Hemineglect

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Hemineglect, also known as unilateral neglect, hemispatial neglect or spatial neglect, is a common and disabling condition following brain damage in which patients fail to be aware of items to one side of space. Neglect is most prominent and long-lasting after damage to the *right hemisphere* of the human brain, particularly following a stroke. Such individuals with right-sided brain damage often fail to be aware of objects to their left, demonstrating neglect of leftward items.

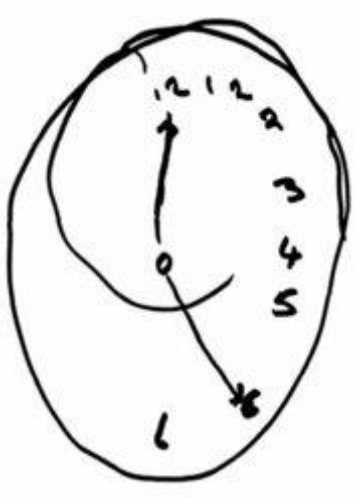

Figure 1: Drawing of a clock by a patient with left-sided neglect.

The deficit may be so profound that patients are unaware of large objects, even people, towards their neglected or *contralesional* side - the side of space opposite brain damage. They may eat from only one side of a plate, write on one side of a page, shave or make-up only the non-neglected or *ipsilesional* side of their face (same side as brain damage). Their drawings may fail to include items towards the neglected side, for example when placing the numbers in a drawing of a clock (Fig.1). Many patients are often also unaware they have a deficit (anosognosia).

Classically, the neglect syndrome has been associated with damage to the *right posterior parietal cortex*. More recent studies have begun to challenge this view, suggesting instead that a more widespread network of areas may be involved, including those that have been implicated in studies of neuroimaging of attention (discussed further in

the Neuroanatomy of neglect below; see also Corbetta & Shulman, 2002 and Husain and Rorden, 2003). Differences in the location and extent of lesions (brain damage) across patients may contribute to the heterogeneity of the condition.

Primary sensory and motor representations may be intact in neglect

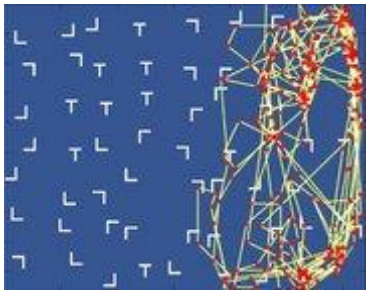

Figure 2: Eye movementsduring visual search in an individual with left-sided neglect attempting to find letter Ts among Ls. Red dots show fixations and yellow lines depict saccadic eye movements from one fixation to another.

Individuals with neglect do not necessarily suffer from any primary disorder of sensation or movement. For example, their visual fields may be completely intact. So they may be able to detect a salient, bright item on their neglected side if it is flashed on a dark background. But even though they may not be blind, patients may fail to report the same stimulus if it is presented in a cluttered background. People with neglect may also have no weakness of their eye or limb muscles, yet fail to direct their gaze or hands to explore contralesional space (e.g., Behrmann et al., 1997; Husain et al., 2001). Their visual search may, instead, be directed only towards items to their ipsilesional side (Fig.2).

Neglect may be multimodal, extending to involve visual, auditory and somatosensory systems. It may also affect memories of scenes - so-called *representational neglect*. In their famous experiment, Bisiach and Luzzatti (1978) asked patients with left-sided visual neglect from Milan to imagine viewing the central square, the Piazza del Duomo, from the cathedral in the centre of the square. They reported that these patients often omitted to mention places or streets off to the left side of the square *from that viewpoint*. However, when asked to imagine looking directly at the cathedral, i.e., shifting their viewpoint by 180 degrees, the same individuals now neglected to mention places on the side of the square they had just reported - ones which now fell to their left from the new imagined point of view. Instead, they now recalled places to the right of the new imagined vantage point.

A gradient of neglect

Importantly, the border between neglected space and non-neglected space is:

- *not* sharp and absolute as in a primary visual field deficit such as hemianopia

- and does *not* necessarily respect (align with) the vertical midline or meridian (Fig. 3).

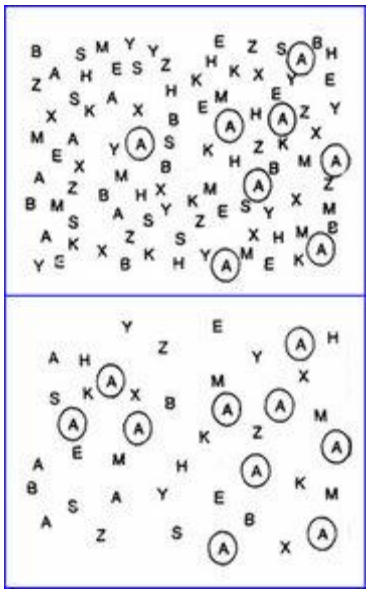

Figure 3: Number of target items found (circled As) on a visual search or cancellation task may vary with the number of distractor items in the array (adapted from Kaplan et al., 1991).

The probability of reporting items varies in many patients (e.g., Kaplan et al., 1991; Smania et al., 1998; Chatterjee et al., 1999):

- with the highest probability being on the ipsilesional side (right side for right brain-damaged patients) and the lowest on the contralesional / neglected side (left side for right-hemisphere patients)
- with the degree of clutter in the visual environment - the greater the number of distractor or non-target items on the ipsilesional side, the greater the neglect of items on the contralesional side (Fig. 3).

Unconscious or implicit processing of neglected information

Several studies have revealed that even though a stimulus to the neglected side of space may fail to be reported, it may nevertheless be processed to a substantial degree - to the level of its identity or meaning (Berti and Rizzolatti, 1992). The most striking examples come from investigations of *semantic priming* (e.g., McGlinchey-Berroth et al., 1993). In one experiment, stimuli to the left which were unreported (neglected) by the patient, nevertheless speeded subsequent responses to a word if it was semantically related to the neglected item (e.g., tree and apple) compared to if it was unrelated (e.g., bed and apple). Another study showed a patient pictures of an undamaged house and one burning with the flames on the left side of the house

(Marshall & Halligan, 1988). When asked which house they would prefer to live in, a patient with left-sided neglect, who did not report seeing the flames of the burning house, nevertheless chose the undamaged house significantly more often. Note that the level to which stimuli may be processed implicitly or unconsciously in neglect patients is far more substantial than that reported in individuals with blindsight who have primary visual field deficits. Functional imaging studies have demonstrated activation in intact early visual areas even when patients have no conscious awareness for visual stimuli (Rees et al., 2000; Rees 2001; Vuilleumier et al., 2001). See also sections in Attention and Consciousness.

Measuring neglect: neuropsychological tests

Neglect may be measured in various ways. Different patients may show deficits on different types of test, so there is no single test used to diagnose the condition (Azouvi et al., 2002; Parton et al., 2004). Many patients will show neglect behaviour in their everyday life when interacting with others, so observation of the patient is crucial. In addition, batteries of neuropsychological tests have been devised to capture and quantify the degree of neglect.

Most batteries include:

- Cancellation task. These are visual search tests, consisting of multiple targets, presented on a sheet of paper in front of the patient who is asked to circle or cancel out all the targets they can find (e.g. Fig. 3)
- Line bisection. The patient has to mark the midpoint of a horizontal line presented on a sheet of paper.
- Copying task. The examiner asks the patient to copy one or more line drawings.

Neuroanatomy of neglect

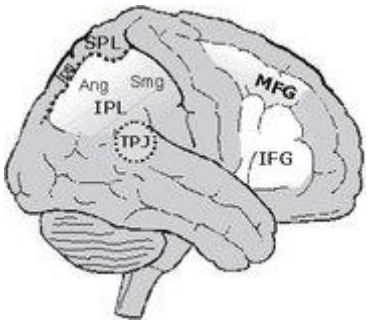

Figure 4: Right hemisphere of human brain showing some cortical areas implicated in neglect including the inferior parietal lobe (IPL) which consists of the angular (Ang) and supramarginal (Smg) gyri; the temporoparietal junction (TPJ); right inferior frontal gyrus (IFG) and middle frontal gyrus (MFG). SPL denotes superior parietal lobe while ips refers to intraparietal sulcus.

Classically, neglect has been associated with lesions of the right *posterior parietal cortex*, particularly the inferior parietal lobe (IPL) or temporoparietal junction (TPJ) (Vallar and Perani, 1986) (Fig.4).

More recently, some authors have proposed a critical association with damage to the right superior temporal gyrus (Karnath et al., 2001), though this view has been strongly challenged (Mort et al., 2003) and remains a subject of much debate and controversy (Doricchi and Tomaiuolo, 2003; Karnath et al., 2004a, 2004b; Mort et al., 2004). What is clear, however, is that there is no one single lesion location associated with the syndrome.

In addition to posterior cortical areas, most researchers agree that *subcortical lesions* (for example, involving the thalamus and basal ganglia) that do not encroach directly on the cortex can lead to neglect, although this may be via indirect effects on overlying cortical regions (Hillis et al., 2002, 2005). Moreover, it has also become evident that isolated lesions of the right *frontal lobe* may be associated with neglect, without involvement of posterior parietal or temporal regions (Husain and Kennard, 1996). Recent studies also implicate *white matter pathways*, connecting, for example, posterior cortical and frontal regions in individuals with neglect (Thiebaut de Schotten et al., 2005; Bartolomeo et al., 2007).

Different patients have different combinations of posterior cortical, frontal, subcortical and white matter damage. This heterogeneity may be a key factor determining the diversity of functional deficits reported in this condition (see Mechanisms underlying neglect).

Left hemisphere damage may also lead to neglect of rightward items, though this is usually less profound and less long-lasting than leftward neglect following right brain damage. The development of language and praxis in left posterior and frontal regions may be a reason for this hemispheric difference.

Mechanisms underlying neglect

Many different cognitive deficits have been identified in patients with neglect (Driver and Mattingley, 1998; Heilman and Watson, 2001; Halligan et al., 2003; Husain and Rorden, 2003; Mesulam, 1999). These experimental findings have led to a range of hypotheses about the

mechanisms underlying the condition. A large number of *dissociations* have been reported with some patients showing deficit A but not B, and others showing B but not A (Vallar, 1998). Many patients show combinations of deficits, but the exact combination differs across patients (Buxbaum et al., 2004).

One way to consider the mechanisms underlying the syndrome is to divide them into *spatial or directional* deficits versus *non-spatial or non-directional*ones.

Spatial or directional attention deficits

Many researchers have proposed that neglect may be due to a deficit in directing spatial attention, specifically in *disengaging attention* from ipsilesional objects and shifting it contralesionally towards the neglected side of space (for reviews see Losier & Klein, 2001 and Bartolomeo & Chokron, 2002). Such a mechanism was originally implicated in patients with visual extinction following unilateral brain damage (Posner et al., 1984). Cueing attention towards the neglected side of space can help to reduce spatial biases, for example in line bisection (Riddoch & Humphreys, 1983).

Other investigators have emphasized a spatially *lateralised bias or gradient* of attention in neglect, due to disruption of the normal balance between the hemispheres in directing attention (Kinsbourne, 1993). Thus, after right hemisphere damage, left hemisphere mechanisms which normally orient attention rightwards may be left relatively unopposed (Corbetta et al., 2005). Hence the ipsilesional bias in attention observed in patients with neglect.

Some researchers have considered the spatial attention deficit in terms of the biased competition theory of attention, with ipsilesional stimuli winning in the competition for selection over contralesional ones in neglect (Duncan et al., 1997). According to such accounts, more stimuli on the non-neglected, ipsilesional side would also hinder attention being directed toward contralesional items (see Fig. 3).

Deficits in spatial frames of reference

Several studies have shown that the degree of neglect may be modulated by the position of stimuli relative to the trunk, head, eye position and even gravitational field (e.g., Ladavas, 1987; Karnath et al., 1998). Thus different egocentric spatial reference frames appear to exert an influence on the sector of space that is neglected. Some investigators have also reported neglect for stimuli in near space or far space in different patients. All these reports have drawn inspiration from computational considerations of the transformations involved in sensorimotor control, as well as neurophysiological studies of the role of monkey posterior parietal cortex in

sensorimotor transformations and motor control (Andersen, 1997). In general, these findings support the hypothesis that there may be a deficit of spatial representation in neglect (Bisiach and Luzzatti, 1978). However, an impaired spatial representation in neglect might also be secondary to reduced attention or exploration of contralesional space.

Spatial or directional motor deficits

Evidence also exists for a deficit in directing eye or limb movements contralesionally or to targets in contralesional space in some individuals with neglect (Heilman et al., 1985; Mattingley et al., 1992). This may be a disorder of initiating movements (sometimes referred to as *directional hypokinesia*) or in slowness of movement execution (termed *directional bradykinesia*). Directional motor deficits may be modulated by locations of visual targets. One study has demonstrated slowness in initiating *leftward* movements to targets in left hemispace, but not those in right hemispace, in right parietal patients with neglect (Mattingley et al., 1998).

Spatial working memory deficits

Recent investigations have revealed that some neglect patients also have difficulty in keeping track of spatial locations across saccadic eye movements (Husain et al., 2001; Mannan et al., 2005). Such a deficit in spatial working memory appears to exacerbate any lateralised biases in these patients. The findings suggest limitations in visual short term memory, particularly for the locations of objects (Pisella et al., 2004; Malhotra et al., 2005; Ferber and Danckert 2006).

Non-spatial attention deficits

A range of techniques has been used to probe non-spatial or non-directional deficits. The attentional blink paradigm has revealed a profound and long-lasting deficit in the temporal dynamics of visual processing for stimuli presented at fixation in right-hemisphere neglect patients (Husain et al., 1997). When attention is engaged on one item, such patients have difficulty in attending to subsequent items for >1 second, even when items are presented centrally, a finding reminiscent of non-spatial extinction in parietal patients (Humpreys et al. 1994).

Bilateral deficits (i.e. on both sides of space) have also been reported in parietal patients, with reduced capacity to encode visual stimuli presented transiently in either visual field (Duncan et al., 1999; Batelli et al., 2001).

Several groups have also reported impaired ability to *sustain attention* or maintain vigilance over protracted periods of time in patients with neglect, even for central auditory stimuli (see Robertson, 2001). Others have shown that there may be a bilateral constriction of the effective

field of vision - the sector of space that can be attended to - which may lead to 'local bias' and failure to attend 'globally' to the periphery (Rafal, 1994; Russell et al., 2004). Deficits in 'global' visual processing have also been reported in non-neglect patients with right temporoparietal lesions (Robertson et al., 1988).

In the past, there has been a great deal of interest in object-based attention deficits in neglect (Driver et al., 1994; for a review, see Walker, 1995), although a pure-object centred deficit is probably extremely rare (Driver and Pouget, 2000).

Combinations of spatial/directional and non-spatial deficits appear to be present in different patients with neglect (Buxbaum et al., 2004). Moreover, some of these deficits can exist in isolation of the neglect syndrome. For example, deficits in spatial working memory or sustained attention have been documented in right-hemisphere patients without neglect. However, when combined with spatially lateralised or directional biases, these deficits can serve to exacerbate the severity of neglect (see Husain & Rorden, 2003).

Attempts to modulate or treat neglect

Several types of therapy or experimental modulation have been attempted to ameliorate neglect (for reviews see Robertson & Halligan, 1999; Barrett et al., 2006; Luate et al., 2006; Singh-Curry & Husain, 2008). These have consisted either of behavioural interventions (sometimes including the use of specialist devices) or drug treatments. The results of these studies have been variable, most likely due to heterogeneity between patients and the small numbers of individuals tested. It is unlikely that one treatment will be suitable for all patients with neglect because, as we have seen, different patients have different combinations of underlying cognitive deficit.

A related concern is that for a particular treatment to be effective it may be crucial that certain brain regions or functions are intact. For example, learning a new strategy may depend upon the integrity of prefrontal cortical regions. Patients who have large parts of such critical brain regions destroyed may not be so responsive to certain treatment approaches. Thus mapping the lesions of patients involved in trials may be important to understand variations in response to therapy.

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