects or faces), as well as spelling (Caramazza & Hillis, 1990) was intact. Other neuropsychological findings were normal, except of a mildly impaired fluency (figural and verbal) and a diminished memory for figural information. There were no visual agnosias and no signs of any language impairments or apraxia.

A retest was performed 5 months after stroke. At this point, A.S. was still handicapped by a mild left hand paresis with difficulties in fine motor manipulations. Apart from a rapid exhaustion during mental and physical activities, he did not forward any complaints. A marked improvement of all signs of hemispatial neglect was obvious. Head and gaze were no longer deviated to the left, and there was no bilateral extinction phenomenon in any modality. A cancellation task (Gauthier, Dehaut, & Joannette, 1989) revealed a diminished error control, but there were no signs of neglect (totally seven omissions, three on the left and four on the right side). The patient named slightly more left-sided than right-sided objects (20 versus 17), when he had to imagine walking along a street of his hometown (same as in acute phase testing). There were no omissions when

copying a scene. However, the left side of the drawing was slightly enlarged, the right side compressed. This indicated, together with discrete but consistent right-sided deviations in line bisection the persistence of some residual, very discrete hemispatial neglect.

### 2.2. Stars-in-the-sky task

As the patient was hemianopic, we could not test for presence of disengagement with the Posner task (Posner et al., 1984) or an equivalent divided visual field task. Also, drawing of a clockface was flawless both with eyes open and closed, and clock-drawing could therefore not be used as a test of disengagement (Anderson, 1993; Di Pellegrino, 1995). Hence we designed a computerized task that requires repeated pointing to random locations on a screen, the "stars-in-the-sky task". Specifically, the patient had to conceive of the black screen (Elo Entuitive 1725L Touchmonitor) as the night sky and to indicate the location of the stars "as they are randomly distributed over the sky". This was done by repeated touches onto the screen with the index finger of the right hand. It was emphasized that no attempts to reproduce particular Zodiac sign should be made. Pointing was at a rate of approximately two stars per second.

Importantly, there were two conditions. In the first condition (baseline), no sensory feedback was given to the patient, i.e., the stars put onto the sky remained invisible. In the second condition, any touch at a certain location would immediately "illuminate" a star (39 on 22 pixels) at the respective location, and once illuminated each star would remain visible for the rest of the task.

A.S. was seated upright in a height-adjustable chair with the center of the touch screen aligned to the midsagittal plane. Viewing distance was approx. 50 cm; eye and head movements were unconstrained. Each condition required the placement of 40 stars, whose *x*- and *y*-coordinates were recorded and whose distance (in pixels) from the vertical midline of the screen was calculated (negative values represent leftward, positive rightward deviations).

### 2.3. Spatial learning task

Classical representational tasks as descriptions of familiar surroundings from memory have the disadvantage that they can, at least partly, be accomplished by means other than visual imagery, for example by accessing long-term or semantic memory (e.g., Bartolomeo, Bachoud-Levi, Azouvi, & Chokron, 2005; Meador, Loring, Bowers, & Heilman, 1987). Trying to minimize this possibility, we developed a spatial learning task.

In this task the patient had to learn and later recall the positions and the sequence of spatially arranged objects while being moved along a clinic hallway (length 25 m, width 2.5 m). 20 different objects were placed on small tables below eye level along the hallway with two starting points (A and B) at its ends (Fig. 2). Objects were arranged in groups of three, alternating on the right and left hand side with one object on each side at starting position A. There were thus 20 objects in total, 10 on each side. Examples of displayed objects comprise an umbrella, a bottle, a coat-hanger and a large-size die (see Fig. 2 for pictograms and constant location of all objects).

Starting points for consecutive runs were counterbalanced according to an ABBA block design. Each block comprised a learning and an immediate recall phase. In the learning phase, A.S. was seated in a wheelchair and was pushed down the hallway and up again, so that each object was once on the left and once on the right side during encoding. All objects were thus equally often presented to the patient's left as to his right during each of the four learning phases. He was instructed to learn the exact position of the objects in the hallway.

In the recall phase, A.S. was blindfolded. He had to name the objects he thought he was passing while being again pushed along the hallway from the starting point to the point at the opposite end of the hallway and back to the start point. Special care was taken to push the wheelchair with a constant velocity, which was the same in both learning and recall phase. There were no constraints for eye or head movements. The rank orders as well as the side of the named objects were recorded.

### 2.4. Single object recognition task

Following the last spatial learning and recall block photographs of all objects were presented, one by one in a randomized order, in the center of a computer

screen (horizontal and vertical stimulus extension approx. 9.9 and 7.5 cm, respectively, exposure duration determined by the patient's response latency). A.S. had to decide by keypress whether the object had been located on the left or right side of the hallway in the previously learned spatial arrangement. There were 4 runs with alternating starting points (ABBA design), and before each run A.S. was told the direction in the hallway he had to mentally evoke (starting point A or B). Thus, each single object had to be imagined twice on the left and twice on the right side, totaling in 80 trials (20 trials per run). It is important to note that during one of these recognition runs an object was either left-sided or right-sided. This is in contrast to the spatial learning task where, each block comprised both a left-sided and a right-sided exposure.

The patient was seated with the center of the laptop screen aligned to the midsagittal plane, and there were no restrictions of eye or head movements. Right hand forced-choice responses were collected with two vertically arranged response keys, one designating "left", the other "right". No time limit was imposed. Accuracy and RT of each response were recorded.

### 3. Results

#### 3.1. Stars-in-the-sky task

In the acute session, one sample *t*-tests revealed that in both feedback and non-feedback conditions the stars were placed significantly to the right of the screen midline (without feedback:  $t = 6.3$ , *d.f.* = 39,  $p < 0.0001$ ; with feedback:  $t = 10.7$ , *d.f.* = 39,  $p < 0.0001$ ). Importantly, the right-side displacement was significantly larger in the feedback than in the non-feedback condition (paired *t*-test,  $t = -2.1$ , *d.f.* = 39,  $p < 0.05$ ).

In the retest session, a comparable number of stars was placed on the right and the left side of the screen (one sample *t*-test; without feedback:  $t = 1.2$ , *d.f.* = 39,  $p = 0.3$ ; with feedback:  $t = 0.7$ , *d.f.* = 39,  $p = 0.5$ ). There was no difference between the two feedback conditions with respect to the horizontal deviation from the screen midline (paired *t*-test,  $t = 0.2$ , *d.f.* = 39,  $p = 0.8$ ). See Fig. 1 for a summary of these results.

#### 3.2. Spatial learning task

A graphical overview of the results in the spatial learning task is provided in Fig. 2. A.S. named significantly more right-sided than left-sided objects in the first block of the acute session (one left, seven right; Chi-square = 4.5,  $p < 0.05$ ). However, in all other blocks (acute and retest session) no significant side-differences regarding the number of named objects was found (cumulated answers in acute session: 46 left, 54 right, Chi-square = 0.6,  $p = 0.4$ ; cumulated answers in retest session: 65 left, 67 right, Chi-square = 0.03,  $p = 0.9$ ).

There was a marked clustering of same-side responses in the acute session (Fig. 2) indicating a lack of side switching. For example, in block 2 there was no side-difference in the number of items recalled, however all right-sided objects were specified first, and only after that left-sided objects were named. Although switching was more frequent in the following blocks, there was still a serial clustering of right-side responses, notably at the beginning of a block. Fig. 2 also illustrates that, in the retest session, the patient's ability to switch between right-sided and left-sided items had markedly improved (number of switches: 16 in acute session, 46 in retest session, Chi-square = 14.5,  $p < 0.001$ ).

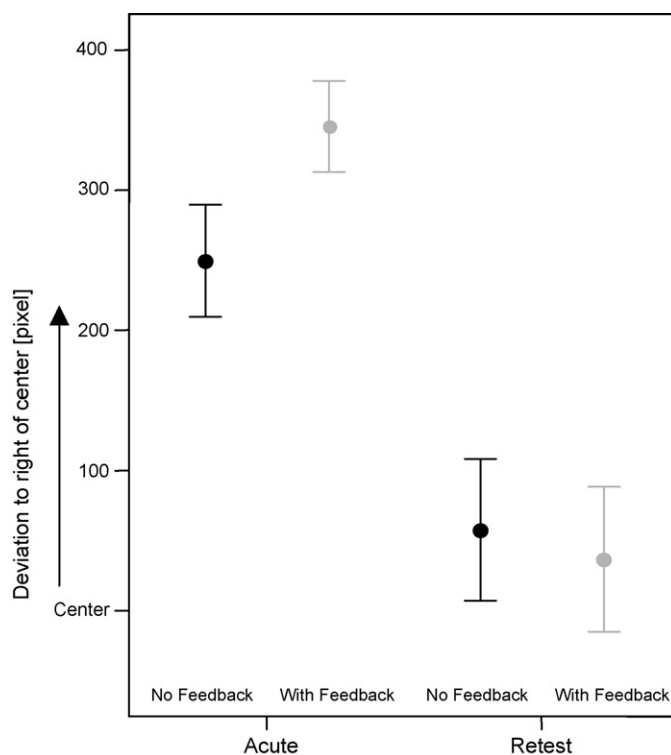


Fig. 1. Stars-in-the-sky task. Mean horizontal deviations ( $\pm$  standard errors) from the center of the screen for the two feedback conditions and the two examination sessions (acute phase and retest).

#### 3.3. Single object recognition task

Four extreme values exceeding three times the interquartile range were excluded. Two of these values were in response to left-sided, two to right-sided stimuli.

Mean RTs (Fig. 3) to photographs depicting left-sided and right-sided objects were compared with one another with a paired *t*-test (e.g., RTs to "umbrella" from imagined start point A to the RTs to "umbrella" from imagined start point B), which revealed neither a side-difference in the acute session ( $t = -0.6$ ; *d.f.* = 15;  $p = 0.6$ ) nor in the retest examination ( $t = -0.5$ ; *d.f.* = 17;  $p = 0.6$ ). There was also no significant side effect within each of the four single runs.

Irrespective of an object's placement in space, A.S. was significantly faster in the retest session than in the acute phase ( $t = 2.3$ ; *d.f.* = 36;  $p < 0.05$ ), but he made numerically more errors (errors in acute phase: 7 (2+2+1+2) to left-sided, 5 (3+1+1+0) to right-sided objects in the 4 consecutive runs; errors in retest session: 9 (0+1+6+2) to left-sided, 10 (1+1+6+2) to right-sided objects in the 4 consecutive runs). Thus, there was no disengagement deficit in this task, in the sense that the patient exhibited no lack of side switching in his key press responses.

### 4. Discussion

In this single-case study we showed that a deficit of disengagement in physical space may be accompanied by a similar

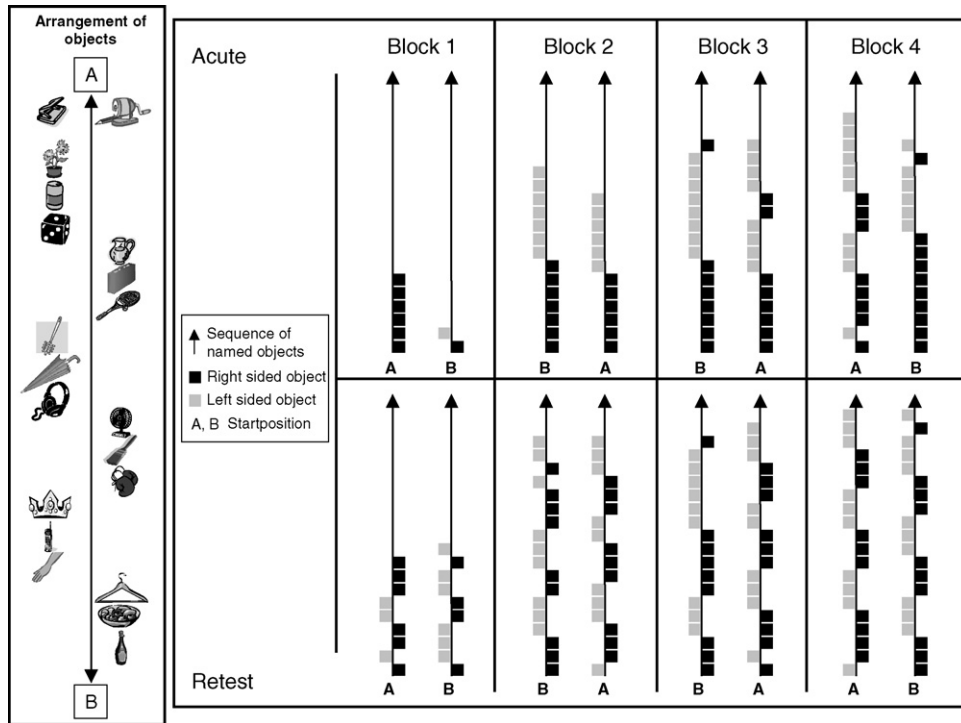


Fig. 2. Spatial learning task. Left panel: Identity of the 20 objects and their fix position along the hallway with starting points A and B. Right panel: Results of the four blocks in the acute phase (above) and retest session (below). For each block the starting point and the sequence of the named objects are shown, black squares denote a right-sided object, grey squares a left-sided object. For example, in the second block of the acute phase, starting from point B the patient first named seven right-sided and then seven left-sided objects.

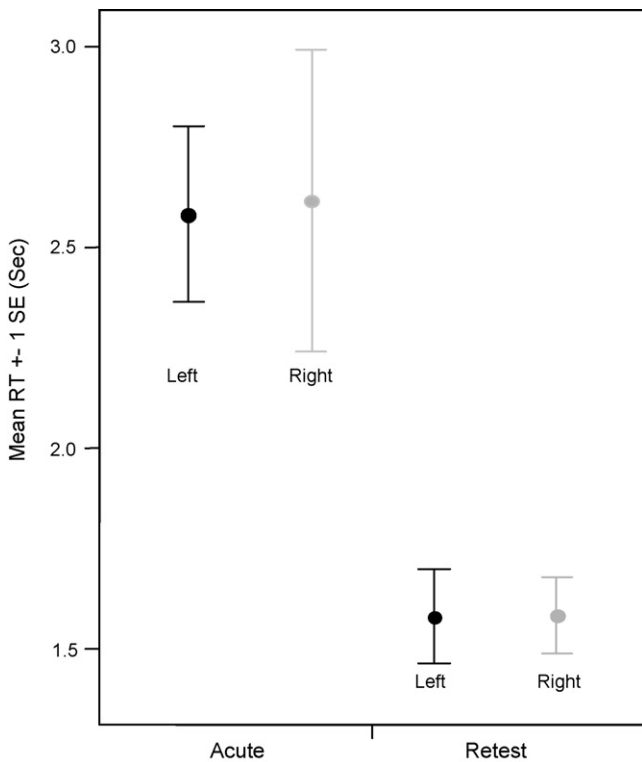


Fig. 3. Single object recognition task. Mean RTs ( $\pm$  standard errors) of correct responses to centrally presented photographs depicting objects left or right-sided with respect to a given perspective in the previous spatial learning task.

deficit also in representational space. The patient's disengagement deficit was quantified here in a task requiring the randomization of spatial locations, in which he was strongly attracted by right-sided visual stimuli. Removal of these stimuli led to a significant improvement of the patient's explorative behavior in the left hemifield. Likewise, his neglect in representational space (clinically evident in descriptions of geographical locations or scenes from memory) appeared to be due to an exaggerated attention towards items associated with the right side of space. This was assessed by a spatial learning task, in which the position and sequence of spatially arranged objects had to be learned. Overall, there were no side-differences in the number of recalled objects from memory. However, such differences became apparent when looking at qualitative characteristics, i.e., the temporal order, of the patient's recall. The patient constantly named right-sided before left-sided objects, producing long clusters of the former items. A comparable strategy had never been observed in any healthy subject during informal testing. While this lack of switching between preferred and non-preferred sides could be taken as a sign of perseveration in the presence of frontal lobe damage, we interpret it as a deficit of disengagement. Had we stopped recall after the first block, the data would simply have pointed to the presence of a neglect in representational space (Fig. 2). Only repeated testing revealed a pattern more commensurate with a disengagement deficit. One advantage of the present task over more conventional scene description or geographical fluency tasks may thus be its potential to uncover attentional mechanisms that evolve over time.



Subsequent to the spatial learning task, the patient was presented with photographs of the objects previously associated with either the left or the right side of space. These were exposed one after the other centrally on a computer screen. The patient was required to indicate by key press the left/right location of the respective object, and the results revealed no side-differences with respect to speed or accuracy. These findings cannot be explained by a generally degraded representation of the left hemispace in neglect (Bisiach, Capitani, Luzzatti, & Perani, 1981; Bisiach & Luzzatti, 1978). According to this view, the performance in this single object recognition task should have been significantly worse for left-sided than for right-sided objects, but this was clearly not the case. We rather suggest a disengagement deficit that comprises several steps. First, in the spatial learning task, an early rightward orientation biased the patient to the initial naming of items associated with the right side of a mental image, much like this was previously shown for scan paths in physical space (De Renzi, Gentilini, Faglioni, & Barbieri, 1989; Gainotti, D'Erme, & Bartolomeo, 1991). Similar orientational biases were previously discussed by (Bartolomeo, D'Erme, & Gainotti, 1994) in connection with the representation of space. Subsequently, on top of this initial exploration asymmetry, a disengagement deficit as hitherto only described in physical space became apparent (see Introduction). The patient seemed to continuously keep his inner eye directed towards the right, a sticking tendency that could not manifest itself in the single-object recognition task in which the patient was repeatedly cued with objects associated with the left side of space. This is reminiscent of classical cuing effects in tests of hemispatial neglect (e.g., Riddoch & Humphreys, 1983). The fact that, in the retest sessions, quantitative and qualitative deficits in the exploration of both real and imaginal space had improved to a comparable degree presents further evidence for a similarity of underlying mechanisms.

Our patient showed multiple extensive right hemispheric ischemias, involving frontal, temporal, parietal and several sub-cortical regions. Thus, the present study can not help pinpoint the critical region for the manifestation of a disengagement deficit, i.e., whether it is the superior parietal lobe (Posner et al., 1984) or rather the temporo-parietal junction (Friedrich, Egly, Rafal, & Beck, 1998). It can also not rule out the involvement of frontal lobe regions, which have been reported to selectively participate in orienting attention within online mental representations (Nobre et al., 2004). Hence, the current debate about the functional neuroanatomy of disengagement (addressed, for instance, in Husain & Rorden, 2003; Losier & Klein, 2001) awaits to be resolved.

In opposition to the disengagement hypothesis are the results reported by Wojciulik, Husain, Clarke, and Driver (2001) and Wojciulik, Rorden, Clarke, Husain, and Driver (2004). These authors used a cancellation task quite similar to the one described in the introduction (Mark et al., 1988). Specifically, one condition required neglect patients to mark targets with a thick red marker (visible condition), while in another condition the targets had to be marked with the cap on the marker (invisible condition, cancellation responses recorded with a carbon paper underneath). Patients' performance was better in the visible than the invisible condition, a result in striking contrast to what would

have been predicted by the disengagement theory. The authors interpreted the observed performance pattern as the consequence of a spatial working memory deficit. In the invisible cancellation conditions patients may have failed to remember which targets they already marked, and as a result returned repeatedly to right-sided items. On the other hand, continuous target visibility in the other condition may have reduced neglect by removing memory load. However, this interpretation cannot account for the results of those tasks described in the introduction (Di Pellegrino, 1995; Mark et al., 1988) nor for the present findings in our own patient. Perhaps spatial working memory requirements are of minor importance in these tasks than in the task by Wojciulik et al. In fact, when the marked stimuli disappear (as in Mark et al., 1988) less spatial memory capacity is needed compared to the situation when no visible information is available, whether the stimuli were already cancelled or not (as in Wojciulik et al. (2004). Thus, two different aspects of the neglect syndrome may have been assessed with these tasks, and these aspects may have been present in both study groups, albeit to varying degrees. In an attempt to disentangle different components of neglect, future work should provide both cancellation tasks to the same patients.

Bartolomeo et al. (2005) recently developed an elegant task to quantify imaginal neglect. In this task patients had to state whether auditorily presented towns or regions were situated to the left or right side of Paris on an imagined map of France. Neglect patients were equally accurate for both sides; however, they were significantly slower for locations to be imagined on the left than for those to be imagined on the right. Analyses of individual data revealed, however, that this side-difference was present in only two out of seven patients and could be confidently attributed to an imaginal impairment and not to a response bias. It is speculative to compare the performances of these two patients with A.S.'s performance, since none of these two evidenced a reliable side asymmetry in a fluency task, and no information about a possible disengagement deficit is available. However, looking at the performance pattern of all three patients, it is very likely that different mechanisms may contribute to representational neglect, as this is reportedly the case in the exploration of physical space. A future challenge is certainly to characterize different mechanisms in imaginal space and to provide methods that quantify them best.

In conclusion, the presence of a disengagement deficit in representational space, if confirmed in future group studies employing different methodologies, would certainly emphasize once more the strong links between visual perception and imagination. At the same time, it would add to our present understanding of the heterogeneous nature of deficiencies in the representation of space. These may in some cases reflect a failure to encode, store or activate left-sided visuospatial memories, but in others primarily an inability to suppress competing information about right-sided items.

### Acknowledgements

This study was in part supported by a grant from the Betty and David Koetser Foundation to P.B. Preliminary results were

presented at the 24th European Workshop on Cognitive Neuropsychology, Bressanone, Italy (January 22–27, 2006). We would like to thank A.S. for his highly motivated cooperation.

## References

- Anderson, B. (1993). Spared awareness for the left side of internal visual images in patients with left-sided extrapersonal neglect. *Neurology*, *43*(1), 213–216.
- Bartolomeo, P., Bachoud-Levi, A. C., Azouvi, P., & Chokron, S. (2005). Time to imagine space: A chronometric exploration of representational neglect. *Neuropsychologia*, *43*(9), 1249–1257.
- Bartolomeo, P., D'Erme, P., & Gainotti, G. (1994). The relationship between visuospatial and representational neglect. *Neurology*, *44*(9), 1710–1714.
- Bartolomeo, P., Sieroff, E., Decaix, C., & Chokron, S. (2001). Modulating the attentional bias in unilateral neglect: The effects of the strategic set. *Experimental Brain Research*, *137*(3–4), 432–444.
- Bisiach, E., Capitani, E., Luzzatti, C., & Perani, D. (1981). Brain and conscious representation of outside reality. *Neuropsychologia*, *19*(4), 543–551.
- Bisiach, E., & Luzzatti, C. (1978). Unilateral neglect of representational space. *Cortex*, *14*(1), 129–133.
- Bisiach, E., Perani, D., Vallar, G., & Berti, A. (1986). Unilateral neglect: Personal and extra-personal. *Neuropsychologia*, *24*(6), 759–767.
- Brott, T., Adams, H. P., Jr., Olinger, C. P., Marler, J. R., Barsan, W. G., Biller, J., et al. (1989). Measurements of acute cerebral infarction: A clinical examination scale. *Stroke*, *20*(1), 864–870.
- Caramazza, A., & Hillis, A. E. (1990). Spatial representation of words in the brain implied by studies of a unilateral neglect patient. *Nature*, *346*(6281), 267–269.
- De Renzi, E., Gentilini, M., Faglioni, P., & Barbieri, C. (1989). Attentional shift towards the rightmost stimuli in patients with left visual neglect. *Cortex*, *25*(2), 231–237.
- Di Pellegrino, G. (1995). Clock-drawing in a case of left visuo-spatial neglect: A deficit of disengagement? *Neuropsychologia*, *33*(3), 353–358.
- Friedrich, F. J., Egly, R., Rafal, R. D., & Beck, D. (1998). Spatial attention deficits in humans: A comparison of superior parietal and temporal-parietal junction lesions. *Neuropsychology*, *12*(2), 193–207.
- Gainotti, G., D'Erme, P., & Bartolomeo, P. (1991). Early orientation of attention toward the half space ipsilateral to the lesion in patients with unilateral brain damage. *Journal of Neurology, Neurosurgery & Psychiatry*, *54*(12), 1082–1089.
- Gauthier, L., Dehaut, F., & Joannette, Y. (1989). The bells test—A quantitative and qualitative test for visual neglect. *International Journal of Clinical Neuropsychology*, *11*(2), 49–54.
- Husain, M., & Rorden, C. (2003). Non-spatially lateralized mechanisms in hemispatial neglect. *Nature Reviews Neuroscience*, *4*(1), 26–36.
- Kerkhoff, G. (2001). Spatial hemineglect in humans. *Progress in Neurobiology*, *63*(1), 1–27.
- Losier, B. J., & Klein, R. M. (2001). A review of the evidence for a disengagement deficit following parietal lobe damage. *Neuroscience & Biobehavioral Reviews*, *25*(1), 1–13.
- Mark, V. W., Kooistra, C. A., & Heilman, K. M. (1988). Hemispatial neglect affected by non-neglected stimuli. *Neurology*, *38*(8), 1207–1211.
- Meador, K. J., Loring, D. W., Bowers, D., & Heilman, K. M. (1987). Remote memory and neglect syndrome. *Neurology*, *37*(3), 522–526.
- Morrow, L. A., & Ratcliff, G. (1988). The disengagement of covert attention and the neglect syndrome. *Psychobiology*, *16*(3), 261–269.
- Nobre, A. C., Coull, J. T., Maquet, P., Frith, C. D., Vandenberghe, R., & Mesulam, M. M. (2004). Orienting attention to locations in perceptual versus mental representations. *Journal of Cognitive Neuroscience*, *16*(3), 363–373.
- Ogden, J. A. (1985). Anterior-posterior interhemispheric differences in the loci of lesions producing visual hemineglect. *Brain & Cognition*, *4*(1), 59–75.
- Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience*, *4*(7), 1863–1874.
- Riddoch, M. J., & Humphreys, G. W. (1983). The effect of cueing on unilateral neglect. *Neuropsychologia*, *21*(6), 589–599.
- Robertson, I. H., & North, N. (1993). Fatigue versus disengagement in unilateral neglect. *Journal of Neurology, Neurosurgery & Psychiatry*, *56*(6), 717–719.
- Vuilleumier, P., Valenza, N., Mayer, E., Reverdin, A., & Landis, T. (1998). Near and far visual space in unilateral neglect. *Annals of Neurology*, *43*(3), 406–410.
- Wojciulik, E., Husain, M., Clarke, K., & Driver, J. (2001). Spatial working memory deficit in unilateral neglect. *Neuropsychologia*, *39*(4), 390–396.
- Wojciulik, E., Rorden, C., Clarke, K., Husain, M., & Driver, J. (2004). Group study of an “undercover” test for visuospatial neglect: Invisible cancellation can reveal more neglect than standard cancellation. *Journal of Neurology, Neurosurgery & Psychiatry*, *75*(9), 1356–1358.