Frames of Reference in Unilateral Neglect

An Investigation of Viewer-, Stimulus-, and Object-Centred Neglect in the Visual and Tactile Modalities

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DECLARATION

I, Monica Skjerve, hereby certify that the work embodied in this thesis is the result of my own original work. To the best of my knowledge, no material previously written by another person is included without due acknowledgement.

Monica Skjerve
September 2011

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Abstract

This thesis is an investigation of viewer-, stimulus, *and* object-centred neglect in both the visual and tactile modalities. The main aim was to provide experimental evidence of neglect in an object-centred frame of reference. It has been proposed that mental rotation of stimuli to upright may underlie previous findings of object-centred neglect, thus the mental rotation hypothesis of object-centred neglect was also investigated. The visual discriminative-cancellation task originally designed by Ota and colleagues (2001), and the tactile version of this task used by Marsh and Hillis (2008), were replicated with Norwegian patients with neglect. These tasks disambiguate viewer- from stimulus-centred neglect. Object-centred neglect is more difficult to disentangle since it involves neglect of the intrinsic left side of an object independently of the left side of the viewer or stimulus. Taking into account Behrmann and Moscovitch's (1994) criterion of utilising stimuli with an intrinsic left and right side to demonstrate object-centred neglect, we introduced three new tasks aimed specifically to distinguish between stimulus- and object-centred neglect. All tasks required Norwegian patients with neglect to discriminate the Norwegian letter 'Æ' (with an intrinsic left side 'A' and a right side 'E') from the letters 'A' and/or 'E'. To disambiguate viewer-, stimulus-, and object-centred neglect, the letters were presented in normal and backward parity and in eight angles of orientation. Discrimination errors were interpreted as either stimulus- or object-centred neglect, whereas omissions on the left side of the page in the letter-*cancellation* version of the task were interpreted as viewer-centred neglect. Vision was precluded in the tactile task, and patients identified tactually each of the letters ('E', 'A', 'Æ') presented individually on a small rectangular board. The results provide evidence of neglect in viewer-, stimulus-, and object-centred frames of reference in the visual modality, and they indicate that visual neglect may occur in all three frames of reference simultaneously. The results also demonstrate that neglect may operate in an object-centred frame of reference in the tactile modality. Numerous studies have investigated object-centred neglect in the visual modality, but no previous study has provided evidence of object-centred neglect in the tactile modality. A computerised version of the Norwegian letter 'Æ' task was used to answer a long-standing question in the literature about the role of mental rotation in previous findings of stimulus- and object-centred neglect. The absence of a mental rotation curve in the 'Æ' letter-identification reaction times demonstrates that the current findings cannot be explained by mental rotation of

the stimuli to upright and re-alignment of all three reference frames. The high accuracy rates demonstrated by neurologically healthy participants in all tasks also indicates that the results cannot be attributed to 'normal' biases in the identification of misoriented letters.

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SECTION 1:

FRAMES OF REFERENCE IN UNILATERAL NEGLECT: VISUAL MODALITY

Chapter 1

Frames of Reference in Unilateral Neglect: Visual Modality

Frames of Reference in Unilateral Neglect: Visual Modality

Individuals with neglect typically fail to report or orient to stimuli in the hemispace opposite to the side of their lesion, despite having intact sensory and motor capabilities. Neglect is typically more frequent and severe following damage to the right hemisphere (Vallar & Perani, 1986; but see Ogden, 1985).[1] Although neglect can occur in one or more sensory modalities, visual neglect appears to be most common, or at least the most commonly reported. An individual with left-side neglect may fail to complete the left side of drawings when attempting to copy an object, may fail to eat food on the left side of the plate, and may ignore other stimuli located to the left (Aimola Davies, 2004). The side of the body opposite the lesion may also be neglected, as evidenced by the observation that patients with neglect may groom only the right side of their face and body (Zoccolotti & Judica, 1991).

Although there is currently general agreement that neglect is caused by an attentional deficit, the exact form of this disruption remains open for investigation. One view suggests that, following lesions to the right-parietal lobe, patients may have difficulties disengaging attention from one side of space to move attention to a new location (Posner, Walker, Friedrich, & Rafal, 1984). Another view suggests that neglect arises as a consequence of reduced competition from the lesioned hemisphere, resulting in attention being distributed more optimally to one side of space. In this latter view, it was hypothesised that attentional distribution is established by the competition between hemispheric systems (Kinsbourne, 1987, 1994).

Regardless of which explanation is invoked, a central issue in the study of neglect concerns how to define the 'left' and 'right' side of what is to be neglected. Patient research has pointed to the existence of different frames of reference proposed to explain how the brain constructs representations of objects in space. These are referred to as viewer-centred, environment-centred, stimulus-centred and object-centred frames of reference.

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[1] As *persisting* left-side neglect after lesions to the right hemisphere is more common than right-side neglect following left-hemisphere damage, the current literature review will use the term neglect to refer to left-side neglect unless otherwise specified.

If spatial attention operates over a viewer-centred frame of reference, then left and right are defined relative to some landmark of the viewer, such as the retinotopic, head, or body midline. This representation is maintained irrespective of the position and orientation of the viewer with regard to objects and the environment (Farah, Brunn, Wong, Wallace, & Carpenter, 1990). The viewer-centred frame of reference is not stable, as the stimulus representations change in accordance with movements of the viewer and the stimuli. In contrast, if spatial attention operates over an environment-centred frame of reference, then left and right are defined with respect to some landmark in the environment. Furthermore, this spatial representation is maintained independently of the position and orientation of the viewer and the objects in the environment. This representation is more stable than the viewer-centred frame of reference as it does not change if the viewer moves (Farah et al., 1990). But if spatial attention operates over either a stimulus- or an object-centred frame of reference, then 'left' and 'right' are defined relative to the object itself. Thus, locations or parts of an object are represented relative to that object. The main distinction between stimulus- and object-centred neglect is that the canonical left and right of the object are maintained independently of the viewer-centred frame of reference only in an object-centred representation.[2] There is evidence to suggest that neglect can arise in one or more frames of reference simultaneously (e.g., Hillis & Rapp, 1998), and that the frame of reference and relative extent of neglect can be modulated by different task contingencies (Baylis, Baylis, & Gore, 2004; Behrmann & Tipper, 1999; Karnath & Niemeier, 2002).

Previous studies have defined what constitutes the 'left' and 'right' side of an object in many different ways. Some authors (e.g., Driver, Baylis, Goodrich, & Rafal, 1994; Driver & Halligan, 1991) have suggested that the principal axis of the object, such as the axis of elongation, determines the left and right side of an object. Others have defined the sides of an object according to the intrinsic handedness of the object

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[2] Hillis, Rapp, Benzing, and Caramazza (1998) use the word 'DOG' to demonstrate the distinction between all three frames of reference. In viewer-centred neglect, the word 'DOG' may fail to be reported if it is presented to the left of the viewer. In stimulus-centred neglect, the letter 'D' of the word 'DOG' may fail to be reported if the word is presented in normal upright orientation but it is expected that the letter 'D' will be reported if the word is presented mirror-reversed. This occurs because report depends on where the letter 'D' falls relative to the stimulus itself, left in normal upright orientation and right when the word 'ƆOꓷ' is mirror-reversed. In object-centred neglect, regardless of whether the word is presented to the left or right of the viewer, or, whether the word is presented upright or upside down, in backward parity, or even vertical, the letter 'D' may fail to be reported because it always falls on the canonical left of the word (also see Caramazza and Hillis, 1990).

(e.g., Behrmann & Moscovitch, 1994). Thus, certain objects, such as asymmetrical letters, have an intrinsic left and right side that can be identified as such independently of orientation in viewer-, environment-, and stimulus-centred coordinates. For example, in object-centred coordinates, the intrinsic left side of the letter 'B' is always the straight side, whereas the intrinsic right side is always the curved side, irrespective of its parity and angle of orientation.

Research has provided firm evidence for the existence of separate viewer- and environment-centred spatial coordinate systems (e.g., Calvanio, Petrone, & Levine, 1987; Farah et al., 1990; Làvadas, 1987). Several researchers have also attempted to disentangle the object-centred frame of reference from the other two, a task that has proven to be methodologically challenging. A history of relevant research may help shed light on some of the problematic methodological issues faced by researchers in this area. The observation of most interest for the current literature review concerns neglect of the left side of individual objects within a scene, such as figures, individual letters, and nonsense shapes, and this review will therefore not focus on research in the area of face neglect[3] or neglect dyslexia, other than to acknowledge the significant contribution of the latter when it becomes relevant under the subheading 'Evidence for Intrinsic Object-Centred Neglect'.

First, the literature review will outline evidence pointing to the existence of stimulus- and object-centred neglect from patients' performance on drawing and copying tasks and from studies of perceptual parsing. As will be discussed, there is evidence that patients with neglect may fail to copy not only the contents of the left side of a display, but also the left side of individual objects making up the display. A review of the experimental evidence specifically for stimulus-centred neglect will then be provided. This includes neglect of the left side of individual stimuli, in stimuli *without* an intrinsic left and right side. Evidence for a separate object-centred frame of reference will then be outlined. The studies described will include objects with an intrinsic left and right side, where the intrinsic handedness of the object is maintained irrespective of its positioning with regard to viewer-, environment-, and stimulus-centred frames of reference. The literature review for Section 1: 'Frames of Reference in Unilateral Neglect: Visual Modality' ends with an outline for the experiments presented in Chapter 2.

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[3] There is evidence to suggest that the processing mechanisms contributing to the visual recognition of faces are different to those utilised for object recognition (see Bruce & Humphreys, 1994, for a review).

Alternative explanations for the findings of object-centred neglect have also been explored. For example, it has been suggested that viewer/environment-centred neglect may be misattributed to object-centred neglect because the patients mentally rotate the stimuli to upright and thereby realign the viewer-, environment-, and object-centred frames of reference (e.g., Buxbaum, Coslett, Montgomery, Farah, 1996; Cubelli & Speri, 2001). It has also been speculated that normal biases in the allocation of visual attention may explain previous findings of object-centred neglect (e.g., Drain & Reuter-Lorenz, 1997; Maguire, Boycott, Bates, & Corballis, 2002). The mental rotation hypothesis for unilateral neglect will be discussed more explicitly in the literature review for Section 2.

As will become evident in this literature review, the terms allocentric, stimulus-centred, object-based, and object-centred neglect have sometimes been used interchangeably in the literature. Whenever possible, in this literature review these terms will first be used as they were by the authors of the studies, but the ultimate aim is to individuate these terms and to evaluate whether there is evidence to support the existence of neglect in a 'true' object-centred frame of reference. In this regard, 'true' object-centred neglect refers to neglect of the canonical left or right of the object irrespective of its location with respect to viewer- and stimulus-centred coordinates. As outlined above, left and right in a viewer-centred frame of reference are defined relative to some landmark of the viewer, such as the retinotopic, head, or body midline. Left and right therefore can change depending on the position of the 'viewer'. See Figure 1 for an illustration of the viewer- and environment-centred reference frames. In contrast, if spatial attention operates in either a stimulus- or an object-centred frame of reference, then 'left' and 'right' are defined relative to the object itself. The terms object-based and object-centred neglect have been used by a number of researchers, but this review aims to demonstrate that more often than not the term stimulus-centred neglect would have been more accurate. The main distinction between stimulus-centred and object-centred neglect is that the canonical left and right of the object are maintained independently of the viewer-centred frame of reference only in an object-centred representation. See Figure 2 for an illustration of the difference between the stimulus- and object-centred frames of reference.

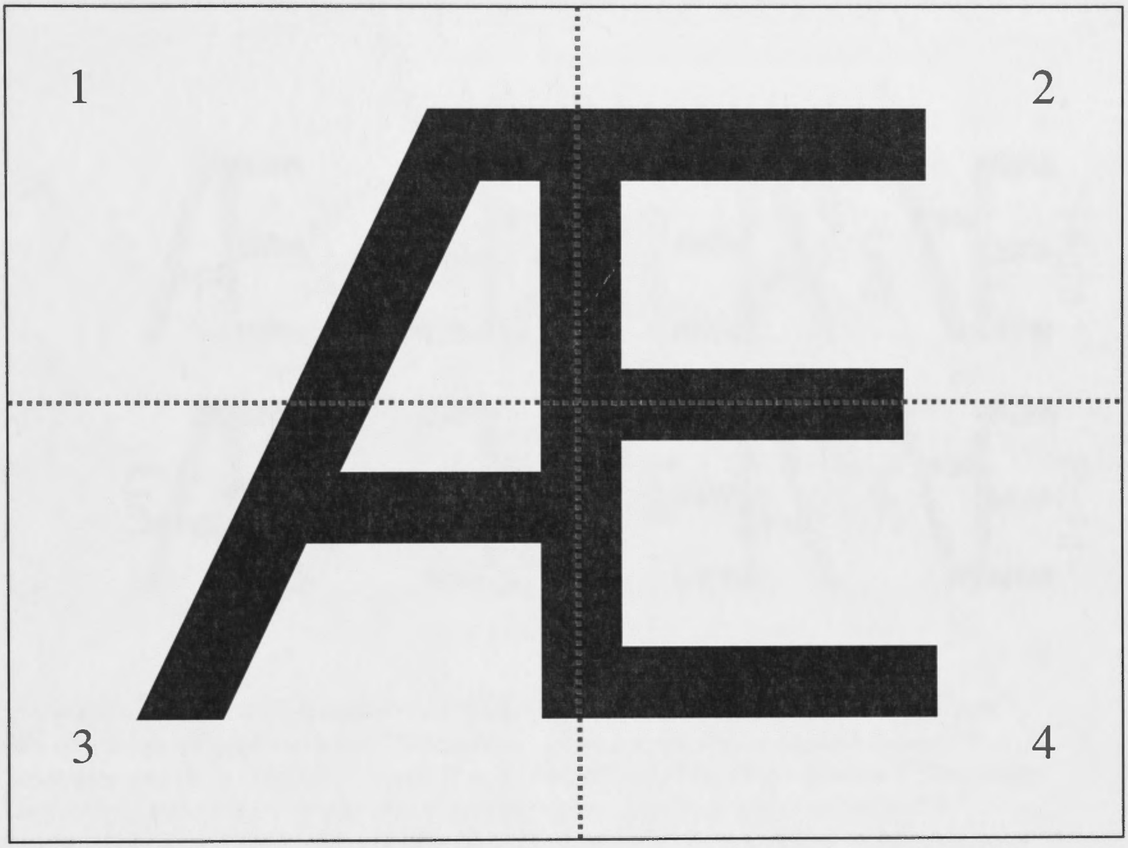

Figure 1. Illustration of viewer- and environment-centred frames of reference: When this image is presented upright, and the viewer is also in an upright position, the viewer- and environment-centred reference frames are aligned. The two left quadrants of the image ('A' part of the letter 'Æ', quadrants 1 and 3) appear on the left as defined by both reference frames. The viewer-centred reference frame can be disentangled from the environment-centred reference frame (e.g., Farah et al., 1990) by rotating the viewer 90° to the left or right of upright, while presenting the image in an upright position. In these conditions, the two left quadrants of the display (quadrants 1 and 3) continue to be the left side as defined by an environment-centred reference frame. Depending on the viewer's rotation, the upper or lower quadrant of the image is now the left as defined by a viewer-centred reference frame. If the viewer is rotated 90° to the left, the two lower quadrants of the image are the left side as defined by a viewer-centred reference frame (quadrants 3 and 4). In contrast, if the viewer is rotated 90° to the right, the two upper quadrants of the image are the left side as defined by a viewer-centred reference frame (quadrants 1 and 2). The quadrants that appear to the left in a viewer-centred reference frame therefore depend on the location of the left side of the image *from the viewer's perspective.*

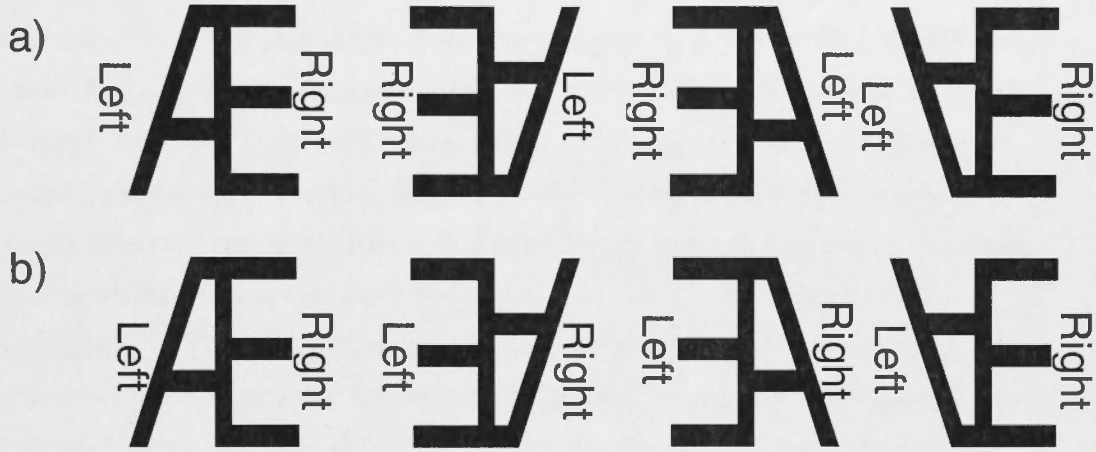

Figure 2. Illustration of stimulus- and object-centred frames of reference: This figure illustrates the left and right side of the letter 'Æ' in: (a) an object-centred frame of reference and (b) a stimulus-centred frame of reference. The object-centred left has been disentangled from the left side as defined by viewer, environment-, and stimulus-centred frames of reference by displaying the object in different angles of orientation *or* in normal and backward parity. The left side of the letter 'Æ' as defined by an object-centred frame of reference is the side where the 'A' part is located *irrespective* of the parity and orientation of the letter. The object-centred left side is therefore independent of all other frames of reference. In contrast, the stimulus-centred left side of the letter is dependent on the location of the left side *from the viewer's perspective.* The stimulus-centred left side is the left side of the midline of the stimulus, and is therefore not independent from the viewer-centred left side.

Evidence for Stimulus- and Object-Centred Neglect from Drawing and Copying Tasks

Early indications that neglect can occur in a stimulus- or object-centred frame of reference came from patient drawings and simple bedside tests requiring patients to copy line drawings of simple scenes, shapes, or figures (e.g., Apfeldorf, 1962; Gainotti, Messerli, & Tissot, 1972; Halligan & Marshall, 1993; Marshall & Halligan, 1993; Seki & Ishiai, 1996). Apfeldorf (1962) published a drawing made by an artist following a cerebral infarction in the right hemisphere. In the drawing of a horse and wagon, the patient failed to draw the left half of individual objects in the picture, even in the intact right hemispace, and despite completing parts of objects placed further into the neglected side of space. Furthermore, Halligan and Marshall (1997) presented an interesting report of an artist, who became impaired in his drawing and painting following a stroke in the right hemisphere. The artist's drawings demonstrated fewer details on the left side compared to the right side. His sculptures were also equally incomplete. In particular, Halligan and Marshall described a sculpture of a woman's head whose left side was incomplete both at the front and the back, even though the sculpture was created on a turntable, and the artist turned both the sculpture and himself around this turntable.

It is important to note that in copying tasks where figures are centred on a sheet of paper, which in turn is aligned with the midsagittal plane of the patient's body, all frames of reference are aligned. It is therefore not possible to assess the influence of the different frames of reference on the copying performance of patients with neglect under this condition. In a copying task where *several* shapes or objects were displayed on a sheet of paper, Gainotti, Messerli, and Tissot (1972) observed two distinct patterns of copying performance in a group of patients with right-hemisphere damage. The stimuli used by Gainotti et al. consisted of several geometric figures or a scene with a house, several trees, and a fence. In each case, the objects were arranged individually from the left side to the right side of the stimulus sheet in a horizontal array. Although some patients failed to copy objects located on the left side of the stimulus sheet (viewer-centred neglect), Gainotti et al. also observed that some patients failed to copy the left half of individual objects in a scene, even in the intact right side of space, and even when they reproduced parts of objects placed further into the neglected hemifield. Similarly, Halligan and Marshall (1992) described a patient who omitted details on the left half of England, yet included Ireland (which is situated further into the neglected hemispace) when asked to draw a map of the United Kingdom.

Halligan and Marshall (1993) argued that the participants in Gainotti et al.'s (1972) study may have shifted their attention from one object in the scene to another, and thereby perceived the scene as a succession of discrete objects rather than a scene. Halligan and Marshall thus utilised a drawing of two flowers, displayed either as two individual objects or as one object united by a common stem and pot. Results demonstrated that their patient with neglect failed to copy the whole left branch of the flower when it was displayed as one object united by a common stem and pot. In contrast, when displayed as two separate objects, the patient omitted components on the left side of each individual flower. Halligan and Marshall concluded that this performance was consistent with neglect in an object-centred frame of reference. Marshall and Halligan (1993) subsequently administered the above copying task to five patients with neglect. Results demonstrated several distinct copying impairments. Of relevance to the current literature review is the distinct difference observed between the copy performance of two of the patients included in the study. One patient failed to copy the left branch of the flower when it was displayed as one object, and the entire left flower when displayed as two individual objects, a performance the authors attributed to page-centred neglect. The second patient's performance was comparable to the patient in Halligan and Marshall's study. This patient failed to copy the left branch when the flowers were displayed as one object, but omitted details on the left side of each individual flower when displayed as two separate objects, a performance indicative of object-centred neglect. Marshall and Halligan suggested that their copying test was a useful screening tool in the investigation of neglect in different frames of reference.

Ogden (2002) conducted a study using a modified version of Halligan and Marshall's (1993) daisy copying task. Two patients with neglect participated: Patient TT and Patient SM. Stimuli were presented at the midsagittal plane of the participant's body. The participants were first required to name and describe four line drawings of daisies. These drawings included a single daisy in a pot, two single daisies each in a separate pot, two single daisies in a single pot, and a two-headed daisy in a pot. The participants were subsequently required to copy these drawings. Patients were also asked to describe and copy three other line drawings of daisies, including a drawing of a single daisy in a pot with the entire left or right side missing, and a drawing of a double-headed daisy in a single pot with a complete head on the left daisy and the right half of the daisy head missing on the right daisy. Finally, patients were required to describe and copy a three-headed daisy in a single pot. Patient TT was able to describe all the daisies accurately, however, his copying demonstrated a failure to draw the left half of each daisy irrespective of the original drawing. Even when drawing the daisy with the entire right side missing, he only drew the right-most petals of the left half. In copying the three-headed daisy, he continued to copy only the right half of the two daisy-heads on the right side and failed to copy the daisy to the left. This performance is slightly different from the performance of Patient PB as described by Halligan and Marshall, possibly indicating that Patient TT perceived each daisy head as a separate object, irrespective of whether the daisies were joined by a stem. These findings were interpreted as evidence of object-based neglect. Patient SM was also able to describe the drawings accurately, but in contrast to Patient TTs performance, she failed to copy the entire left daisy head in drawings containing more than one daisy. Patient SM's performance was interpreted as evidence of environment-centred neglect.

Behrmann and Plaut (2001) criticised previous findings of object-based neglect in copying tasks allowing for free viewing and free copying. They argued that because copying is a sequential task, each object remains the focus of attention for some time. Under these conditions, each individual object as it is drawn becomes the entire environment for the patient with neglect, and apparent object-based neglect may therefore be a manifestation of environment-centred neglect. To overcome this problem, Behrmann and Plaut asked their two participants with neglect to copy a daisy presented individually in four different orientations. By presenting the daisy in different orientations, Behrmann and Plaut argued that the 'left' and 'right' of the object (the daisy) was disentangled from the left and right as defined by egocentric coordinates. They argued that the copying performance reflected a combination of object- and viewer-centred neglect as evidenced by omissions of details of the daisy to the left (as defined both by viewer- and object-centred frames of reference). They concluded that multiple frames of reference may interact, and thus will determine the performance of patients with neglect on copying tasks. (The authors also created a computational characterisation of the interaction between neglect in viewer- and object-centred frames of reference, see Behrmann and Plaut for details).

The research published on drawing and copying performance of patients with neglect indicates a possibility that neglect may exist in both stimulus- and object-centred coordinates. However, as copying tasks are usually completed under conditions of free viewing, this is not conclusive evidence. In copying tasks, the viewer- and stimulus-centred frames of reference are usually confounded due to the object to be copied being positioned on the midsagittal plane of the patient's body or the patient shifting attention from one object in the scene to another.

Evidence for Stimulus- and Object-Centred Neglect from Studies of Perceptual Parsing

Pia, Neppi-Mòdona, Procopio, Ricci, Gindri, and Berti (2004) showed that one can dissociate space-based and object-based neglect by defining the structure of stimuli in terms of perceptual parsing. Pia et al. investigated the effect of separating the components of an image on space- and object-based neglect. Image separation was accomplished by manipulating space or by utilising different colours. Participants consisted of twenty patients with lesions to the right hemisphere and with left neglect. Pia et al. utilised a modified version of a line-cancellation task, as well as Marshall and Halligan's (1993) daisy-copying task. The perceptual units were parsed by colour and/or spatial proximity, yielding a total of four different stimulus conditions: (a) not parsed; (b) parsed by colour; (c) parsed by proximity; (d) parsed by colour and proximity (see Figure 3). Results demonstrated a decrease in space-based neglect and an increase in object-based neglect in the parsed-by-colour condition on the line-cancellation task. In this condition, there was a reduction of omissions on the left side of the stimulus-sheet (space-based neglect) and an increase of omissions on the left side of the individual stimulus displays (as defined by two different colours). This was interpreted as evidence of object-based neglect. Furthermore, object-based neglect decreased in the daisy-copying task when parsed by spatial proximity, as the daisies were now viewed as two separate objects rather than one. Overall, the stimuli parsed by colour *and* proximity produced the largest decrease in space-based neglect as well as the largest increase in object-based neglect. Pia et al. suggested that parsing activates object-based representations, which are relatively intact in patients with space-based neglect, but impaired in patients with object-based neglect. They speculated that the activation of the relatively spared object-based representation in patients with space-based neglect contributes to an improvement of neglect whereas the same activation in patients with object-based neglect leads to a deterioration of neglect.

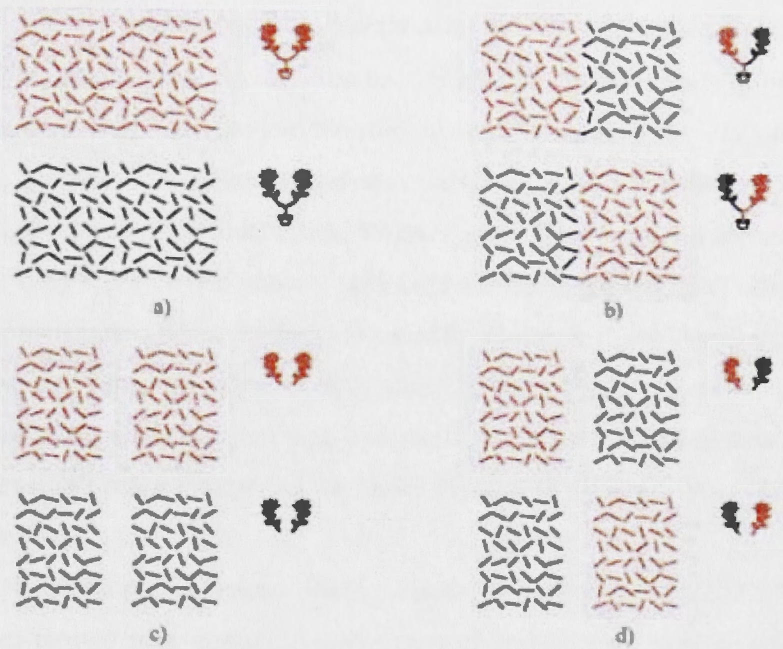

Figure 3. Illustration of the four different stimulus conditions in Pia et al.'s (2004) study: (a) not parsed; (b) parsed by colour; (c) parsed by proximity; (d) parsed by colour and proximity (figure adapted from Pia et al., 2004).

Similarly, Humphreys and Riddoch (1994) demonstrated that perceptual parsing could modulate the frame of reference of neglect in a patient with neglect following stroke of the left hemisphere. This patient demonstrated neglect for lines on the right side of the page in a line-cancellation task. When the central portion of lines on the stimulus sheet was erased so that the stimulus sheet contained two distinct blocks of lines, the pattern of the patient's performance changed. He now missed more lines on the *left* half of each individual block. Buxbaum and Coslett (1994) documented a related finding. They reported that patients with neglect were impaired in reporting the left half of chimeric figures. When the two halves of the chimeric figures were separated by a gap, however, detection of the left half of the chimeric figure improved. Thus, when presented as two objects rather than one object, the patients' performance improved. Buxbaum and Coslett interpreted the above findings as evidence of a form of object-based neglect.

Neppi-Mòdona, Savazzi, Ricci, Genero, Berruti, and Pepi (2002) investigated what they termed array-centred (viewer-centred) and subarray-centred (stimulus-centred) neglect in the performance of patients with neglect on a line-cancellation task. They noted that most previous research has reported data from single cases or a small group of patients, and they sought to quantify the incidence of array- and subarray-centred neglect in a large group consisting of 116 patients with neglect. They modified a line-cancellation task by deleting the central column to generate two separate sets of stimuli grouped by proximity. They predicted that array-centred neglect would be manifested by a failure to cross out the lines on the left half of the sheet of paper. In contrast, subarray-centred neglect would be evident by omissions of lines located on the left side in each set of stimuli. Results demonstrated that the performance of 73 patients was consistent with array-centred neglect, with neglect of the left set of stimuli sometimes also extending into the right subarray. In contrast, only seven patients performed in accordance with neglect in a subarray-centred frame of reference, with neglect of lines appearing on the left within each of the two subarrays. Neppi-Mòdona et al. also documented that the performance of seven other patients was consistent with the co-occurrence of array- and subarray-centred neglect. The authors noted that the presence of subarray-centred neglect may be underestimated, as 43 patients demonstrated severe array-centred neglect extending to the right half of the subarray located further to the left, which may mask the presence of neglect in a subarray-centred frame of reference. Neppi-Mòdona et al. concluded that their study confirmed findings from previous single-case and small group studies by demonstrating that neglect can appear in single or multiple frames of reference.

Although the research on patients' drawing and copying performance, as well as the studies on perceptual parsing outlined above, indicates the possibility that neglect may operate in an object-centred frame of reference, it is better described as stimulus-centred neglect. The research merely describes neglect of the left side of a stimulus, which can be further confused with neglect in retinotopic coordinates in conditions of free viewing. That is, the handedness of the stimuli included in the above studies depends on where the left and right side of the stimuli are located according to the midline of the stimuli *from the viewer's perspective*. As the handedness of the stimuli is not independent from the viewer-centred frame of reference, the above findings are therefore better described as stimulus-centred neglect. The stimulus-centred frame of reference is not strictly speaking separated from the viewer-centred frame of reference in conditions of free viewing, as the retinotopic midline realigns the viewer- and stimulus-centred left and right sides. The results from the studies outlined above may therefore ultimately be due to stimulus- and/or viewer-centred neglect. The stimulus-centred frame of reference may, however, be separated from the viewer-centred frame of reference when the viewer's head and trunk midlines are aligned and the viewer is required to maintain central fixation -- if the stimuli are presented either to the left or to the right of these midlines. This is illustrated by a study conducted by Driver, Baylis, and Rafal (1992), described in detail in the next section.

Evidence for Stimulus-Centred Neglect from Tasks Requiring Judgments about Shapes, Objects, and Figures

A number of researchers have demonstrated that neglect can operate in a stimulus-centred frame of reference, but it has been methodologically challenging to disentangle the object-centred frame of reference from the stimulus-centred frame of reference. The experimental evidence for the existence of stimulus-centred neglect will first be reviewed, before describing research attempting to provide evidence of neglect in an object-centred frame of reference.

Driver, Baylis, and Rafal (1992) provided evidence that neglect can occur on the left side of individual objects in space irrespective of their position within an egocentric frame of reference. They used a figure-ground experimental paradigm where an object is perceived as standing out from the background. In other words, the decision as to what constitutes the object depends on the perceptual system's choice about what is figure and what is ground. In their task, a rectangle presented on a computer screen was divided into segments normally perceived as a small green section (figure) against a red background (ground). The green section could be located on the far right side or far left side within the rectangle. When located on the far right side, the dividing contour was on the left side of the green section, whereas when positioned on the far left side, the contour was on the right side of the green section. The participant in the study, a patient with neglect, was required to remember the vertical contour dividing the red and green section on each trial and to make a decision as to whether it matched an irregular vertical line presented after each display. Driver et al. stated that inaccurate responses when the shape is located in the left end of the rectangle could be attributed to an attentional deficit in the left side of space. In contrast, if neglect can apply to the left side of objects, then the patient should be less accurate when the shape is located at the right end of the rectangle, as the dividing contour is now located on the left side of the object. Results demonstrated that the critical variable affecting performance was the location of the dividing contour. In other words, the patient made more errors when the dividing contour was located on the left side of the object (the green section) even when this section was located in the right side of space; a finding interpreted as evidence of neglect of the contralesional side of objects. The above findings cannot be attributed to neglect in a retinotopic frame of reference as the patient was required to fixate centrally, and eye movements were monitored. The stimulus-centred frame of reference was therefore disentangled from the viewer-centred frame of reference.

Marshall and Halligan (1994) provided further evidence for the occurrence of neglect on the left side of individual objects in space. The patient in their study, Patient RB, demonstrated neglect following a right-hemisphere stroke. Patient RB was shown figures with a vertical boundary created by the two colours of the figure. In other words, the boundary was simply the contrast between the two colours. The boundary could be in the middle of the figure, with a different colour on the left and right side, yielding a left and a right sub-figure. The patient's task was to copy the boundary contours of the left or the right sub-figure. The figure could also consist of a central sub-figure in one colour, with a different colour on either side of it, yielding a figure with left, central, and right sub-figures. In these trials, the patient's task was to copy the left, central, or right sub-figure. Each figure was displayed individually on a sheet of paper, which was centred on the patient's midsagittal plane. Results demonstrated that Patient RB's copies were more accurate and detailed when he copied the left sub-figure, in which case the dividing contour was located on the right side of the sub-figure. In contrast, when copying the right sub-figure, the dividing contour (which was now located on the left side of the sub-figure) lacked detail, and it was usually reproduced as a straight line. Thus, RB demonstrated that he could copy the right boundary of an object, yet he failed to reproduce the identical dividing contour when it was marking the left contour of an object. When copying central sub-figures, RB only produced the dividing contour on the right side of the figure.

These findings were replicated with vertically elongated figures, and were also demonstrated when Patient RB was required to make same/different judgments about two shapes. When comparing two stimuli presented one above the other, RB made more errors when judging if the two right sub-figures were identical than when he made the same judgments about two left sub-figures. Marshall and Halligan (1994) interpreted their findings as evidence of what they refer to as 'object-centred' neglect. As eye movements were not controlled for in Marshall and Halligan's study, the above results can be explained purely in terms of neglect in a retinotopic frame of reference. In other words, the patient may have fixated on the middle of the individual sub-figures, leading to neglect of the left boundary in the right and central sub-figures, but no neglect with the right boundary in the left sub-figure. Marshall and Halligan argued against this possibility, highlighting that the findings were replicated with vertically elongated stimuli subtending a very small visual angle. The results are consistent with the findings of Driver et al. (1992), however, as the studies did not include objects with an intrinsic left and right side, the findings from both studies can be better categorised as evidence of stimulus-centred neglect rather than a demonstration of neglect in an object-centred frame of reference.

Chatterjee (1994) conducted a study seeking to disentangle object-centred neglect from neglect in a viewer-centred frame of reference. Eight patients with left-side neglect participated in the study. The experimental task required the patients to photograph lines and objects. The lines were individually attached against a white background on a wall and the objects were displayed individually on a table in front of the participants. All objects were presented aligned with the midsagittal plane of the patients' body. The patients were asked to centre the line in the viewfinder of the camera before taking a photo. There were no internal markings in the viewfinder.

Chatterjee hypothesised that if the patients neglected the left side of space in the viewfinder, then the objects would be positioned in the right side of the photograph. Conversely, if the patients neglected the left side of the objects to be photographed, then they would be positioned on the left side in the photograph. Results demonstrated that four patients consistently placed objects toward the right side of the picture, a performance Chatterjee interpreted as viewer-centred neglect. In contrast, three other patients positioned the objects in the left side of the photograph, which Chatterjee interpreted as evidence of object-centred neglect. One patient had a variable performance, sometimes placing the objects in the right half of the photograph and other times in the left half. Chatterjee speculated that this patient's performance could be attributed to the co-occurrence of neglect in both viewer- and object-centred frames of reference. Chatterjee interpreted the above findings as evidence of a double dissociation between viewer- and object-centred neglect.

Pavlovskaya, Glass, Soroker, Blum, and Groswasser (1997) claimed to find evidence for object-centred neglect in a study comparing the performance of two patients with neglect to that of four neurologically healthy participants. The task was to identify simple, prelearned patterns that were briefly (and individually) displayed on a computer screen. The participants made their response by pressing a key on a computer keyboard to indicate the identity of the shape. The participants were required to fixate at a central fixation point (or precue) in the middle of the screen prior to the presentation of each stimulus. The brief presentation time prevented more than one fixation during stimulus exposure. Allocation of attention within each object was manipulated by moving the object to the left or right. In this way, the central fixation point could be in a position corresponding to the centre of the object, or to the left or right half of the object. Pavlovskaya et al. hypothesised that neurologically healthy participants should be more accurate in their identification of the shapes when the fixation point was precued in the centre of the object. In contrast, they predicted that patients with neglect should be more accurate when 'forced' by the fixation point to allocate their attention to the left side of the object, that is when the precue appeared in a position corresponding to the left side of the object. Results confirmed Pavlovskaya et al.'s hypotheses. Control participants were more accurate when the precue was centred on the stimuli, and their performance declined with precuing either to the left or right side of the objects. In contrast, patients with neglect demonstrated a higher accuracy in object identification when stimuli were shifted to the right so that the precue was in a position corresponding to the left side of the object, and their performance gradually declined with leftward shifts of the stimuli so that the precue was in a position corresponding to the centre or to the right side of objects. Pavlovskaya et al. interpreted these results as evidence that neglect can operate in an object-centred frame of reference. They further noted that patient performance could best be accounted for by neglect co-occurring in the viewer- and object-centred coordinate frames. Pavloskaya et al. emphasised that the patients confused one shape with another irrespective of which hemispace they were displayed in. They interpreted this as further evidence of object-centred neglect. They interpreted the finding that the patients did worse overall in the left hemispace compared to the right hemispace as evidence that an egocentric component also influenced the results.

Di Pellegrino, Frassinetti, and Basso (1995) designed a study utilising chimeric figures in an attempt to provide evidence for object-centred neglect. Chimeras consist of one half of two different figures or objects, joined in the middle. The participant, a patient with right-hemisphere damage and neglect, was required to name chimeric and complete figures presented individually on a sheet of paper. The paper was centred on the midsagittal plane of the patient's body. The figures were displayed in three different angles of orientation, including upright, and rotated 90° to the left or right of upright. When rotated, the object-centred frame of reference was disentangled from the egocentric frame of reference. Di Pellegrino et al. predicted that if neglect operated in an object-centred frame of reference, then the patient should fail to detect the left half of the chimeric figures irrespective of angle of orientation. Viewer-centred neglect, in contrast, would be evident by the failure to report the left half of the chimeric figures when presented in an upright orientation *only*. Results demonstrated that the patient was highly accurate at identifying the complete figures irrespective of their orientation. With the chimeric figures, the patient made a large number of left-side omissions when the stimuli were presented upright. Furthermore, the patient continued to report fewer left-side stimuli (as defined by an object-centred frame of reference) when the figures were rotated 90° to the left or right of upright, although the magnitude of the left-right difference was smaller than in the upright condition. Di Pellegrino et al. interpreted their findings as evidence that neglect can occur in an object-centred frame of reference. They interpreted the larger number of omissions when the stimuli were presented upright, and the relative improvement in neglect when the figures were presented rotated, as evidence that their patient FB demonstrated neglect in an object-centred frame of reference, but that his "neglect [also] involves a viewer-centred, abstract description of the stimulus accessed after a normalising process of mental rotation has taken place" (p. 775).

Farah, Brunn, Wong, Wallace, and Carpenter (1990) claimed not to find evidence of object-centred neglect in a study aiming to disambiguate neglect in viewer-, environment, and object-centred frames of reference. These authors showed patients with neglect line drawings of common objects and animals. Sixteen letters were scattered across each picture, ensuring that each quadrant contained four letters. The patients' task was to name the object or animal in the picture before reading all of the letters. When both the patient and picture were upright, letters on the quadrants to the left appeared on the left as defined by viewer-, environment-, and object-centred frames of reference. Farah et al. disentangled the viewer-centred frame from the environment-centred frame by rotating the patients 90° clockwise or counterclockwise. Evidence for separate viewer- and environment-centred frames of reference was indicated by the naming of fewer letters on the left (as compared to the right), with respect to both frames when these were decoupled. That is, the patients continued to name fewer letters in the left quadrants of the picture itself (the environment-centred frame of reference), but they also named fewer letters from the quadrants on the left *from the viewer's perspective,* which in the rotated conditions were either the upper or lower quadrants of the picture. Additionally, this study examined whether visual neglect can operate in an object-centred frame of reference, achieved by rotating the stimulus display 90° while keeping the patient upright. In this condition, Farah et al. failed to find a difference between the number of letters read on the left and right as defined by an object-centred frame, that is the left and the right side of the picture *irrespective* of its orientation.

Although the averaged performance of the group of patients studied by Farah et al. (1990) did not support the existence of object-centred neglect, three of the ten patients demonstrated neglect in object-centred coordinates when the data was reanalysed by Hillis and Rapp (1998) to look at individual patient data. These three individuals more frequently omitted letters appearing on the left than the right side of the object when the object was rotated in a clockwise or counterclockwise direction. As will be discussed in more detail under the subheading 'Evidence for Intrinsic Object-Centred Neglect', there are reasons as to why researchers believe even these findings do not constitute evidence of 'true' object-centred neglect. For example, it has been argued that the division between left and right in objects without an intrinsic left and right side is dependent on viewpoint. The imposition of handedness in these objects is therefore not independent from a viewer-centred representation, which indicates that the findings of 'object-centred' neglect documented by Di Pellegrino et al. (1995) and Hillis and Rapp (1998) may ultimately be due to neglect in a viewer- and/or stimulus-centred frame of reference.

Driver and Halligan (1991) argued that the failure to demonstrate object-based effects in the study conducted by Farah et al. (1990) could be due to the fact that the background drawings were irrelevant to the letter-naming task. In this regard, Driver and Halligan suggested the patients may have concentrated on the individual letters scattered across the object rather than the object itself, making it unnecessary to maintain the object-centred frame of reference. As a result, the patients may have ignored the 'background' object. In an attempt to rectify these shortcomings, Driver and Halligan devised another experiment that sought to demonstrate the occurrence of visual neglect in object-centred coordinates. These authors defined the handedness of an object relative to its principal axis of elongation. Their case-study participant, a patient who manifested profound left neglect, was required to judge whether two nonsense shapes that were vertically elongated and bottom heavy were identical or different when presented one above the other. If dissimilar, they differed on one side only. The shapes were both presented either upright or tilted 45° left or right of upright. When the principal axis of each object was vertically upright, the viewer-, environment-, and object-centred frames of reference were aligned. In this condition, the patient failed to notice differences on the left. When the object was tilted, the object-centred frame of reference was disentangled from the other frames of reference. In this case, the patient continued to neglect disparities to the left of the objects' principal axes even when these differences were located to the right in other coordinate systems. Driver and Halligan interpreted this as clear evidence that neglect may occur for information appearing on the left of individual objects regardless of their spatial location.

Driver, Baylis, Goodrich, and Rafal (1994) raised the possibility that Driver and Halligan's (1991) results could be explained purely in terms of egocentric coordinates rather than object-centred neglect. Driver et al. argued that the original interpretation was based on the belief that viewer-centred neglect manifests in *absolute* terms. In this consideration, the patient should neglect *all* stimuli presented to the left while reporting *all* information appearing to the right. Driver et al. pointed to evidence suggesting that *relative* lateral position may be a factor of greater importance than absolute position in determining viewer-centred neglect. In line with this latter argument, Driver et al.

highlighted that with regard to any point along the left side of the stimuli utilised by Driver and Halligan there were features located further to the right in *relative* terms within a viewer-centred frame of reference, even when the shapes were tilted 45° in a clockwise direction. Driver et al. suggested that Driver and Halligan could have misinterpreted viewer-centred neglect as apparent object-centred neglect. Furthermore, these authors argued that to provide firm evidence for the existence of a separate object-centred frame of reference it is necessary to demonstrate object-centred neglect when the location of a target is manipulated according to the object's principal axis, while keeping this target's location constant with regard to a viewer-centred frame of reference. Driver et al. accomplished this in a very ingenious experiment by utilising an array of equilateral triangles (see Figure 4). An equilateral triangle has three possible principal axes, and the shape can be seen to point in one of three directions depending on which of the principal axes predominates. By utilising an array of triangles, Driver et al. manipulated the configuration so that it was perceived to point either toward the top left or the top right. The task was to identify a gap in the centre of the horizontal line located at the top of a target triangle in each configuration. Depending on the direction of the principal axis, this gap would either fall to the left or to the right of this axis. The three participants, who all suffered from left visual neglect, more frequently failed to detect a gap when this gap was situated to the left of the predominant principal axis than when it was located to the right of this axis. Driver et al. argued that this result cannot reflect viewer-centred neglect since the target-gaps were always located in the same egocentric position, and therefore interpreted their findings as clear evidence for axis-based neglect, which they believe is a form of object-centred neglect.

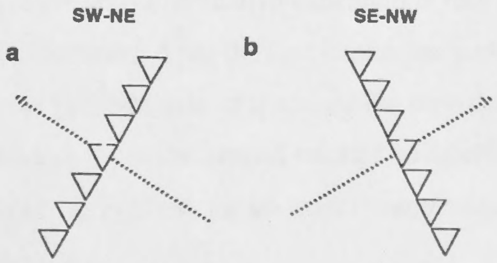

Figure 4. Examples of the two display configurations utilised by Driver et al. (1994): (a) gap in the central triangle falls on the right side of the dominant axis, and (b) gap in central triangle falls on the left side of the dominant axis (figure adapted from Driver et al., 1994).

Ota, Fujii, Suzuki, Fukatsu, and Yamadori (2001) developed two new figure discriminative-cancellation tasks for the purpose of investigating whether viewer-centred (which the authors refer to as body-centred) and stimulus-centred neglect can be dissociated in patients with neglect. The circle discriminative-cancellation task included twenty complete circles and forty incomplete circles that were evenly distributed on both sides of the vertical midline of a sheet of paper. Fifty percent of the incomplete circles had a missing segment on the right side, whereas the remaining incomplete circles had a missing segment on the left side. The second task, the triangle discriminative-cancellation task, was identical to the circle discriminative-cancellation task, except that the circles were substituted with equilateral triangles that were either complete or had a segment missing. Two participants with neglect were required to circle all complete stimuli and to cancel all incomplete stimuli. Errors on the left side of the page were interpreted as viewer-centred neglect, whereas incorrectly identifying stimuli with a missing segment on the left side as complete was interpreted as evidence for stimulus-centred neglect. The results indicated that one patient omitted more stimuli on the left side of the sheet of paper as compared to the right side of the paper. The accuracy for this patient's responses on the right side of the sheet was high. Ota et al. interpreted this as evidence for viewer-centred neglect. Contrary to Patient 1's results, Patient 2 responded to stimuli on both the left and the right side of the paper. Patient 2, however, made more mistakes when the object itself had a missing segment located on the left side than when it was a complete object or an object with a missing segment on the right side. That is, he erroneously identified stimuli with a missing segment on the left side as complete. Ota et al. interpreted this as evidence for stimulus-centred neglect.

Ota, Fujii, Tabuchi, Sato, Saito, and Yamadori (2003) later described a patient's performance on the above circle discriminative-cancellation task who had experienced two successive cerebral infarctions. After the first stroke, the patient demonstrated stimulus-centred neglect in the right side of space. At the time there was no evidence to indicate body-centred neglect. After the second stroke five months later, the patient demonstrated body-centred neglect, but she no longer manifested neglect in a stimulus-centred frame of reference.

Grimsen, Hildebrandt, and Fahle (2008) provided evidence of a dissociation between egocentric and allocentric neglect. Twenty-one participants with neglect following stroke of the middle cerebral artery in the right hemisphere were included in the study. Participants were required to search for target features among standard stimuli on a computer screen. The target features were known to induce parallel or serial visual search. The display consisted of ten stimuli arranged in two rows of five stimuli per row. In one condition, the critical feature was a thick vertical item on the left or right side of one of the ten stimuli (parallel search). In the second condition, the target stimulus was defined by a much more subtle change to either the left or right side of one of the stimuli (serial search). Examples of target features were displayed on the computer screen throughout the task, and participants made their responses by pressing keys on a computer keyboard. Grimsen et al. hypothesised that egocentric neglect would be manifested in omissions in target detection for targets located on the left side of the display. In contrast, allocentric neglect would be evident by the failure to detect changes to the left side of individual stimuli in the array, irrespective of positioning within the display. Results demonstrated that four patients omitted targets primarily located in the column located on the left side of the display, while they were highly accurate in target detection on the right side of the display. This finding was interpreted as evidence of egocentric neglect. Four other participants demonstrated a different pattern of results. These participants omitted more targets when located on the left side of an individual stimulus, irrespective of their positioning within the display; a finding interpreted as neglect in an allocentric frame of reference. Grimsen et al. concluded that their findings present evidence for the involvement of at least two frames of reference during visual search. The results published by Ota et al. (2001) and Grimsen et al. provide two simple and elegant methods for distinguishing between egocentric and allocentric neglect, but provides no further evidence that neglect can operate in an object-centred frame of reference.

Savazzi, Neppi-Mòdona, Zettin, Gindri, and Posteraro (2004) conducted a study investigating the effects of experimentally determining the viewer-centred left-right orientation of an object when the object is later presented in the opposite direction. They experimentally established the viewer-centred left-right orientation by repeatedly displaying the object to the participants in a particular orientation during a line-bisection task. Participants in their study consisted of ten patients with right-hemisphere damage and one patient with left-hemisphere damage, all with evidence of contralesional neglect. The patients were required to bisect 20cm-long line drawings of a basset hound individually presented on a sheet of paper that was positioned aligned with the midline of the patients. The participants completed twenty trials repeated in five separate sessions. In fifteen trials, the basset hound was oriented with its head on the right side of space and its tail on the left side of space. In the last trial the stimulus orientation was reversed so that the basset hound now had its head in the left side of space. In four trials interspersed throughout each session, the basset hound was oriented vertically. The results demonstrated a reversal in the direction of the bisection error in the final reversed stimulus presentation for three of the patients. Although the bisection error was not reversed, it was markedly reduced in one other patient. Savazzi et al. interpreted these findings as evidence that reversal of the left-right canonical orientation of a stimulus may induce a reversal from contralesional to ipsilesional neglect. For the remaining patients, the reversal of the stimuli did not affect their bisection error, and they continued to manifest a rightward bisection error as defined according to a viewer-centred representation.

To investigate whether the above results were due to the head of the basset hound being the more informative feature of the drawing, and the head therefore drawing the patients' attention to the left side of the page in the reversed trials, Savazzi et al. (2004) conducted a second experiment where the orientation of the stimulus was reversed. That is, in fifteen trials the head of the basset hound was located on the left side of the page, whereas its tail was located on the right side of the page. Again, the orientation of the stimulus was reversed in the last trial so that the head was now positioned on the right side of the page. Thirteen patients with right-hemisphere damage and contralesional neglect participated in the second study. Results again demonstrated a reversal in the direction of the bisection error in three patients in the last trial. Three patients also experienced a reduction in their rightward bisection bias. Savazzi et al. proposed that familiarisation with the stimulus (the basset hound), through repeated exposure, anchored neglect to one side of the basset hound, and directly contributed to the reversal of neglect observed in a few patients in the 'reversed' condition. They suggested that the complete reversal of the bisection error can be attributed to object-centred neglect. Furthermore, they proposed that the decrement of the rightward bias observed in a few other patients is best explained by the co-occurrence of neglect in viewer- and object-centred frames of reference, whereas they suggested that the results for the remaining patients who demonstrated no error variation in the tasks was evidence of viewer-centred neglect.

Savazzi, Mancini, Veronesi, and Posteraro (2009) have more recently made strong claims of finding evidence of object-centred neglect in a study similar to that of Savazzi et al. (2004). Savazzi et al. (2009) raised the possibility that Savazzi et al.'s

(2004) findings were due to the patient expecting to see a particular part of the stimulus (either the head or the tail), and therefore making more effort to search for this part in the last mirror-reversed trial, thereby contributing to the reversal or reduction in the right-side bisection error. They designed another experiment aiming to control for this possibility by utilising nonsense stimuli consisting of lines with a square and circle positioned on the left and right end. They argued that their nonsense stimuli were less salient than the stimuli used by Savazzi et al. (2004), and reasoned that this should therefore minimise the possibility of the participant searching for the more familiar part of the stimulus. Participants consisted of 19 patients with damage to the right hemisphere. Of these, 14 demonstrated neglect and the remaining five patients served as controls. The task was largely identical to Savazzi et al.'s (2004) task, and the participants were required to centrally bisect the stimuli presented individually on a sheet of paper presented at the midsagittal plane of the participant's body. Instead of only one mirror-reversed trial, Savazzi et al. (2009) included three mirror-reversed trials at the end of each session. The rationale for this was to investigate whether the reversal or reduction of the rightward bias was stable and to thereby also provide further evidence against the 'familiarity' effect. They hypothesised that if the results were due to a 'familiarity' effect, then the patients should progressively bisect the lines further toward the right (as defined by a viewer-centred frame of reference) in the mirror-reversed trials. In contrast, they suggested that if the bias is stable in the mirror-reversed condition, the results would provide firm evidence of neglect operating in an object-centred frame of reference. Savazzi et al. (2009) also requested participants to draw the stimuli following the bisection trials. They argued that if the patient drew the stimulus in the 'original' canonical presentation, despite it being presented mirror-reversed in the last three trials, this would provide further support for an object-centred explanation of the results. Results demonstrated no effect of presentation (of the stimuli) with the control participants. The results from patients with neglect replicated the findings of Savazzi et al. (2004). As a group, the patients in Savazzi et al.'s (2009) study demonstrated a reduction in their rightward bias in the mirror-reversed condition. Individual data analysis demonstrated that the bisection error was reversed in one patient, and reduced in four other patients. The observation that the participants' bisection error was stable (and was not reduced) over all three trials (rather than just the one reversal trial) in the mirror-reversed condition was interpreted as evidence that the effect was due to neglect in an object-centred frame of reference and not because of a 'familiarity' effect. Savazzi et al. (2009) interpreted these results as evidence of object-centred neglect, and stated that "even nonsense objects can produce a higher-order, viewer-independent, canonical orientation of such an object, and neglect of the left-side of such canonical representations can occur" (p. 5). They interpreted the results from nine (of fourteen) patients who reliably drew the nonsense stimulus according to its original presentation after completion of the mirror-reversed trials as further evidence that the object was coded according to a high-level viewer-independent representation, even though this pattern of results was also evident in three of the five control patients.

Despite Savazzi et al.'s (2009) excitement about their findings, it can still be argued that the handedness of their stimuli (and the stimuli used by Savazzi et al. 2004) is imposed by the viewer, and not by stimulus-invariant properties. Therefore, it cannot be argued that their results reflect object-centred neglect. Instead, their findings are ultimately due to a stimulus-, or viewer-centred representation. As the stimuli were presented at the midsagittal plane of the participants' body, the experiments do not disentangle the stimulus-centred frame of reference from the viewer-centred frame of reference, and the results may therefore be due to neglect in a stimulus-centred frame of reference and/or viewer-centred neglect. In objects with a canonical (or intrinsic) left and right side, the handedness is constant, which cannot be argued in the case of the so-called 'canonical' handedness of the stimuli utilised by Savazzi et al. (2004, 2009).

From the evidence considered in the current section, it is clear that neglect can operate in a stimulus-centred frame of reference. Most of the experiments were completed in conditions of free viewing. As was discussed in relation to drawing and copying tasks, and studies of perceptual parsing, the stimulus-centred frame of reference is confounded with the viewer-centred frame of reference when the object to be responded to is positioned on the midsagittal plane of the patient's body, or when the patients shifts attention from one object in the scene to another. Driver et al. (1992) and Pavloskaya et al. (1997), however, have documented firm evidence of stimulus-centred neglect, due to their experimental requirements for maintaining central fixation and/or by presenting stimuli briefly and thereby preventing more than one fixation during stimulus exposure. Results from Di Pellegrino et al. (1995) and Hillis and Rapp's (1998) reanalysis of Farah et al.'s (1990) raw data suggest that neglect may operate in an object-centred frame of reference but it has been argued that the division of left and right in objects without intrinsic handedness is dependent on viewpoint. The imposition of handedness in these objects is therefore not independent from a viewer-centred representation and may therefore be better accounted for by neglect in a viewer- and/or stimulus-centred frame of reference.

Evidence for Stimulus-Centred Neglect from Reaction Time Tasks

Baylis, Baylis, and Gore (2004) published results documenting the co-occurrence of scene-based and object-based neglect for individual patients with neglect. Furthermore, these authors demonstrated that the frame of reference of visual neglect can vary within one task depending on task instructions. Three patients with contralesional neglect following left- or right-hemisphere damage were presented target letters, located in one of four possible locations on a computer screen. The different displays were created with two large shapes, one centred on the left and one centred on the right half of the display. The two shapes overlapped the two possible target locations in their respective side of the display, and were represented in different colours. The participants were required to detect a target letter that was equally likely to occur in any of four possible locations in the display. There were two conditions: (a) target letter was to be reported irrespective of its position in the display (scene-based task); (b) target letter was to be reported only if it was located within a specified shape in the display (object-based task). The stimuli and detection task were kept constant, and only the task instructions changed. In the scene-based task, participants were slower to report target letters presented in the contralesional side of the computer screen, a finding interpreted as evidence of scene-based neglect. In the object-based task there was no difference in reaction times between the left and right side of the display. Instead, the participants were slower at detecting targets located in the left side of the individual shapes in the display, a finding interpreted as evidence of object-based neglect. Baylis et al. stated that their results illustrate that the frames of reference in neglect can co-occur in the same individual, and can be changed with different task instructions. They suggested that the instructions provided to the patients in their study might have contributed to "the definition of a task-relevant region in the display – either the entire display or a single object within the display" (p. 245). For this reason, they proposed that neglect would be manifested on the contralesional side of the task-relevant region, which could be the left side of a display or the left side of individual objects within the display. In theory, this means that one should be able to elicit viewer-, stimulus-, and object-centred neglect within the same task *without* the modification of task instructions. An example of this would be inclusion of a procedure that required the patient to attend to the entire display as well as individual objects within the display simultaneously. (The Ota et al. (2001) discriminative-cancellation task is an example of such a task.)

Tipper and Behrmann (1996) investigated whether visual neglect can operate in object-centred coordinates. This study was based on the observation that the allocation of attention to an object by neurologically healthy individuals prior to motion can accompany the object, and thus facilitate its processing in a subsequent novel spatial location. Tipper and Behrmann presented patients, as well as a group of eight age-matched controls without a history of neurological injury, with a display containing two circles (one coloured red and the other blue). In one part of the experiment, the two circles were disconnected, whereas in the other part they were connected with a horizontal bar to form a barbell. The participants' task was to make a judgment as to whether a target was present in one of the circles. There were two experimental conditions. In the *static* condition, the stimuli remained stationary, whereas in the *moving* condition, the stimuli revolved 180° around the central midpoint in a clockwise or counterclockwise direction. Following rotation, the two circles had replaced each other's position, thus setting the side of space and the side of the stimulus in opposition. Tipper and Behrmann hypothesised that if attention accesses an object-centred frame of reference, then target detection should be inhibited in the right side of space following rotation of the connected display because the neglected left side of the object would now appear in the ipsilateral side of space. Furthermore, a facilitation of target detection should be observed in the left side of space following rotation of the barbell, since the well-attended right side of the object would now appear in the contralateral side of space. This pattern of results, however, should only be observed with the connected display, where the two circles were joined to form a single object, and not when the two circles were disconnected, as these would appear as two separate objects. There were no significant results in the reaction times of the control participants. Consistent with predictions, the patients were found to have an inhibition in target detection on the right and facilitation in target detection on the left following rotation of the connected stimuli relative to the static condition, but not following rotation of the disconnected stimuli. The same pattern of results was also observed when eye movements were controlled. Tipper and Behrmann interpreted the observed modulation of neglect as clear evidence that attention can be allocated within an object-centred frame of reference. If neglect had operated in an object-centred frame of reference *only*, one would have expected a complete reversal of target detection from the contralateral to the ipsilateral side space in the connected display. As target detection was improved, but not completely reversed, Tipper and Behrmann suggested that this is due to neglect simultaneously operating in location-based representations. Based on these findings, they concluded that attention can operate in more than one frame of reference simultaneously.

Behrmann and Tipper (1999) later replicated and extended the findings from the study above. They sought to further investigate whether location-centred (viewer/environment-centred) and object-centred neglect can be observed concurrently in the same task. Six patients with neglect were selected to participate, based on their demonstration of object-centred neglect on the task designed by Tipper and Behrmann (1996). The experimental design was similar to that of Tipper and Behrmann, but in addition to the rotating barbell, they also included two static squares, which were always present in the stimulus display. The squares were located on the left and right side of the display, and they were not connected. One circle of the barbell was located immediately above the left square, whereas the other circle was located immediately below the right square. Following rotation, the circle previously located above the left square would now be situated immediately above the right square, whereas the other would now be positioned immediately below the left square. Thus, the line connecting the two circles in the barbell would move from 45° to the left of vertical to 45° to the right of vertical, or vice versa (see Figure 5).

Behrmann and Tipper (1999) predicted that if location- and object-centred neglect can occur simultaneously in the same task, then the left static object (the square) should be neglected *as well as* the left rotating barbell, even after rotation of the barbell so that the object-centred left is located in the right side of space. They stated that a comparison between the static and moving conditions would provide an indication of the relative influence of object-centred neglect. Neglect of the static object (the square) would indicate location-centred neglect, while neglect of the barbell would indicate neglect in an object-centred frame of reference. Participants were required to detect targets appearing in either one of the squares or one of the two circles of the barbell (and on one third of trials there was no target). Patients were highly accurate in detecting the target, however, reaction times varied depending on target location. As predicted, the reaction time data for the moving barbell replicated the findings of Tipper and Behrmann (1996). That is, following rotation of the barbell, there was inhibition in target detection on the right and facilitation in target detection on the left (as defined by viewer-centred coordinates), which was indicative of object-centred neglect. In comparison, patients were slower in detecting targets appearing on the left of the static objects, irrespective of barbell rotation. This latter finding was interpreted as evidence of location-centred neglect. Thus, a left-side disadvantage was observed both on the left as defined in a viewer-centred frame of reference and on the left according to object-centred coordinates, even when the object-centred left occurred in the right side of space. Behrmann and Tipper concluded that neglect can operate in both object- centred and location-centred frames of reference simultaneously. Although the results from the studies of Baylis et al. (2004), Tipper and Behrmann, and Behrmann and Tipper indicate an object-centred *deficit* as reflected in reaction times, it should be noted that the patients were able to detect the left-side targets. The conclusions of object-centred neglect were therefore based on a relative reaction time disadvantage rather than a failure to actually report stimuli on the left in both the viewer- and object-centred frame of reference.

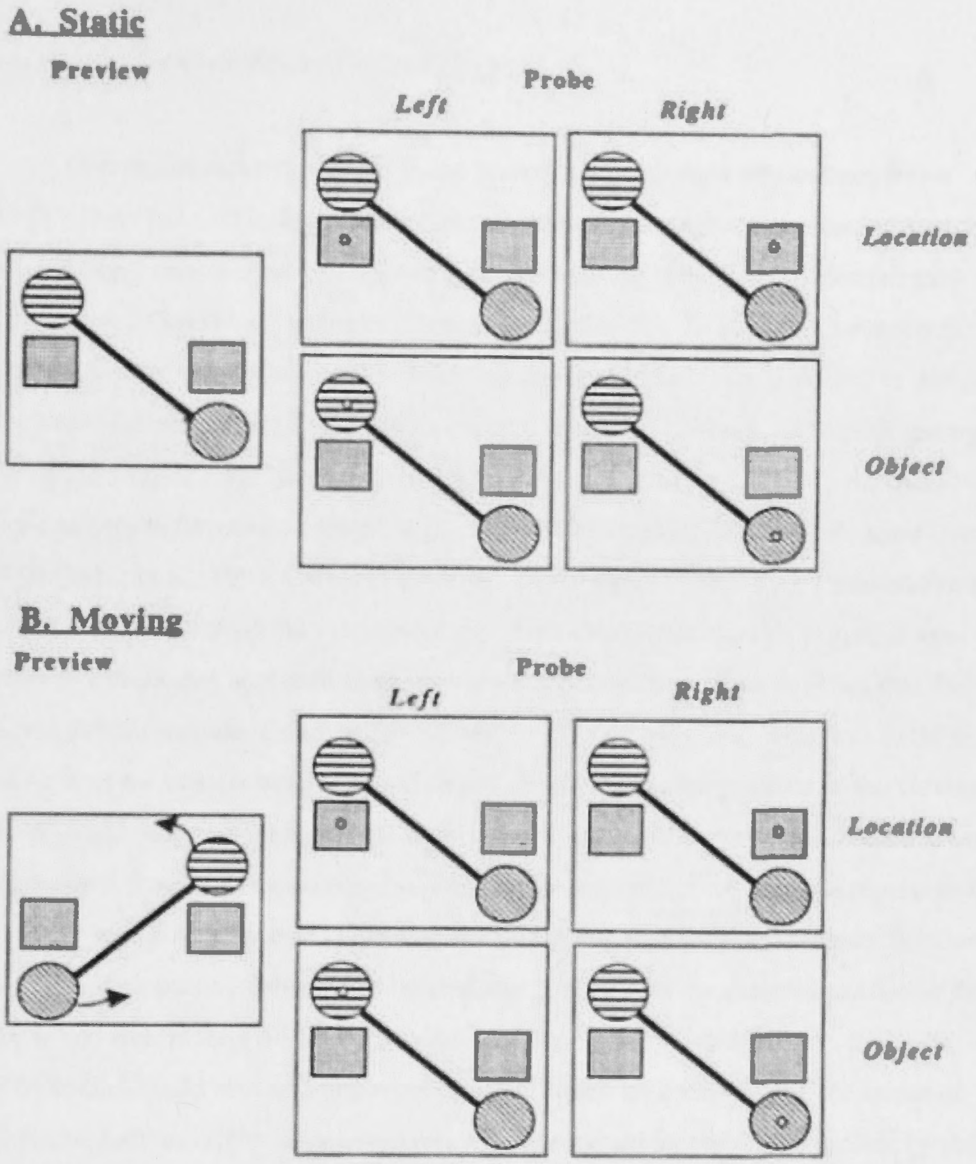

Figure 5. Illustration of the stimuli used by Behrmann and Tipper (1999): (A) static condition, and (B) moving condition. Target probes can be seen in one of the squares or in one of the circles (figure adapted from Behrmann & Tipper, 1999).

Evidence for Intrinsic Object-Centred Neglect

One might argue that the division between left and right when based on an object's principal axis is dependent on viewpoint: only the separating line between left and right may be imparted by allocentric co-ordinates of the object's principal axis, whereas handedness may be imposed on either side of this division in an egocentric manner. For this reason, the evidence for 'object-centred' neglect discussed to this point may better reflect neglect in a stimulus-centred frame of reference, as the left and right side of the stimulus will depend on the side of the axis from *the viewer's perspective.* Previous results for object-centred neglect (e.g., Chatterjee, 1994; Di Pellegrino et al., 1995; Driver et al., 1994; Driver & Halligan, 1991; Farah et al., 1990; Pavlovskaya et al., 1997) may therefore have depended on which side of the object's principal axes the letters or differences appeared from the viewer's perspective. That is, given that the studies did not include stimuli with an intrinsic left and right side, what was to the left and right of the objects would have changed depending on the position of the viewer. The findings may ultimately be due to a stimulus-centred representation, which is not independent from a viewer-centred representation, and therefore does not represent firm evidence for the existence of neglect in an object-centred frame of reference. Similarly, for the reasons outlined above, the handedness imposed on the stimuli included in the Tipper and Behrmann (1996), Behrmann and Tipper (1999), and Savazzi et al. (2004, 2009) studies could also reflect a representation based on a viewer-centred frame of reference. Left and right of these stimuli was determined by the division made by the principal axis, and handedness was imposed in an egocentric manner as it depended on the location of these sides with respect to the viewer.

Driver and Pouget (2000) also criticised interpretations of previous results as object-centred neglect, and argued that most of these findings can be explained in terms of neglect in an egocentric frame of reference. In particular, they noted that an egocentric gradient of impairment could provide an explanation for findings of neglect in an object-centred frame of reference. According to this view, the neural response to stimuli is gradually impaired toward the patients' left (as defined by an egocentric frame of reference). The left side of individual objects will invoke a weaker response compared to the right side, irrespective of position within the visual field. Driver and Pouget therefore argued that several of the previous findings of object-centred neglect (e.g., Driver & Halligan, 1991; Driver et al., 1994; Pavlovskaya et al., 1997) can be attributed to egocentric neglect. Driver and Pouget suggested several alternative explanations for the findings of Pavlovskaya et al. (1997). They proposed that the results could be explained purely by the egocentric gradient of impairment outlined above. Furthermore, they noted the possibility that fixating on a particular region of the object may have boosted its representation, causing an exaggeration in the left-right gradient when the patients fixated on the right side of the object with the opposite effect with fixation on the left side of the object. Driver and Pouget acknowledged that object-centred representations may exist, but concluded that these cannot be demonstrated by merely comparing left-right differences in performance when stimuli are displayed in different lateral positions.

Behrmann and Moscovitch (1994) are in agreement with Driver and Pouget's (2000) perspective, and have argued that attentional allocation within an object-centred frame of reference is unnecessary if object identification does not require specification of the canonical left and right side of that particular object. In objects with an intrinsic handedness, however, an object's left and right side needs to be specifically marked and maintained to ensure accurate representation of the object. Therefore, Behrmann and Moscovitch claim that one is not able truly to conclude that attention can be allocated within an object-centred frame of reference without demonstrating neglect for objects with an intrinsic handedness, independent of the spatial location of the left side of these objects with regard to viewer- and environment-centred coordinate systems. Behrmann and Moscovitch expected the distribution of attention to be influenced by an object-centred frame of reference *only* in inherently asymmetrical objects (such as the letter 'B'), in which an intrinsic principal axis is necessary to maintain the canonical representation. Before their findings are discussed, it is important to consider the work of Laeng, Brennen, Johannessen, Holmen, and Elvestad (2002) and Caramazza and Hillis (1990a, 1990b), who have also used objects with an intrinsic left and right side in the investigation of object-centred neglect.

Laeng et al. (2002) investigated whether the neglect observed in their patient (AE) was restricted to one specific frame of reference or better explained by the co-occurrence of neglect in several frames of reference. Two neurologically healthy control participants also participated. The task was to identify the colours of two cubes, one positioned in the left hemispace and the other in the right hemispace. The time taken to name the colours was measured separately for the two cubes. The participants were informed that there would always be two cubes present, and they were asked to name the colours of both cubes as quickly as possible. Between trials, participants closed their eyes while the cubes were arranged for the next trial. During the experiment, the cubes were either positioned on a table in front of the participants or were held by the experimenter, one in each hand. In the latter condition, by holding the cubes, the experimenter's role was as an extension of the object. All frames of reference were aligned when the experimenter had her back toward the patient. In contrast, when the experimenter rotated from having her back toward the patient to facing the patient, the object-centred frame of reference could be disambiguated from the viewer-centred reference frame by exhibiting the left side of the object (the cube held in the experimenter's left hand) in the right side of space for the participant. Laeng et al. predicted that if Patient AE experienced neglect in viewer- and object-centred frames of reference, then reaction times would be slowest when the cube was held in the experimenter's left hand and at the same time also located in the left side of space for the participant (when the experimenter had her back to the participant). In this case the viewer- and object-centred frames of reference were aligned. Results demonstrated that the patient and the control participants were accurate in their colour reporting and never failed to report the colour of the two cubes. As predicted, Patient AE's worst performance occurred when the experimenter held the cube with her left hand and the cube was also located in the contralesional left side of space for the patient (both frames of reference were aligned). The performance improved when the experimenter held the cube in her right hand and faced the patient so that the cube was in the left hemispace of the patient. The performance further improved when the experimenter held the cube with her left hand in the right hemispace of the patient. Patient AE achieved the fastest reaction time when the cube was held with the experimenter's right hand, which was in the right hemispace for the patient. Overall performance was worse in the left side of space than in the right side of space. Neither hemispace nor body orientation affected the reaction times of the control participants.

Laeng et al. (2002) further investigated the importance of the object-centred frame of reference as separated from the viewer-centred frame. Patient AE performed the same task as in the previous experiment, but this time by viewing the experimenter holding the cubes in a mirror. In this condition, the experimenter stood behind the patient's back. The patient viewed the experimenter in a mirror positioned in front of him. Without the mirror, the experimenter's left hand when the experimenter faced the patient, was located in the right side of space for the patient. But, when viewed in the mirror, the experimenter's left hand was now positioned in the left side of space as seen by the patient. Similarly, without the mirror, the experimenter's left hand, when the experimenter was positioned with her back toward the patient, was located in the left side of space for the patient. When viewed in the mirror, the experimenter's left hand was now positioned in the right side of space as seen by the patient. Laeng et al. predicted the same pattern of results as they obtained in their previous study. In accordance with predictions, when viewed in the mirror, Patient AE was slowest to report the colour of the cube held by the experimenter's left hand with the experimenter facing the patient. In this condition, the cube was located on the left side of the patient as defined by both viewer- and object-centred frames of reference. Performance was better when the experimenter held the cube in her left hand with her back toward the patient. Although the cube was now in the experimenter's left hand, it was located on the right side of space as seen by the patient. There was no further improvement in performance as an effect of hemispace and body orientation. Overall, AE was once again slower in the left hemispace than in the right hemispace. The main effect for body orientation also demonstrated that AE was slower when the experimenter faced him in the mirror than when she had her back toward him. Hemispace and body orientation had no effect on the control participants' reaction times. The authors interpreted these findings as evidence that neglect can occur simultaneously in both viewer- and object-centred frames of reference, and argued that they achieved the same effects as documented by Tipper and Behrmann (1996). That is, facilitation of target detection on the left following rotation of the left side of the object (the experimenter's hand) into the right side of space for the patient. Laeng et al. concluded that this was evidence for object-centred neglect as the intrinsic left side of the object (the experimenter's left hand) contributed to the neglect.

Two points are important to make about Laeng et al.'s (2002) study. The first of these points was discussed above as it also applies to the experiments conducted by Baylis et al. (2004), Tipper and Behrmann (1996), and Behrmann and Tipper (1999). Patient AE was always able to name the colour of the cube on the left side in both viewer- and object-centred coordinates. Therefore, although Laeng et al. (2002) have demonstrated an elegant way to disambiguate the object-centred frame of reference from the viewer-centred frame of reference, the conclusions are based on a relative reaction time disadvantage rather than a failure to actually report stimuli on the left in these frames of reference. This indicates that the pattern of results does point to the existence of an object-based effect, but one cannot conclude that this patient experienced *neglect* of objects in an object-centred frame of reference. The second point is that the task was to name the colour of the cubes held in the experimenter's left or right hand. The objects therefore did not constitute a part of the experimenter's body, which was the object used to dissociate the object-centred from the viewer-centred frame of reference. In other words, the manipulation of the object-centred frame of reference was irrelevant to the task of identifying the colour of the cubes. Driver and Halligan (1991) have put this same argument forward as a potential explanation for Farah et al.'s (1990) failure to find evidence of object-centred neglect. Although the manipulation by Laeng et al. does appear to separate the object-centred from the viewer-centred frame of reference, the object-centred effect would be much more convincing if the patient's task had been to name or identify something that was part of the object itself. This could for example be achieved if the experimenter had worn multi-coloured sleeves or gloves, and the task was to name as many of the colours as possible.

Perhaps the clearest and most undisputed evidence of object-centred neglect has come from the work of Caramazza and Hillis (1990a, 1990b) in the area of neglect dyslexia. Their Patient NG demonstrated right-side neglect following a stroke in the left hemisphere. Patient NG was required to read and write words of various lengths. When the word was printed horizontally, all reference frames were aligned. The word-centred frame of reference was disambiguated from the viewer- and stimulus-centred frames of reference by displaying the words vertically and mirror-reversed. Results demonstrated that NG's errors in reading and spelling occurred only on the right side of a word (that is, the end of a word), irrespective of whether the letters were presented in horizontal, vertical, or mirror-reversed form. In other words, NG's errors involved the canonical right side of words even when the right side was located on the left side as defined by viewer- and stimulus-centred coordinates, a finding interpreted as evidence of word-centred neglect.

In a series of studies, Behrmann and Moscovitch (1994) required patients with neglect to report outline colours of objects and letters. The objects were rotated 90° to the left and right of upright to disambiguate the object-centred frame of reference from the viewer/environment-centred frame of reference, and the object-centred frame of reference from the stimulus-centred frame of reference. With upper-case asymmetrical letters, such as the letters P, R, and E, the straight line is always the left side of the object as defined by an object-centred frame of reference, irrespective of orientation. In contrast, the left side as defined by a stimulus-centred frame of reference will depend on the orientation of the letter. If the letter is rotated 90° to the left, the left side of the stimulus is now the top half of the letter, but when rotated to the right, the left side is now the bottom half of the letter. The object- and stimulus-centred frames of reference can also be disambiguated by parity. Again the left side of the letters would be the straight line in an object-centred frame of reference, irrespective of parity. But when displayed upright in backward parity, the straight line would be the *right* side as defined by a stimulus-centred frame of reference. Behrmann and Moscovitch (1994) tested five patients with neglect in their first experiment. These patients first named the pictures presented (objects and animals), and then reported the outline colours of these real world stimuli. Results demonstrated that the patients reported fewer colours on the left compared to the right side of the picture as defined by a viewer/environment-centred frame of reference. There was no difference between the number of colours reported on the left and right side of the objects as defined by an object-centred frame of reference. That is, irrespective of the objects' orientation, the patients continued to manifest neglect in a viewer/environment-centred frame of reference *only,* by reporting fewer colours on the left as compared to the right side of the letters when left and right was defined by the patients' midline.

In Behrmann and Moscovitch's (1994) second experiment, seven patients with neglect first named and then reported the outline colours of uppercase asymmetrical letters with an intrinsic left and right side. The patients reported fewer outline colours on the left as compared to the right side of the letters when viewer/environment- and object-centred frames of reference were aligned. But in this experiment, patients also reported fewer outline colours on the left side of the letters as defined by an object-centred frame of reference. To investigate whether the object-centred effect can also occur with symmetrical letters, Behrmann and Moscovitch replicated their second experiment. Six patients with neglect were tested. Once again, the task was to name the letter before reporting the outline colours. Viewer- or environment-centred neglect was evident for both asymmetrical and symmetrical letters; patients reported fewer outline colours from the left as compared to the right side of the letters as defined by a viewer/environment-centred frame of reference. There was also evidence of object-centred neglect, however, this effect was present with asymmetrical letters *only,* and not with symmetrical letters. That is, patients reported fewer outline colours on the intrinsic left side of asymmetrical letters, but there was no left-right difference on symmetrical letters or pictures of objects or animals that did not have an intrinsic left and right side. Behrmann and Moscovitch interpreted their findings as evidence for the notion that for objects with no inherent left-right handedness it is unnecessary to mark and distinguish the two sides, as handedness in these objects is determined exclusively in a stimulus-centred manner. For this reason, Behrmann and Moscovitch maintained that objects with a canonical left and right side are required to demonstrate object-centred neglect. Based on their findings, Behrmann and Moscovitch concluded that regardless of orientation, it is the intrinsic handedness of the object that gives rise to object-centred neglect of asymmetrical stimuli.

Behrmann and Moscovitch (1994) examined the individual patient data in their study, and found that four of the six patients exhibited evidence of both object- and viewer/environment-centred neglect, whereas two patients demonstrated viewer-centred neglect *only*. Note that this pattern is similar to what was found in Hillis and Rapp's (1998) reanalysis of Farah et al.'s (1990) data. These findings illustrate the importance of single-case studies in the study of rare neurological disorder, as interesting results from individual patients may be washed out when combined with results from a group of patients.

Summary

The literature reviewed illustrates that the term 'object-centred neglect' remains an ambiguous concept, at least for non-word stimuli. The terms stimulus-centred and object-centred have been used interchangeably despite their different meanings. The review has outlined a number of studies providing evidence of neglect in a stimulus-centred frame of reference. In contrast to the numerous demonstrations of stimulus-centred neglect, the evidence of neglect occurring in an object-centred frame of reference is scarce. Only a few researchers, such as Caramazza and Hillis (1990a, 1990b), Behrmann and Moscovitch (1994), and Laeng et al. (2002) can claim to have found some evidence for 'true' object-centred neglect. But even the evidence of object-centred neglect provided in the studies of Laeng et al. has been questioned. Laeng et al. demonstrated an object-centred effect in that their patient with neglect was slower to report the the colour of a cube when positioned on the intrinsic left side of an object than when it was positioned on the intrinsic right side of an object. But even though their patient was slower to report the cube positioned on the intrinsic left side of an object, he was always able to *report* the colour of the cube. Given that he never failed to report the cube, this result cannot be interpreted as object-centred neglect.

Perhaps the clearest and most undisputed evidence of object-centred neglect comes from the study conducted by Caramazza and Hillis (1990a, 1990b). Caramazza and Hillis provided evidence of object-centred neglect of the right side of words in a patient with a left-hemisphere brain injury. Outside the area of neglect dyslexia, however, only Behrmann and Moscovitch have been able to provide 'firm' evidence of object-centred neglect on the intrinsic left side of individual objects.

Outline for Experiments

The goal of the first section of this thesis is specifically to examine whether visual neglect can occur in an object-centred frame of reference, and to introduce our new 'Æ' letter-cancellation task to disambiguate viewer-, stimulus-, and object-centred neglect. All patients were first administered the Ota et al. (2001) discriminative-cancellation task, in which participants were required to circle complete stimuli and to cross out incomplete stimuli. Failure to circle complete stimuli or to cross out incomplete stimuli on the left side of the page is an indication of viewer-centred neglect. Placing a circle around incomplete stimuli with a left gap on either side of the page is an indication of stimulus-centred neglect. All patients were then administered our new 'Æ' letter-cancellation task. The aim was, not only to distinguish viewer- from stimulus-centred neglect (left of viewer versus left of stimulus), but also to distinguish stimulus- from *object-centred neglect* (left of stimulus versus canonical left side of object). The circle (or triangle) stimuli in the original Ota et al. cancellation task were replaced with the Norwegian letters 'A', 'E' and 'Æ'. The viewer-, stimulus-, and object-centred frames of reference were disambiguated by displaying the letters across the page, in normal and backward (mirror-reversed) parity, and in each of eight different angles of orientation (presented in 45° increments rotated clockwise from upright 0°). Omissions on the left side of the page are an indication of viewer-centred neglect, while errors in following instructions with respect to the letter 'Æ' on both sides of the page are interpreted as either stimulus- or object-centred neglect. Neglect in an object-centred frame of reference is neglect of the canonical left side of the letter 'Æ', the 'A' part of the letter, irrespective of parity and angle of orientation. In contrast, neglect in a stimulus-centred frame of reference is neglect of the 'A' part of the letter 'Æ' only when it is located on the left side as defined by a stimulus-centred frame of reference.

In Chapter 2 we introduce our new 'Æ' letter-cancellation task and present the results from five Norwegian patients tested using the task designed by Ota et al. (2001) and our new 'Æ' letter-cancellation task. The data from both tasks are analysed using a group design and as individual cases, to demonstrate the importance of single-case analysis in the investigation of a rare neurological disorder such as persisting unilateral neglect.

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Chapter 2

Disambiguating Viewer-, Stimulus-, and Object-Centred Neglect: Five Patients with Visuospatial Neglect

**Disambiguating Viewer-, Stimulus-, and Object-Centred Neglect:
Five Patients with Visuospatial Neglect**

General Methods

Participants

Participants consisted of five patients with persisting neglect, and three neurologically healthy individuals (two females and one male; age range: 55 to 62 years). The neurologically healthy participants were right-handed (M = 93.94; SD = 10.50, where -100 indicates extreme left handedness and +100 indicates exclusive right handedness) according to the Edinburgh Handedness Inventory (Oldfield, 1971), and they had not suffered previous neurological injury or illness. Norwegian was the first language of all participants and none of the participants had dyslexia.

All patients were recruited from St. Olavs Hospital in Trondheim (Norway). The study was approved by the Mid-Norway Regional Committee for Medical Research Ethics and the Human Research Ethics Committee at the Australian National University. Tests were conducted in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki. All participants read an explanatory statement containing information regarding the study and signed a consent form prior to their participation. The neurologically healthy participants were paid $5/hour for their participation.

Neuroimaging

Case descriptions relating to brain damage for patients HH, BN, JF and HT were provided by the neuroradiologist at St. Olavs hospital and they are based on all available data, including previous clinical scans and the research scans acquired for this study.

A research MRI was *not* conducted for patient VR because the he died before the study was completed. Patient VR was a 52-year old right-handed (*Laterality Quotient* = 100; where -100 indicates extreme left handedness and +100 indicates exclusive right handedness; Oldfield, 1971) Norwegian man who had suffered a middle cerebral artery stroke in 2004.

Brain images were acquired using a 3T Intera MRI whole body scanner (Philips Medical Imaging, Best, Netherlands). After a scout-scan, AC-PC aligned axial, sagittal and coronal T2-weighted (TR=4540 ms, TE=97 ms, NEX=1, slice thickness = 5.91 mm, pixels = 0.60 x 0.60 mm, FOV = 336 x 384) or FLAIR (TR=9000 ms, TE=114 ms, NEX=1, slice thickness = 5.91 mm, pixels = 0.72 x 0.72 mm, FOV = 280 x 320) images were acquired followed by a 3D T1-weighted SPGR coronal sequence (TR=8.4644 ms, TE=3.8916 ms, NEX=1, slice thickness = 1.00 mm, pixels = 0.9375 x 0.9375 mm, FOV = 256 x 256), using a Philips 8-channel head coil. T1-weighted images were then converted to isotropic dimensions (1.00 mm^3). Acquisitions were repeated if the patient moved excessively creating image artifact. Total scanning time for each patient was approximately 30 minutes.

Patient HH is a 64-year old right-handed Norwegian man. He has a severe left hemiparesis and is confined to a wheelchair. A research MRI conducted for this study (see Figure 1) showed evidence of a very large right-hemisphere infarct, with gliosis. The infarct extended to the basal ganglia and thalamus on the right side. There were small areas spared in the basal and medial parts of the frontal lobe, basal parts of the temporal lobe, and medial parts of the occipital lobe. Secondary to extensive substance-loss, there was atrophy of the right crus cerebri, Wallerian degeneration of the corticospinal pathways in the pons, and there was no flow signal in the right internal carotid artery. There was also evidence of secondary expansion of the right ventricle. In the left hemisphere, there were small unspecific white-matter lesions, but this was unremarkable.

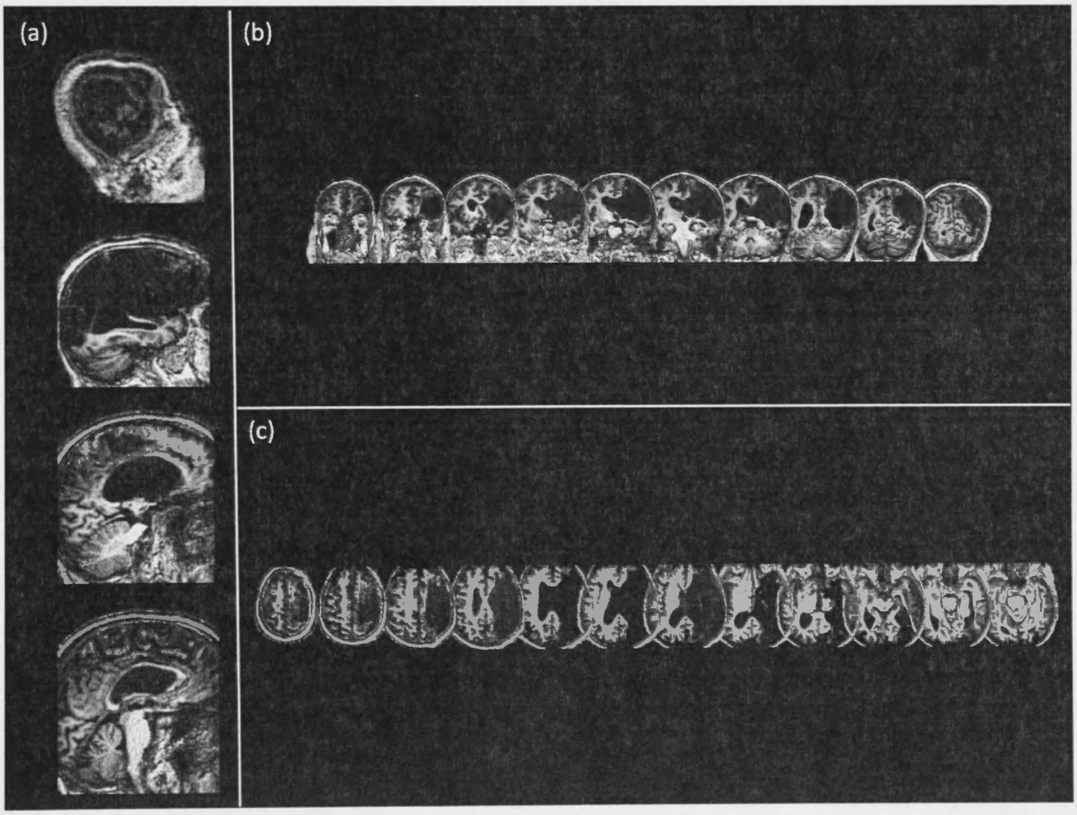


Figure 1. T1-weighted brain MR images of patient HH:

(a) Sagittal from right to midsagittal in steps of 21mm

(b) Coronal from frontal to occipital in steps of 15mm (from left to right)

(c) Axial from top to bottom in steps of 8mm (from left to right).

Patient BN is a 66-year old right-handed (*Laterality Quotient* = 100; Oldfield, 1971). He suffered a middle cerebral artery infarct in 2004, with damage to the right temporal-occipital region, and, in 2005, he suffered a new large infarct of the right basal ganglia including the right caudate nucleus. A research MRI conducted for this study (see Figure 2) showed evidence of a right-hemisphere infarct, which extended to large parts of the right temporal lobe where there was necrosis of basal and medial parts. The area of the infarct included the right basal ganglia and thalamus. The hippocampus was atrophic. There was substance loss and gliosis, with changes extending posteriorly to the basal parts of the right occipital lobe. Secondary to substance loss, there was an expansion of the right ventricle.

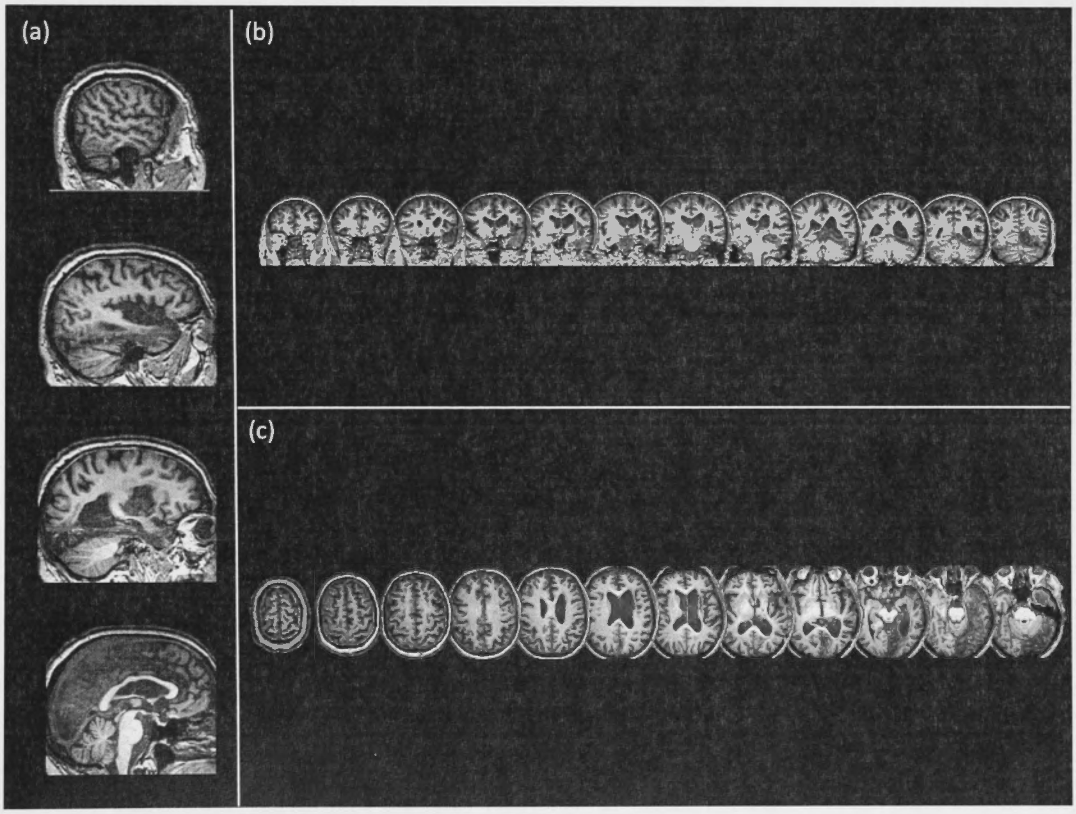


Figure 2. T1-weighted brain MR images of patient BN:

(a) Sagittal from right to midsagittal in steps of 21mm

(b) Coronal from frontal to occipital in steps of 10mm (from left of page)

(c) Axial from top to bottom in steps of 8mm (from left of page).

Patient JF is a 47-year old right-handed (*Laterality Quotient* = 82; Oldfield, 1971) Norwegian man with 12 years of education. He suffered a ruptured arteriovenous malformation in the Sylvian fissure of the right hemisphere. Patient JF has a severe left hemiparesis and is confined to a wheelchair. A research MRI conducted for this study (see Figure 3) showed evidence of a right-side craniotomy, substance loss in large areas of the right temporal lobe and in basal lateral parts of the frontal lobe, and gliosis. Secondary to substance-loss, there was atrophy of the right side of the crus cerebri and Wallerian degeneration of the brain stem. There was also evidence of secondary expansion of the right ventricle.

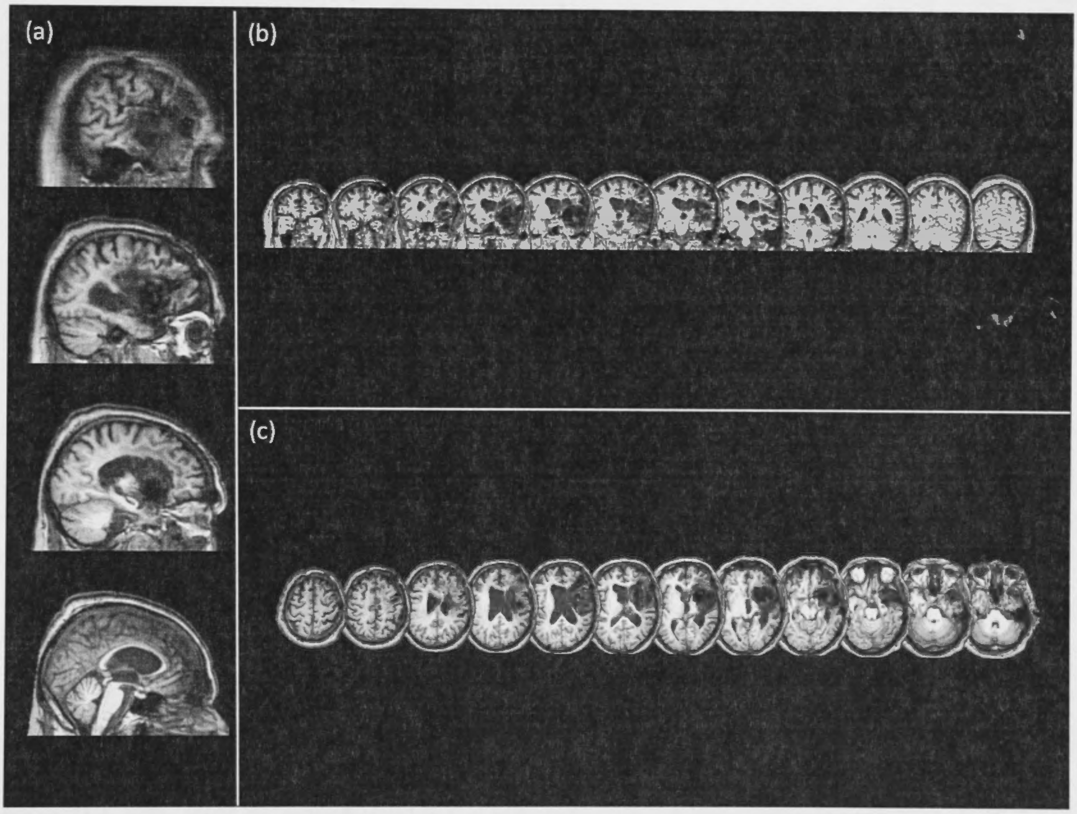


Figure 3. T1-weighted brain MR images of patient JF:

(a) Sagittal from right to midsagittal in steps of 21mm

(b) Coronal from frontal to occipital in steps of 10mm (from left of page)

(c) Axial from top to bottom in steps of 8mm (from left of page).

Patient HT is a 54-year old right-handed (*Laterality Quotient* = 100; Oldfield, 1971) Norwegian woman with 12 years of education. She experienced a subarachnoid bleed from a large intracerebral haematoma in the right temporal lobe. Patient HT has a severe left hemiparesis and is confined to a wheelchair but cared for in her family home. A research MRI conduced for this study (see Figure 4) showed evidence of a clipped right-side aneurysm, following an extensive right-side infarction. There was a shunt in the extracranial space on the right side. Substance-loss was found in areas of the temporal and frontal lobe, and there was gliosis of the surrounding brain mass. Secondary to substance-loss, there was atrophy of the right side of the crus cerebri and Wallerian degeneration of the brain stem. There was also marked enlargement of the right ventricle.

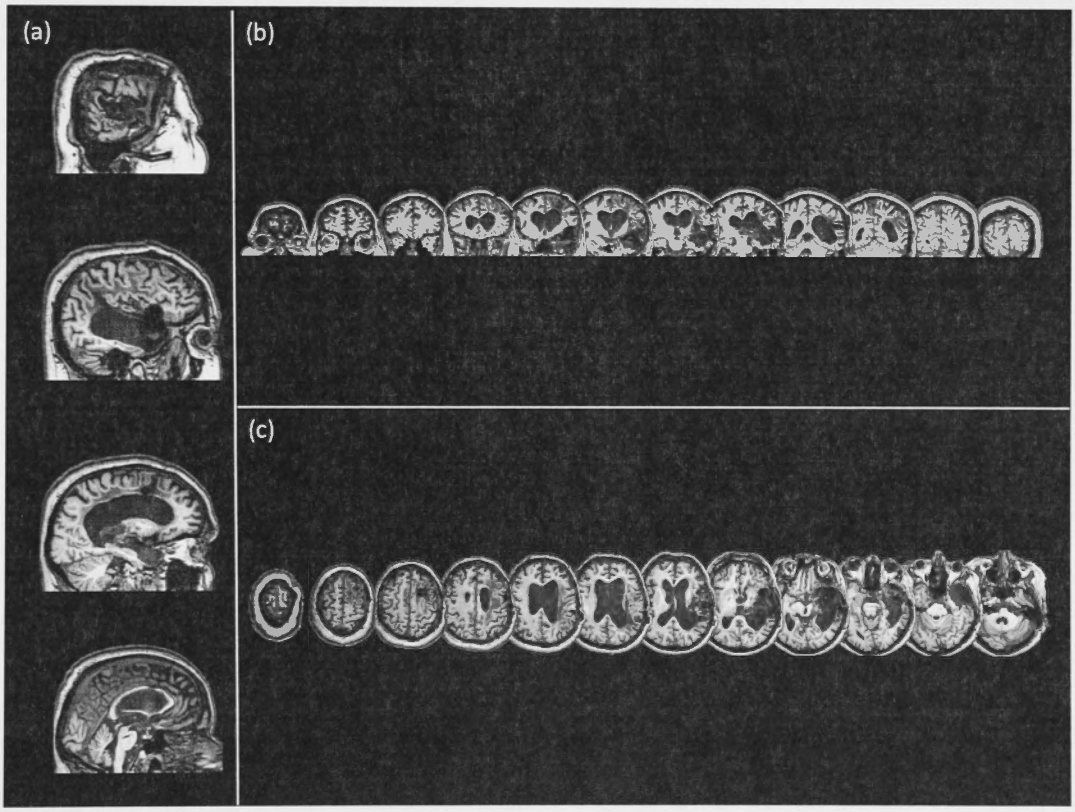


Figure 4. T1-weighted brain MR images of patient HT:

(a) Sagittal from right to midsagittal in steps of 21mm

(b) Coronal from frontal to occipital in steps of 10mm (from left of page)

(c) Axial from top to bottom in steps of 8mm (from left of page).

Neuropsychological Assessment of Neglect

Neglect was assessed with the following tests:

- Line Crossing, Letter Cancellation, Star Cancellation, Figure and Shape Copying, Line Bisection and Representational Drawing subtests from the Behavioural Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987);
- Schenkenberg Line Bisection (Schenkenberg, Bradford, & Ajax, 1980):
  % Deviation Score = (measured left half - true half) / true half x 100
- Map Search subtest from the Test of Everyday Attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994);
- Bells Test (Gauthier, Dehaut, & Joanette, 1989);
- The Balloons Test (Edgeworth, Robertson, & McMillan, 1998);
- Ogden Scene Task (Ogden, 1985, p. 64):
  Score=5 no evidence of neglect
  Score=4 if only the chimney or the contralesional window of the house was missing
  Score=3 if the contralesional half of a tree or the house was missing
  Score=2 if the contralesional tree was completely missing
  Score=1 if the contralesional tree plus more of drawing on the same side was missing.
- Rey Complex Figure Test, Recognition Trial (RCFT; Meyers & Meyers, 1995) using a % Neglect Score (20 internal items on left side and 20 internal items on right side of Rey Figure (see Aimola, 1999, Appendix Manual, p. 27-30):
  Score=100% no evidence of neglect (items accurately drawn and correctly placed)
  Score=<50% neglect (items recognisable, even though they may not be accurately drawn, but they are incorrectly placed)
  Score=0 neglect with severe visuospatial difficulties (items unrecognisable and incorrectly placed).

See Table 1 for the results from the patients' performance on these measures.

Table 1

Patient Performance on Tests of Neglect

	HH	**VR**	**BN**	**JF**	**HT**
Age	64	52	66	47	54
Year of Injury	1998	2003	2004	2005	2001
Edinburgh Handedness	N/A	100	100	82	100
BIT Line Crossing	36 (36)	35 (36)	36 (36)	**32** (36)	36 (36)
- Left Side of Page	18	17	18	14	18
- Right Side of Page	18	18	18	18	18
BIT Letter Cancel.	35 (40)	36 (40)	**23** (40)	**25** (40)	26 (40)
- Left Side of Page	n/a	18	n/a	6	13
- Right Side of Page	n/a	18	n/a	19	13
BIT Star Cancel.	**35** (54)	**44** (54)	**51** (54)	**30** (54)	**36** (54)
- Left Side of Page	N/A	17	N/A	9	10
- Right Side of Page	N/A	27	N/A	21	26
BIT Figure/Shape	**0** (4)	**2** (4)	**3** (4)	**0** (4)	3 (4)
BIT Line Bisection	**6** (9)	**1** (9)	**6** (9)	**6** (9)	**4** (9)
BIT Drawing	3 (3)	**2** (3)	3 (3)	**0** (3)	**1** (3)
Schenkenberg	**30.9%**	**8.4%**	**14.2%**	**8.3%**	1.6%
Map Search	N/A	20 (80)	**16** (80)	**11** (80)	**18** (80)
- Left Side of Page	N/A	12	0	0	0
- Right Side of Page	N/A	8	16	11	18
Bells Test	**11 (35)**	**25 (35)**	**21 (35)**	**18 (35)**	30 (35)
- Left Side of Page	0 (15)	8 (15)	4 (15)	0 (15)	12 (15)
- Right Side of Page	10 (15)	12 (15)	14 (15)	13 (15)	13 (15)
- Middle of Page	1 (5)	5 (5)	3 (5)	5 (5)	5 (5)
Balloons Test	N/A	**42%**	N/A	**29%**	**50%**
Ogden Scene	**1** (5)	3 (5)	**4** (5)	**1** (5)	**2** (5)
Rey Complex Figure, Recognition Trial: % Neglect Score					
- Left Side of Rey	**0%**	**37.5%**	80%	**0%**	**27.5%**
- Right Side of Rey	**62.5%**	**75%**	77.5%	**37.5%**	**72.5%**

Note: Bold indicates evidence of neglect; N/A indicates that this information was not available for patients HH and BN.

Experimental Procedure

The participants were tested individually in a distraction-free room. They were seated at a desk with the stimulus sheet centred on the desk at the participant's body midline. Participants used a pen held in their right hand to make responses. No restrictions were imposed on head or eye movements and there was no time limit to complete the task. Upon completion of the task, participants were asked whether they had checked all of the stimuli, and whether they were certain they had not made any mistakes.

Experiment 1. Discriminative-Cancellation Task (Circles and Triangles)

Stimuli and Procedure

The Ota, Fujii, Suzuki, Fukatsu, and Yamadori (2001) discriminative-cancellation task was made up of two types of experimental sheets, circles in one sheet and triangles in the other. The stimuli were presented in black font on a white background. The patient was presented with an A3 landscape page of either sixty circles or sixty triangles; twenty were complete circles (or triangles) and forty were incomplete circles (or triangles) of which twenty had a gap on the left side and twenty had a gap on the right side. The size of the gap in the incomplete stimuli was 5mm. The incomplete circles had open gaps but the cut ends of the incomplete triangles were joined so that the figures were closed. For each of the three kinds of triangles, half were upside down. The patient was instructed to circle all complete circles (or triangles) and to cross out all incomplete circles (or triangles). The diameter of the circles was 15.5mm, as was each side of the triangles. The stimuli were drawn in a random manner on the sheet of paper but with the number of stimuli arranged evenly on either side of the vertical midline. For all participants, there were two trials for each of the two types of experimental sheets (circles or triangles), with the A3 page presented upside down in the second trial of each type.

Control participants were tested in two sessions and given two trials of each task in each session. Control participants completed a total of eight trials. Patient HH was tested in one session and given two trials of each task in this session. Patient HH therefore performed a total of four trials. Patients VR and BN were tested in two sessions and given two trials of each task in each of these sessions. These participants therefore performed a total of eight trials. Patients JF and HT were also tested in two sessions, and given two trials of each task in each of these sessions; but patients JF and HT were tested in an additional two sessions, in which they were given two trials of the circle-cancellation task *only*. Thus, patients JF and HT performed a total of 12 trials. Figure 5 illustrates how the trials were administered, in this example for patients JF and HT who completed the largest number of trials.

			Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
VISUAL	Circle Task	Page Upside Up	*	*			*	*	
		Page Upside Down	*	*			*	*	
	Triangle Task	Page Upside Up	*	*					
		Page Upside Down	*	*					
	Æ Letter Task 1	Page Upside Up	*	*	*	*	*	*	*
		Page Upside Down	*	*	*	*	*	*	*
	Æ Letter Task 2	Page Upside Up	*	*	*	*	*	*	*
		Page Upside Down	*	*	*	*	*	*	*
	Æ Letter Task 3	Page Upside Up	*	*	*	*	*	*	*
		Page Upside Down	*	*	*	*	*	*	*

Figure 5. Order of administration for patients JF and HT: Discriminative-cancellation task (circle and triangle) was administered in Session One, and again in Sessions Two, Five and Six; Norwegian 'Æ' Letter-Cancellation Task was administered in all seven sessions.

Results

Group Analysis: Neurologically Healthy Control Participants

The accuracy data was not formally analysed for the neurologically healthy participants because they were highly accurate in responding to all stimuli in the discriminative-cancellation task (no gaps = 99.38%; left gaps = 99.38%; right gaps = 99.59%). They responded correctly to 99.03% of stimuli on the left side of page and 99.86% of stimuli on the right side of page.

Group Analysis: Five Patients with Persisting Neglect

The dependent variable in this data is accuracy: the number of correct responses out of a fixed number of trials, so a binary logistic regression (binomial GLM) model is best suited for this data. We also wish to test some hypotheses regarding subsets of the data, so the best approach is to start with a model for the entire data-set and then decompose it into the appropriate subsets. We begin with a model incorporating all of the data, so that we are predicting the proportions by side of page (left, right) and by stimulus (no gap, left gap, right gap).

A random-intercepts 2-level logistic regression for the five patients yielded a model with main effects for side of page, left gap and right gap, and a side of page by left-gap interaction effect. Coefficient estimates, Wald statistics, and 95% confidence intervals are displayed in Table 2. The patients responded correctly to fewer stimuli on the left side of page (66.89%) than on the right side of page (84.02%), a finding interpreted as evidence of viewer-centred neglect. The main effects for left and right gap indicate that the patients responded correctly to more stimuli with no gap (81.02%) compared to stimuli with a left gap (71.14%) or to stimuli with a right gap (74.20%).

The side of page by left-gap interaction is illustrated in Figure 6 and indicates that the patients responded correctly to more stimuli with no gap than to stimuli with a left gap on the right side of page, but that there was no such difference on the left side of page. The side of page by right-gap interaction effect failed to reach significance. However, a model including both interaction terms was significantly better than a main-effects-only model (χ^2 (2) = 7.662, p = .0217), so for ease of interpretation both interaction terms have been retained in the final model.

To determine if there was a significant difference between the left-gap and the right-gap condition, another random-intercepts 2-level logistic regression for the five patients was conducted using left gap as a base group. Results from this analysis indicated that even though the patients' performance was not as good with stimuli with a left *or* right gap compared to stimuli with no gap, they did worse with the left-gap stimuli compared to the right-gap stimuli at the p = .05 level (z = 1.96). This analysis therefore demonstrated that as a group, the patients with neglect responded correctly to fewer stimuli on the left side of page than on the right side of page. They also responded correctly to fewer stimuli with a left or right gap compared to stimuli with no gap, but the difference between stimuli with a left gap and stimuli with no gap was only evident on the right side of page. The patients also correctly responded to fewer stimuli with a left gap compared to stimuli with a right gap.

The discriminative-cancellation task therefore classified the patient group as having both viewer- and stimulus-centred neglect.

Table 2

Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page, Left Gap and Right Gap

Variables	Coefficient	S.E.	Z	p	95% Lower	CI Upper
Side of Page	0.872	0.111	7.890	0.000	0.655	1.089
Left Gap	-0.860	0.141	-6.090	0.000	-1.137	-0.584
Right Gap	-0.609	0.143	-4.250	0.000	-0.890	-0.328
Side of Page by Left Gap	-0.383	0.140	-2.730	0.006	-0.658	-0.108
Side of Page by Right Gap	-0.253	0.143	-1.770	0.077	-0.533	0.027
(Constant)	1.855	0.684	2.710	0.007	0.515	3.195

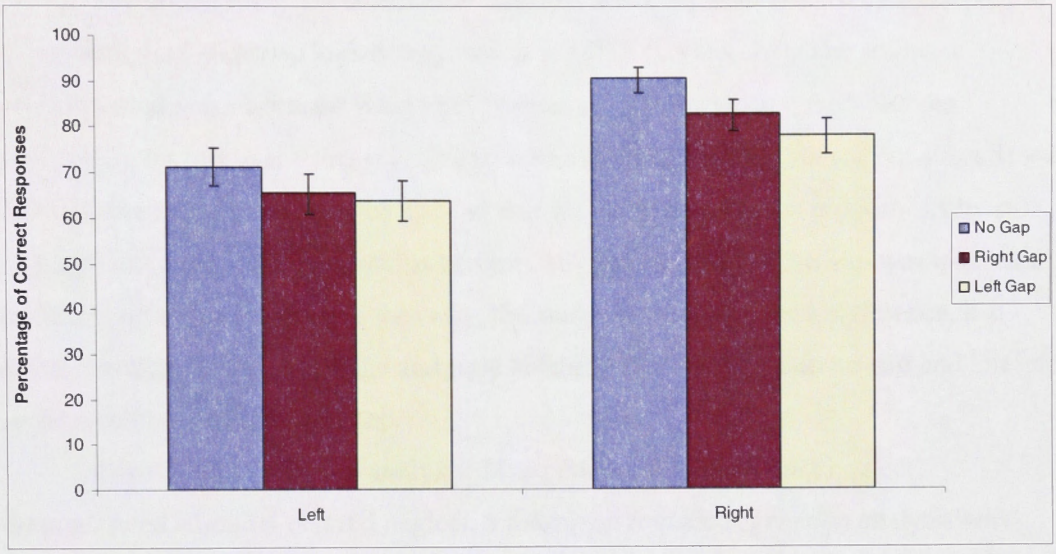


Figure 6. Percentage of correct responses to stimuli with no gap, right gap and left gap as a function of side of page. Error bars indicate 95% confidence interval.

Single-Case Analysis

The discriminative-cancellation task was analysed individually for each patient using backward stepwise logistic regression in SPSS (version 16). The stepwise criterion used was backward wald with probability for entry being 0.05 and the probability for removal being 0.1. The data (correctly circled or crossed out stimuli) was classified by side of page and by gap, so that we are predicting the proportions by side of page (left, right) and by stimulus (no gap, left gap, right gap). No gap was used as a base group for the analysis. In this way, the analysis demonstrates a difference, if it exists, between left side of page and right side of page, and between no gap and left gap *or* between no gap and right gap.

Given that the 'Group analysis: Five patients with persisting neglect' demonstrated stimulus-centred neglect, a *follow-up logistic regression* analysis was performed individually for each patient, specifically to assess stimulus-centred neglect. The data (correctly circled or crossed out stimuli) was classified by side of page and by gap, so that we are predicting the proportions by side of page (left, right) and by stimulus (left gap, right gap). Poorer responses to left-gap compared to right-gap stimuli indicate stimulus-centred neglect in this analysis.

Unless otherwise stated, the designated alpha for all analyses was $\alpha = .05$ to ensure adequate power.

Patient HH. The best model (χ^2 (1) = 104.153, $p < .001$; see Table 3) had a main effect for side of page ($t = 29.351$, $p < .001$). Patient HH responded correctly to fewer stimuli on the left side of page (0%) than on the right side of page (54.17%), a finding interpreted as viewer-centred neglect. The absence of a significant main effect or interaction for gap indicated that there was no difference in accuracy between stimuli with no gap (30.00%) and stimuli with a left gap (25.00%) or between stimuli with no gap (30.00%) and stimuli with a right gap (26.25%). See Figure 7.

Table 3

Patient HH: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (No Gap, Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	2.279	.421	29.351	9.764	1	.000
(Constant)	-2.116	.421	25.303	.121	1	.000

For the *follow-up logistic regression* analysis, the best model (χ^2 (1) = 64.283, $p < .001$; see Table 4) had only a main effect for side of page ($t = 18.605$, $p < .001$). Patient HH again responded correctly to fewer stimuli on the left side of page (0%) than on the right side of page (51.25%), a finding interpreted as viewer-centred neglect.

Overall, the discriminative-cancellation task classified patient HH as having viewer-centred neglect *only*.

Table 4

Patient HH: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	2.222	.515	18.605	9.222	1	.000
(Constant)	-2.173	.515	17.796	.114	1	.000

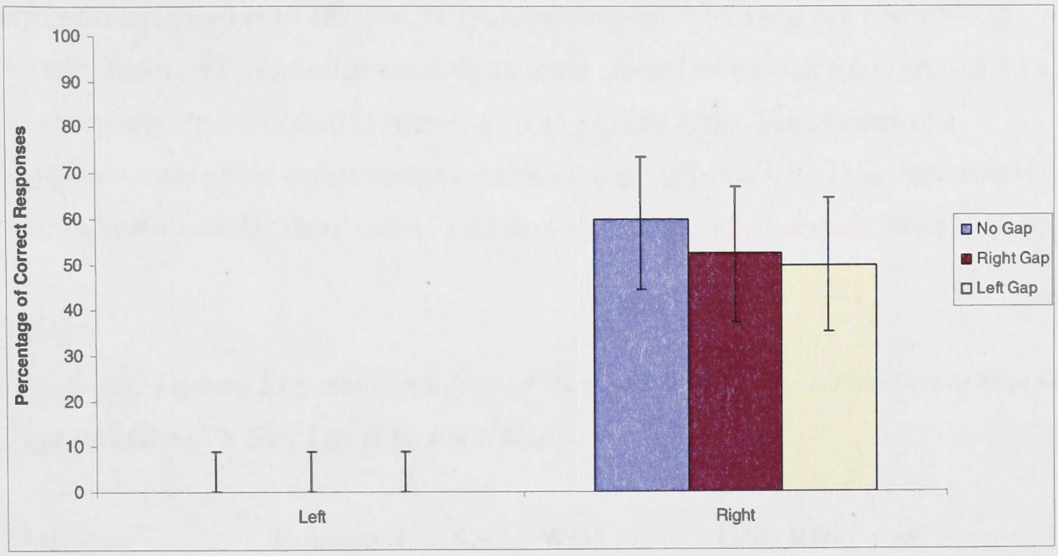


Figure 7. Patient HH: Percentage of correct responses to stimuli with no gap, right gap and left gap as a function of side of page. Error bars indicate 95% confidence interval.

Patient VR. The best model (χ^2 (2) = 17.844, p = .001; see Table 5) had a main effect for left gap (t = 10.187, p = .001) and a main effect for right gap (t = 9.543, p = .002). Patient VR responded correctly to fewer stimuli with either a left gap (88.13%) or a right gap (88.75%) than to stimuli with no gap (98.75%). The absence of a significant main effect or interaction for side of page (left side = 93.75%; right side = 90.00%) indicated that there was no evidence of viewer-centred neglect. See Figure 8.

Table 5

Patient VR: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (No Gap, Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Left Gap	-2.010	.630	10.187	.134	1	.001
Right Gap	-1.952	.632	9.543	.142	1	.002
(Constant)	3.970	.583	46.414	53.000	1	.000

The *follow-up logistic regression* analysis failed to yield any significant results (χ^2 (3) = 1.505, p = .681). Overall, the discriminative-cancellation task classified patient VR as having *neither* viewer- nor stimulus-centred neglect. Although the gap main effect obtained in the initial analysis indicated higher accuracy in responding to stimuli with no gap compared to stimuli with a gap, it is unlikely to reflect stimulus-centred neglect because there was no difference in accuracy between responses to stimuli with a left or right gap.

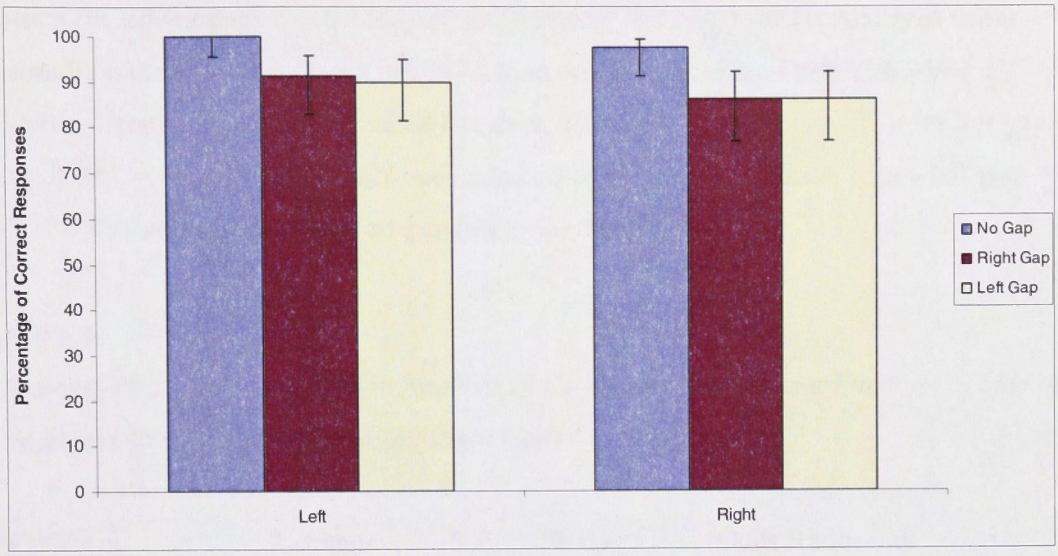


Figure 8. Patient VR: Percentage of correct responses to stimuli with no gap, right gap and left gap as a function of side of page. Error bars indicate 95% confidence interval.

Patient BN. The best model (χ^2 (2) = 15.696, p = .001; see Table 6) had a main effect for side of page (t = 5.146, p = .023). Patient BN responded correctly to fewer stimuli on the left side of page (92.08%) than on the right side of page (96.25%), a finding interpreted as viewer-centred neglect. There was also a main effect for left gap (t = 9.436, p = .002). Patient BN responded correctly to fewer stimuli with a left gap (89.38%) than to stimuli with no gap (96.88%). See Figure 9.

Table 6

Patient BN: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (No Gap, Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.881	.389	5.146	2.414	1	.023
Left Gap	-1.420	.462	9.436	.242	1	.002
Side of Page by						
Left Gap	-.819	.462	3.138	.441	1	.076
(Constant)	3.501	.389	81.188	33.139	1	.000

For the *follow-up logistic regression* analysis, the best model (χ^2 (1) = 5.414, p = .020; see Table 7) had only a main effect for gap (t = 4.893, p = .027). Patient BN responded correctly to fewer stimuli with a left gap (89.38%) than to stimuli with a right gap (96.25%), a finding interpreted as stimulus-centred neglect. The absence of a significant main effect or interaction for side of page (left side = 90.63%; right side = 95.00%) indicated that there was no significant evidence for viewer-centred neglect when the no gap condition was removed from the analysis.

Overall, the discriminative-cancellation task classified patient BN as having viewer- and stimulus-centred neglect.

Table 7

Patient BN: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Gap	.509	.230	4.893	1.664	1	.027
(Constant)	2.588	.230	126.533	13.310	1	.000

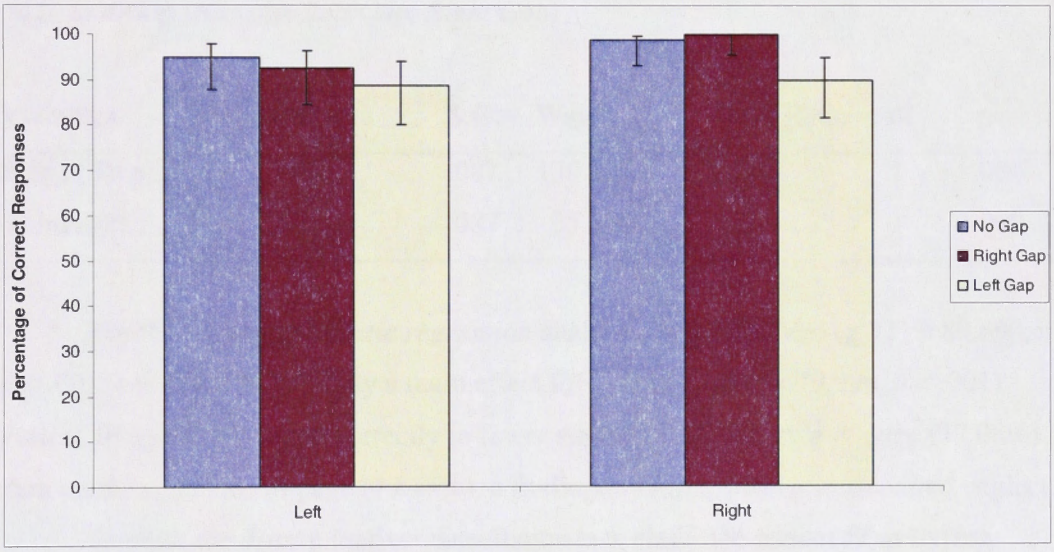


Figure 9. Patient BN: Percentage of correct responses to stimuli with no gap, right gap and left gap as a function of side of page. Error bars indicate 95% confidence interval.

Patient JF. The best model (χ^2 (1) = 149.740, $p < .001$; see Table 8) had a main effect for side of page ($t = 130.126$, $p < .001$). Patient JF responded correctly to fewer stimuli on the left side of page (38.33%) than on the right side of page (82.22%), a finding interpreted as viewer-centred neglect. The absence of a significant main effect or interaction for gap indicated that there was no difference in accuracy between stimuli with no gap (64.58%) and stimuli with a left gap (57.92%) or between stimuli with no gap (64.58%) and stimuli with a right gap (58.33%). See Figure 10.

Table 8

Patient JF: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (No Gap, Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.992	.087	130.126	2.698	1	.000
(Constant)	.521	.087	35.869	1.684	1	.000

For the *follow-up logistic regression* analysis, the best model (χ^2 (1) = 89.690, $p < .001$; see Table 9) had only a main effect for side of page ($t = 79.990$, $p < .001$). Patient JF again responded correctly to fewer stimuli on the left side of page (37.08%) than on the right side of page (79.17%), a finding interpreted as viewer-centred neglect.

Overall, the discriminative-cancellation task classified patient JF as having viewer-centred neglect *only*.

Table 9

Patient JF: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.922	.103	79.990	2.515	1	.000
(Constant)	.398	.103	14.911	1.489	1	.000

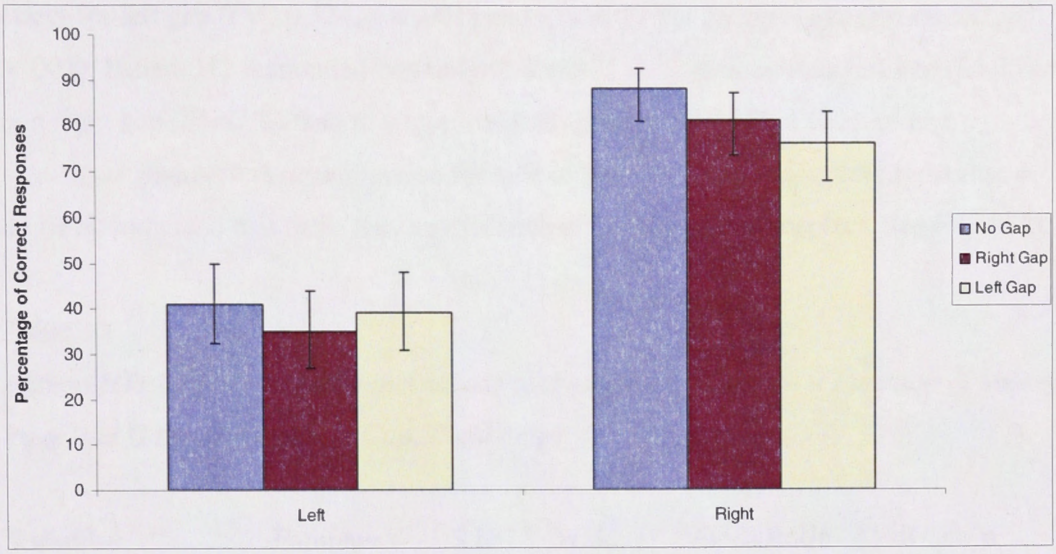


Figure 10. Patient JF: Percentage of correct responses to stimuli with no gap, right gap and left gap as a function of side of page. Error bars indicate 95% confidence interval.

Patient HT. The best model (χ^2 (2) = 23.583, p < .001; see Table 10) had a main effect for left gap (t = 20.324, p < .001) and a main effect for right gap (t = 10.582, p = .001). Patient HT responded correctly to fewer stimuli with either a left gap (76.25%) or a right gap (81.67%) than to stimuli with no gap (92.08%). The absence of a significant main effect or interaction for side of page (left side = 83.06%; right side = 83.61%) indicated that there was no evidence of viewer-centred neglect. See Figure 11.

Table 10

Patient HT: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Gap (No Gap, Left Gap, Right Gap)

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Left Gap	-1.252	.278	20.324	.286	1	.000
Right Gap	-.930	.286	10.582	.394	1	.001
(Constant)	2.407	.233	106.292	11.100	1	.000

The *follow-up logistic regression* analysis failed to yield any significant results (χ^2 (3) = 2.221, p = .528). Overall, the discriminative-cancellation task classified patient HT as having *neither* viewer- nor stimulus-centred neglect. Although the gap main effect obtained in the initial analysis indicated higher accuracy in responding to stimuli with no gap compared to stimuli with a gap, it is unlikely to reflect stimulus-centred neglect as there was no significant difference in accuracy between responses to stimuli with a left or right gap.

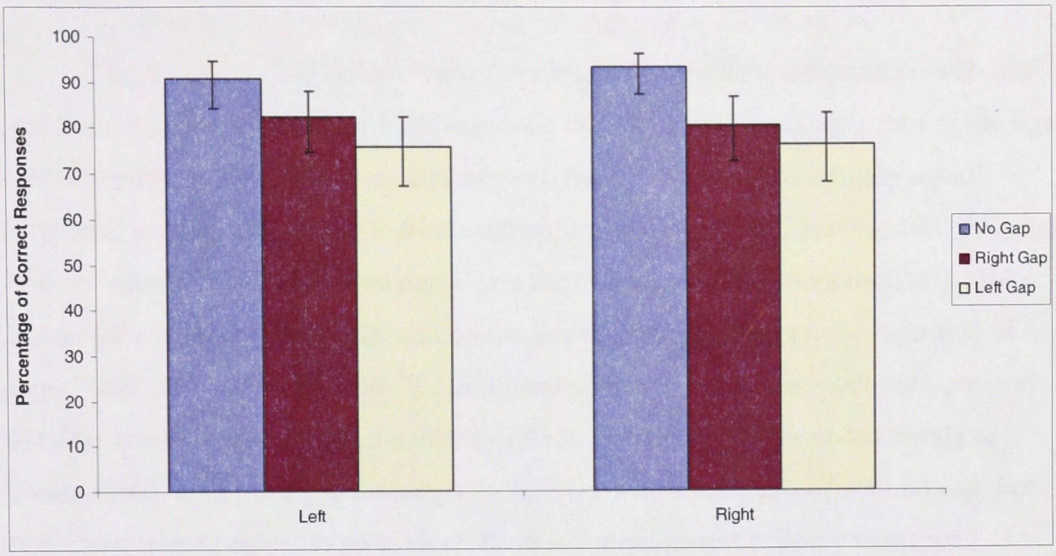


Figure 11. Patient HT: Percentage of correct responses to stimuli with no gap, right gap and left gap as a function of side of page. Error bars indicate 95% confidence interval.

Summary for Series of Single-Cases

The Ota et al. (2001) discriminative-cancellation task investigated viewer- and stimulus-centred neglect. Poorer responses on the left side of page compared to the right side of page indicated viewer-centred neglect. Poorer responses to left-gap stimuli compared to right-gap stimuli indicated stimulus-centred neglect. Patients HH, BN, and JF demonstrated viewer-centred neglect on the discriminative-cancellation task. They responded correctly to fewer stimuli on the left side of page than on the right side of page. Whereas patients HH and JF demonstrated viewer-centred neglect *only,* patient BN also demonstrated stimulus-centred neglect. Patient BN responded correctly to fewer stimuli with a left gap than to stimuli either with a right gap or with no gap. For stimulus-centred neglect to be evident, there is a requirement not only to respond correctly to fewer left-gap stimuli than stimuli with no gap, but also to respond correctly to more right-gap stimuli compared to left-gap stimuli because otherwise the results would indicate a general difficulty with stimuli with a gap. Both patients VR and HT correctly responded to fewer left-gap stimuli than stimuli with no gap, but there was no such difference between left-gap and right-gap stimuli. Patients VR and HT therefore exhibited no neglect on the discriminative-cancellation task.

Only patient BN exhibited a statistically significant difference between stimuli with a left gap and stimuli with a right gap. But it is obvious from the individual patient graphs that, with the exception of patient VR, the difference in responding to left gap, right gap, and no gap stimuli is in the direction predicted, which may explain the overall result of stimulus-centred neglect in the group analysis.

Experiment 2. Norwegian 'Æ' Letter-Cancellation Task

Stimuli and Procedure

The new Norwegian 'Æ' letter-cancellation task consisted of an A3 landscape page with sixty-four letters in eight different orientations (from upright = 0° to 335° in 45° increments). The letters were presented in a random manner on the sheet of paper but arranged evenly on either side of the vertical midline. They were presented in black font on a white background. There were sixteen uppercase 'E' letters (1.7cm x 1.5cm), sixteen uppercase 'A' letters (1.7cm x 1.5cm) and thirty-two uppercase Norwegian 'Æ' letters (1.7cm x 2.3cm). The letters 'E' and 'A' were presented in normal parity only, but the letter 'Æ' was presented in both normal and backward parity (see Figure 12). In each session, the participant was given three sets of task instructions, translated from Norwegian[4]: Task, 1, Draw a circle around all letter 'E's; Task 2, Draw a line through all letters except the letter 'E'; or Task 3, Draw a circle around all letter 'E's and draw a line through all other letters. For all participants, there were two trials for each of the three task instructions, with the A3 page presented upside down in the second trial of each task.

Control participants were tested in five sessions and given two trials of each task in each session. Control participants completed a total of 30 trials. Patient HH was tested in two sessions and given two trials of each task in each session yielding a total of 12 trials. Patients VR and BN were tested in four sessions and given two trials of each task in each session, yielding a total of 24 trials. Patients JF and HT were tested in seven sessions and given two trials of each task in each of these sessions, yielding a total of 42 trials.

[4] Task Instruction 1: Tegn en sirkel rundt alle bokstavene E.
Direct translation: Draw a circle around all letter 'E's.
Task Instruction 2: Sett et strek gjennom alle bokstavene unntatt bokstaven E.
Direct translation: Draw a line through all letters except the letter 'E'.
Task Instruction 3: Tegn en sirkel rundt alle bokstavene E og sett et strek gjennom alle andre bokstaver.
Direct translation: Draw a circle around all letter 'E's and draw a line through all other letters.

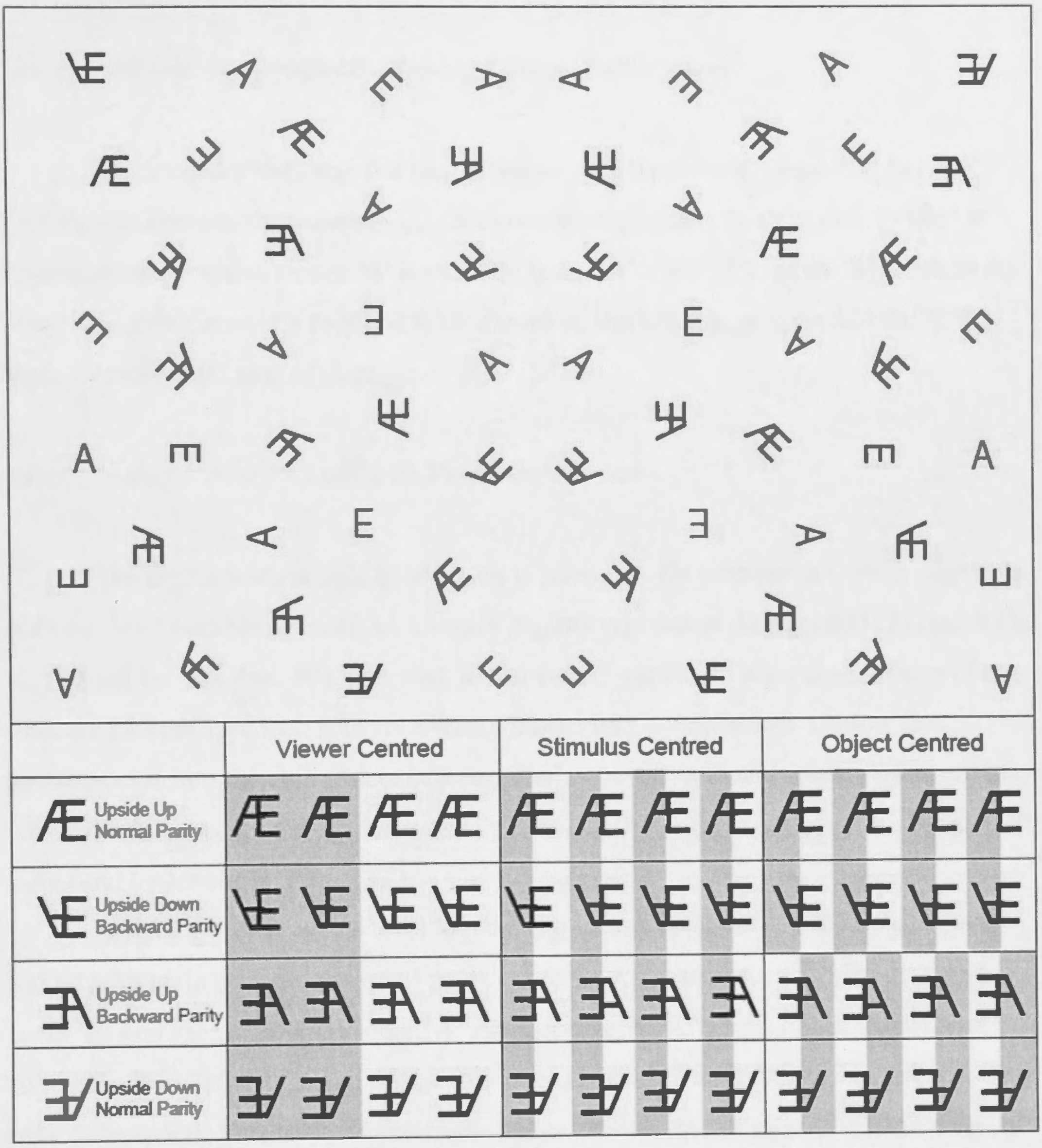


Figure 12a. (top panel): 'Æ' letter-cancellation task;

Figure 12b. (bottom panel) Illustration of viewer-, stimulus-, and object-centred neglect: Shaded areas indicate: viewer-centred neglect (left side of stimulus sheet), stimulus-centred neglect (left side of stimulus letter as displayed), and object-centred neglect (canonical left side, that is, 'A' part of the letter 'Æ', irrespective of orientation or parity).

Results

Group Analysis: Neurologically Healthy Control Participants

The accuracy data was not formally analysed for the neurologically healthy participants because they were highly accurate in responding to all stimuli in the 'Æ' letter-cancellation task (letter 'E' = 99.48%; letter 'A' = 99.58%; letter 'Æ' = 99.74%). They responded correctly to 99.48% of stimuli on the left side of page and 99.79% of stimuli on the right side of page.

Group Analysis: Five Patients with Persisting Neglect

The dependent variable in this data is accuracy: the number of correct responses out of a fixed number of trials, so a binary logistic regression (binomial GLM) model is best suited for this data. We also wish to test some hypotheses regarding subsets of the data, so the best approach is to start with a model for the entire data-set and then decompose it into the appropriate subsets. We begin with a model incorporating all of the data but ignoring task, so that we are predicting the proportions by side of page (left, right) and by letter ('E', 'A', 'Æ').

A random-intercepts 2-level logistic regression for the five patients yielded a model with main effects for side of page, letter 'E' and letter 'A', and side of page by letter 'E' and side of page by letter 'A' interaction effects (all $p < .001$). Coefficient estimates, Wald statistics, and 95% confidence intervals are displayed in Table 11. The patients responded correctly to fewer stimuli on the left side of page (70.70%) than on the right side of page (87.40%), a finding interpreted as evidence of viewer-centred neglect. There were significantly more correct responses to the letter 'E' (85.54%) and to the letter 'A' (79.62%) compared to the letter 'Æ' (75.52%). The side of page by letter 'E' and side of page by letter 'A' interactions are illustrated in Figure 13 and indicate that patients responded correctly to more of the letters 'E' than 'Æ' and more of the letters 'A' than 'Æ' on the right side compared to the left side of page. That is, the difference in accuracy between the letters was larger on the right side of page. A model including both interaction terms was significantly better than a main-effects-only model ($\chi^2(2) = 45.767, p < .0005$).

Table 11

Logistic Regression Analysis of Accuracy Data as a Function of Side of Page and Letter Identity

Variables	Coefficient	S.E.	Z	p	95% Lower	CI Upper
Side of Page	0.416	0.046	8.990	0.000	0.325	0.507
Letter 'E'	1.036	0.111	9.320	0.000	0.818	1.254
Letter 'A'	0.400	0.089	4.520	0.000	0.226	0.573
Side of Page by Letter 'E'	0.653	0.111	5.880	0.000	0.435	0.870
Side of Page by Letter 'A'	0.350	0.088	3.950	0.000	0.177	0.523
(Constant)	1.204	0.412	2.920	0.003	0.397	2.012

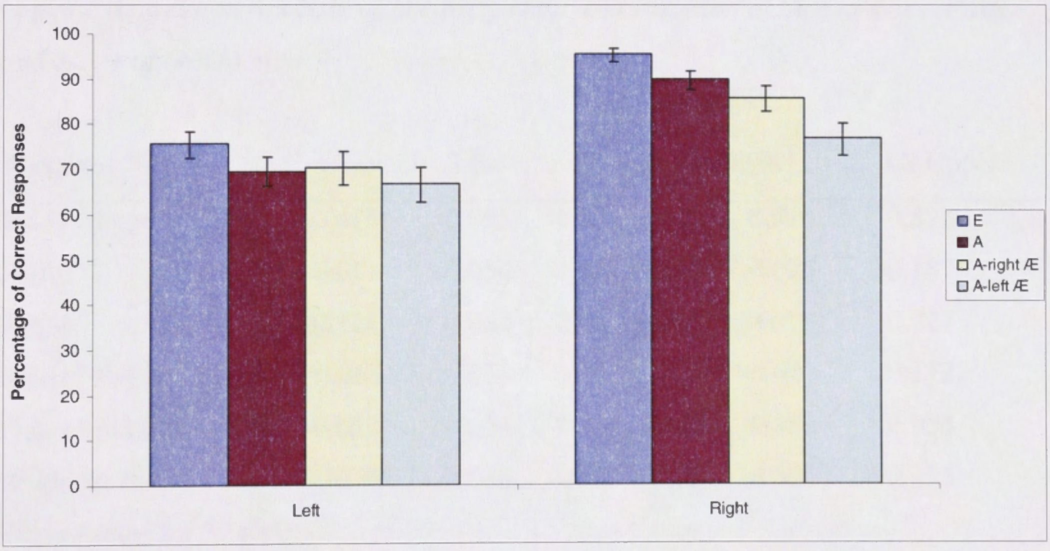


Figure 13. Percentage of correct responses to the letters 'E', 'A', and 'Æ' as a function of side of page. Error bars indicate 95% confidence interval.

The overall low accuracy in the identification of the letter ‘Æ’ (75.52%) compared to the letters ‘E’ (85.54%) and ‘A’ (79.62%) indicates the presence of either stimulus- or object-centred neglect. A follow-up random-intercepts 2-level logistic regression for the five patients was performed to assess the data for the letter ‘Æ’ *only*, classified by side of page (left, right), parity (normal, backward), and orientation (upside-up: 0, 45, 315 degrees; or upside-down: 135, 180, 225 degrees). (We excluded presentations at 90° or 270 because the ‘A’ side of the letter ‘Æ’ was toward the top or bottom rather than toward the left or right in the viewer-centred frame of reference.) This analysis yielded a model with main effects for side of page and angle, and angle by parity and side of page by angle by parity interaction effects. Coefficient estimates, Wald statistics, and 95% confidence intervals are displayed in Table 12. A model including all interaction terms was significantly better than a main-effects-only model ($\chi^2(4) = 23.048$, $p < .0005$).

Table 12

Logistic Regression Analysis of Accuracy Data as a Function of Side of Page, Parity, and Angle of Orientation

Variables	Coefficient	S.E.	Z	p	95% Lower	CI Upper
Side of Page	0.416	0.055	7.63	0.000	0.310	0.523
Parity	0.081	0.054	1.50	0.135	-0.025	0.187
Angle	0.121	0.054	2.24	0.025	0.015	0.227
Side of Page by Parity	0.066	0.054	1.23	0.220	-0.040	0.172
Side of Page by Angle	-0.053	0.054	-0.98	0.325	-0.159	0.053
Angle by Parity	-0.229	0.054	-4.22	0.000	-0.335	-0.123
Side of Page by Angle by Parity	-0.123	0.054	-2.27	0.023	-0.229	-0.017
(Constant)	1.303	0.437	2.98	0.003	0.447	2.159

The patients responded correctly to the letter ‘Æ’ on the right side of page (82.10%) more than on the left side of page (68.95%), a finding interpreted as evidence of viewer-centred neglect. Accuracy in responding to the letter ‘Æ’ displayed in an upright orientation was 77.08% and to letters displayed upside-down was 72.66%. The angle by parity interaction illustrated in Figure 14 indicates that letters displayed in normal and backward parity yield opposite effects depending on whether the letter 'Æ' was upside-up or upside-down. Performance was better for the backward letter (79.17%) compared to the normal letter (75.00%) when it was presented in an upright orientation, however, performance was *reversed* when the letter was upside-down. That is, performance was better for the normal letter (77.08%) compared to the backward letter (68.23%) when it was presented upside-down.

Neglect may involve both a stimulus-centred component and an object-centred component. Recall that the patients are required to circle 'E' and to cross out all other letters. If the patients inaccurately identify the letter 'Æ' as the letter 'E', then they are likely to also respond inaccurately, either by erroneously circling the letter 'Æ' or by failing to cross out this letter in accordance with task instructions. Performance is likely to involve a stimulus-centred component for the following reason: When the letter 'Æ' was displayed upright in normal parity *and* upside-down in backward parity, the 'E' part of the letter 'Æ' was located on the right side in a stimulus-centred frame of reference. When this was the case, accuracy in responding to the upright letter 'Æ' was 75.00% and to the upside-down letter 'Æ' was 68.23%. This performance was impaired in comparison to the patients' overall accuracy in responding to the letters 'E' (85.54%) and 'A' (79.62%). Thus, it is likely that the patients responded to the letter 'Æ' as if it was the letter 'E'. They therefore did not cross out the letter 'Æ' because they failed to detect the 'A' part of the letter, which was located on the left side in a stimulus-centred frame of reference.

Although the patients' performance improved when the letter was displayed upright in backward parity (79.17%) *and* when the letter was displayed upside-down in normal parity (77.08%), their performance was still *overall* somewhat impaired compared to their accuracy rates in responding to the letters 'E' and 'A'. This finding indicates the presence of an object-centred component. In these instances, the 'A' part of the letter 'Æ' was located on the *right* side in a stimulus-centred frame of reference but on the *left* side in an object-centred frame of reference (refer to Figure 14). We suggest that the patients continued to respond as if the letter was an 'E' some of the time, neglecting the 'A' part of the letter which was now located on the *left* side only in an object-centred frame of reference but on the more intact *right* side as defined by a stimulus-centred frame of reference. Although the results indicate both stimulus-centred and object-centred neglect, the increased accuracy rates for the two latter stimulus combinations suggest that, even if it is of smaller magnitude than the stimulus-centred component, the object-centred component exists.

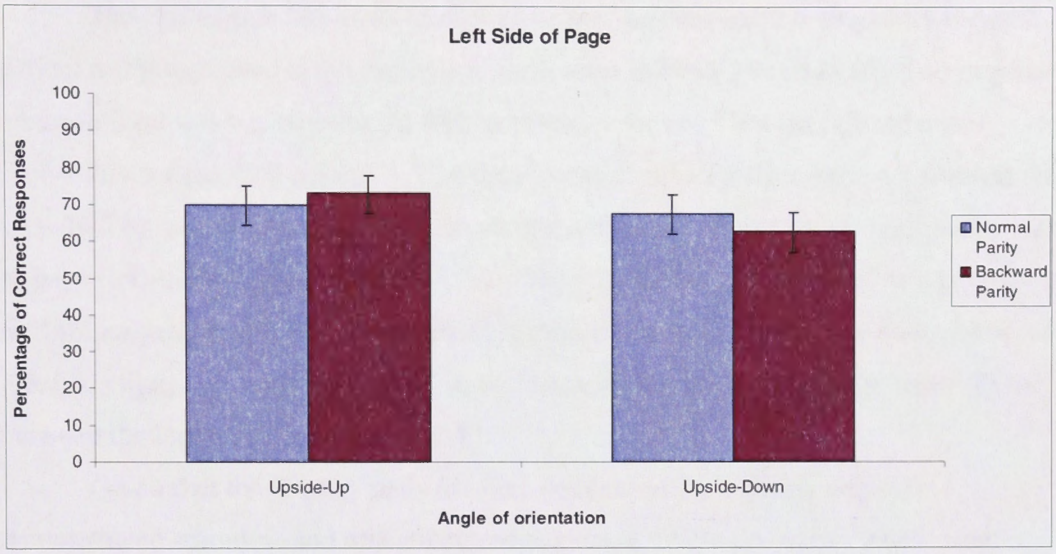
Importantly, the model also had a significant side of page by angle by parity interaction. Given that side of page had a large main effect, but no significant two-way interaction effects, the angle by parity interaction was examined separately on the left and right side of page. As reported in Table 13, there was an obvious difference between the patients' accuracy in responding to the letters 'E', 'A', and 'Æ' on the right side of page. More specifically, on the right side of page, the patients were more accurate in responding to the letters 'E' and 'A' than to the letter 'Æ'. This difference was not obvious on the left side of page. Although the patients were more accurate in responding to the letter 'E' than to the letter 'Æ' on the left side of page, there does not seem to be any difference between the letters 'A' and 'Æ' in terms of accuracy rates. For this reason, we can say that the stimulus- and object-centred effects are more pronounced on the right side of page, although the pattern of results in terms of the angle by parity orientation is replicated on the left side of page. It is possible that the fewer responses overall on the left side of page may have contributed to the smaller effect on this side of page. By splitting the data up in terms of side of page, we confirmed that the angle by parity interaction did not reach significance on the left side of page ($z = -1.55$, $p = .121$), but was highly significant on the right side of page ($z = -4.21$, $p < .0005$).

Table 13

Percentage of Correct Responses as a Function of Side of Page and Letter Identity

Side of Page	Letter 'E'	Letter 'A'	Letter 'Æ'
Left	75.52	69.40	68.95
Right	95.57	89.84	82.10
Mean	85.54	79.62	75.52

(a)



(b)

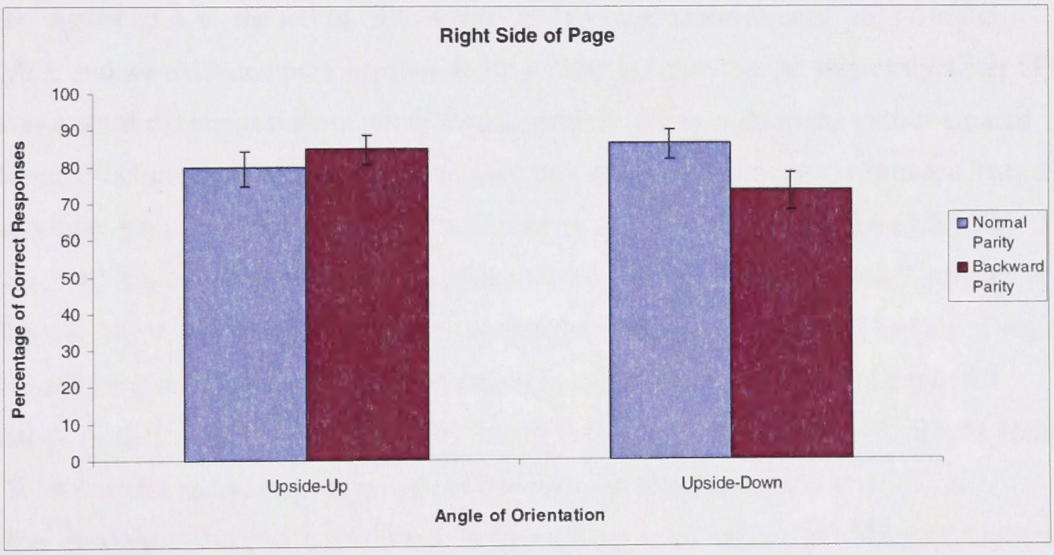


Figure 14. Percentage of correct responses to the letter 'Æ' as a function of parity and angle of orientation on the (a) left side of page and on the (b) right side of page.

Single-Case Analysis: Design

The Norwegian 'Æ' letter-cancellation task was analysed individually for each patient using backward stepwise logistic regression in SPSS (Version 16). The stepwise criterion used was backward wald with probability for entry being 0.05 and the probability for removal being 0.1. The data (correctly circled or crossed out stimuli) was classified by side of page and by letter, so that we are predicting the proportions by side of page (left, right) and by letter ('E', 'A', 'Æ'). The letter 'Æ' was used as a base group for the analysis. In this way, the analysis demonstrates a difference, if it exists, between left side of page and right side of page, and between the letter 'E' and the letter 'Æ' *or* between the letter 'A' and the letter 'Æ'.

Given that the 'Group analysis: Five patients with persisting neglect' demonstrated stimulus- and object-centred neglect, a *follow-up logistic regression* analysis was performed specifically to assess stimulus- and object-centred neglect. We investigated correct responses to the letters 'Æ' and 'A' *only*. With the letter 'Æ', we distinguished A on the left of 'Æ' (A-left 'Æ') from A on the right of 'Æ' (A-right 'Æ'), and we excluded presentations at 90° or 270° because the 'A' side of the letter 'Æ' was toward the top or bottom rather than toward the left or right in the viewer-centred frame of reference. The follow-up analyses also included a comparison between Task 2 and Task 3 for correct responses to the letters 'A', 'A-left 'Æ', and A-right 'Æ'. The letter 'E' was excluded from this analysis as it was only presented in Task 3, and not in Task 2. The data (correctly circled or crossed out stimuli) was classified by side of page, by task, and by letter, so that we are predicting the proportions by side of page (left, right), by task (Task 2, Task 3) and by letter ('A', A-left 'Æ', A-right 'Æ'). The A-right 'Æ' letter was used as a base group for the analysis. In this way, the analysis demonstrates a difference, if it exists, between A-right 'Æ' and A-left 'Æ' and between A-right 'Æ' and the letter 'A'. Poorer responses to A-left 'Æ' compared to A-right 'Æ' indicated stimulus-centred neglect whereas better response to letter 'A' compared to A-right 'Æ' indicated object-centred neglect. When required, *additional* statistical comparisons were conducted with the (2xK) Q′ test (Michael, 2007), which is used in single-case analyses to test the hypothesis of equal proportions. The Q′ statistic has a χ^2 distribution with K–1 degrees of freedom, where K equals the number of experimental conditions. Unless otherwise stated, the designated alpha for all analyses was $\alpha = .05$ to ensure adequate power.

Patient HH. The best model (χ^2 (1) = 141.613, $p < .001$; see Table 14) had a main effect for side of page (t = 121.242, $p < .001$). Patient HH responded correctly to fewer letters on the left side of page (26.95%) than on the right side of page (78.52%), a finding interpreted as viewer-centred neglect. The absence of a significant main effect for letter indicates that there was no overall difference in accuracy between the letter 'Æ' (52.73%) and the letter 'E' (57.81%) or between the letter 'Æ' (52.73%) and the letter 'A' (47.66%).

We also confirmed that patient HH demonstrated no significant difference between correct responses to the letters 'E' and 'A' ($Q'(1) = 1.82$, $p = .1771$). Accordingly, we compare a model in which these letters are combined. The resulting model was significant (χ^2 (1) = 141.613, $p < .001$), and does not provide a significantly worse fit to the data, so we cannot reject the simpler model that combines the letters 'E' and 'A' and compares these to the letter 'Æ'. The interpretation is clear: there is a significant main effect for side of page *only*.

Table 14

Patient HH: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Letter 'E', 'A', and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of page	1.130	.103	121.242	3.096	1	.000
(Constant)	.147	.103	2.038	1.158	1	.153

For the *follow-up logistic regression* analysis, the best model (χ^2 (3) = 100.261, $p < .001$; see Table 15) had a significant main effect for side of page (t = 70.947, $p < .001$). Patient HH responded correctly to fewer letters on the left side of page (24.38%) than on the right side of page (74.38%), a finding interpreted as viewer-centred neglect (see Figure 15). The main effect for task was also significant (t = 18.076, $p < .001$). Patient HH responded correctly to more letters in Task 2 (56.88%) than in Task 3 (41.88%). The main effects for A-left 'Æ' and for letter 'A' failed to reach significance but there was a significant task by letter 'A' interaction (t = 10.311, $p = .001$). These results indicate that although there was no overall difference in accuracy between A-left 'Æ' (50.00%) and A-right 'Æ' (51.04%), or between the letters A' (47.66%) and A-right 'Æ' (51.04%), patient HH's performance was better for A-right 'Æ' compared to the letter 'A' in Task 2 but not in Task 3 ($Q'(1) = 10.51$, $p < .0052$) (see Figure 16).

Overall, the 'Æ' letter-cancellation task classified patient HH as having viewer-centred neglect *only.*

Table 15

Patient HH: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page, Task, and Letter 'A' and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of page	1.131	.134	70.947	3.099	1	.000
Task	-.740	.174	18.076	.477	1	.000
Task by Letter 'A'	.863	.269	10.311	2.371	1	.001
(Constant)	-.033	.129	.067	.967	1	.796

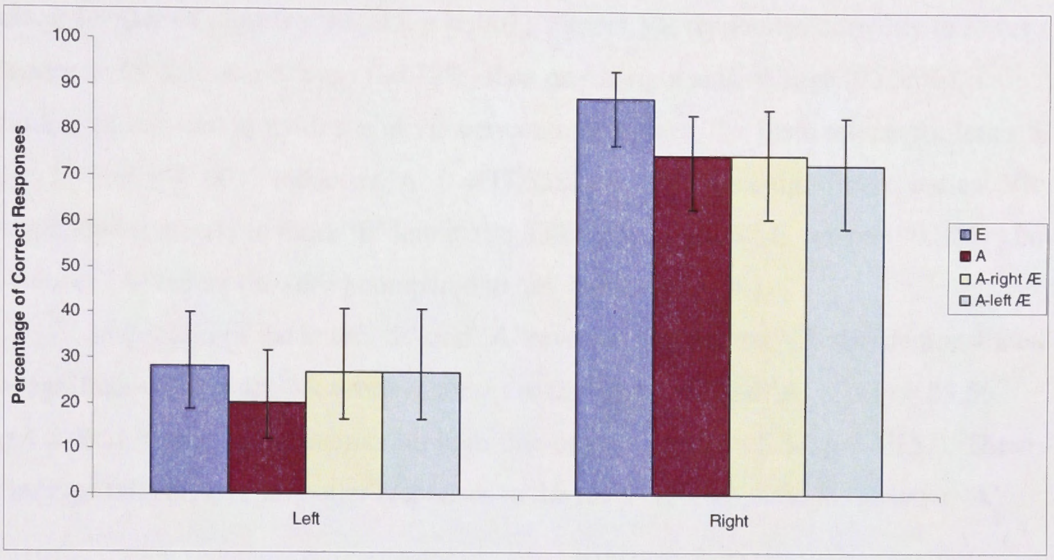


Figure 15. Patient HH: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of side of page. Error bars indicate 95% confidence interval.

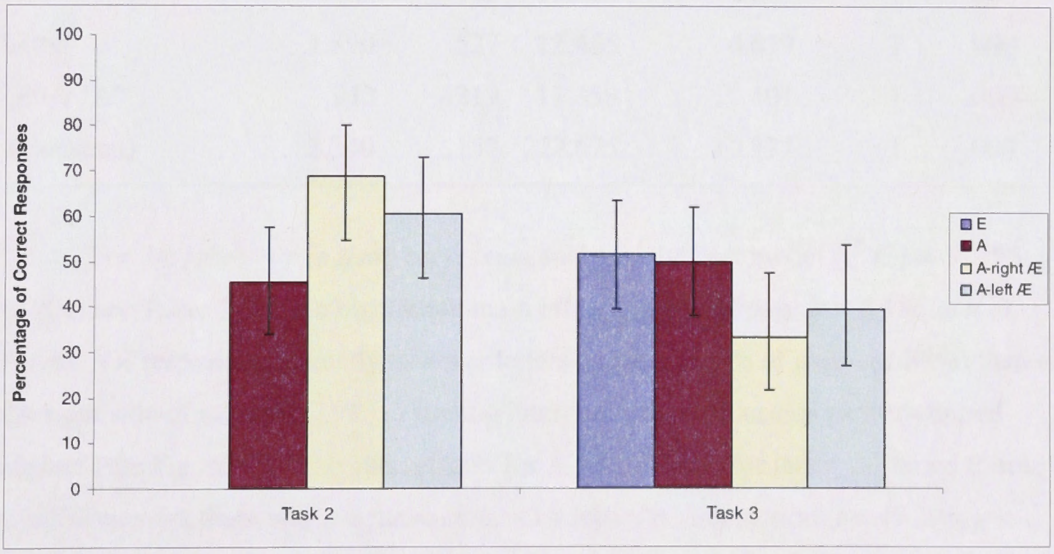


Figure 16. Patient HH: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of task. Error bars indicate 95% confidence interval.

Patient VR. The best model (χ^2 (3) = 68.491, $p < .001$; see Table 16) had a main effect for side of page ($t = 13.275$, $p < .001$). Patient VR responded correctly to fewer letters on the left side of page (86.72%) than on the right side of page (93.55%), a finding interpreted as evidence of viewer-centred neglect. The main effects for letter 'E' ($t = 12.856$, $p < .001$) and letter 'A' ($t = 17.358$, $p < .001$) were significant. Patient VR responded correctly to more 'E' letters (98.83%) compared to 'Æ' letters (90.82%) but to fewer 'A' letters (80.08%) compared to 'Æ' letters (90.82%).

Inspection of the letters 'E' and 'A' revealed that patient VR also demonstrated a significant difference between responses to the letters 'E' and 'A' ($Q'(1) = 33.56$, $p = .0001$), alongside an interaction with side of page ($Q'(2) = 5.84$, $p = .0157$). These findings indicate overall better responses to the letter 'E' compared to the letter 'A'.

Table 16

Patient VR: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Letter 'E', 'A', and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.407	.112	13.275	1.503	1	.000
Letter 'E'	1.890	.527	12.856	6.619	1	.000
Letter 'A'	-.913	.219	17.358	.401	1	.000
(Constant)	2.340	.157	222.675	10.377	1	.000

For the *follow-up logistic regression* analysis, the best model (χ^2 (3) = 68.296, $p < .001$; see Table 17) had a significant main effect for side of page ($t = 5.186$, $p = .023$). Patient VR responded correctly to fewer letters on the left side of page (81.88%) than on the right side of page (90.31%), a finding interpreted as evidence of viewer-centred neglect (see Figure 17). The main effects for A-left 'Æ' and for letter 'A' failed to reach significance but there was a significant task by letter 'A' interaction ($t = 45.396$, $p < .001$). These results indicate that although there was no overall difference in accuracy between A-left 'Æ' (88.54%) and A-right 'Æ' (91.67%), or between the letters 'A' (80.08%) and A-right 'Æ' (91.67%), patient VR's performance was poorer for the letter 'A' compared to A-right 'Æ' in Task 2 but not in Task 3 ($Q'(1) = 27.39$, $p < .0001$) (see Figure 18).

Overall, the 'Æ' letter-cancellation task classified patient VR as having viewer-centred neglect *only*.

Table 17

Patient VR: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page, Task, and Letter 'A' and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.290	.127	5.186	1.337	1	.023
Side of Page by Task	-.247	.127	3.797	.781	1	.051
Task by Letter 'A'	1.389	.206	45.396	4.009	1	.000
(Constant)	2.071	.139	221.917	7.933	1	.000

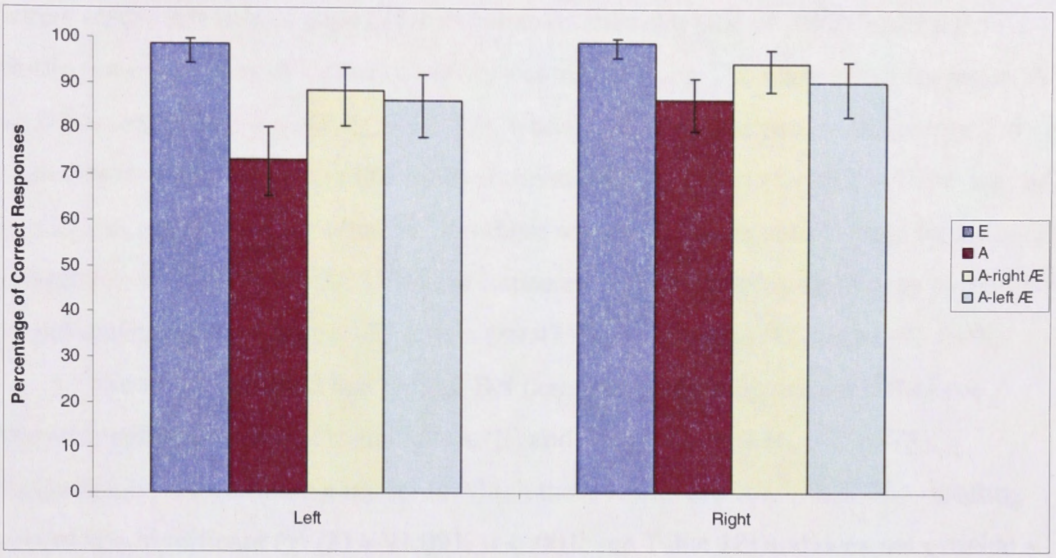


Figure 17. Patient VR: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of side of page. Error bars indicate 95% confidence interval.

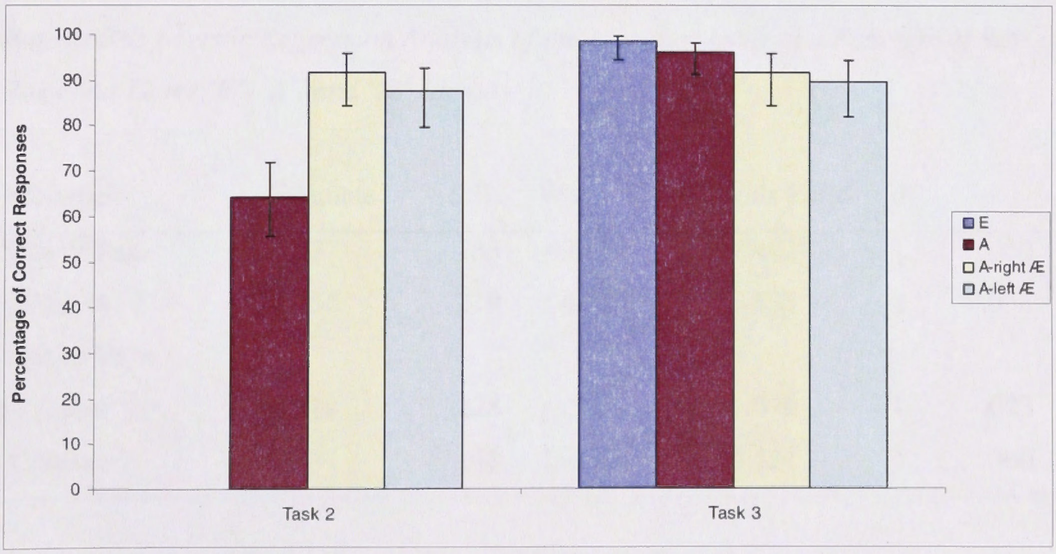


Figure 18. Patient VR: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of task. Error bars indicate 95% confidence interval.

Patient BN. The best model (χ^2 (3) = 94.790, $p < .001$; see Table 18) had a main effect for side of page ($t = 43.118$, $p < .001$). Patient BN responded correctly to fewer letters on the left side of page (77.15%) than on the right side of page (96.29%), a finding interpreted as evidence of viewer-centred neglect. The main effect for letter 'A' was also significant ($t = 4.320$, $p = .038$), which indicated that patient BN responded correctly to more 'Æ' letters (88.67%) compared to 'A' letters (83.98%). There was no significant main effect for letter 'E' but there was a significant side of page by letter 'E' interaction ($t = 5.187$, $p = .023$), which indicated that on the left side of page patient BN responded correctly to more 'Æ' letters (80.47%) compared to 'E' letters (72.66%).

We also confirmed that patient BN demonstrated no significant difference between correct responses to the letters 'E' and 'A' ($Q'(1) = 0.16$, $p = .6878$). Accordingly, we compare a model in which these letters are combined. The resulting model was significant (χ^2 (2) = 91.091, $p < .001$; see Table 18) and does not provide a significantly worse fit to the data, so we cannot reject the simpler model that combines the letters 'E' and 'A' and compares these to the letter 'Æ'. The interpretation is clear: Patient BN performs better on the right side of page (96.29%) compared to the left side of page (77.15%).

Table 18

Patient BN: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Letter 'E', 'A', and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.877	.133	43.118	2.402	1	.000
Letter 'A'	-.455	.219	4.320	.635	1	.038
Side of Page by Letter 'E'	.518	.228	5.187	1.679	1	.023
(Constant)	2.344	.146	256.931	10.424	1	.000

For the *follow-up logistic regression* analysis, the best model (χ^2 (3) = 63.107, $p < .001$; see Table 19) had a significant main effect for side of page ($t = 34.997$, $p < .001$). Patient BN responded correctly to fewer letters on the left side of page (77.50%) than on the right side of page (95.00%), a finding interpreted as viewer-centred neglect (see Figure 19). The main effect for task was significant ($t = 3.866$, $p = .049$). Patient BN responded correctly to fewer letters in Task 2 (80.63%) than in Task 3 (91.88%). The main effects for A-left 'Æ' and for letter 'A' failed to reach significance but there was a significant task by letter 'A' interaction ($t = 4.222$, $p = .040$). These results indicate that although there was no overall difference in accuracy between A-left 'Æ' (85.42%) and A-right 'Æ' (90.10%), or between the letters 'A' (83.98%) and A-right 'Æ' (90.10%), patient BN's performance was poorer for the letter 'A' compared to A-right 'Æ' in Task 2 but not in Task 3 ($Q'(1) = 5.68$, $p < .0171$) (see Figure 20).

Overall, the 'Æ' letter-cancellation task classified patient BN as having viewer-centred neglect *only*.

Table 19

Patient BN: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page, Task, and Letter 'A' and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.813	.137	34.997	2.254	1	.000
Task	.304	.154	3.866	1.355	1	.049
Task by Letter 'A'	.497	.242	4.222	1.644	1	.040
(Constant)	2.103	.145	210.966	8.193	1	.000

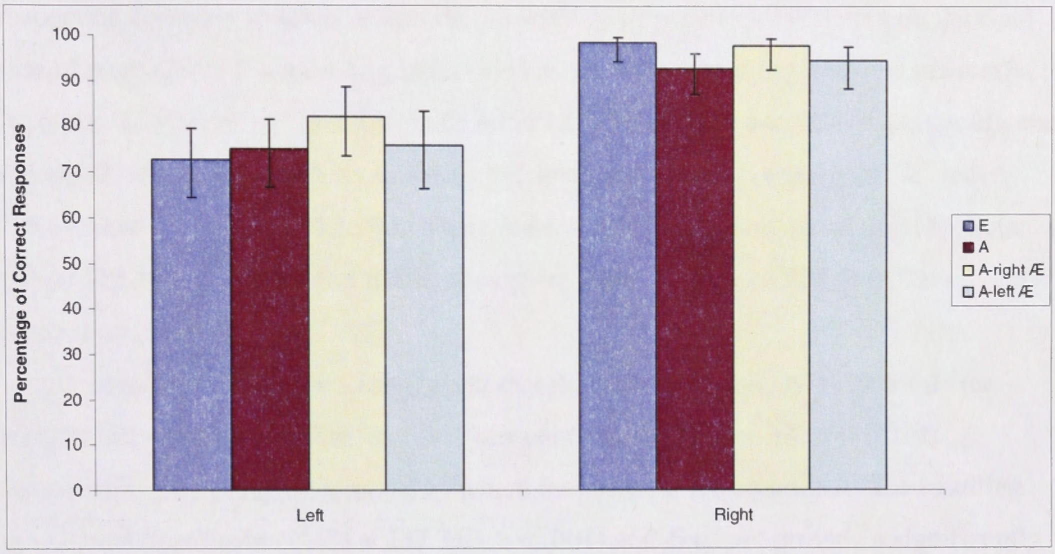


Figure 19. Patient BN: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of side of page. Error bars indicate 95% confidence interval.

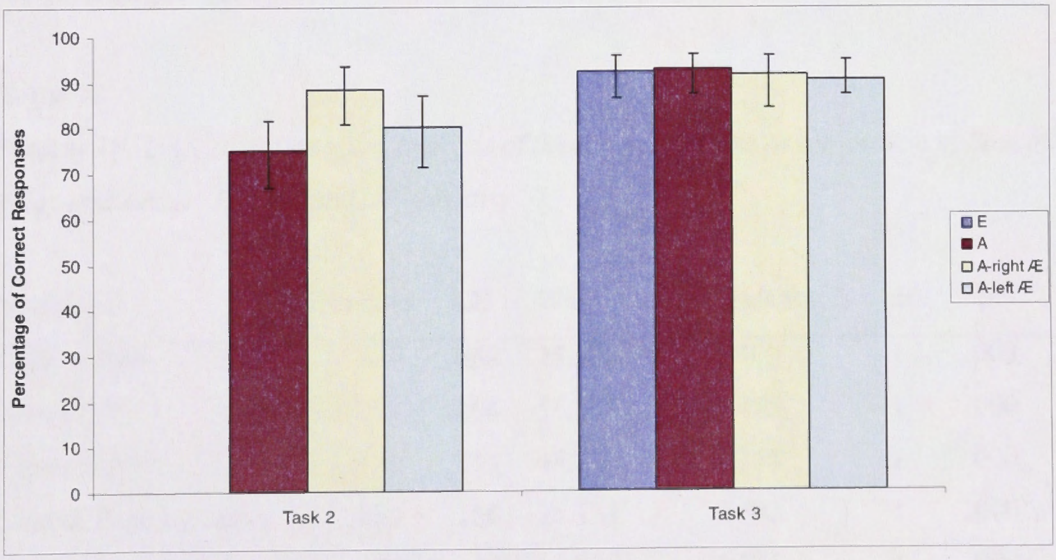


Figure 20. Patient BN: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of task. Error bars indicate 95% confidence interval.

Patient JF. The overall model was significant (χ^2 (5) = 239.741, $p < .001$; see Table 20). There was a main effect for side of page ($t = 25.178$, $p < .001$). Patient JF responded correctly to fewer letters on the left side of page (53.24%) than on the right side of page (78.13%), a finding interpreted as viewer-centred neglect. The main effects for letter 'E' ($t = 56.105$, $p < .001$) and letter 'A' ($t = 48.220$, $p < .001$) were significant. Patient JF responded correctly to fewer 'Æ' letters (56.14%) compared to 'E' letters (75.89%) or 'A' letters (74.55%). There were also a significant side of page by letter 'E' ($t = 25.132$, $p < .001$) and a side of page by letter 'A' ($t = 13.937$, $p < .001$) interaction.

Inspection of Table 20 suggested that the letters 'E' and 'A' may not differ significantly from each other, and this was confirmed ($Q'(1) = .14$, $p = .7039$). Accordingly, we compare a model in which these letters are combined. The resulting model was significant (χ^2 (3) = 237.310, $p < .001$) and does not provide a significantly worse fit to the data, so we cannot reject the simpler model that combines the letters 'E' and 'A' and compares these to the letter 'Æ'. The interpretation is clear: there is a significant main effect for side of page and for letter. There is also an interaction effect with responses to the letter 'Æ' significantly lower compared to responses to the letters 'E' and 'A', and the left-right (side of page) difference is greater for the letters 'E' and 'A' than for the letter 'Æ'.

Table 20

Patient JF: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Letter 'E', 'A', and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.343	.068	25.178	1.409	1	.000
Letter 'E'	1.246	.166	56.105	3.475	1	.000
Letter 'A'	1.010	.145	48.220	2.745	1	.000
Side of Page by Letter 'E'	.834	.166	25.132	2.302	1	.000
Side of Page by Letter 'A'	.543	.145	13.937	1.721	1	.000
(Constant)	.253	.068	13.781	1.289	1	.000

For the *follow-up logistic regression* analysis, the best model (χ^2 (7) = 162.566, $p < .001$; see Table 21) had a significant main effect for side of page ($t = 17.680$, $p < .001$). Patient JF responded correctly to fewer letters on the left side of page (51.96%) than on the right side of page (73.93%), a finding interpreted as viewer-centred neglect. The main effect for task was significant ($t = 12.596$, $p < .001$). Patient JF responded correctly to more stimuli in Task 2 (67.50%) compared to Task 3 (58.39%). There was also a significant task by side of page interaction ($t = 12.658$, $p < .001$). This interaction indicates that the viewer-centred effect was of smaller magnitude in Task 2 (left side of page = 62.50%; right side of page = 72.50%) compared to Task 3 (left side of page = 41.43%; right side of page = 75.36%).

Table 21

Patient JF: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page, Task, and Letter 'A' and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.336	.080	17.680	1.399	1	.000
Task	-.298	.084	12.596	.743	1	.000
Side of Page by Task	.239	.067	12.658	1.270	1	.000
Letter 'A'	.768	.173	19.745	2.156	1	.000
Letter A-left 'Æ'	-.559	.160	12.214	.572	1	.000
Side of Page by Letter 'A'	.528	.152	12.130	1.696	1	.000
Task by Letter A-left 'Æ'	.332	.139	5.700	1.394	1	.017
(Constant)	.499	.115	18.725	1.648	1	.000

There was a significant main effect for the letter 'A' ($t = 19.745$, $p < .001$) and a side of page by letter 'A' interaction ($t = 12.130$, $p < .001$), which indicated object-centred neglect only on the right side of page (see Figure 21). Patient JF responded correctly to significantly more 'A' letters (89.73%) compared to A-right 'Æ' letters (70.24%) on the right side of the page. There was also a significant main effect for A-left 'Æ' ($t = 12.214$, $p < .001$) and a task by A-left 'Æ' interaction ($t = 5.700$, $p = .017$), which indicated stimulus-centred neglect only in Task 2 (see Figure 22). Patient JF responded correctly to significantly fewer A-left 'Æ' letters (47.62%) compared to A-right 'Æ' letters (70.24%) in Task 2.

Overall, the 'Æ' letter-cancellation task classified patient JF with viewer-, stimulus-, and object-centred neglect. Object-centred neglect was evident in both Task 1 and Task 2, but it was evident on the right side of page *only*. Stimulus-centred neglect was evident in Task 2 *only*.

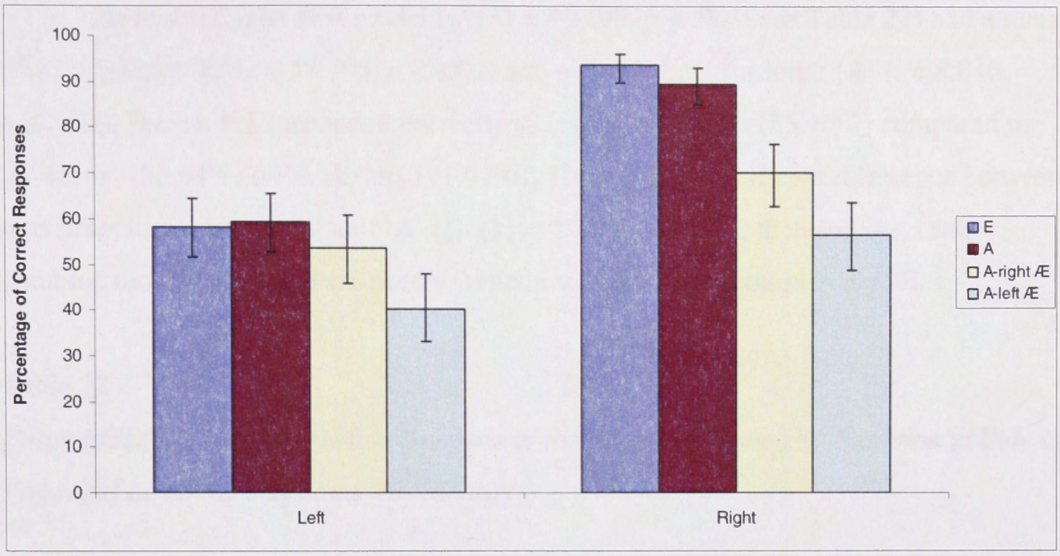


Figure 21. Patient JF: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of side of page. Error bars indicate 95% confidence interval.

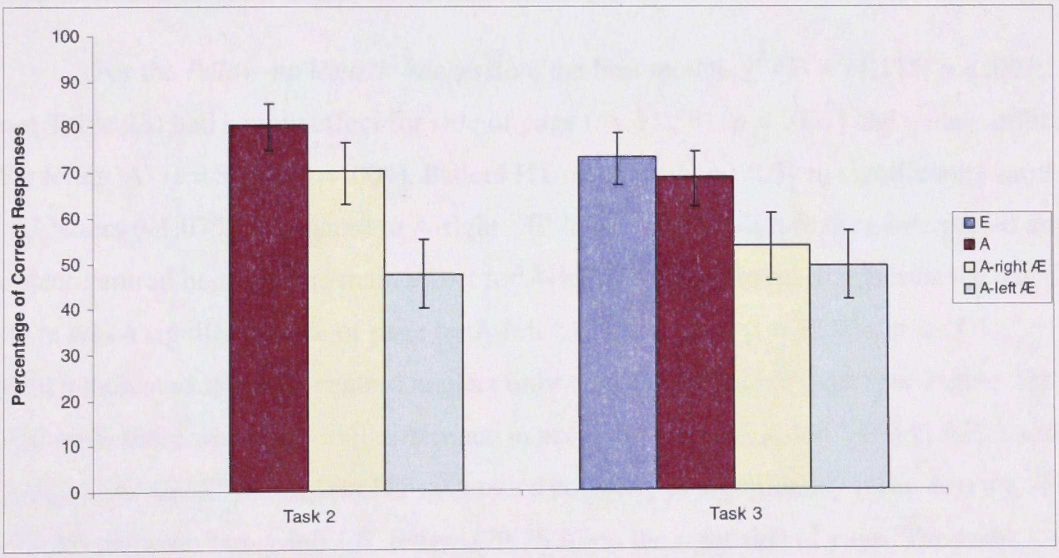


Figure 22. Patient JF: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of task. Error bars indicate 95% confidence interval.

Patient HT. The best model (χ^2 (3) = 41.199, p < .001; see Table 22) had a main effect for letter 'E' (t = 27.795, p < .001) and a main effect for letter 'A' (t = 8.810, p = .003). Patient HT responded correctly to fewer 'Æ' letters (85.16%) compared to 'E' letters (95.54%) or 'A' letters (91.07%). There was a significant difference between responses to the letters 'E' and 'A' (Q' (1) = 4.72, p = .0298), therefore we cannot combine these letters, and we need to remain with the more complex model.

Table 22

Patient HT: Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page and Letter 'E', 'A', and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.147	.077	3.631	1.158	1	.057
Letter 'E'	1.278	.242	27.795	3.591	1	.000
Letter 'A'	.561	.189	8.810	1.752	1	.003
(Constant)	1.748	.094	345.052	5.745	1	.000

For the *follow-up logistic regression*, the best model (χ^2 (3) = 24.175, p < .001; see Table 23) had a main effect for side of page (t = 11.581, p = .001) and a main effect for letter 'A' (t = 8.122, p = .004). Patient HT responded correctly to significantly more 'A' letters (91.07%) compared to A-right 'Æ' letters (87.20%), a finding interpreted as object-centred neglect. The main effect for A-left 'Æ' failed to reach significance but there was a significant side of page by A-left 'Æ' interaction (t = 12.854, p < .001), which indicated stimulus-centred neglect only on the right side of page (see Figure 23). Although there was no overall difference in accuracy between A-left 'Æ' (83.63%) and A-right 'Æ' (87.20%), patient HT responded correctly to significantly more A-right 'Æ' (92.26) compared to A-left 'Æ' letters (79.76%) on the right side of page. The main effect for task failed to reach significance, nonetheless we have presented Figure 24 below, for ease of comparison with the other patients.

Overall, the 'Æ' letter-cancellation task classified patient HT with viewer- and object-centred neglect, and with stimulus-centred neglect on the right side of page *only*.

Table 23

Patient HT. Logistic Regression Analysis of the Accuracy Data as a Function of Side of Page, Task, and Letter 'A' and 'Æ' Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Side of Page	.392	.115	11.581	1.480	1	.001
Letter 'A'	.562	.197	8.122	1.755	1	.004
Side of Page by						
Letter A-left 'Æ'	-.700	.195	12.854	.496	1	.000
(Constant)	1.778	.111	258.203	5.917	1	.000

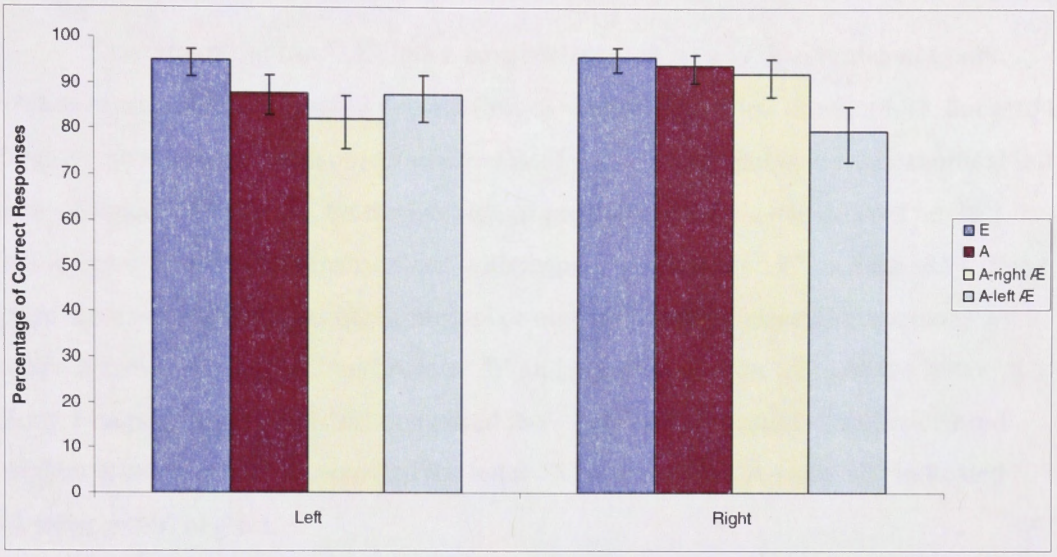


Figure 23. Patient HT: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of side of page. Error bars indicate 95% confidence interval.

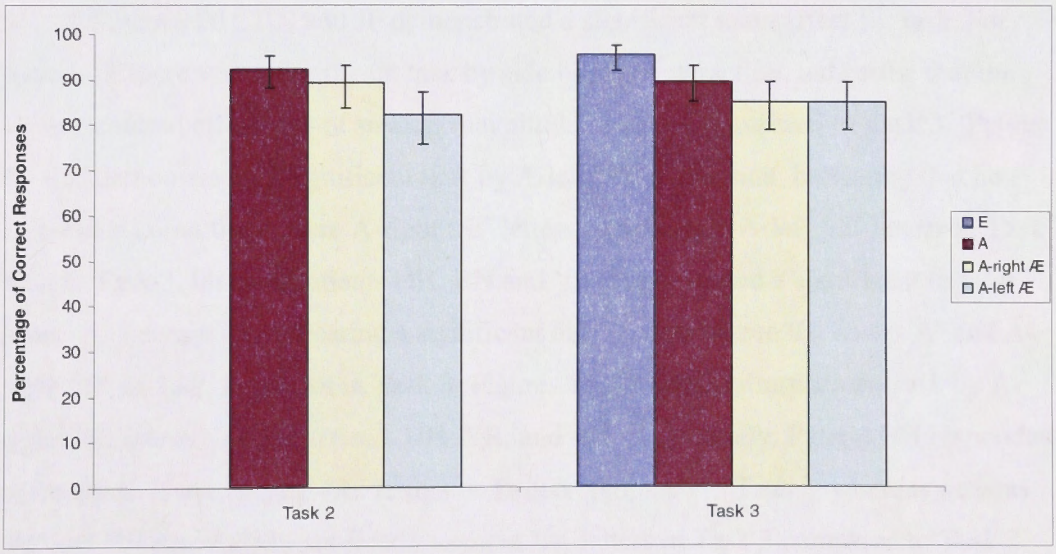


Figure 24. Patient HT: Percentage of correct responses to the letters 'E', 'A', A-right 'Æ' and A-left 'Æ' as a function of task. Error bars indicate 95% confidence interval.

Summary for Series of Single-Cases

The aim of our new 'Æ' letter-cancellation task was to distinguish not only viewer- from stimulus-centred neglect (left of viewer versus left of stimulus), but also to distinguish stimulus- from *object-centred neglect* (left of stimulus versus canonical left side of object). Omissions on the left side of page indicated viewer-centred neglect, while errors in following instructions with respect to the letter 'Æ' on both sides of the page were interpreted as either stimulus- or object-centred neglect. Comparisons were made between A-right 'Æ' and A-left 'Æ' and between A-right 'Æ' and the letter 'A'. Poorer responses to A-left 'Æ' compared to A-right 'Æ' indicated stimulus-centred neglect whereas better response to the letter 'A' compared to A-right 'Æ' indicated object-centred neglect.

All five patients (patients HH, VR, BN, JF, and HT) demonstrated viewer-centred neglect on the 'Æ' letter-cancellation task. They all responded correctly to fewer stimuli on the left side of page than on the right side of page, as evidenced by a significant main effect for side of page. Patient JF demonstrated a significant side of page by letter 'Æ' interaction, which indicated that the left-right (side of page) difference was greater for the letters 'E' and 'A' than for the letter 'Æ'.

Patients HH, BN and JF demonstrated a significant main effect for task. For patient JF there was a significant task by side of page interaction, indicating that the viewer-centred effect was of smaller magnitude in Task 2 compared to Task 3. Patient JF also demonstrated a significant task by A-left 'Æ' interaction, indicating that he responded correctly to more A-right 'Æ' letters compared to A-left 'Æ' letters in Task 2 than in Task 3. Instead, patients HH, BN and VR demonstrated a significant task by letter 'A' interaction, indicating a significant difference between the letters A' and A-right 'Æ' in Task 2, but not in Task 3. Figures 16, 18 and 20 illustrate the task by A-right 'Æ' interaction for patients HH, VR, and BN, respectively. Patient HH responded correctly to fewer A-right 'Æ' letters in Task 3 compared to Task 2, whereas patients VR and BN responded to correctly to more 'A' letters in Task 3 compared to Task 2.

Patients JF and HT responded correctly to fewer 'Æ' letters compared to 'E' letters or 'A' letters, and for patient JF this difference interacted with side of page, indicating a difference on the right side of page *only*. These findings suggest the presence of either stimulus- or object-centred neglect. The follow-up analysis demonstrated better responses to A-right 'Æ' compared to A-left 'Æ', indicating stimulus-centred neglect for both patients JF and HT. For patient JF, the stimulus-centred effect was evident in Task 2 *only,* and not in Task 3. For patient HT, the stimulus-centred effect was evident on the right side of page *only,* and not on the left side of page. The follow-up analysis also demonstrated a better response to letter 'A' compared to A-right 'Æ', indicating object-centred neglect for both patients JF and HT. For patient JF, the object-centred effect was observed on the right side of page *only,* and not on the left side of page. For patient HT, the object-centred effect was observed irrespective of side of page and task. Refer to Table 24 for a summary of the results.

Table 24

Neglect in Viewer-, Stimulus-, and Object-Centred Frames of Reference: Results from the Group Analyses and from the Single-Case Analyses

	Discriminative-Cancellation Task	Norwegian 'Æ' Letter-Cancellation Task
Group	VCN, SCN	VCN, SCN, OCN
Patient HH	VCN	VCN
Patient VR	No neglect	VCN
Patient BN	VCN, SCN	VCN
Patient JF	VCN	VCN, SCN, OCN
Patient HT	No neglect	VCN, SCN, OCN

Discussion

The aim of the present study was to investigate whether visual neglect can operate in an object-centred frame of reference in a group of five patients with neglect, while simultaneously examining for the presence of viewer-centred and stimulus-centred neglect. The analysis of the data also sought to investigate potential differences between a group analysis and a single-case analysis. That is, whether it was more informative to analyse data from patients with rare neurological disorders as a group or as single cases. It has previously been shown that different methods of analysis can yield important differences in results. For example, Farah, Brunn, Wong, Wallace, and Carpenter (1990) failed to find evidence of object-centred neglect in a study aimed at disambiguating neglect in viewer-, environment, and object-centred frames of reference. Although the averaged performance of the group of patients studied by Farah et al. *did not* support the existence of object-centred neglect, three of the ten patients demonstrated neglect in object-centred coordinates when the data was reanalysed by Hillis and Rapp (1998) to look at individual patient data.

The current experiments also replicated and extended the work of Ota et al. (2001), using the discriminative-cancellation task. The task consists of complete and incomplete stimuli (circles *or* triangles) scattered across a sheet of paper, and patients are required to circle complete stimuli and to cross out all other stimuli. A failure to respond to stimuli on the left side of page is an indication of viewer-centred neglect, whereas a failure to detect the missing left segments in the incomplete stimuli is an indication of stimulus-centred neglect. The Norwegian 'Æ' letter-cancellation task was also introduced with the aim of providing a method for disambiguating neglect in three frames of reference: viewer-, stimulus-, *and* object-centred. In this task the letters 'E', 'A', and 'Æ' were scattered across a sheet of paper, and the participants were instructed to circle all 'E' letters and/or to cross out all letters except the letter 'E'. The object-centred frame of reference was disentangled from other reference frames by displaying the letters in normal and backward parity and in eight different angles of orientation. Again, a failure to respond to stimuli on the left side of page was interpreted as viewer-centred neglect but errors in responding to the letter 'Æ' was interpreted as either stimulus-centred or object-centred neglect.

Table 24 summarises the patients' performance on the discriminative-cancellation task and the Norwegian 'Æ' letter-cancellation task, both as group data and as single-case data. The results of the discriminative-cancellation task indicated a clear presence of viewer-centred neglect in the patient group. This was evident from the finding that the participants responded correctly to fewer stimuli on the left side of page than on the right side of page. Participants also made more errors in responding to the incomplete stimuli than to the complete stimuli. The patients were less accurate in their responses to stimuli with a left *or* right gap compared to complete stimuli, and they did significantly worse with the left-gap stimuli compared to the right-gap stimuli. It should be noted that the difference between no gap stimuli and stimuli with a left gap was evident on the right side of page *only*. The relatively worse performance in response to stimuli with a left gap indicates the presence of left stimulus-centred neglect in the patient group on the right side of page.

When looking at the results from the single-case analyses, the results were somewhat different. Patients HH and JF demonstrated evidence of viewer-centred neglect, but only Patient BN demonstrated evidence of viewer- and stimulus-centred neglect. Patients VR and HT failed to demonstrate neglect in either viewer-centred or stimulus-centred frames of reference. Therefore, the group analysis provided evidence for the presence of both viewer- and stimulus-centred neglect, but it does not highlight the individual differences in performance on the discriminative-cancellation task. This finding highlights the importance of analysing data from rare neurological disorders as single cases.

It is important to consider statistical power here also. It is possible that the stimulus-centred effect failed to reach significance due to there being fewer trials at the single-case-level than at the group-level analysis. This is of particular relevance for the comparisons between left and right gaps. Whereas there are a larger number of stimuli in the left and right side of page comparison, the number of stimuli decreases in the left and right gap comparison. We will use patient HH to illustrate this point. In the side of page analysis, there were a total of 120 stimuli for the left side of page and 120 stimuli for the right side of page comparison. In the left-right gap comparison we compared 80 left-gap stimuli to 80 right-gap stimuli. Patients JF and HT were administered more trials of the discriminative-cancellation task. In the side of page analyses for patients JF and HT, there were a total of 360 stimuli for the left side of page and 360 stimuli for the right side of page comparison. In the left-right gap comparison, we compared 240 left-gap stimuli to 240 right-gap stimuli. But even with the increased number of trials, the stimulus-centred effect did not reach significance at the case level whereas it did for

Patient BN, who was administered only 160 left-gap stimuli and 160 right-gap stimuli. Patient BN was the only person who demonstrated stimulus-centred neglect on the single-case analysis of the discriminative-cancellation task.

The results obtained on the discriminative-cancellation task can be compared to the results reported by Ota et al. (2001) and Marsh and Hillis (2008). Ota et al. reported the results from two patients who completed the discriminative-cancellation task. Patient 1 responded to fewer stimuli on the left side of page than on the right side of page, indicating viewer-centred neglect. In contrast, Patient 2 responded to stimuli across both the left and right side of page, but made more errors with stimuli with the left side missing than with complete stimuli or stimuli with the right side missing, indicating stimulus-centred neglect. Marsh and Hillis also demonstrated a dissociation between viewer- and stimulus-centred frames of reference in patients with acute neglect. Out of the 98 patients completing the task, seventeen participants exhibited viewer-centred neglect on the visual version of the test, while only four demonstrated stimulus-centred neglect. In our study, we also found that viewer-centred neglect was more frequent than stimulus-centred neglect. On the discriminative-cancellation task, three patients exhibited viewer-centred neglect, whereas only one patient demonstrated stimulus-centred neglect. As will be discussed shortly, when tested with the 'Æ' letter-cancellation task, the number of patients who exhibited viewer-centred neglect in the single-case analysis increased to 100 percent.

When the data was analysed as a group, the results for the 'Æ' letter-cancellation task provided evidence of viewer-centred neglect: patients responded to fewer stimuli on the left side of page compared to the right side of page. The group analysis also provided evidence of stimulus- and object-centred neglect in that the patients demonstrated lower accuracy when they responded to the letter 'Æ' compared to the letters 'E' and 'A'. It was proposed that the pattern of responses to the letter 'Æ' would provide a method not only to distinguish viewer- from stimulus-centred neglect – as in the Ota et al. (2001) task – but also to distinguish stimulus- from object-centred neglect. More specifically, replacing the stimuli (circles and triangles) used in the discriminative-cancellation task with a letter which has an intrinsic left and right side, allowed us to investigate object-centred neglect, that is neglect of the 'A' part of the letter 'Æ' (the intrinsic left side) irrespective of side of page, parity, or angle of orientation. Stimulus-centred neglect would be demonstrated by neglect of the 'A' part of the letter 'Æ' *only* when located on the left side as defined by a stimulus-centred frame of reference. The angle by parity interaction demonstrated the presence of both stimulus- and object-centred neglect in the group analysis. Stimulus-centred neglect was demonstrated by reduced accuracy in responses when the letter was displayed so that the 'A' part of the letter 'Æ' was located on the left (when displayed upright in normal parity *and* upside-down in backward parity) as defined by a stimulus-centred frame of reference. The participants responded as if the letter was an 'E' and failed to cross out the letter 'Æ' because they failed to detect the 'A' part of the letter when asked to cross out all letters except the letter 'E'. Although there was some improvement in the patients' performance when the letter 'Æ' was displayed upright in backward parity *and* upside-down in normal parity, performance was impaired compared to responses to the letters 'A' and 'E'. The patients continued to incorrectly respond as if to the letter 'E'; they failed to detect the intrinsic left side of the letter (the 'A' part), despite this side now being located on the intact right side as defined by a stimulus-centred frame of reference. This finding suggests the presence of object-centred neglect.

The relative improvement in the patients' performance when the letter 'Æ' was displayed upright in backward parity *and* upside-down in normal parity could suggest that object-centred neglect may be less severe than stimulus-centred neglect. Alternatively, the improvement in performance may be due to performance reflecting object-centred neglect *only* in these conditions. Instead the patients' performance when the 'A' part is located on the left side in a stimulus-centred frame of reference may reflect the cumulative impact of neglect in both stimulus- and object-centred reference frames, as these forms of neglect are not disambiguated in these conditions. As the patients moved their gaze to focus on each stimulus on the sheet, the presence of neglect in a retinotopic frame of reference also may be contributing to the stimulus-centred results. A three-way interaction between side of page, parity, and angle of orientation confirmed this interpretation of the results, but suggested that the effect is more pronounced on the right side of page than on the left side of page. We speculated that the smaller effect on the left side of page has occurred because the patients responded to fewer stimuli on this side of the page due to their viewer-centred neglect. A lower response rate therefore provides less of an opportunity to observe the angle by parity interaction on the left side of page.

The results from the single-case analyses highlight individual differences in patient performance on the Norwegian 'Æ' letter-cancellation task. To investigate stimulus- and object-centred neglect, the single-case analysis investigated correct responses to the letters 'Æ' and 'A' only. With the letter 'Æ', we distinguished A-left 'Æ' from A-right 'Æ'. Better responses to A-right 'Æ' compared to A-left 'Æ' indicated stimulus-centred neglect whereas better responses to the letter 'A' compared to A-right 'Æ' indicated object-centred neglect. Patients HH, VR, and BN demonstrated neglect in a viewer-centred frame of reference *only.* Evidence for this was demonstrated by correctly responding to fewer stimuli on the left side of page compared to the right side of page. Patients JF and HT demonstrated evidence of neglect in viewer-, stimulus-, and object-centred frames of reference concurrently. Patient JF demonstrated stimulus-centred neglect in Task 2 *only.* He responded correctly to fewer A-left 'Æ' letters compared to A-right 'Æ' letters in Task 2 but not in Task 3. Patient HT demonstrated stimulus-centred neglect on the right side of page *only.* She responded correctly to fewer A-left 'Æ' letters compared to A-right 'Æ' letters on the right side of page but not on the left side of page. Both patients JF and HT demonstrated object-centred neglect. For patient JF, the object-centred neglect was evident on the right side of page *only.* He responded correctly to significantly more 'A' letters compared to A-right 'Æ' letters on the right side of page but not on the left side of page.

Although the group analysis for the Norwegian 'Æ' letter-cancellation task provided evidence for the presence of viewer-, stimulus-, and object-centred neglect in the patient group, it failed to highlight the individual differences in performance. It became evident in the single-case analyses that viewer-, stimulus-, and object-centred neglect only co-occur in two of the five patients. In fact, three of the patients demonstrated evidence of viewer-centred neglect *only.* The results from the group analysis once again failed to illustrate nuances in individual patient performance. This highlights the importance of analysing data from rare neurological disorders as single cases.

The results from the 'Æ' letter-cancellation task can be compared to the findings from the discriminative-cancellation task. Although both tasks provided evidence of viewer- and stimulus-centred neglect, the new 'Æ' letter-cancellation task further distinguished between neglect in stimulus- *and* object-centred frames of reference. Numerous researchers have claimed to provide evidence for the existence of object-centred neglect (e.g., Behrmann & Tipper; Di Pellegrino, Grassinetti, & Masso, 1995; Driver, Baylis, Goodrich, & Rafal, 1994; Driver & Halligan, 1991; Savazzi, Mancini, Veronesi, & Posteraro, 2009; Savazzi, Neppi-Mòdona, Zettin, Gindri, & Posteraro, 2004; Tipper & Behrmann, 1996) but these studies have not taken into account the requirement that objects require an intrinsic left and right side to show object-centred neglect, as stipulated by Behrmann and Moscovitch (1994). Most previous results can therefore be better described as evidence of stimulus-centred neglect rather than object-centred neglect. Behrmann and Moscovitch demonstrated object-centred neglect in a task that required patients with neglect to report outline colours of uppercase asymmetrical letters. They utilised stimuli with an intrinsic left and right side to investigate neglect in viewer-, environment-, and object-centred frames of reference. They found that patients reported fewer outline colours from the left as compared to the right side of the letters as defined by a viewer/environment-centred frame of reference. They also found that patients reported fewer outline colours on the intrinsic left side of asymmetrical letters, a finding interpreted as object-centred neglect. The 'Æ' letter-cancellation task described in the present study takes Behrmann and Moscovitch's criteria into account. Our results are consistent with the findings of Behrmann and Moscovitch, and provide experimental evidence of the existence of a distinct object-centred frame of reference.

The administration of standard tests of neglect (such as the Behavioural Inattention Test or the Bells Test) provided evidence of neglect in a viewer-centred frame of reference *only*. From Table 1 it can be seen that only a small number of the standard tests of neglect produced evidence of viewer-centred neglect in *all* patients. Even BIT Line Crossing, which is perhaps the most widely used test of visual neglect, produced evidence of neglect only in patient JF. Patient HH, who reliably demonstrated evidence of viewer-centred neglect in the discriminative-cancellation task and the new 'Æ' letter-cancellation task failed to demonstrate neglect on several of the standard tests of neglect. This highlights the importance of administering several tests of neglect as some tests may not reliably assess the presence of neglect even in patients who clearly demonstrate neglect in the visual modality. Collectively, the standard tests of neglect administered to the five patients in the current study demonstrated the presence of viewer-centred neglect. If time permits the administration of only a few standard tests of neglect, then it would be recommended to administer some of the more sensitive tests. In our experience, these would include BIT Star Cancellation, BIT Drawing, Schenkenberg Line Bisection, Bells Test, Balloons Test, Ogden Scene, and Rey Complex Figure.

The addition of tests that also investigate neglect in stimulus- and object-centred frames of reference provided additional important information regarding the nature of the deficits that may not be identified with standard tests of neglect. This is what we have demonstrated in the current paper in a group of five patients with neglect. The results from the present study provide evidence that *together*, the discriminative-cancellation task originally described by Ota et al. (2001) and the new 'Æ' letter-cancellation task described in the current study, can reliably be used to assess for the presence of viewer-, stimulus-, and object-centred neglect. The advantage of the new letter-cancellation task is that it can also distinguish stimulus- from object-centred neglect. The current findings provide conclusive evidence that neglect can operate in an object-centred frame of reference.

The results obtained in the current study emphasise the importance of single-case research in the study of rare neurological disorders. Our study focused on a series of five single cases with *persisting* neglect, that is, neglect persisting for more than three months. This single-case approach illustrates that the individual patterns of results can be vastly different. The grouping of the data produces overall results that do not reflect individual patient data, and valuable information regarding individual results may be lost as a consequence. Although we have demonstrated the importance of single-case research in the study of rare neurological disorders, we have also speculated that the failure to find statistical differences in data may be due to lack of power in the single-case research. For this reason, it can be important to analyse data from rare disorders both individually and as a group.

It appears that our new 'Æ' letter-cancellation task detected viewer-centred neglect more reliably than the discriminative-cancellation task originally described by Ota et al. (2001). Viewer-centred neglect was detected in all five patients compared to only two patients in the discriminative-cancellation task. In addition, our new 'Æ' letter-cancellation task detected stimulus-centred neglect in two patients that was not picked up by the discriminative-cancellation task. (Only on one occasion does the 'Æ' letter-cancellation task appear to let us down: It fails to detect stimulus-centred neglect for patient BN.) Although the responses required in the two tasks (circle, cross out) are the same, the decisions leading up to the response may be more complex in the 'Æ' letter-cancellation task. In the letter-cancellation task, the participant is required to choose between three alternatives ('E', 'A', 'Æ') before making a response. In contrast, in the discriminative-cancellation task, the only requirement was to detect the presence of a gap. Recall that in the 'Æ' letter-cancellation task, the participants were required to respond to some stimuli and not respond to others in Task 1 and Task 2, whereas in

Task 3, they had to respond to all letters displayed on the page. The participants were required to identify the letter first in order to make a decision as to whether the letter was to be circled and/or crossed out. For this reason, it is argued that the 'Æ' letter-cancellation task is more complex than the circle-cancellation task, and we suggest that this makes our new task more sensitive to detecting both viewer- and stimulus-centred neglect than the discriminative-cancellation task. Most importantly, the Norwegian letter-cancellation task provides more information regarding the nature of neglect because it can distinguish between stimulus- and object-centred neglect.

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SECTION 2:

A MENTAL ROTAION HYPOTHESIS OF OBJECT-CENTRED NEGLECT?

Chapter 3

A Mental Rotation Hypothesis of Object-Centred Neglect?

A Mental Rotation Hypothesis of Object-Centred Neglect?

In the previous section, we demonstrated that neglect can operate in an object-centred frame of reference. Buxbaum, Coslett, Montgomery, and Farah (1996) have criticised previous findings, and they have suggested that object-centred neglect may be explained by mental rotation of stimuli to upright. Mental rotation of stimuli to upright realigns all spatial coordinate systems and thus makes a distinction between viewer-, stimulus-, and object-centred neglect impossible. Here we specifically examine the mental rotation hypothesis of unilateral neglect. The section starts with an overview of the findings suggesting that mental rotation underlies object-centred neglect, and follows with an overview of the mental rotation literature. The literature review will conclude with a discussion regarding whether it is plausibile that object-centred neglect can be explained by the mental rotation hypothesis.

Buxbaum et al. (1996) reported that the object-centred effects found by Behrmann and Moscovitch (1994) may be due to mental rotation of the stimuli to upright, which returns the object-centred frame of reference into alignment with both viewer- and environment centred frames of reference. In this regard, viewer/environment-centred neglect may appear as if it is object-centred. Based on this reasoning, Buxbaum et al. conducted a study investigating whether object-based neglect would be observed when a patient with neglect was instructed to mentally rotate stimuli to upright as opposed to when the patient was instructed to deliberately refrain from mental rotation.

The stimuli consisted of asymmetrical and symmetrical objects and animals, and upper-case asymmetrical and symmetrical letters. The outline of all stimuli consisted of different coloured segments. The stimuli were presented individually at a 90° angle of rotation (left or right) from upright, and the patient was asked first to name the object (or animal) or letter depicted, and then to report as many outline colours as possible. The procedure was identical to that employed by Behrmann and Moscovitch (1994). Results showed that the apparent object-based effect was influenced by the instructions. Thus, when asked to mentally rotate the stimuli, the patient reported fewer colours from the left as compared to the right side of space (viewer- and/or environment-centred neglect) *as well as* reporting fewer colours on the left as compared to the right side of the stimuli (apparent object-based neglect). When asked to strategically refrain from mental rotation, however, the patient exhibited neglect of the left side of space only (that is, the upper and lower end of the letters depending on left or right rotation). Based on these results, Buxbaum et al. (1996) concluded that the patient's object-based neglect depended on imagined orientation, and was consistent with the presence of neglect as defined by viewer- and/or environment-centred frames of reference. It could not consequently be a reflection of object-based neglect arising as a result of the intrinsic handedness of objects. Buxbaum et al. therefore suggested that these were instances where viewer- and/or environment-centred neglect of the object may be misinterpreted as object-based neglect. These authors highlighted that the same effect was observed with all stimuli, including asymmetrical letters, which Behrmann and Moscovitch previously found to elicit object-centred neglect. Buxbaum et al. therefore suggested that, in these conditions, viewer- and/or environment-centred neglect of the object may be misinterpreted as object-based neglect.

The mental rotation hypothesis provides insight into a strategy that may have confounded previous results, but it fails to give an adequate explanation for why participants in the study conducted by Behrmann and Moscovitch (1994) only showed object-centred neglect with asymmetrical stimuli and not with *all* stimuli, as was found in the study conducted by Buxbaum et al. (1996). Buxbaum et al. explained this discrepancy as a reflection of mental rotation of only the asymmetrical letters, by the participants in Behrmann and Moscovitch's study. This explanation is in stark contrast to findings from earlier research on mental rotation, as will be discussed in more detail shortly, which suggests that the identification of misoriented asymmetric letters does *not* normally require mental rotation (Corballis, 1982).

Cubelli and Speri (2001) also attempted to disambiguate neglect in egocentric and object-centred frames of reference. Although they did not use objects with an intrinsic left and right side, they claimed to find evidence to support Buxbaum et al.'s (1996) interpretation that mental rotation to upright may underlie previous findings of object-centred neglect. The eight patients with neglect participating in Cubelli and Speri's study were required to name chimeric stimuli consisting of objects and animals. The stimuli were created by cutting selected pictures in half and attaching each half to a non-matching picture. The chimeric pictures were selected based on high accuracy of identification by neurologically healthy participants. The pictures were displayed individually and aligned with the patients' midline. They were presented at 0, 90, 180, and 270° from upright in both normal and mirror-reversed parity. The object-centred frame of reference was disambiguated from the egocentric frame in the rotated conditions. Cubelli and Speri stated that omissions on the left part of the horizontal stimuli would be an indication of neglect in a viewer-centred frame of reference. The failure to name the left part of the figure irrespective of rotation would be interpreted as object-centred neglect. They also suggested that when the stimuli were displayed in 90° and 270° rotations, there should be no difference in terms of which side of the picture is neglected by patients with egocentric neglect. That is, the patients should always neglect the side of the picture that falls on the left side in a viewer-centred frame of reference, irrespective of orientation. This means neglect of the bottom half of the picture when rotated 90°, but neglect of the top half of the picture when rotated 270°. Results demonstrated that patients made more omissions overall when the figures were presented upright or upside-down. In these orientations, the errors were largely due to neglect of the left side of the figure as defined in an egocentric frame of reference, a finding interpreted as egocentric neglect. There was no difference in omissions when the figure was rotated 90° to the right, which again was interpreted as evidence of neglect in an egocentric frame of reference. In contrast, when the figures were rotated 270° (in other words 90° to the left), the patients made more omissions on the left side of the figure as defined by an object-centred frame of reference. As object-centred neglect was only evident in this particular angle of orientation, and not consistent across orientations, Cubelli and Speri concluded that their result could *not* be attributed to neglect in an object-centred frame of reference. They suggested that in this particular orientation, the more informative part of the figure (the top half) fell in the neglected left side of space. To compensate for the unavailability of the more informative features, Cubelli and Speri proposed that the patients mentally rotated the figure to upright prior to naming the objects. In this way, the egocentric and object-centred frames of reference were aligned, and the result is therefore better accounted for by viewer-centred neglect. Cubelli and Speri concluded that previous research demonstrating object-centred neglect can be accounted for by alternative explanations, such as mental rotation of stimuli to upright, and that convincing evidence for object-centred neglect was therefore yet to be demonstrated.

Mental Rotation in Judgments about Shapes and Letters

Mental rotation of stimuli to upright has been implicated in a number of tasks. Previous research has demonstrated that individuals may mentally rotate the internal representations of objects to make certain decisions or judgments (e.g., Cooper, 1975; Cooper & Shepard, 1973; Shepard & Metzler, 1971). Response latency data demonstrate that the time required to make these judgments or discriminations is proportional to the amount of reorientation required. Shepard and Metzler (1971) were the first to document evidence of mental rotation. They investigated the time required for their eight participants to determine whether pairs of line drawings of three-dimensional shapes were the same or different as a function of the angular difference between the presented objects. Shepard and Metzler found that the participants' reaction time increased linearly with increasing angular difference between the objects, and concluded that the participants mentally rotated one of the shapes into congruence with the other to facilitate a comparison for making a same or different judgment. It has subsequently been demonstrated that mental rotation is involved in normal or mirror-reversed judgments of alphanumerical characters, numbers, letter-like symbols, as well as two- and three-dimensional shapes (e.g., Cooper, 1975, 1976; Cooper & Shepard, 1973; Corballis & McMaster, 1996; Corballis, Nagourney, Shetzer, & Stefanatos, 1978; Corballis, Zbrodoff, & Roldan, 1976; Eley, 1982; Hamm, Johnson, & Corballis, 2004; Hock & Tromley, 1978; Jolicoeur, Regehr, Smith, & Smith, 1985; Steiger & Yuille, 1983; Young, Palef, & Logan, 1980), same or different judgments of two-dimensional shapes (Cooper & Podgorny, 1976), and judgments about the left and right sides of alphanumerical characters and natural objects (Corballis & Cullen, 1986; Corballis & McMaster, 1996; Jolicoeur, 1985). Similarly, mental rotation has been implicated in symmetry judgments (Corballis & Roldan, 1975), hand laterality judgments (e.g., Cooper & Shepard, 1975; De Lange, Hagoort, & Toni, 2005), and laterality judgments about human figures (e.g., Harris, Harris, & Caine, 2002; Parsons, 1987). It has been reported that when the direction of rotation is not specified, response latency gradually increases from upright to 180° displacement from upright, and then symmetrically decreases in orientations from 180° to 360° (e.g., Cooper & Shepard, 1975). Cooper and Shepard (1973) also provided evidence that the time taken to determine whether letters were normal or backward increased linearly as a function of angular departure from upright. Cooper and Shepard interpreted this finding as evidence that the participants mentally rotated the character to an upright position, to compare it to a stored representation of the normal upright version of the character.

As indicated previously, it has been demonstrated that mental rotation to upright is required to make parity judgments or judgments about the left and right side of individually presented alphanumerical characters (e.g., Cooper & Shepard, 1973; Corballis & McMaster, 1996). Although mental rotation to upright is necessary to make parity judgments of alphanumerical characters, the *identification* of misoriented alphanumerical characters does not commonly require mental rotation to upright. Corballis, Zbrodoff, Shetzer, and Butler (1978) conducted a study investigating the time required to name misoriented letters and numerals. They expected identification not to require mental rotation to upright, and therefore predicted that the identification latency would be independent of angular orientation. Eight participants identified the uppercase letters G, J, and R, and the numerals 2, 5, and 7. The stimuli were presented individually in normal and backward parity and in six different angles of orientation of 60° increments from upright. Although the results indicated that the latency to name alphanumerical characters depended to some extent on angular deviation from upright, Corballis et al. maintained that reaction time did not resemble those obtained in experiments explicitly investigating mental rotation of the same stimuli (see also Jolicoeur, Snow, & Murray, 1987). They further noted that this effect was restricted to backward characters and was observed to flatten out with practice. The reduction in reaction time with practice is in contrast to tasks requiring mental rotation to upright, which has been shown to be extremely resistant to practice effects (e.g., Cooper and Shepard, 1973). Corballis et al. noted that as the numerals 2 and 5 may be confused (e.g., a backward 2 may be confused with a normal 5), this may have induced an occasional mental rotation strategy to facilitate the identification of these numerals, which may have impacted on the overall identification latencies. They concluded that the identification of misoriented letters and numerals does not normally require mental rotation to upright.

The conclusions from the findings of Corballis et al. (1978) were subsequently supported by the findings of Corballis and Nagourney (1978). Corballis and Nagourney investigated reaction time latencies in the classification of rotated characters as letters or numerals. They suggested that the identification of characters precedes classification, and therefore examined whether the more complex task of classification required mental rotation to upright. The stimuli consisted of the uppercase letters G, J, and R, and the numbers 2, 5, and 7, which were displayed in normal and backward parity in six different angles of orientation. The six participants were required to press one response key if the character displayed was a letter and another response key if the character was a number. Results illustrated that there was no effect of angular orientation on reaction time latencies. Based on this finding, Corballis and Nagourney concluded that the classification of rotated characters as letters or numerals does not require mental rotation even though classification is a more complex task than the identification of letters and numbers. This supports the interpretation of this finding, put forward by Corballis et al., showing that mental rotation is not required in the identification of misoriented letters and numerals.

White (1980) conducted an experiment attempting to validate Corballis et al.'s (1978) and Corballis and Nagourney's (1978) findings. The stimuli included in the White experiment were the same as the stimuli utilised by Corballis et al. (G, J, R, 2, 5, 7), and were presented individually in normal and backward parity and in six different angles of orientation in 60° increments from upright. The stimuli were presented in three different conditions: (a) version condition: the words, 'forward' or 'backward' preceded the stimulus presentation; (b) category condition: the words, 'letter' or 'number' preceded the stimulus presentation; (c) name condition: one of the stimulus characters preceded each stimulus presentation. The participants' task was to respond as quickly as possible by pressing two keys simultaneously when the stimulus character matched the preceding cue. When there was a mismatch between the character and its preceding cue, the participants were not required to respond. Results demonstrated a characteristic mental rotation curve in the reaction time data in the version condition where the participants were required to decide the parity (normal or backward) of a character. This result confirmed previous findings demonstrating that mental rotation to upright is necessary to make parity judgments of alphanumerical characters (e.g., Cooper & Shepard, 1973). There was no effect of angular orientation in the reaction time data from the category and name conditions. Consistent with Corballis et al. and Corballis and Nagourney, White concluded that the identification or categorisation of misoriented letters and numbers does not require mental rotation to upright.

Similar to the findings of Corballis et al. (1978), Corballis and Nagourney (1978), and White (1980), Simion, Bagnara, Roncato, and Umiltà (1982) also failed to find an effect of angular displacement from upright on the identification of upper- and lower-case alphanumerical letters (Experiment 3) (see also Young, Palef, & Logan, 1980). It has also been demonstrated that mental rotation is not necessary in the identification of misoriented and relatively unfamiliar letter-like symbols (Eley, 1982). Although the evidence presented above uniformly suggests that mental rotation to upright is not required in the identification of misoriented alphanumeric letters, Corballis and McLaren (1984) have provided evidence that mental rotation may be required to discriminate between certain letters. Corballis and McLaren investigated the necessity for mental rotation in both the discrimination of left-right mirror images as well as up-down mirror images. The stimuli consisted of the lowercase letters b, d, p, and q. They hypothesised that identification of the stimuli would induce mental rotation to upright because letter parity specification is required to distinguish the letter b from the letter d, or the letter p from the letter q. The stimuli were presented individually in six different angles of orientation in 60° increments from upright. Six participants were required to identify the stimuli in four different identification conditions: (a) identify the stimulus as the letter b or d; (b) identify the stimulus as the letter p or q; (c) identify the stimulus as the letter b or p; (d) identify the stimulus as the letter d or q. Results demonstrated that reaction time increased as a function of angular departure from upright, a finding interpreted as evidence that mental rotation to upright was required to make the letter discriminations. The letters included in Corballis and McLaren's study are exceptional due to the requirement of mirror-image discrimination, to facilitate letter identification.

It is clear from the literature reviewed that with the exception of the lowercase letters b, d, p, and q (and possibly the uppercase letters M and W), mental rotation is not required in the identification of individually presented misoriented alphanumerical characters. This is in contrast to the literature examining the effect of misorientation on response latency in the identification of letter strings or words and nonwords. Kolers and Perkins (1969a) investigated the time taken for ten participants to read strings of letters displayed in normal and backward parity, both upright and upside-down. The letter strings were presented in two different conditions: (a) letter condition: every letter was followed with a blank space; (b) pseudoword condition: the letters were displayed in strings corresponding to the length of words. The participants were required simply to read the letters printed on the page in both conditions. Kolers and Perkins (1969a) found that it took longer overall for participants to name letters in the pseudoword condition than in the letter condition. They suggested that this constituted initial evidence that word recognition may operate differently to the identification of single letters. Furthermore, Kolers and Perkins' (1969a) data suggested that reading strings of letters presented upside-down may take longer than reading strings of letters displayed in an upright orientation. It is important to note that the stimuli utilised by Kolers and Perkins (1969a) included the letters b, d, p, and q. Based on Corballis and McLaren's (1984) findings of mental rotation in the discrimination of these letters, it is reasonable to expect that these letters may have contributed to an increase in the time required to identify the misoriented characters. Kolers and Perkins (1969b) also reported that the errors made in the identification of these four letters accounted for the majority of identification errors.

Koriat and Norman (1984) first investigated the role of mental rotation in the reading of misoriented words. Twenty participants were required to read five-letter words and nonwords presented individually in one of six different angles of orientation (in 60° increments from upright). The stimuli remained visible until the participant pressed one of two keys indicating classification of a word as a real word or as a nonword. Results demonstrated that reaction time increased with increasing deviation from upright both for words and nonwords, a finding interpreted as evidence that mental rotation is required both for reading and classifying misoriented words. One observation worth pointing out from Koriat and Norman's (1984) data is that there seems to be only a small difference in reaction time between letters presented upright and 60° to the left or right of upright. There was, however, a large difference in reaction time between these more upright orientations and the relative upside-down orientations (120, 180, 240°). This finding was replicated by Koriat and Norman (1985), who varied the number of letters in the word string to investigate the effect of this manipulation on performance. This experiment was identical to the study by Koriat and Norman (1984), except that the stimuli consisted of words and nonwords of 2-, 3-, 4-, and 5-letters. Results indicated that although the characteristic mental rotation curve was evident in response latency to all words and nonwords irrespective of length, it became more pronounced with increasing string length.

Koriat and Norman's (1984, 1985) findings indicate that mental rotation is involved in the reading of misoriented words, but Farah and Hammond (1988) provided evidence that a patient who was impaired on mental rotation tasks could accurately read words presented upside-down. It should be noted that Farah and Hammond's results remain somewhat inconclusive in that they only included words presented upright and upside-down. Words presented in other angles of orientation would be required in order to assess for a mental rotation strategy in the reading of misoriented words. Furthermore, there was evidence to suggest that the patient was encoding the word by identifying letters individually, and he also sometimes spelt the words out loud. This may be a strategy to facilitate word recognition to compensate for mental rotation impairments. In the absence of mental rotation deficits, however, Koriat and Norman's (1984, 1985) findings suggest that individuals engage in a mental rotation strategy to identify misoriented words.

The findings presented here have implications for the interpretation of previous findings of object-centred neglect for individually presented alphanumerical letters or words. As has been discussed, Buxbaum et al. (1996) suggested that Behrmann and Moscovitch's (1994) findings of object-centred neglect may be due to the patients having mentally rotated the alphanumerical characters to upright, thereby realigning the object-centred frame of reference with the viewer- and environment-centred frames of reference. Buxbaum et al. suggested that Behrmann and Moscovitch's findings may therefore represent neglect in a viewer- and/or environment-centred frame of reference rather than neglect in an object-centred frame of reference. But from the evidence presented here (e.g., Corballis et al., 1978; Corballis & Nagourney, 1978; Simion et al., 1982; White, 1980) it seems rather unlikely that the patients included in Behrmann and Moscovitch's study mentally rotated the alphanumerical characters to upright. It should also be noted that the stimuli included uppercase alphanumerical characters that cannot be confused with each other (B, D, E, F, K, I, P, Q, R), which makes it even less likely that there was mental rotation of the stimuli. Buxbaum et al.'s mental rotation hypothesis thus fails to give an adequate explanation of the results obtained by Behrmann and Moscovitch. The findings of Behrmann and Moscovitch are therefore likely to represent evidence of 'true' object-centred neglect.

Koriat and Norman's (1984, 1985) findings of mental rotation in the reading and classification of misoriented words provides a challenge to Caramazza and Hillis' (1990a, 1990b) interpretation of Patient NG's right-side neglect when reading and spelling. Patient NG's errors in reading and spelling occurred on the intrinsic right side of a word *only,* and irrespective of orientation, a finding interpreted as object-centred neglect. Based on the evidence presented, it is possible, if not highly likely, that Patient NG may have engaged in a mental rotation strategy to identify and spell the misoriented words. Buxbaum et al.'s (1996) mental rotation hypothesis may therefore be more applicable to Caramazza and Hillis' findings. The mental rotation of words to upright would have realigned the object-centred frame of reference with the viewer- and environment-centred frame of reference.

Mental Rotation in Identification of Misoriented Objects

Jolicoeur (1985) designed a series of experiments to investigate the effects of angle of orientation in the identification of natural objects. Jolicoeur suggested that even though the identification of misoriented alphanumerical characters does not induce mental rotation, the effects of orientation may be evident in the response latency to objects. This is because objects are more complex and not as well learned as alphanumerical letters. The sixteen participants who took part in the first experiment were required to name watercolour drawings of natural objects, such as animals, foods, and furniture, that were individually displayed in six different angles of orientation (in 60° increments from upright). Results demonstrated that the time to name the objects increased as a function of angular displacement from upright. However, the effects of orientation, decreased with repeated testing. This finding was interpreted as evidence that practice or familiarity with stimuli may attenuate the effect of orientation on response latency. The results were replicated in a second experiment in which twelve participants were required to name black-and-white drawings of natural objects, which differed in terms of familiarity. Again, results demonstrated an increase in the time to name objects as they were rotated further from upright, an effect that was observed to decrease with repeated testing. The mental rotation curve was evident with both familiar and less familiar objects, but the less familiar objects took longer to name than the familiar objects in all orientations. In another experiment, Jolicoeur demonstrated that the effect of orientation in identification time is comparable to that found in a mental rotation task. In this experiment, twelve participants were required to press one of two response keys to indicate whether an object was facing left or right when upright, a task known to induce mental rotation. The response latency to make this left-right judgment was found to be equivalent to that observed in the initial two experiments, where subjects were required to identify misoriented objects. This latter finding added support to Jolicoeur's conclusion that the identification of misoriented objects requires mental rotation to upright. Jolicoeur's finding of a mental rotation curve in the time required to name misoriented objects has subsequently been replicated by Maki (1986), Jolicoeur (1988), Jolicoeur and Milliken (1989) and McMullen and Jolicoeur (1990).

Despite these findings, there is a debate in the literature as to whether the recognition of misoriented objects requires mental rotation to upright. The main argument against the requirement for mental rotation is the observation that the effect of orientation in object identification is reduced with practice, whereas it remains largely unchanged for left-right and parity judgments. Similarly, Corballis (1988) has pointed out a logical difficulty in the assumption that mental rotation is required for object identification in that it would be difficult, if not impossible, to know how to mentally rotate to upright an object with an unknown identity. Jolicoeur, Corballis, and Lawson (1998) suggest that a strategy other than mental rotation is involved in the recognition of misoriented objects. Results from Farah and Hammond (1988) have also been cited as evidence against the requirement of mental rotation in the identification of rotated objects. They described a patient who was unable to mentally rotate stimuli to upright, but who was still able to identify misoriented objects. Furthermore, the patient's identification of the objects was never intact irrespective of the object orientation: the accuracy rates ranged from 72% to 78%. More recently, Harris, Harris, and Caine (2002) have described Patient CB, a woman with severe mental rotation impairments, who was highly accurate (95% accuracy rate) in identification of misoriented objects and silhouettes. As with the identification of misoriented words, however, it may be possible that alternative strategies were utilised to aid object identification in the presence of mental rotation deficits.

The findings of Jolicoeur (1985), Maki (1986), Jolicoeur (1988), Jolicoeur and Milliken (1989), and McMullen and Jolicoeur (1990) suggest that researchers should be cautious in the use of natural objects in the investigation of object-centred neglect. As has been discussed, Hillis and Rapp (1998) reanalysed the raw data for individual participants included in Farah, Brunn, Wong, Wallace, and Carpenter (1990) study and found evidence of object-centred neglect in three of ten participants. These three participants more frequently omitted letters appearing on the left than on the right side of an object when the object was rotated in a clockwise or counter clockwise direction. Without reaction time evidence for the absence of a mental rotation curve in the patients studied by Farah et al., it is possible that these three patients mentally rotated the objects to upright prior to identification. The object-centred frame of reference may have been realigned with the viewer- and environment-centred frames of reference, and the results may therefore be better accounted for by neglect in a viewer- and/or environment-centred frame of reference.

Mental Rotation in Hand Laterality Judgments and Laterality Judgments of Human Figures

The evidence so far suggests that the identification of misoriented letters does not require mental rotation to upright whereas mental rotation is required to make left - right judgments about alphanumerical stimuli. Similar findings have been documented from research on mental rotation and hand laterality judgments as well as laterality judgments of human figures. It appears that mental rotation is not necessary to identify a picture of a hand as a hand, however, mental rotation is required to judge the laterality of the hand (Cooper & Shepard, 1975).

Cooper and Shepard (1975) investigated the effect of orientation on the time taken to identify a hand as a left or a right hand. They presented line drawings of left and right hands individually in six different angles of orientation (in 60° increments from upright), either the palm up or palm down (with the back of the hand facing the participants). The eight participants were required to press one of two buttons as soon as they had determined whether the hand presented was a left or a right hand. Cooper and Shepard found that the time taken to make a hand laterality judgment increased as a function of angular displacement from upright, a finding interpreted as evidence that mental rotation was required to make judgments about the laterality of hands. Parsons (1987a) replicated Cooper and Shepard's findings, and also showed that it took participants more time to make laterality judgments when the palm of the hand faced the participants than when the back of the hand faced the participants.

Parsons (1987b) also investigated the effect of orientation in judgments as to whether an arm belonged to the left or right half of the body. Ten participants were shown line drawings of the front and back of a human body with either the left or right arm outstretched. The drawings were presented individually in twelve different angles of orientation (in 30° increments from upright). The participants were required to press one of two buttons as quickly as possible to indicate whether the outstretched arm belonged to the left or right side of a human figure. Results demonstrated that subjects took longer to make laterality judgments with drawings of human bodies facing them than with drawings of the back of a body. This is presumably because the figure when facing the participant must be turned around so that its left and right side correspond to the left and right side of the viewer. This rotation is not required when the figure is depicted from the back. Furthermore, reaction time was found to increase as a function of angular departure from upright, findings indicative of the requirement to mentally rotate the figure to make a laterality judgment. This finding has recently been replicated by Harris et al. (2002).

In contrast to previous research utilising, for example, alphanumerical stimuli, where participants have reported the use of a strategy to mentally rotate stimuli, the participants included in Parsons' study (1987a; 1987b) reported that they imagined reorienting their own self to the orientation of the stimulus. Irrespective of the strategy involved, the results of Cooper and Shepard (1975) and Parsons have implications for the findings of object-centred neglect reported by Laeng, Brennen, Johannessen, Holmen, and Elvestad (2002). The participant in Laeng et al.'s study was required to name the colour of cubes positioned either on a table or held by the experimenter. Laeng et al. proposed that the experimenter functioned as if she herself was a part of the object when holding the cubes. They separated the object-centred frame of reference by presenting the left side of the object (the cube held by the experimenter's left hand) in the right side of space. Reaction time to name the colour of cubes was impaired, both for cubes located in the left side of space and for cubes located on the left side of the object (the cube held in the experimenter's left hand). These findings were interpreted as evidence of both viewer- and object-centred neglect. As indicated previously, mental rotation is involved in judgments of both hand laterality and laterality judgments relating to the left and right side of a human body. If manipulation of the object-centred frame of reference was to be effective, the patient must have assigned laterality to the left and right hands, which is likely to have included some form of mental transformation. For the patient to assign laterality, the mental rotation of the experimenter (or the imagined reorientation of the patient) would realign the object-centred frame of reference with the viewer-centred frame of reference. Laeng et al.'s results could therefore also be explained by neglect in a viewer-centred frame of reference. Laeng et al. does, however, illustrate a very elegant method of distinguishing viewer- from object-centred neglect, a method that can be applied to other objects with an intrinsic left and right side (e.g., asymmetrical uppercase letters) whose identification has not been found to require mental rotation to upright.

Summary

The literature on mental rotation reviewed above indicates that the mental rotation hypothesis put forward by Buxbaum et al. (1996) may apply to some but not to all explanations of object-centred neglect. Evidence of mental rotation has been documented in the reading of misoriented words, in the identification of misoriented objects, in the assignment of laterality to hands, and in the laterality judgments of the left and right side of a human body but mental rotation has not been documented in the identification of misoriented alphanumeric letters. Therefore, the findings of object-centred neglect reported by Caramazza and Hillis (1990a; 1990b), Laeng et al. (2002), and Hillis and Rapp (1998; from the reanalysis of individual patient data from Farah et al., 1990) may be due to a realignment of the viewer-, environment-, and object-centred frames of reference, following mental rotation. These findings do not constitute 'true' evidence of object-centred neglect. The only evidence of object-centred neglect to date appears to be the findings reported by Behrmann and Moscovitch (1994)[5], who utilised uppercase alphanumerical characters as stimuli. But Behrmann and Moscovitch's findings of object-centred neglect have also been challenged by evidence showing that informational asymmetries may play a role in the allocation of visual attention (Drain & Reuter Lorenz, 1997; Maguire, Bates, Boycott, & Corballis, 2002). Although this hypothesis fails to adequately account for previous findings of object-centred neglect, it highlights the importance of testing neurologically healthy participants to determine whether it is the features of the stimuli and/or the task demands that lead to results that could be misattributed to neurological deficits. The literature outlined above, as well as the findings from Buxbaum et al., also illustrate the importance of controlling for mental rotation in future research on object-centred neglect to avoid potential misinterpretations of patient data.

[5] There is also one patient study (Aimola Davies and Corballis, under review) that has found evidence of object-centred neglect using a mental rotation paradigm with the letter 'R' presented (individually) in normal or backward parity and in eight different angles of orientation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). This study will be reviewed in the General Discussion.

Outline for Experiments

The goal of the second section of this thesis is specifically to investigate the mental rotation hypothesis of object-centred neglect. We tested four of the five patients presented in Chapter 2: 'Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect' on our new Norwegian letter 'Æ' task. This time the task was simply to identify the letters presented individually on a computer monitor by pressing specifically marked keys on a computer keyboard. The viewer- and stimulus-centred frames of reference were indistinguishable in this task because the letter stimuli were presented centrally on a computer screen. The stimulus- and object-centred frames of reference were disambiguated by displaying the letters in normal and backward (mirror-reversed) parity, and in each of eight different angles of orientation (presented in 45° increments rotated clockwise from upright 0°). Errors in identification of the letter 'Æ' are interpreted as either stimulus- or object-centred neglect. Neglect in an object-centred frame of reference is neglect of the canonical left side of the letter 'Æ', the 'A' part of the letter, irrespective of parity and angle of orientation. In contrast, neglect in a stimulus-centred frame of reference is neglect of the 'A' part of the letter 'Æ' only when it is located on the left side as defined by a stimulus-centred frame of reference.

This computerised version of the Norwegian letter 'Æ' task, which we will refer to here as the *'Æ' letter-identification task*, not only investigates the distinction between stimulus- and object-centred neglect but it also takes advantage of the known fact that mental rotation of misoriented stimuli has an established time course. Longer reaction times are expected for responses to the letter 'Æ' if the mental rotation hypothesis of object-centred neglect is correct. We predicted that mental rotation would not be required for the identification of misoriented letters. Reaction times will therefore not vary as a function of angular displacement from upright. By using a computerised letter-identification task that allows for measurement of both response times and accuracy, we investigate the claim that "mental rotation of a shape and subsequent neglect of the egocentric left side of the rotated spatial representation may result in egocentric neglect which masquerades as 'object-based' neglect" (Buxbaum et al., 1996, p. 114).

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Chapter 4

Evidence Against the Mental Rotation Hypothesis of Object-Centred Neglect: Four Patients with Visuospatial Neglect

Evidence Against the Mental Rotation Hypothesis of Object-Centred Neglect: Four Patients with Visuospatial Neglect

General Methods

Participants

Participants consisted of patients HH, VR, BN, and HT – four of the five patients presented in Chapter 2: ('Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect'). Sixteen neurologically healthy individuals (twelve females and four males; 44 to 61 years of age, $M = 53.75$: $SD = 4.69$) also participated in this study. The neurologically healthy participants were right-handed ($M = 96.69$, $SD = 7.13$, where -100 indicates extreme left handedness and +100 indicates exclusive right handedness) according to the Edinburgh Handedness Inventory (Oldfield, 1971). The control participants had not suffered previous neurological injury or illness. Norwegian was the first language of all participants and none of the participants had dyslexia.

The study was approved by the Mid-Norway Regional Committee for Medical Research Ethics and the Human Research Ethics Committee at The Australian National University. Tests were conducted in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki. All participants read an explanatory statement containing information regarding the study and signed a consent form prior to their participation. The neurologically healthy control participants were paid $5 per hour for their participation.

Stimulus and Materials

The stimuli consisted of the uppercase alphanumerical letter 'Æ', subtending a visual angle of 1.7° x 2.3°, and the letters 'E' and 'A', each subtending a visual angle of 1.7° x 1.5°. The letter 'Æ' was the stimulus of most interest as it contains identifying information on both the left and right side of the letter. The stimuli were presented in white font on the black background. The letter 'Æ' was presented with the same frequency in normal and backward (mirror-reversed) parity. The letters 'E' and 'A' were displayed in normal parity *only*. The stimuli were presented in each of eight different angles of orientation, in 45° increments rotated clockwise from upright (0°).

Each trial began with a 500ms central fixation stimulus (+), subtending a visual angle of 0.7° x 0.7°. This fixation cross was replaced by letter stimuli, which were presented one at a time and remained on screen until the participant made a response. As the proportion of letters (letter 'E' = 16, letter 'A' = 16, letter 'Æ' = 16) was the same, this yielded a total of 48 stimuli that were presented twice for a total of 96 stimuli in each block. Each stimulus was presented randomly in five blocks of 96 trials, totalling 480 trials. The stimuli were prepared using Graphic Converter V5.1, and presented on an Apple Macintosh 14 inch laptop computer using PsyScript software (Bates & D'Oliveiro, 2003).

Procedure

Participants were tested individually in a distraction-free room. They were instructed to sit comfortably in front of a computer screen, and were given verbal instructions and practice trials prior to the commencement of the experiment. The task was to indicate the identity of a letter in each experimental trial, and to use the right dominant hand to press one of three clearly labelled response keys on a standard computer keyboard that was attached to the laptop computer. The three keys on the keyboard were each labelled 'E', 'A', or 'Æ'

At the beginning of each block, the following instructions appeared on the screen:[6]

> The letter 'A' 'E', or 'Æ' will be shown on the screen.
> Press down the 'A' button if the letter shown is an 'A'.
> Press down the 'E' button if the letter shown is an 'E'.
> Press down the 'Æ' button if the letter shown is an 'Æ'.
> Press down the 'SPACEBAR' when you are ready to begin.

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[6] In Norwegian, the task instructions were as follows:
Bokstaven 'A', 'E', eller 'Æ' vil bli vist på skjermen.
Trykk ned 'A' knappen hvis bokstaven vist er en 'A'.
Trykk ned 'E' knappen hvis bokstaven vist er en 'E'.
Trykk ned 'Æ' knappen hvis bokstaven vist er en 'Æ'.
Trykk ned mellomromstasten når du er klar til å begynne.

The experimental trials then commenced. Each trial began with a central fixation cross ('+'), which was replaced by one of the letters. The letter remained on screen until the participant made a response. This response initiated the next trial. Testing took approximately 30 minutes. Between each of the experimental blocks, participants were given an opportunity to rest and chat for a few minutes, which helped to maintain interest and to reduce fatigue. Upon completion of the final trial, participants were invited to comment on their experience with the task and to ask questions regarding the experiment.

Results

Identification of the Letters 'E', 'A', and 'Æ': Accuracy

The accuracy data was not formally analysed for the neurologically healthy participants (overall errors < 1%) or for three patients (HH, VR, HT) who were highly accurate overall (all accuracy > 93%) on the 'Æ' letter-identification task. These three patients were particularly accurate in the identification of the letter 'Æ' (all accuracy > 96%), the letter of most interest in the current study. Refer to Table 1 for accuracy data for all participants.[7]

Here we present the analysis for the letter-*identification* task only for patient BN, who was highly accurate in the identification of the letters 'E' (99.38%) and 'A' (100.00%). But, in comparison, patient BN was impaired in the identification of the letter 'Æ' (90.63%). On all trials when patient BN inaccurately identified the letter 'Æ', he *always* reported it to be the letter 'E'. Therefore on all of these incorrect trials with the letter 'Æ', patient BN failed to detect the 'A' part of the letter 'Æ'.

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[7] Note that although Patients VR and HT were highly accurate overall, they were not as accurate with identification of the letter 'A' (VR = 93.75%; HT = 95.63%) as they were with the letters 'E' (VR = 99.38%; HT = 98.13%) or 'Æ' (VR = 99.38%; HT = 96.25%).

Table 1

Correct responses for the 'Æ' Letter-Identification Task

	Control Participants		Patient BN	
Stimulus	Proportion	%	Proportion	%
Letter 'E'	2536/2560	99.06%	159/160	99.38%
Letter 'A'	2528/2560	98.75%	160/160	100%
Letter 'Æ'	2555/2560	99.80%	145/160	90.63%
Total	7619/7680	99.21%	464/480	96.67%
Letter 'Æ'*	1915/1920	99.74%	105/120	87.5%
A-left Letter 'Æ'*	957/960	99.69%	45/60	75%
A-right Letter 'Æ'*	958/960	99.79%	60/60	100%

	Patient HH		Patient VR		Patient HT	
Stimulus	Proportion	%	Proportion	%	Proportion	%
Letter 'E'	157/160	98.13%	159/160	99.38%	157/160	98.13%
Letter 'A'	159/160	99.38%	150/160	93.75%	153/160	95.63%
Letter 'Æ'	158/160	98.75%	159/160	99.38%	154/160	96.25%
Total	474/480	98.75%	475/480	98.96%	464/480	96.67%
Letter 'Æ'*	118/120	98.33%	120/120	100%	114/120	95.00%
A-left Letter 'Æ'*	58/60	96.67%	60/60	100%	56/60	93.33%
A-right Letter 'Æ'*	60/60	100%	60/60	100%	58/60	96.67%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

The 'Æ' letter-*identification* task for patient BN was analysed using backward stepwise logistic repression in SPSS (Version 16) with letter ('E', 'A', 'Æ') as a within-subject factor. The letter 'Æ' was used as a base group for the analysis. In this way, the analysis demonstrates a difference, if it exists, between the letter 'E' and the letter 'Æ' *or* between the letter 'A' and the letter 'Æ'. The dependent variable was accuracy in responding to the letters displayed on a computer screen. The stepwise criterion used was backward wald with probability for entry being 0.05 and the probability for removal being 0.1. Unless otherwise stated, the designated alpha for all analyses was $\alpha = .05$ to ensure adequate power. When required, *additional* statistical comparisons were conducted with the (2xK) Q′ test (Michael, 2007), which is used in single-case analyses to test the hypothesis of equal proportions. The Q′ statistic has a χ^2 distribution with K–1 degrees of freedom, where K equals the number of experimental conditions.

For patient BN, the overall model was significant (χ^2 (2) = 24.680, $p < .001$; see Table 2). The main effects for letter 'E' ($t = 7.915$, $p = .005$) and letter 'A' ($t = 6.005$, $p = .014$) were significant. BN correctly identified fewer 'Æ' letters (90.63%) compared to 'E' letters (99.38%) or 'A' letters (100%). We also confirmed that patient BN demonstrated no significant difference between correct responses to the letters 'E' and 'A' ($Q'(1) = 0.16$, $p = .6878$). Accordingly, we compare a model in which the letters 'E' and 'A' are combined. The resulting model was significant (χ^2 (1) = 24.154, $p < .001$), and does not provide a significantly worse fit to the data, so we cannot reject the simpler model that combines the letters 'E' and 'A' and compares these to the letter 'Æ'. The interpretation is clear: BN correctly identified fewer 'Æ' letters compared to 'E' or 'A' letters.

Table 2

Logistic Regression Analysis of BN's Accuracy Data as a Function of Letter Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Letter 'E'	2.427	.836	7.915	11.328	1	.005
Letter 'A'	3.532	1.441	6.005	34.196	1	.014
(Constant)	2.239	.267	70.244	9.387	1	.000

A follow-up logistic regression was performed specifically to assess stimulus- and object-centred neglect for patient BN. In this analysis we investigated correct responses to the letters 'Æ' and 'A' *only.* With the letter 'Æ', we distinguished A on the left of 'Æ' (A-left 'Æ') from A on the right of 'Æ' (A-right 'Æ'), and we excluded presentations at 90° and 270° because the 'A' side of the letter 'Æ' was toward the top or bottom rather than toward the left or right in the viewer-centred frame of reference. The data (correctly identified letters) was classified by letter, so that we are predicting the proportions by letter ('A', A-left 'Æ', A-right 'Æ'). The A-right 'Æ' was used as a base group for the analysis. In this way, the analysis demonstrates a difference, if it exists, between A-right 'Æ' and A-left 'Æ' and between A-right 'Æ' and the letter 'A'. Poorer responses to A-left 'Æ' compared to A-right 'Æ' indicated stimulus-centred neglect, whereas better response to the letter 'A' compared to A-right 'Æ' indicated object-centred neglect.

The best model (χ^2 (1) = 43.858, $p < .001$; see Table 3) had a significant main effect for A-left 'Æ' ($t = 17.116$, $p = .001$). Patient BN demonstrated stimulus-centred neglect: he correctly responded to fewer A-left 'Æ' letters (75.00%) compared to A-right 'Æ' letters (100%). There was no evidence of object-centred neglect, that is, there was no difference in accuracy between 'A' letters (100%) and A-right 'Æ' letters (100%). The 'Æ' letter-identification task classified BN with stimulus-centred neglect *only.* Recall that patient BN also demonstrated stimulus-centred neglect on the Ota et al. (2001) *visual* discriminative-cancellation task, where he was required to circle complete stimuli and to cross out incomplete stimuli. He responded correctly to fewer stimuli on the left than on the right side of page (92.08% versus 96.25%), and he responded correctly to fewer stimuli with a left gap (89.38%) compared to stimuli with a right gap (96.25%).

Table 3

Logistic Regression Analysis of BN's Accuracy Data as a Function of Letter Identity

Variables	Estimate	S.E	Wald	Odds Ratio	df	p
Letter A-left 'Æ'	-4.321	1.045	17.116	.013	1	.000
(Constant)	5.398	1.002	29.009	221.000	1	.000

Identification of the Letter 'Æ': Reaction Time for Neurologically Healthy Participants

The mean reaction time data of the neurologically healthy control participants was subjected to a repeated measures analysis of variance (ANOVA), where angle of orientation (0, 45, 90, 135, 180, 225, 270, 315° rotation from upright) and parity (normal, backward) were the within-subjects factors. All data was included in this analysis, including incorrect responses. The ANOVA test assumption of homogeneity of variance (sphericity) was not met for the main effect of angle of orientation, and Greenhouse-Geisser adjustments were made to the degrees of freedom for this condition. There were no significant main effects or interactions.

The main effect of angle of orientation was not significant ($F(3.979, 59.688) = .149$, $p = .962$, partial eta-squared = .010). The main effect of parity was not significant ($F(1, 15) = .394$, $p = .540$, partial eta-squared = .026): there was no difference in reaction times for letters presented in normal parity (739.47ms) and letters presented in backward parity (744.60ms). There was no angle of orientation by parity interaction ($F(7, 105) = .924$, $p = .491$, partial eta-squared = .058). The absence of a mental rotation curve in the neurologically healthy control participants' data (see Figure 1) demonstrates that mental rotation was not required for the identification of misoriented letters, and specifically not required for the identification of the letter 'Æ'. If mental rotation had been necessary for letter identification, the reaction time data would have shown an increase as a function of angular displacement from upright.

Identification of the Letter 'Æ': Reaction Time for Patient BN

Patient BN's mean reaction times for responses to the letter 'Æ' were also subjected to a repeated measures ANOVA, where angle or orientation (0, 45, 90, 135, 180, 225, 270, 315° rotation from upright) and parity (normal, backward) were the within-subjects factors. All data was included in this analysis, including incorrect responses. The ANOVA test assumption of homogeneity of variance (sphericity) was not met for the main effect of angle of orientation and the angle by parity interaction, and Greenhouse-Geisser adjustments were made to the degrees of freedom for this condition.

The main effect of angle of orientation was not significant, ($F(2.062, 18.558) = .591$, $p = .569$, partial eta-squared = .062). The main effect of parity did not reach significance, ($F(1, 9) = 3.590$, $p = .091$, partial eta-squared = .285): there was no significant difference in reaction times for letters presented in normal parity (1125.73 ms) and letters presented in backward parity (1329.65 ms).[8] There was no angle of orientation by parity interaction ($F(1.739, 15.647) = 1.077$, $p = .356$, partial eta-squared = .107). As predicted, the characteristic mental rotation curve was not evident in the reaction time for letter identification. See Figure 1, which illustrates that there was no mental rotation curve in the responses made by patient BN to the letter 'Æ'.

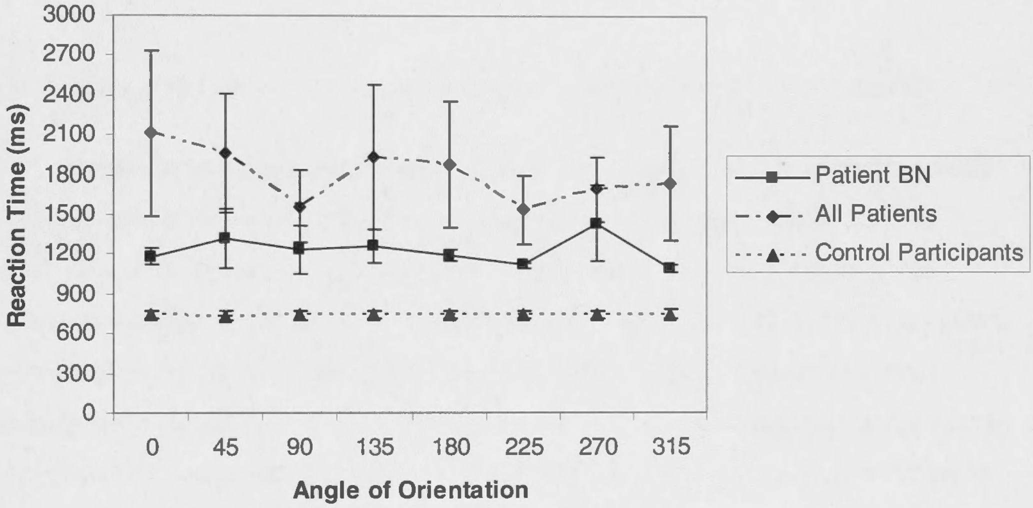

Figure 1. Mean reaction times and standard errors for identification of the letter 'Æ', as a function of angular displacement from upright for 'Patient BN', 'All Patients' with neglect (BN, HH, VR, HT), and sixteen neurologically healthy 'Control Participants'.

Identification of A-left 'Æ' Compared to A-right 'Æ': Reaction Time Comparison

To investigate whether stimulus-centred neglect (differences in accuracy for A-left 'Æ' compared to A-right 'Æ') was evident in patient BN's reaction time data, as it was in his accuracy data, we used the Revised Standardized Difference Test (RSDT;

[8] Although the main effect of parity did not reach significance, a 200ms difference between normal and backward parity cannot be completely ignored. But we would argue that if patient BN had transformed backward letters to normal parity prior to letter identification, then it would be expected that he mentally rotated the letters to upright *first*. We return to this point in the Discussion, with support from Cooper and Shepard (1973).

Crawford & Garthwaite, 2005) to compare patient BN's results to the neurologically healthy control participants.[9] The results demonstrated that patient BN was significantly slower at identification of A-left 'Æ' (1224.80 ms, $z = 4.215$) compared to A-right 'Æ' letters (1159.00 ms, $z = 3.303$), $t(15) = 2.720$, $p = .01581$, two-tailed. This finding provides further support for our interpretation of the accuracy data, showing that patient BN has stimulus-centred neglect. Analysis with the RSDT demonstrated that the estimated percentage of the control population showing a more extreme difference than patient BN, in the time to respond to A-left 'Æ' compared to A-right 'Æ' letters, was less than 1% (.79%).

Identification of the Letter 'Æ': Reaction Time for Patients BN, HH, VR, and HT

Our prediction that identification of misoriented letters does not require mental rotation to upright was also investigated in the mean reaction time data of all four patients (*BN,* HH, VR, HT) analysed together. A repeated measures ANOVA was conducted, where angle of orientation (0, 45, 90, 135, 180, 225, 270, 315° rotation from upright) and parity (normal, backward) were the within-subjects factors. Incorrect responses were included in this analysis but outliers (top 1% of reaction time data) were replaced with the mean reaction time for the outlier's respective condition, resulting in five reaction time replacements for the letter 'Æ' in total. No replacements were made for patients BN and VR, two replacements were made for patient HH, and two replacements were made for patient HT. For patient HT, an additional reaction time deemed to be impossibly fast was also substituted with the mean for its respective condition. The ANOVA test assumption of homogeneity of variance (sphericity) was met for all main effects and interactions. There were no significant main effects or interactions.

The main effect of angle of orientation was not significant ($F(7, 21) = 1.950$, $p = .112$, partial eta-squared = .394). The main effect of parity was not significant, ($F(1, 3) = .246$, $p = .654$, partial eta-squared = .076): there was no significant difference in reaction times for letters presented in normal parity (1767.88ms) and letters presented in backward parity (1834.09ms). There was no angle of orientation by parity interaction

[9] This test converts the patient's raw scores on two tests (X and Y) to z scores, and allows us to test (1) whether the patient's scores for X and Y are significantly different, and (2) whether the difference in the patient's scores for X and Y (i.e., the difference score) is significantly different from the difference demonstrated by the control population.

($F(7, 21) = .694$, $p = .677$, partial eta-squared = .188). Once again, reaction time did not differ as a function of angular displacement from upright. Figure 1 illustrates that there was no mental rotation curve in the group of four patients with neglect when responding to the letter 'Æ'.

Summary

The computerised 'Æ' letter-identification task took advantage of the known fact that mental rotation of misoriented stimuli has an established time course. The task was simply to identify the letters presented individually on a computer monitor by pressing specifically marked keys on a computer keyboard. Longer reaction times were expected for responses to the letter 'Æ' *if* the mental rotation hypothesis of stimulus- or object-centred neglect was correct. Results from the group of neurologically healthy control participants, from the group of four patients with neglect, and from patient BN alone demonstrated that there was no mental rotation curve in the responses made to the letter 'Æ'. Mental rotation was therefore not required for the identification of misoriented letters, and was specifically not required for the identification of the letter 'Æ'. Furthermore, there was no significant difference in reaction times between letters presented in normal parity and letters presented in backward parity.

Patient BN demonstrated stimulus-centred neglect on the computerised 'Æ' letter-identification task, as demonstrated by correctly responding to fewer A-left 'Æ' letters compared to A-right 'Æ' letters. In addition to a difference in accuracy between A-left 'Æ' letters and A-right 'Æ' letters, patient BN was also slower to identify A-left 'Æ' letters compared to A-right 'Æ' letters. This finding indicates that the stimulus-centred effect was also evident in the reaction time data. There was no evidence of object-centred neglect.

Discussion

The main aim of the current study was to investigate the mental rotation hypothesis of object-centred neglect, and specifically to examine whether there is evidence for mental rotation of stimuli to upright in the process of identification and report of asymmetrical upper-case letters. Four patients with visuospatial neglect were tested with our new 'Æ' letter-identification task. Participants were required to identify the letters 'E', 'A', and 'Æ' presented individually on a computer screen by pressing clearly labelled keys on a computer keyboard. The task took advantage of the known fact that mental rotation of misoriented stimuli has an established time course. We predicted that mental rotation was not required for the identification of misoriented letters, and that reaction times would therefore *not* vary as a function of angular displacement from upright. By using a computerised letter-identification task that allowed for measurement of both reaction time and accuracy, we investigated the claim that "mental rotation of a shape and subsequent neglect of the egocentric left side of the rotated spatial representation may result in egocentric neglect which masquerades as 'object-based' neglect" (Buxbaum, Coslett, Montgomery, & Farah, 1996, p. 114). The mental rotation paradigm was also used to investigate the distinction between stimulus- and object-centred neglect. Here we have reported accuracy and reaction time data for all four patients tested, and for sixteen neurologically healthy participants. We went on to investigate further patient BN's data because his *accuracy* for the identification of the letter 'Æ' was impaired in comparison to his accuracy for the identification of the letters 'E' and 'A'. The data was not analysed for the neurologically healthy participants or for patients HH, VR, and HT because all of these participants were highly accurate in the identification of all letters included in the task. They were particularly accurate in the identification of the letter 'Æ', the letter of most interest in the current study.

The results for patient BN on our new 'Æ' letter-identification task supported our predictions, and demonstrated that stimulus-centred neglect could *not* be due to mental rotation of stimuli to upright. The absence of a mental rotation curve in patient BN's reaction time data indicates that mental rotation to upright was not a strategy used in the identification of the letters presented. Buxbaum, Coslett, Montgomery, and Farah (1996) claimed that previous findings of object-centred neglect were due to mental rotation of stimuli to upright, which thereby realigns the object-centred frame of reference with the viewer-, environment, and stimulus-centred frames of reference. We sought to investigate mental rotation as a possible explanation for patient BN's neglect, but also to explore whether this strategy is a likely explanation of previous findings of object-centred neglect. The absence of a mental rotation curve in BN's individual reaction time data provided solid evidence that the identification of misoriented letters does *not* require mental rotation to upright. This finding was further supported by the absence of a mental rotation curve in the data of the four patients with unilateral neglect and from the group of neurologically healthy control participants.

The lack of a significant reaction time difference between letters presented in normal parity and letters presented in backward parity also demonstrated that it was unnecessary to convert a backward letter to normal prior to letter identification. If transformation of backward letters to normal was required for letter identification, then it would be expected that the letters would be mentally rotated to upright *first*. Cooper and Shepard (1973) demonstrated that the time taken to determine whether letters were normal or backward increased linearly as a function of angular departure from upright. This finding was interpreted as evidence that mental rotation to upright was required for comparison to a stored representation of the normal upright version of the character. A decision regarding letter parity (normal or backward) therefore requires mental rotation to upright *first* so that the letter can be compared to the stored representation of the normal upright version of the letter in question. If a letter is to be 'flipped' from backward parity to normal parity, then the parity of the letter needs to be established first, so as to confirm the necessity to 'flip' the letter. In other words, how would one know whether it would be necessary to 'flip' a letter without having established the parity of the letter? Given that there was no evidence of mental rotation to upright in the reaction time data, it is unlikely that the participants 'flipped' backward letters to normal. The absence of a significant difference in reaction times between letters presented in normal and backward parity confirmed this.

In addition to investigating the mental rotation hypothesis of unilateral neglect, the 'Æ' letter-identification task was also developed to investigate further the distinction between stimulus- and object-centred neglect. In the new 'Æ' letter-*identification* task, the object-centred frame of reference was disentangled from the stimulus-centred frame of reference by displaying the letters in normal and backward parity and in eight different angles of orientation. Errors in responding to the letter 'Æ' were interpreted as either stimulus- or object-centred neglect. Patient BN's lower accuracy rate in the identification of the letter 'Æ' compared to the letters 'E' and 'A' on this task suggested that he had either stimulus- or object-centred neglect. When incorrect, he consistently reported that the letter 'Æ' was the letter 'E'. To separate stimulus- from object-centred neglect, we investigated correct responses to the letters 'Æ' and 'A' only. With the letter 'Æ', we distinguished A-left 'Æ' from A-right 'Æ'. A better response to A-right 'Æ' compared to A-left 'Æ' indicates stimulus-centred neglect. A better response to the letter 'A' compared to A-right 'Æ' indicates object-centred neglect. Overall, the findings demonstrate that not only did Patient BN correctly identify more of the 'A' and 'E' letters than the 'Æ' letters, but he also correctly identified more of the A-right 'Æ' letters than the A-left 'Æ' letters. His performance on this task was therefore due to neglect in a stimulus-centred frame of reference.

As the stimuli in this task were displayed individually and centred on a computer screen, the task does not distinguish between viewer- and stimulus-centred neglect. That is, the left side in a stimulus-centred frame of reference and the left side in a viewer-centred frame of reference were not disambiguated. Patient BN's results may therefore be due to neglect in a viewer- and/or stimulus-centred frame of reference. The evidence of viewer- *and* stimulus-centred neglect from the Ota et al. (2001) discriminative-cancellation task and evidence of viewer-centred neglect from the 'Æ' letter-cancellation task, as well as from standard tests of neglect suggests that patient BN's performance on the letter-identification task may be due to a combination of neglect in viewer- and stimulus-centred frames of reference. If, however, viewer-centred neglect affected the results, one may have also expected patient BN to occasionally neglect the 'E' part of the letter 'Æ', and thereby incorrectly identify A-right 'Æ' letters as 'A' letters. Given that this did not occur, it is more likely that the results are primarily due to neglect in a stimulus-centred frame of reference.

The finding of most importance from the Norwegian 'Æ' letter-identification task was that there was no evidence of a mental rotation curve in the reaction time data for any of the neglect patients or for the neurologically healthy control participants, and perhaps most crucially, for patient BN: the patient with stimulus-centred neglect. Therefore, our findings have implications for the interpretation of previous findings of object-centred neglect when individually presented alphanumerical letters are utilised as stimuli. This evidence argues against the mental rotation hypothesis of object-centred neglect, and in support of Behrmann and Moscovitch (1994). These results are likely to represent 'true' object-centred neglect rather than viewer-, environment-, and/or stimulus-centred neglect masquerading as object-centred neglect due to the mental rotation of stimuli to upright. It should also be noted that the stimuli utilised by Behrmann and Moscovitch included uppercase alphanumerical characters that cannot be confused with each other (B, D, E, F, K, I, P, Q, R), which makes it even less likely that mental rotation of the stimuli was induced. Although mental rotation has been implicated in a number of tasks (e.g., normal or mirror-reversed judgments and left and right side judgments of alphanumerical characters and shapes, symmetry judgments, as well as laterality judgments of hands and human figures), there was no evidence from the current study to suggest that the *identification* of misoriented alphanumerical characters require mental rotation to upright.

Our findings are consistent with those obtained by Corballis, Zbrodoff, Shetzer, and Butler (1978). These authors investigated the time required to name misoriented letters (G, J, and R) and numerals (2, 5, and 7) presented individually in normal and backward parity. They demonstrated that the latency to name alphanumerical characters depended to some extent on angular deviation from upright, but noted that this effect was restricted to backward characters and that it was observed to flatten out with practice, an effect not observed in tasks requiring mental rotation to upright (e.g., Cooper & Shepard, 1973). Corballis et al. speculated that confusion between the numerals 2 and 5 may have induced an occasional mental rotation strategy, which may have impacted on the overall identification latencies. They concluded that the identification of misoriented letters and numerals does not normally require mental rotation to upright. This conclusion was subsequently supported by the findings of Corballis and Nagourney (1978), White (1980), and Simion, Bagnara, Roncato, and Umilta (1982) (see also Young, Palef, & Logan, 1980). Corballis and McLaren (1984) have provided evidence that mental rotation is involved when specification of the letter's parity is necessary to distinguish between certain letters, such as discrimination between the letters b and d, and the letters p and q. These letters are exceptional due to the requirements of mirror-image discrimination to facilitate letter identification. The letters included in the 'Æ' letter-identification task do not require specification of parity for letter identification, as demonstrated by the lack of a mental rotation curve in the reaction time data.

We believe this finding, that mental rotation is not required in the identification of misoriented letters, settles the debate surrounding the mental rotation hypothesis of unilateral neglect once and for all, at least for the use of asymmetrical upper-case letters in the study of unilateral neglect. Not only did we demonstrate that identification of misoriented letters does not require mental rotation to upright, we demonstrated this finding both in neurologically healthy participants and in patients with neglect. Future research that makes use of misoriented common objects, human figures and hands, in the study of object-centred neglect, will need to include a test of mental rotation in their tasks. Although identification of misoriented asymmetrical letters (as we have used in our study) does not require mental rotation, mental rotation *has* been implicated in the identification (and in laterality judgments) of common objects, human figures, and hands.

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SECTION 3:

FRAMES OF REFERENCE IN UNILATERAL NEGLECT: TACTILE MODALITY

Chapter 5

Frames of Reference in Unilateral Neglect:
Tactile Modality

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Tactile Modality

Patients with neglect typically fail to report or orient to stimuli in the hemispace opposite to the side of their lesion, despite having intact sensory and motor capabilities. Neglect is typically more frequent and severe following damage to the right hemisphere (Vallar & Perani, 1986; but see Ogden, 1985).[10] Although neglect can occur in one or more modalities, visual neglect appears to be most common, or at least it is the most commonly reported. An individual with left-side neglect in the visual modality may fail to complete the left side of drawings when attempting to copy an object, may fail to eat food on the left side of the plate, and may ignore other stimuli located to the left (Aimola Davies, 2004).

A vast amount of research exists in the area of visual neglect. In contrast, research on neglect in the tactile modality has been relatively ignored. "Tactile neglect generally indicates the presence of omissions in detecting stimuli in the absence of visual control. These omissions occur either when subjects are required to report unseen stimuli on their bodily surface or when they are engaged in a searching task in extrapersonal space" (Beschin, Cazzani, Cubelli, Della Sala, & Spinazzola, 1996, p. 41). Studies investigating tactile neglect have used different definitions of tactile neglect. For example, in preliminary investigations of impairments in the tactile modality (e.g., De Renzi, Faglioni, & Scotti, 1968; De Renzi & Scotti, 1969), a tactile spatial impairment was described as a difficulty in the tactile identification of shapes, without the aid of vision. These investigations included patients with damage to the right- or left-hemisphere, and the focus was on tactile spatial impairment rather than tactile neglect. Other researchers have subsequently defined tactile *neglect* as a rightward bias in tactile search and exploration performance, with an associated impaired ability to search for, locate, and respond to targets positioned in the contralesional side of space, without the aid of vision. Tactile neglect has also been defined according to a rightward bias in tactile line- and rod-bisection tasks. Additionally, tactile neglect has been described as the impaired ability to detect somatosensory stimuli delivered to locations (usually the hand or arm) on the contralesional side of the body in the absence of

[10] As left-side neglect after lesions to the right hemisphere is more common than right-side neglect after lesions to the left hemisphere, this literature review will use the term neglect to refer to left-side neglect unless otherwise specified.

sensory deficits. More recently, Marsh and Hillis (2008) provided evidence for the existence of tactile neglect in a stimulus-centred frame of reference. In this context, stimulus-centred neglect was defined as a failure to detect differences in stimuli when these differences were located on the contralesional side of individual stimuli irrespective of their location in a viewer-centred frame of reference.

This literature review will first outline the early research investigating the co-occurrence of neglect in the visual and tactile modality. Following this, a review of research investigating neglect in a variety of search tasks, as well as a review of studies examining performance on tactile line- and rod-bisection tasks, will be provided. The review will also outline recent research that has attempted to separate viewer- from stimulus-centred tactile neglect. The literature review for Section 3: 'Frames of Reference in Unilateral Neglect: Tactile Modality' ends with an outline for the experiments presented in Chapter 6.

Historical Research Investigating Neglect in the Tactile Modality

Early research focused on tactile spatial impairment and did not consistently make the distinction between spatial impairments and neglect. De Renzi, Faglioni, and Scotti (1968) and De Renzi and Scotti (1969) sought to investigate whether right-hemisphere damage is associated with a tactile spatial impairment. In De Renzi et al.'s study, patients with unilateral damage to the right- or left-hemisphere were required to place blocks of different shapes into their corresponding cut-outs on a form-board without the aid of vision. The participants completed five timed trials of the test. Results demonstrated that the performance of patients with lesions to the right hemisphere *with* a visual field deficit (VFD) were significantly impaired in that they took longer to complete the task compared to right-hemisphere patients without a VFD and left-hemisphere patients. Based on these results, the authors concluded that damage to the posterior area of the right hemisphere is associated with impairment in spatial abilities.

De Renzi and Scotti (1969) conducted a study aiming to evaluate the performance of patients with right- or left-hemisphere lesions on a tactile shape discrimination task. The participants' task was to explore (with their ipsilesional forefinger) wooden blocks individually presented behind a curtain, and to identify and point to an identical block mounted on a board with six different stimuli within a 60-second time limit. Patients with lesions to the right hemisphere were more impaired than left-hemisphere patients, as indicated by slower response times in the block-identification task. Additionally, patients with a VFD were slower than patients without a VFD. Although not significant, mean response times demonstrated that the patients with right-hemisphere lesions *and* a VFD performed more poorly than any other subgroup. De Renzi and Scotti interpreted the results as evidence that the posterior cerebral area, and the right hemisphere in particular, is associated with spatial abilities. De Renzi and Scotti indicated that performance on the task may have been influenced by deficits in both the visual and tactile modalities, given the task required matching tactile with visual information.

In 1970, these researchers (De Renzi, Faglioni, & Scotti) were also the first to investigate tactile space exploration. Their study aimed to explore the relationship between unilateral brain damage and performance on separate visual and tactile space exploration tasks. Participants comprised 121 patients with unilateral damage to the right or left hemisphere and thirty control participants who were hospitalised with diseases or injuries not involving the brain. In the visual task, participants were shown a number on a card and were required to point to the matching number on a large display board placed in front of them. The board contained the numbers 0 to 99 displayed in a random order. The numbers to be identified were equally located in the four quadrants of the display board. Results indicated that the performance of patients with damage to the left hemisphere were equal to the control group. Patients with right-side injury and *without* a VFD also performed like controls, that is, they were faster than patients with a VFD in locating the number when it was located on the left side of the display board. Patients with damage to the right hemisphere who also had a VFD were *slowe*st in locating numbers on the left side of the display board (De Renzi, Faglioni, & Scotti).

The tactile task required participants to search with their forefinger for a marble located in a maze that was hidden from view (De Renzi et al., 1970). The marble was always located in the end of one of four lateral arms of the maze. Results demonstrated that only patients with damage to the right hemisphere, who also had a VFD, failed to locate the marble within the 90-second time limit when it was placed in the contralesional side of space. Up until this time, research had focused on tactile spatial impairment without making the claim that neglect can occur in the tactile modality. But based on their finding, De Renzi et al. (1970) suggested that neglect can occur in the tactile modality in the same manner that it has been demonstrated in the visual modality. The study was later criticised for hiding the maze behind a curtain and allowing the patients to leave their eyes open. Beschin, Cazzani, Cubelli, Della Sala, and Spinazzola (1996) suggested that the results may have been confounded by visual interference from the environment. That is, patients may have been attracted to the visual information in the right side of space, which could potentially have induced or exaggerated the demonstration of neglect in the tactile modality. Later studies have typically blindfolded participants rather than hiding the stimuli behind a curtain in order to overcome this potentially confounding factor (e.g., Chedru, 1976; Gentilini, Barbieri, De Renzi, & Faglioni, 1989).

De Renzi et al. made the claim that neglect can occur in the tactile modality in 1970, and a number of researchers have subsequently investigated the co-occurrence of visual and tactile neglect by utilising procedures similar to the maze test used by De Renzi et al. Some have used variations of the maze test (e.g., Caneman, Levander, & Tegnér, 1992; Villardita, 1987), whereas others have used search tasks in which the patients are required to press keys on a keyboard (e.g., Chedru, 1976; Gentilini et al., 1989) or search for and/or identify other stimuli in space (e.g., Haeske-Dewick, Canavan, & Hömberg, 1996; Karnath & Perenin, 1998; Schindler, Clavagnier, Karnath, Derex, & Perenin, 2006; Weintraub & Mesulam, 1987). As illustrated below, these studies have yielded somewhat conflicting results.

Villardita (1987) compared the performance of patients with and without unilateral visual neglect on a modified version of the maze test first utilised by De Renzi et al. (1970). The subjects consisted of 46 individuals with right-hemisphere lesions (with and without visual neglect) and 27 patients with damage to the left hemisphere. Visual neglect was assessed by a line-crossing task and a drawing-copying task, and twenty of the right-hemisphere patients were classified with visual neglect according to these tasks. Instead of recording the time taken to search for the marble, Villardita recorded the total number of marbles that the participants were able to locate in the left and right half of the maze within a three-minute time limit. Participants were required to do the task blindfolded. In contrast to previous research, Villardita found that patients with neglect located more marbles in the left, visually neglected, side of space. Thus, Villardita failed to confirm any correspondence between visual and tactile neglect, and suggested that neglect in different modalities may be dissociable. Villardita further proposed that due to the intact (tactile) modality compensating for the visual neglect, patients were able to reach more marbles in the left as compared to the right side of space.

Caneman, Levander, and Tegnér (1992) sought to confirm Villardita's (1987) results in another study utilising De Renzi et al.'s (1970) maze test. Additionally, they attempted to clarify whether the discrepancy in the results obtained by Villardita and by De Renzi et al. were due to the different recording techniques (search time versus total number of marbles located in the left and right hemispace) or to possible environmental visual interference. The latter refers to the possibility that visual input could have a negative impact on performance in tasks requiring tactile responses. Fifteen patients with neglect in the visual modality participated in the study. All patients demonstrated evidence of unilateral neglect on at least one of the following tests: (a) letter cancellation; (b) line bisection; (c) reading; (d) figure copying. The patients were required to locate a marble placed in one of the four lateral arms of the maze as quickly as possible in two different test conditions. In the visual condition, the maze was placed behind a curtain and the patients had their eyes open, whereas in the tactile condition, patients were blindfolded. Both search time (with a time limit of 90 seconds) and the first lateral arm of the maze to be explored were recorded. In the visual condition, patients located the marbles faster when they were placed on the right side than on the left side. Furthermore, subjects more frequently started their search in the right side of the maze. Results from the tactile condition were consistent with the results from the visual condition, and thereby demonstrated that the availability of visual stimuli did not affect either search time or which hemifield was first explored. These results are consistent with De Renzi et al.'s original findings but in stark contrast to Villardita's results, as they did not support Villardita's description of tactile compensation of visual neglect.

The literature outlined above provides preliminary evidence that neglect can occur in the tactile modality. Beschin et al. (1996) designed a study aimed to provide evidence that tactile neglect can occur independently from visual neglect, and to determine whether tactile neglect can occur along the radial dimension of space (near space versus far reaching space). Moreover, these researchers sought to ascertain whether searching time and number of omissions gradually increased from the unaffected side to the contralesional side, as some research (e.g., Làdavas, 1990) has demonstrated with visual neglect. Beschin et al. used a modified version of the maze test designed by De Renzi et al. (1970). Participants consisted of eight patients with lesions to the right hemisphere. Five of these patients demonstrated visual neglect on one or more of the following standard tests of neglect: (a) line cancellation; (b) letter cancellation; (c) Bells test. Participants were blindfolded and required to locate a marble as quickly as possible, within a time limit of 2 minutes. The marble was always located in the end of one of the eight lateral arms of the maze. If there were zero omissions in the ipsilesional side of space, along with four or more omissions of targets in the contralesional side of space, this was interpreted as tactile neglect. Based on these criteria, four of the patients demonstrated tactile neglect. Two of these (Patients 6 and 7) demonstrated left neglect, whereas two (Patients 2 and 8) displayed neglect for far space only. Of these four patients, only Patients 7 and 8 demonstrated visual neglect on the standard tests of neglect that were administered. In order to clarify whether a gradient in performance exists from the unaffected hemispace to the neglected one, each half maze was divided into two segments for the purpose of scoring. In this way, both horizontal and radial dimensions consisted of four sectors. Beschin et al. examined both the number of omissions as well as the time spent searching for the marble in each of the sectors. Results from the two patients who demonstrated left tactile neglect indicated that the number of omissions gradually increased from the unaffected side to the neglected side. An increase in searching time was also apparent in the contralesional side of space. Similarly, Patients 2 and 8, with radial neglect, omitted most marbles in the section of the maze located furthest away, a finding interpreted as tactile neglect for far reaching space. Although Patients 2 and 8 both located fewer marbles in far reaching space than in near space, only Patient 2 demonstrated increased searching time in far space. The patients in the Beschin et al. study were also administered a visual condition of the task, equivalent to the tactile condition except that they were not blindfolded. In this condition, none of the patients failed to locate the marble within the time limit. Beschin et al. suggested that the tactile neglect cannot be a representation of a visual form of neglect given that the patients were always able to locate the marble within the time limit in the visual condition. They also highlighted that one of the patients with neglect in the tactile modality (Patient 6) also failed to demonstrate neglect in the visual modality on a visual neglect test battery, a finding interpreted a further support of the claim that tactile neglect cannot be a representation of a visual form of neglect.

Due to the somewhat different experimental conditions (blindfolded versus hidden from view), different order of experimental conditions (blindfolded first or not blindfolded first), different recording techniques (search time versus first hemispace explored versus total number of marbles located within a specified time-limit), different time limits or no time limit (60-seconds, 90-seconds, 2 minutes, or 3 minutes versus no time limit) utilised in the studies outlined above, the results are somewhat difficult to interpret. Other experimental procedures (discussed below) have also been used in the investigation of unilateral neglect in the visual and tactile modalities. For example, in Chedru's (1976) study, 91 patients (with unilateral lesions to the right or left hemisphere) with major (affecting daily activities) or minor (only displayed in drawing or writing tasks) neglect were seated in front of a keyboard and were required to press all keys on the keyboard as quickly as possible. The participants were required initially to do the task blindfolded and subsequently with eyes open. Results demonstrated that all patients (right and left hemisphere) with a VFD exhibited a preference for pressing keys located on the ipsilateral side of their lesion when they had their eyes open (neglect for stimuli located on the contralateral side of space tended to be more marked for patients with damage to the right hemisphere). Only patients with lesions to the right hemisphere *without* a VFD demonstrated this preference in the blindfolded condition. Chedru suggested that the latter result reflects "a kind of spatial neglect which develops (or is reinforced) when visual inputs are cut off" (p. 1060). Based on the finding of a reduction in neglect in the blindfolded condition, Chedru speculated that vision induces (or exaggerates) difficulties in exploring the side of space located contralaterally to the side of a lesion. Chedru's results are in contrast to the findings of De Renzi et al. (1968, 1970) and De Renzi and Scotti (1969) who found that patients *with* a VFD performed worse, compared to patients without a VFD, on tactile shape discrimination tasks or a task requiring patients to locate a marble that was hidden from view. Patients with a VFD were found to have more severe tactile spatial impairments than patients without a VFD. Chedru's findings, however, can be compared to Villardita's (1987) results. Although Villardita did not examine the effect of VFD on performance, results indicated that the patients in this study located more marbles in the left side of space. Thus, the patients in Villardita's study and the patients with a VFD in Chedru's study failed to demonstrated tactile neglect.

Gentilini, Barbieri, De Renzi, and Faglioni (1989) argued that the key-tapping task utilised by Chedru (1976) may have lacked sensitivity in terms of detecting neglect as it does not require active searching or exploration of space. Gentilini et al. therefore modified the task by requiring patients to locate six keys that produced a sound when they were pressed, and in this way increasing the searching demands of the task. Thirty patients with unilateral lesions to the right or left hemisphere participated in the study. The participants were informed that the six sound-producing keys were equally distributed on the left and right half of the keyboard, and that they were required to locate as many of these as possible by pressing ten keys in each trial. As in Chedru's experiment, participants did the task both with their eyes blindfolded and eyes open. The visual and tactile tasks were administered in separate sessions, half performed the visual task first and the other half performed the tactile task first. Patients with right-hemisphere damage with or without visual neglect (as tested by a reading test and a circle test, in which the patients had to point to circles that were symmetrically arranged on a cardboard sign) demonstrated a preference for pressing keys located in the right side of space when their eyes were open. In contrast, only patients with visual neglect exhibited this preference in the blindfolded condition. Patients with damage to the left hemisphere failed to demonstrate neglect in either task. These results are somewhat different to Chedru's findings, which documented visual tactile neglect in patients *with* a VFD irrespective of the side of their lesion, and tactile neglect only in patients with lesions to the right hemisphere *without* a VFD. Gentilini et al. attributed the discrepancy in results to the increased search demands of their modified task. It should also be noted that the patients in Chedru's study *all* did the task blindfolded first, and then with their eyes open in the same session. Gentilini et al. administered their visual and tactile tasks in separate sessions, and counterbalanced the order or administration. It is possible that the different procedures may have contributed to disparate results.

In most studies investigating the association between unilateral neglect in the visual and tactile modalities (e.g., Caneman et al., 1992; Chedru, 1976; De Renzi, 1970; Fujii, Fukatsu, Kimura, Saso, & Kogure, 1991; Gentilini et al., 1989; Halsband, Gruhn, & Ettlinger, 1985; Hjaltason, Caneman, & Tegnér, 1993; Villardita, 1987), the data have been analysed as group data and no firm conclusions can therefore be made with regard to double dissociations. Beschin et al. (1996) suggested that a multiple single-case approach is more productive in searching for dissociations. By utilising this procedure, Cubelli, Nichelli, Bonito, De Tanti, and Inzaghi (1991) reanalysed the data from Gentilini et al.'s (1989) study. This reanalysis demonstrated a double dissociation between neglect in the visual and tactile modalities. Four of the subjects demonstrated visual neglect in the search for sound-producing keys, but were unimpaired in the tactile condition of this task. Three other patients demonstrated the opposite pattern, with a right hemifield preference only when blindfolded. Five patients demonstrated a preference for the right side of the keyboard both blindfolded and with their eyes open. Cubelli et al. compared patient performance on the visual exploration task to performance on the reading test that was included as one of two screening measures for neglect. Seven patients were found to be impaired on both tests. Two patients were impaired on the reading test only, and two different patients were impaired on the keyboard exploration task only. Cubelli et al. do not appear to provide information regarding patient performance on the screening measures of neglect for the patients with tactile neglect only.

In Gentilini et al.'s (1989) experiment, participants were required to make a fixed number of responses (10) in each trial, and they also had a fixed number of keys to find. This modified version of Chedru's (1976) task does not require the participants to search the entire keyboard, which consisted of 40 keys in total. It is possible that participants developed a strategy that concentrated responses in a smaller area of the keyboard, which may have been just as efficient as a random search across the 40 keys. To overcome this shortcoming, Weintraub and Mesulam (1987) designed a task that required participants with right- or left-hemisphere damage to search for a single plastic bead on a board placed in front of them. The bead was fixed in one of a number of predetermined positions distributed symmetrically on the left and right sides of the board. This task therefore increased search demands by requiring the patients to search the entire board until the target was located. The participant's hand was placed at the bottom centre of the board prior to the commencement of each trial. Patients were not selected based on manifestations of visual neglect and were not administered any standard tests of neglect. Results demonstrated that patients with right-hemisphere lesions required longer searching time to locate the bead when it was fixed at the left side of the board than in the ipsilesional hemispace. There was no right-left difference in searching time for participants with lesions to the left hemisphere. Weintraub and Mesulam eliminated the possibility that the results reflected a generalised slowness of reaching in patients with right-hemisphere damage by comparing the time taken to reach toward the bead when it was fixed to a position in the centre of the board. There was no difference between patients with right- and left-hemisphere lesions on this task. Weintraub and Mesulam did not, however, investigate the time taken to reach toward the bead when fixed on the *left* side of the board. It is well known that patients with right-hemisphere injury may be reluctant to initiate and perform motor activities toward and into the neglected hemispace (Tegnér & Levander, 1991). A comparison between groups regarding differences in the time taken to reach toward the bead when fixed to a position in the left side of space would therefore have been a better indication as to whether the results reflected a generalised slowness of reaching.

Weintraub and Mesulam (1987) also designed a shape-cancellation task to investigate patterns of visual neglect in patients with right- or left-hemisphere lesions. The participants' task was to circle target stimuli (fifteen in total) that were randomly distributed among 75 non-target shapes on a sheet of paper. The target stimuli were distributed symmetrically on the left and right side of the paper. Results demonstrated that patients with right-hemisphere injury made more target omissions both in the left and right hemispace compared to patients with lesions in the left hemisphere. As the visual and tactile study used different patient groups, no inferences can be made regarding the relationship between visual and tactile neglect. Weintraub and Mesulam did not appear to include standard tests of neglect in their study, and it is therefore impossible to make comparisons between patient performance on standard tests and their performance on the experimental tasks.

Haeske-Dewick, Canavan, and Hömberg (1996) suggested that no conclusions could be drawn from Weintraub and Mesulam (1987) findings regarding a relationship between visual and tactile neglect. Although Weintraub and Mesulam had a visual version of their tactile task, the test materials for the visual and tactile tasks were not equivalent, either for the search strategy required or the space to be explored, and different patient groups participated in the visual and tactile tasks. Haeske-Dewick et al. designed their study to explore whether patients with identified visual neglect also demonstrate visual neglect on tasks requiring performance in a wider peripersonal space. Participants included 30 patients with unilateral lesions to the brain with or without visual neglect. Visual neglect was assessed with the star cancellation and line bisection subtests from the Behavioural Inattention Test. The subjects were first required to identify rough squares glued to the surface of a board whilst blindfolded. The squares were equally distributed on the left and right sides of the board. The same task was subsequently performed without a blindfold. Patients who were identified with visuospatial neglect by conventional neglect tests also demonstrated neglect on Haeske-Dewick et al.'s visual task (without the blindfold). Patients with lesions to the right hemisphere both with and without visual neglect, as assessed with both the conventional tests and the experimental task, demonstrated tactile neglect when blindfolded. In this condition, they identified fewer squares on the contralesional side of the board. Patients who also had been identified with visuospatial neglect on the standard tests of neglect typically performed worse on the tactile task than patients without visual neglect.

Interim summary

Research investigating impairments in the tactile modality have used different definitions of what constitute a tactile spatial impairment, and early research did not make the distinction between spatial impairments and tactile neglect. De Renzi et al. (1968) and De Renzi and Scotti (1969) described a tactile spatial impairment as a difficulty in the tactile identification of shapes without the aid of vision. They concluded that damage to the posterior area of the right hemisphere is associated with impairment in spatial abilities. Other researchers have more recently defined tactile *neglect* as a rightward bias in tactile search and exploration performance, with an associated impaired ability to search for, locate, and respond to targets positioned in the contralesional side of space, without the aid of vision.

De Renzi et al. (1970) were the first to investigate tactile space exploration. They required participants to search with their forefinger for a marble located in a maze that was hidden from view. Based on their finding that only patients with damage to the right hemisphere, who also had a VFD, failed to locate the marble within the time limit when it was placed in the contralesional side of space, De Renzi et al. suggested that neglect can occur in the tactile modality in the same manner that it has been demonstrated in the visual modality. The early research included patients with unilateral damage to the right- or left-hemisphere with or without a VFD, without documentation of the presence of neglect in the visual modality. A number of researchers subsequently investigated the co-occurrence of visual and tactile neglect by utilising procedures similar to the maze test used by De Renzi et al. Some used variations of the maze test (e.g., Beschin et al., 1996; Caneman et al., 1992; Villardita, 1987), whereas others used search tasks in which the patients were required to press keys on a keyboard (e.g., Chedru, 1976; Gentilini et al., 1989), or search for a single object fixed to a table in front of participants (e.g., Weintraub & Mesulam, 1987). Research from these studies yielded different results. Some researchers (e.g., Villardita, 1987) failed to confirm any correspondence between visual and tactile neglect, whereas others (e.g., Caneman et al., 1992) found results from the tactile search condition to be consistent with results from the visual search condition. Furthermore, results were found to depend on the experimental conditions. For example, Gentilini et al. (1989) found that patients with right-hemisphere damage demonstrated a preference for pressing keys in the right side of space when their eyes were open. In contrast, only patients with visual neglect demonstrated this preference in the blindfolded condition. Due to the somewhat different experimental conditions (blindfolded versus hidden from view), different order of experimental conditions (blindfolded first or not blindfolded first), different recording techniques (search time versus first hemispace explored versus total number of marbles (or keys on a keyboard) located within a specified time-limit), different time limits or no time limit (60-seconds, 90-seconds, 2 minutes, or 3 minutes versus not time limit) utilised in these studies, the results are somewhat difficult to interpret. Furthermore, not all studies utilised standard tests to document neglect in the visual modality, and if they did, their methods varied from widely used standard tests of neglect (e.g., subtests from the Behavioural Inattention Test) to less common tests of neglect (e.g., a circle test in which the patients had to point to circles that were symmetrically arranged on a cardboard sign). It is therefore difficult in some of the studies to draw conclusions regarding the presence or absence of visual neglect in the patients included. Some studies include experimental tasks that tested for both visual *and* tactile neglect (e.g., Beschin et al., 1996), but the tasks were sometimes not comparable or different patient groups participated in the visual and tactile tasks (e.g., Weintraub & Mesulam, 1987). Others tested for tactile neglect *only* (e.g., Caneman et al., 1992; Villardita, 1987).

Beschin et al. (1996) suggested that results from studies where the experimental apparatus was hidden from view rather than the patient being blindfolded may have been confounded by visual interference from the environment. In this way, the patients may have been attracted to the visual information in the right side of space, which could potentially have induced or exaggerated the demonstration of neglect in the tactile modality. For this reason, subsequent studies typically blindfolded participants rather than hiding the stimuli behind a curtain in order to overcome this potentially confounding factor. Beschin et al. also raised a concern that studies investigating the association between unilateral neglect in the visual and tactile modalities have analysed the data as a group, and no firm conclusions can therefore be made with regard to double dissociations. They suggested that a multiple single-case approach is more productive in searching for dissociations. By utilising this procedure, Cubelli et al.

(1991) reanalysed the data from Gentilini et al.'s study, and demonstrated a double dissociation between neglect in the visual and tactile modalities.

Patterns of Search Performance in Patients with Tactile Neglect

Karnath and Perenin (1998) noted that patients with neglect typically demonstrate a disturbance in visual search performance. That is, they tend to fixate and search on the ipsilesional side while neglecting stimuli located on the contralesional side. They conducted a study aiming to explore whether patients with neglect also exhibit this disturbance in the tactile domain. The participants, six patients with neglect and six age-matched normal controls subjects, were required to search for a target on a table placed in front of them, with their ipsilesional index finger for 1 minute. The researchers did not place the target on the table until the end of the search period. Results demonstrated that the control subjects symmetrically explored both sides of space, whereas in patients with neglect, search performance was systematically skewed to the ipsilesional side of the board.

A recent study conducted by Olk and Harvey (2006) further investigated exploration behaviour in patients with neglect. Olk and Harvey argued that although patients with neglect may fail to explore the contralesional side of space, they may also repeatedly return to stimuli in the ipsilesional side of space. Olk and Harvey maintained that extensive searching in one half of space contributes to increased detection rates ipsilesionally and that contralesional detection rates may deteriorate as a consequence. Participants consisted of 25 patients with unilateral right-hemisphere infarct: twelve patients with neglect and thirteen control patients without neglect as assessed by the Behavioural Inattention Test. Participants were required to point to stimuli fixed on a cardboard. Stimuli consisted of 20 squares and 20 circles that were symmetrically distributed on the left and the right side of the board. The participants' task was to either point to all stimuli on the board, or point to the circles *only.* The participants first completed the tasks with the aid of vision, and then performed the same tasks blindfolded. As expected, results indicated that patients with neglect omitted more stimuli in the left half of space than control patients. Overall, both control participants and patients with neglect demonstrated deterioration in their performance in the blindfolded condition. However, for a subgroup of the patients with neglect, the detection rate on the left half of the board was observed to improve in the blindfolded condition. Results also demonstrated that both patients with neglect and control participants more frequently returned to previously indicated stimuli in the condition where they had to point to *all* stimuli on the board. Interestingly, whereas the rate of return in control participants was significantly higher in the blindfolded condition, the patients' performance was not affected by blindfolding. This latter finding is in contrast to Olk and Harvey's expectations, as they argued that the patients' performance should improve in the blindfolded condition (that is, they should return less frequently to previously indicated stimuli) due to the salience of visual information being reduced with the blindfold. Olk and Harvey found no association between omissions and repetitive search performance in patients with neglect, and concluded that different mechanisms cause these symptoms. They suggest that it is important to consider repetitive search performance in the assessment of neglect, in addition to omissions, which is more traditionally used in tests assessing neglect.

Skakoon-Sparling, Vasquez, Hano, and Danckert (2011) conducted a study examining tactile exploratory search behaviour in patient ME, a patient with superior parietal damage and optic ataxia. Although patient ME exhibited acute visual neglect post-stroke, these symptoms had resolved at the time of testing nine months later (as assessed by line bisection and star cancellation). Seven neurologically intact control participants were also included in the study. The participants were required to use their right or left hand to search for target pegs among distractor pegs distributed across a large wooden board. The target pegs were pseudo-randomly distributed across the board, ensuring that each quadrant contained an equal number of target pegs. The board was positioned either horizontally or vertically, and centred at the participant's midline in both conditions. The participants initially completed a visual search and pointing task where they were asked to point to each of the target pegs in order to familiarise themselves with the task. Participants were then blindfolded and asked to tactually search for and locate all target pegs on the board and to verbally report their identification of target pegs. Overall, the results indicated that patient ME spent more time searching for and was more accurate in target detection in the right side of space than in the left side of space. Patient ME spent less time than controls searching in the left side of space, but spent more time than controls searching in the lower right quadrant of the display. It was also evident that, with the exception of the lower right quadrant of the display, patient ME was much less accurate at identifying targets than controls, a finding consistent with the results documented by Olk and Harvey (2006).

Although Olk and Harvey did not find a difference between patients with neglect and controls in the rate of return to previously indicated targets, Skakoon-Sparling et al. found that patient ME revisited more targets on the stimulus board than control participants.

Schindler, Clavagnier, Karnath, Derex, and Perenin (2006) argued that most studies investigating the relationship between visual and tactile neglect use stimuli that are relatively small in size (e.g., marbles in a maze or keys on a keyboard) and thus may evaluate object-related exploration rather than search performance within a larger space. Haeske-Dewick et al. (1996) and Karnath and Perenin (1998) avoided this issue by utilising larger search boards for comparing visual and tactile space exploration. However, Schindler et al. pointed out that neither study examined the extent of the visual or tactile search biases, as only each half of the board (or the two lateral sections in each hemifield) were analysed. To rectify this shortcoming, Schindler et al. designed a study to investigate the pattern of visual and tactile search deficits in patients with neglect by dividing the search board into smaller sections and comparing performance across the smaller sectors. Participants included 10 patients with neglect, 10 patients without neglect, and 10 age-matched normal subjects. The patients were assigned to the neglect group if they demonstrated signs of neglect on three of four screening tests: (a) letter cancellation; (b) line bisection; (c) clock drawing; (d) reading test. The participants were seated in front of a semi-circular board extending over a 240° search field. Ninety-six geometrical objects were randomly placed on the surface of the board. On top of each object there was a letter or a number. In the visual task, participants were required to identify the shape and the letter/number on top of as many stimuli as possible. In the tactile task, the blindfolded participants were requested to identify as many shapes as possible by using their ipsilesional hand. No time limit was given, and each trial ended when the subject indicated that s/he had completed the search. It is unclear from Schindler et al.'s article whether the participants were informed of the total number of shapes located on the board, but it appears that they were not informed and instead were asked to identify as many stimuli as possible. The position of each object identified by the patients was calculated (in degrees of angle) with respect to its location in relation to the centre line of the search board. Objects identified on the left half of the board were assigned a negative value, whereas objects identified on the right were given a positive value. The results demonstrated that the neglect patients' centre of activity was shifted to the right in both the visual and tactile modalities. In the visual task, the most activity was demonstrated at 68.2°, whereas in the tactile task the most activity was demonstrated at 39.8°. In both modalities, a gradual decrease in search frequencies was observed at both ends of the distribution (i.e., to the left and right of the centre of activity). These results are consistent with previous reports of less severe symptoms of neglect in blindfolded tactile tasks as compared to visual tasks (e.g., Chedru, 1976). Consistent with Skakoon-Sparling et al.'s (2011) findings, results also showed that the search activity included a substantial number of repetitions. The repetition rate was higher in patients with neglect than in control participants, in both the visual and tactile conditions. Schindler et al. speculated that the increased rate of repetition may be due to perseverative tendencies in patients with lesions including the frontal lobe or an additional spatial working memory disorder.

Vallar, Rusconi, Geminiani, Berti, and Cappa (1991) conducted a study aiming to investigate whether visual input affects exploratory performance in patients with neglect. A total of 110 patients with unilateral brain lesions took part in the study (66 patients with right-hemisphere damage and 44 patients with left-hemisphere damage). Neglect was assessed with a "cancellation task sensitive to extrapersonal neglect" (Vallar et al., p. 231). The participants' task was to pick up plastic balls that were placed on a board in front of them. The balls were evenly distributed in the left and right half of the board. Participants did the task both blindfolded (tactile condition) and with their eyes open (visual condition). Patients with right-hemisphere damage made more omission errors than patients with left-hemisphere damage, and a higher proportion of the errors were located in the contralesional side of the board both in the visual and the tactile conditions. Additionally, patients made more errors in the tactile condition than they did in the visual condition. Vallar et al. suggested that the better performance observed in the visual task may be due to both visual and tactile-kinaesthetic information being available in this condition. In the tactile task, however, performance is relying on the tactile-kinaesthetic spatial system *only,* leading to a relative deterioration in performance. This explanation is in stark contrast to previous findings (e.g., Gentilini et al., 1989) demonstrating relatively minor deficits in tactile neglect as compared to visual neglect. Recall that the patients in Gentilini et al.'s (1989) study performed worse overall in the visual condition than in the tactile condition. Gentilini et al. found that only patients with evidence of visual neglect (on a reading test and a circle test) exhibited neglect on their tactile task. Vallar et al. explained this discrepancy as a reflection of the characteristics of the tasks. In Vallar et al.'s study, participants were required to return their hand to a midsagittal position before each individual stimulus response (e.g., before picking up the next ball). This was not a requirement in the Gentilini et al. (1989) study. Vallar et al. suggested that in their own study, the task requirements interfered with the participant's propensity to be pathologically attracted to visible stimuli located on the ipsilesional side of space, and this contributed to the advantage demonstrated in the visual condition.

A perhaps more plausible account of Vallar et al.'s (1991) finding of better performance in the visual task compared to the tactile task comes from evidence that exploratory behaviour can be enhanced by reducing the salience of visual information on the ipsilesional side of space. For example, Mark, Kooistra, and Heilman (1988) and Làdavas, Umiltà, Ziani, Brogi, and Minarini (1993) demonstrated that patients with neglect performed more exploratory behaviours in the left side of space when required to erase or pick up stimuli than when required to cross out or point to the stimuli. The patients in the experiment by Mark et al. were required to perform a line cancellation task by either crossing out lines or erasing lines drawn onto a porcelain board. Ten patients with neglect, as assessed by the omission of two or more lines located on the left side of page in a line cancellation task, participated in the study, and performed the crossing out task before the erasing task. Results indicated that omissions in the left side of space were more frequent in the condition where the patients crossed out the lines than in the conditions were the lines were erased. Mark et al. observed that the patients tended to erase the lines on the right side of the display first, and gradually move into the left side of space. Performance in the left side of space therefore improved when the lines were physically removed.

Làdavas et al. (1993) conducted a study comparing the performance of patients with perceptual neglect to patients with directional hypokinesia on two tasks requiring the participants to either point to or pick up 20 tokens symmetrically distributed on a display. Each task was completed once with the aid of vision and once blindfolded. The blindfolded condition of each task was always completed immediately after the visual condition. Participants consisted of 15 patients with damage to the right hemisphere. Of these, 10 demonstrated evidence of neglect by omitting at least 50% of the stimuli on the left side of page on either a bell cancellation test or a letter cancellation test. The evidence of neglect in five of these 10 patients was found to be due to directional hypokinesia based on performance on a test initially described by Tégner and Levander (1991). Làdavas et al. predicted that the performance of patients with perceptual neglect should improve either when patients picked up the tokens or when they performed the task blindfolded. They expected no such improvement in patients with directional hypokinesia. Results indicated that that the patients with perceptual neglect performed better on the left side of space when the tokens were picked up than in the pointing task when they had their eyes open. There was no such difference in the blindfolded condition. Neither patients with directional hypokinesia nor control patients demonstrated this effect. Furthermore, patients with directional hypokinesia and the control group omitted more stimuli when blindfolded. In contrast, patients with neglect performed better on both tasks in the blindfolded condition than they did with the aid of vision in the pointing task. Mark et al. (1998) and Làdavas et al. interpreted their findings as evidence in support of the hyperattentional hypothesis of unilateral neglect, suggesting that due to a strong bias toward maintaining focal attention on the rightmost position, patients fail to disengage their attention and thereby omit stimuli located further to the left. By removing or erasing stimuli on the right, patients were able to gradually shift their attention towards the left. The finding of better performance in the visual task than in the tactile task documented by Vallar et al. (1991) is therefore likely to be due to the task requirement of removing stimuli rather than because of the availability of both visual and tactile-kinaesthetic information in the visual condition as suggested by Vallar et al.

The improvement in performance in the blindfolded condition in comparison to the pointing task with eyes open, as documented by Làdavas et al. (1993), is interesting considering the expectation of the increased difficulty associated with precluding vision. These results are, however, consistent with the findings documented by Chedru (1976) and Gentilini et al. (1989), who also described relatively minor deficits in tactile neglect compared to visual neglect. The patients in the studies of Chedru and Gentilini et al. demonstrated a preference to tap keys on the ipsilesional side of a keyboard with the aid of vision, a bias that was reduced in the blindfolded condition. Consistent with the findings of Vallar et al. (1991), the patients in the study by Làdavas et al. performed better in the visual picking up condition than in the blindfolded conditions.

Another explanation for the better performance observed in the visual task compared to the tactile task in the study by Vallar et al. (1991) and Làdavas et al. (1993) includes the observation that an action of an object may improve unilateral neglect. Robertson, Nico, and Hood (1995) conducted a study to investigate whether the intention to manipulate or act on objects would lead to a change in the manifestation of unilateral neglect. They included 10 patients with evidence of unilateral neglect from line cancellation and letter cancellation tasks in their study. The patients were presented with metal rods of three different lengths, and were required to either point to the centre of each rod or reach for the rod as if to pick it up in a way that it would be balanced. The task was completed with eyes open. The order of administration of the tasks was counterbalanced, and the location on the rod where patients either pointed to or reached for the rod was measured from the end of the rod. Results demonstrated that the rightward bias observed in the pointing condition was significantly reduced in the reaching condition. The study of Robertson et al. demonstrated that a change in the purpose of very similar actions on an object has a significant effect on the manifestation of unilateral neglect in the visual modality, a finding subsequently replicated both for patients with neglect (e.g., Robertson et al., 1997) and with neurologically intact participants (e.g., Hughes, Bates, & Aimola Davies, 2004). Hughes, Bates, and Aimola Davies (2004) demonstrated that although neurologically intact individuals tend to bisect lines in the opposite direction to patients with neglect (left instead of right), this error was eliminated when participants were asked to pick rods up by the centre. The better result in the visual than in the tactile condition observed by Vallar et al (1991) may therefore be due to the visual condition requiring an action on an object that could be seen by the participants. Although an action was also required in the tactile condition, the positive influence of the action may have been counteracted by the need to also explore.

Interim summary

Karnath and Perenin (1998) noted that patients with neglect tend to demonstrate a skewed visual search performance where they fixate and search on the ipsilesional side and neglect stimuli located on the contralesional side. They demonstrated that patients with neglect also exhibit this disturbance in the tactile domain. Olk and Harvey (2006) predicted patients with neglect to also repeatedly return to stimuli in the ipsilesional side of space, and although they found that both patients with neglect and control participants more frequently returned to previously indicated stimuli, they failed to find any association between omissions and repetitive search performance in patients with neglect. Consistent with the findings of Olk and Harvey, Skakoon-Sparling et al. (2011) also found that patient ME, a patient with parietal damage and optic ataxia, spent more time searching for and was more accurate in target detection in the right side of space than in the left side of space. Although Olk and Harvey failed to find an association between omissions and repetitive search performance, Skakoon-Sparling et al. found patient ME to revisit more targets on the stimulus board than control participants. Schindler et al. (2006) conducted a study requiring participants to search for shapes placed on the surface of a semi-circular board over a 240° search field in both a visual and tactile condition. They found the centre of activity was shifted to the right in both the visual and tactile modalities for patients with neglect, and also found that the repetition rate was higher in patients with neglect than in control participants. Vallar et al. (1991) sought to examine whether visual input affects exploratory performance in patients with neglect. Participants were required to pick up plastic balls that were placed on a board in front of them. Vallar et al. found participants to make more omission errors in the tactile condition than they did in the visual condition, and suggested that the better performance in the visual task may be due to both visual and tactile-kinaesthetic information being available in this condition. When visual information is precluded, performance is relying on the tactile-kinaesthetic spatial system *only,* contributing to deterioration in performance. This explanation does not fit with reports of comparatively minor deficits in tactile neglect as compared to visual neglect (e.g., Gentilini et al., 1989). A better explanation for Vallar et al.'s results comes from evidence that exploratory behaviour can be enhanced by reducing the salience of visual information on the ipsilesional side of space. For example, Mark et al. (1988) and Làdavas et al. (1993) demonstrated that patients with neglect performed more exploratory behaviours in the left side of space when required to erase or pick up stimuli than when required to cross out or point to the stimuli. Mark et al. and Làdavas et al. interpreted their findings as evidence in support of the hyperattentional hypothesis of unilateral neglect, suggesting that due to a strong bias toward maintaining focal attention on the rightmost position, patients fail to disengage their attention and thereby omit stimuli located further to the left. By removing or erasing stimuli on the right, patients were able to gradually shift their attention towards the left. The finding of better performance in the visual task than in the tactile task documented by Vallar et al. is therefore likely to be due to the task requirement of removing stimuli. This is consistent with the observation that an action of an object may improve unilateral neglect. Robertson et al. (1995) demonstrated that the rightward bias observed when patients were required to point to the midpoint of a rod was significantly reduced when patients were required to reach to the midpoint. The better result in the visual than in the tactile condition observed by Vallar et al. may therefore be due to the visual condition requiring an action on an object that could be seen by the participants. Although an action was also required in the tactile condition, the positive influence of the action may have been counteracted by the need to also explore.

Tactile Neglect on Line- and Rod-Bisection Tasks

Fujii, Fukatsu, Kimura, Saso, and Kogure (1991) conducted a study to investigate whether patients with visual neglect also demonstrated tactile neglect on a line-bisection task. The visual stimuli consisted of black horizontal lines in four different lengths. The tactile stimuli consisted of thin sticks in four different lengths (80mm, 120mm, 160mm, 200mm), mounted on a piece of cardboard, of the same length as the visual stimuli. The participants consisted of 10 patients with neglect in the visual modality, as assessed by a line cancellation task and a copying task, and 10 control patients with diseases not affecting the nervous system. Their task was to bisect the visual stimuli in the centre. On completion of this task, the participants were blindfolded and asked to run their index finger along the tactile stimuli and to stop at the estimated midpoint. On the tactile task, the participant's finger was placed at the centre of the stick prior to the commencement of each trial, and there were no limitations as to how many times the participants could run their finger along the stick before making a decision about the midpoint. Participants were not required to return to the midpoint at any time during the trial, but were returned to the centre of the stick prior to the commencement of the next trial. In the visual task, patients with neglect estimated the midpoint to be to the right of the true midpoint, while on the tactile task their performance was the same as the control group. Thus, Fujii et al. failed to find evidence of the existence of neglect in the tactile modality. Fujii et al. suggested that their failure to demonstrate tactile neglect may have been due to the line-bisection task not being sensitive to detecting neglect in this modality. Furthermore, Fujii et al. also said that the visual and tactile tasks were not equivalent, in that they required different exploration strategies, which may have confounded the results.

Hjaltason, Caneman, and Tegnér (1993) attempted to rectify Fujii et al.'s (1991) failure to control for differences in task demand between visual and tactile conditions in another study investigating visual and tactile rod bisection in patients with neglect.

Participants consisted of 36 patients with damage to the right or left hemisphere *with* or *without* neglect. Neglect was assessed by the following tests: (a) line cancellation; (b) letter cancellation; (c) figure copying; (d) reading. In the visual condition, patients were required to indicate the midpoint of a plastic rod by pointing to it. In the tactile condition, patients were blindfolded and asked to run the index finger along the rod, and to stop at the estimated midpoint. The latter task was also performed without a blindfold in a visuo-tactile condition. The finger was positioned at the right or left end of the rod (an equal number of times) at the beginning of each trial. The results showed that only patients with damage to the right hemisphere *with* neglect made significant deviations from the midpoint of the rod in the visual condition. This study failed to demonstrate tactile neglect. That is, the patients did not deviate from the midpoint in either the tactile condition or the visuo-tactile condition. The authors speculated that tactile exploration of the rod reduced neglect. Again, the findings of both Hjaltason et al. and Fujii et al. (1991) are consistent with evidence that an action of an object may improve unilateral neglect. Robertson et al. (1995) demonstrated that the rightward bias observed when patients were required to point to the midpoint of a rod was significantly reduced when patients were required to reach to the midpoint. The failure to find evidence of tactile neglect by Hjaltason et al. and Fujii et al. may be due to the tactile condition requiring an action on an object. This action may have precluded the opportunity to detect neglect in the tactile modality. Although other studies (e.g., Chedru, 1976; De Renzi et al., 1970) have found evidence of tactile neglect when participants have been encouraged to explore the stimuli prior to making a response, exploration in this sense is different from an action on an object. In the studies of Hjaltason et al. and Fujii et al., tactile exploration was a requirement for the completion of the task. In the studies by Chedru (1976) and De Renzi et al. (1970), although tactile exploration was encouraged, it was not a requirement.

Chokron, Colliot, Bartolomeo, Rhein, Eusop, Vassel, and Ohlmann (2002) conducted a study aiming to clarify whether the spatial bias observed in patients with neglect is due to an ipsilateral shift of the egocentric frame of reference. Chokron et al. argued that this shift is responsible for the impaired performance on the left side of space observed in patients with neglect. According to this prediction, neglect should be equally severe across all sensory modalities, a suggestion that is in sharp contrast to results from some of the previous research, which has indicated that visual neglect is often more frequent and severe than neglect in other modalities. To investigate this hypothesis, Chokron et al. tested 12 patients with unilateral neglect in a straight-ahead pointing task and in visual and tactile bisection tasks. The presence of neglect was assessed by a battery of tests, including: (a) line cancellation; (b) bell cancellation; (c) letter A cancellation; (d) line bisection; (e) figure copying; (f) identification of overlapping figures. In the straight-ahead pointing task, patients, who were blindfolded, were requested to point straight ahead with their ipsilesional hand. The position of the hand was recorded when the patient indicated that s/he was pointing straight ahead. Results demonstrated no significant difference between the patients' subjective straight ahead and the objective middle. In the tactile bisection task, participants were required to explore two rods (10cm and 22cm in length), centred with respect to their sagittal middle, before stopping at the estimated midpoint. The patients were blindfolded, and the finger of the patient was always placed at one extremity of the rod to initiate a trial. There was an equal number of trials starting on the left and right end of the rod. Again results demonstrated no significant difference between the subjective estimated midpoint and the objective middle of the rod. In the visuo-motor bisection task, patients were required to bisect two lines of the same length as the tactile stimuli. Although the name of the task implies the involvement of a particular motor component, the task was simply to bisect the lines, and could therefore be better described as the visual bisection task. The lines were centred with respect to the subjects' sagittal middle. The trial ended when the participant marked the estimated subjective midpoint with a pencil. Results demonstrated a significant rightward deviation of the subjective midpoint of the longer lines, however, there was no difference between the subjective and objective midpoint of the shorter lines. Due to the failure to demonstrate a rightward shift in the straight-ahead pointing task and the tactile task, results did not support the hypothesis of a systematic ipsilesional shift of the frame of reference in patients with neglect. Chokron et al.'s study is, however, subject to the same limitations as Fujii et al.'s (1991) study in that the visual and tactile tasks were not equivalent as they required different exploration strategies. That is, the tactile condition required the tactile exploration of a rod, whereas the visual condition was simply a visual line-bisection task. The tasks could have been made more comparable by also including the visuo-tactile condition employed by Hjaltason et al. (1993).

Interim summary

Tactile neglect has also been defined according to a rightward bias in tactile line- and rod-bisection tasks. Fujii et al. (1991), Hjaltason et al. (1993), and Chokron et al. (2002) all investigated whether patients with unilateral neglect also demonstrated tactile neglect on a tactile line-bisection task. All studies required participants to bisect lines, sticks, or rods, in a visual and in a tactile condition. The visual condition involved bisecting lines drawn on a piece of paper, or indicating the midline of a rod by pointing to it. The tactile conditions involved the participants running their finger along tactile stimuli before stopping at the estimated midpoint. Although all studies found evidence of neglect in the visual conditions, none were able to demonstrate neglect in the tactile conditions. Again, the findings of Fujii et al., Hjaltason et al., and Chokron et al. are consistent with evidence that an action of an object may improve unilateral neglect. The failure to find evidence of tactile neglect in these studies is most likely due to the tactile condition requiring an action on an object. This action may have precluded the opportunity to detect neglect in the tactile modality.

Viewer- and Stimulus-Centred Frames of Reference in Tactile Neglect

More recently, research in the area of tactile neglect has started to investigate whether neglect in the tactile domain can occur in separate frames of reference, as has been demonstrated with neglect in the visual modality (e.g., Behrmann & Moscovitch, 1994; Calvanio, Petrone, & Levine, 1987; Driver, Baylis, Goodrich, & Rafal, 1994; Driver & Halligan, 1991; Farah, Brunn, Wong, Wallace, & Carpenter, 1990; Làdavas, 1987; Tipper & Behrmann, 1996). While a large number of studies of visual neglect have considered the role of viewer- and stimulus-centred frames of reference, very little research has been conducted to investigate this in tactile neglect.

Bisiach, Capitani, and Porta (1985) first conducted a study to investigate the role of egocentric (head- or trunk-centred) coordinate systems in tactile neglect. Fifteen blindfolded patients with neglect (as assessed by a cancellation task) (with no control group included in the study) were required to pull out pegs attached to the bottom of each of thirty-seven adjoining hexagonal cells, grouped to form a large hexagonal wooden apparatus. The head- and trunk-centred coordinate systems were separated by displacing the apparatus to the right and/or by turning the participant's head to the right.

Results demonstrated that the left-right difference was largest when all egocentric coordinates were aligned, that is, when both the apparatus and the vertical midline of the head, eyes, and trunk were aligned. Patients in this condition omitted more pegs on the left than on the right side of the apparatus. There was no left-right difference when the apparatus was placed on the right of both the head- and trunk-centred coordinates. But when the apparatus was displaced to the right and the head and the eyes were aligned with the centre of the apparatus, and when the apparatus was placed in front of the participants with the head and eyes turned to the right, the participants again omitted more stimuli on the left than on the right side of the apparatus. However, the left-right difference was smaller than when all egocentric coordinates were aligned. Bisiach et al. concluded that the head and trunk midline affect the performance of patients with neglect in tactile exploration tasks.

Chokron and Imbert (1995) conducted another study investigating the role of head- and trunk-centred coordinates in a straight-ahead pointing task. Participants included one patient with neglect and 30 normal control subjects. Neglect was established by performance on a series of tasks, including line crossing, line bisection, numbering, drawing, and writing. The patient's task was to point straight ahead, whilst blindfolded, in three different experimental conditions: (a) trunk and head aligned at 0°; (b) trunk oriented 15° to the left while the head remained at 0°; (c) trunk oriented 15° to the right while the head remained at 0°. In addition, the patient commenced the task in four different starting positions (15° and 30° to the left or right of the objective centre). Results demonstrated that pointing deviated to the right of the objective centre when the trunk and head were aligned. Recall that Chokron et al. (2002) found no significant difference between patients' subjective straight ahead pointing and the objective middle in their task. It is important to note that it is unclear whether the severity of neglect is comparable between the 12 patients included in the study by Chokron et al. and the single-case patient included in Chokron and Imbert's study. Differences in neglect severity may have contributed to disparate results. Chokron and Imbert also found that trunk rotation significantly affected the deviation, with leftward deviation when the trunk was rotated to the left and rightward deviation when the trunk was rotated to the right. Starting point also had an impact on deviation when the trunk was rotated to the left or right of the head. Results demonstrated more pronounced leftward pointing deviations in the left starting position when the trunk was rotated to the left. The opposite was observed when the trunk was oriented to the right, with a larger rightward bias when the starting point was to the right. Chokron and Imbert interpreted these findings as evidence that the trunk midline is more important than the head midline in determining the performance of patients with neglect in straight-ahead pointing tasks.

The studies by Bisiach et al. (1985) and Chokron and Imbert (1995) did not separate the head- and gaze-centred coordinate systems. Beschin, Cubelli, Della Sala, and Spinazzola (1997) sought to rectify this in a study investigating the role of three egocentric coordinate systems (retinotopic-, head-, or trunk-centred) in tactile neglect. Their participant was a patient who demonstrated severe tactile neglect on a search task. Neglect in the visual modality was established by performance on a clinical battery of tests for neglect, including line cancellation, bells cancellation, letter cancellation, figure copying, and drawing tasks. The tactile task was identical to that used by Beschin et al. (1996), and consisted of a maze with eight lateral arms. As in Beschin et al.'s (1996) study, the patient was required to locate a marble placed in the end of one of the lateral arms of the maze, as fast as possible, and within a time-limit of 120 seconds. The patient was tested in five different conditions: (a) retinotopic-, head-, and trunk-centred coordinate systems were aligned with the apparatus; (b) apparatus was positioned 30° to the right of the midline of the trunk, and the retinotopic- and head-midline were aligned with the centre of the apparatus; (c) centre of the apparatus was aligned to the trunk midline, and the retinotopic- and head-midline remained at 30° to the right; (d) centre of the apparatus was aligned to the trunk- and head-midline, but the retinotopic midline remained at 30° to the right; (e) apparatus was positioned 30° to the right of the midline of the trunk and the head, and the retinotopic midline was aligned with the centre of the maze. Results illustrated that the orientation of the trunk most strongly affected the patient's performance on the tactile task, while the retinotopic and head coordinates did not appear to be important. This was shown by the finding that, when the maze was located on the right side of the patient's body midline (aligned to the gaze or head, condition e) there was no difference in the patient's performance on the left and right side of the maze. In contrast, when the maze was centred on the trunk, but to the left of the gaze and head (condition c), the patient performed significantly better on the right side compared to the left side of the maze. In order to investigate the influence of gaze-centred coordinates on performance, the participant could not be blindfolded in Beschin et al.'s (1997) study. As mentioned previously it is important to keep in mind the potential implication that vision could have on performance on tactile tests. It has been suggested that patients may be attracted to visual information in the right side of space, which may have a negative impact on tactile search performance and therefore be a confounding factor in results (Beschin et al., 1996). The results should therefore be interpreted with caution. But the absence of a gaze-centred component in the results may indicate a higher likelihood that the results are a true reflection of performance related to trunk-centred coordinates.

Importance of 'Relative' Position in Space in Tactile Neglect

Another line of research has defined tactile neglect with respect to an impaired ability to detect somatosensory stimulation delivered to locations (usually the hand or arm) on the contralesional side of the body in the absence of sensory deficits.[11] A number of researchers (discussed below) have investigated the effect of the stimulated limb's relative position in space on neglect and/or extinction. Extinction in this regard refers to the failure to detect double simultaneous stimulation delivered to two points on the patient's body (usually the left and right hand), while accurately detecting single stimulation delivered to a position on the left or right side of the body.

Pierson-Savage, Bradshaw, Bradshaw, and Nettleton (1988) argued that previous studies of tactile neglect have been largely qualitative in nature. They sought to provide a quantitative indication of tactile hemispatial deficits by utilising a reaction time measure. Pierson-Savage et al. utilised a vibrotactile reaction time task to investigate the ability of patients with neglect to detect somatic stimulation, and they manipulated the spatial location of the ipsilesional hand. Participants included 10 patients with left hemispatial neglect. Visual neglect was established either by performance on line cancellation, drawing, and copying tasks, or based on behavioural evidence of personal neglect. The task was to detect vibrating stimulation delivered by a transducer attached to the ipsilesional index finger. Responses were made by pressing a button placed underneath the index finger. Participants were requested to press the button as soon as they detected the vibration from the transducer. The index finger was positioned 65° to the left or to the right of midline. Participants were tested with eyes open in a prerehabilitation condition and both with eyes open and eyes closed in a postrehabilitation condition. Rehabilitation consisted of teaching patients strategies to

[11] Tactile neglect has sometimes (and perhaps more accurately) been referred to as somatosensory neglect. For the purpose of keeping the terminology consistent throughout, the terms tactile neglect and tactile extinction are used in this literature review.

compensate for difficulties in attending to stimuli located on the left. Results demonstrated that reaction time was significantly faster in the right hemifield than in the left hemifield in the prerehabilitation condition. In the postrehabilitation condition, these results were reversed, with a left hemifield advantage when patients had their eyes open. In contrast, there was a right-side advantage when patients had their eyes closed. Pierson-Savage et al. suggested that the reversal of the results in the eyes open condition (between pre- and post-rehabilitation) may be due to having learned visual strategies that lead to an overcompensation of the patients' difficulties in directing attention to the left side, an effect which disappeared in the eyes closed condition. It is unclear whether the reduction of the right-side advantage from the prerehabilitation condition (eyes open) to the postrehabilitation (eyes closed) condition can be explained by less severe symptoms of neglect in blindfolded tactile tasks generally, as has been demonstrated by previous research, or is better explained by the effects of rehabilitation. This potential confound could have been avoided by having the patients perform the task with their eyes closed in the prerehabilitation condition.

Valenza, Seghier, Schwartz, Lazeyras, and Vuilleumier (2004) conducted a study seeking to further investigate the effect of hand position in egocentric space on tactile extinction. Their participant was a 68-year-old male with right parietal damage and evidence of left visual neglect and tactile extinction following stroke. Evidence of left neglect came from observations that the patient was slower to detect visual targets in the left side of space than in the right side of space. The patients did not omit any stimuli in cancellation tests. Tactile extinction was assessed by a standard confrontation technique in which single or double simultaneous stimulation was delivered to the patient. The patient accurately identified all single stimulation, but only detected one stimulation delivered to the left during double simultaneous trials. The experiment required that the patient detect single and double simultaneous stimulation delivered to the right hand and elbow in two spatial conditions: (a) right hand and elbow located in the ipsilesional side of space; (b) elbow remained in the ipsilesional side of space whereas the hand was located in the contralesional side of space. Valenza et al. do not specify whether the patient's eyes were open or closed during testing. Results demonstrated that during double simultaneous stimulation trials, the patient detected fewer trials when the stimulated hand was located in the contralesional than in the ipsilesional side of space. The patient was highly accurate in detecting single stimulation irrespective of hand position. Valenza et al. interpreted their findings as a demonstration of "the role of higher spatial coordinates in attention and extinction" (p. 143).

In the visual modality, patients do not necessarily only neglect parts of an object or a scene in the left visual field but they may also neglect the stimulus located furthest to the left among a number of stimuli, even when these are located in the intact right visual field. Moscovitch and Behrmann (1994) designed a study to investigate whether similar principles are evident in the tactile modality. Eleven patients with visual neglect, as assessed by the Sunnybrook Battery for Neglect, and tactile extinction were assessed using a modified procedure of double simultaneous stimulation. With their eyes closed, participants were presented with a light touch to two points on either side of their ipsilesional wrist. The wrist was kept in a constant location in the ipsilesional side of space. The stimulations were presented on each side separately, or simultaneously on both sides of the wrist. There were an equal number of trials in each condition. This procedure is usually conducted by presenting somatic stimulation to the left and right hands when the hands are located on the respective sides of the body's somatosensory midline. However, in this condition the somatotopic and spatial frames of reference are aligned. Moscovitch and Behrmann therefore separated the somatotopic and spatial frames of reference by stimulating two nearby positions on one side of the midline only. Patients were tested in two different conditions, with the palm up or with the palm down. Results showed that neglect primarily occurred on the contralesional side of the wrist (as defined spatially), irrespective of hand position (palm up or down). There was a higher number of neglect errors during simultaneous tactile stimulation to the dorsal (on the side of the thumb) surface in the palm-down condition and to the ulnar (on the side of the little finger) surface in the palm-up condition. To eliminate the possibility that the results were due to an inability to detect two simultaneously presented tactile stimulations, Moscovitch and Behrmann demonstrated that the patients were capable of detecting double stimulation when presented vertically along the midline of the arm. Moscovitch and Behrmann concluded that consistent with the visual system, hemineglect in the tactile modality is defined "with respect to a higher-order spatial frame of reference and not only with respect to a sensory, somatotopic frame of reference" (p. 153).

Mattingley and Bradshaw (1994) also conducted a study investigating the allocation of attention to tactile stimulation delivered to the ipsilesional hand in patients with neglect. As for Moscovitch and Behrmann (1994), the aim of the study was to investigate whether patients with neglect exhibit impairments in responding to tactile stimulation located in a relative left position within the intact ipsilesional hemifield. Mattingley and Bradshaw indicated that the Moscovitch and Behrmann method of stimulus delivery (a light touch by the use of cotton wool or a finger) lacked standardisation with respect to intensity and duration. Mattingley and Bradshaw used vibrotactile stimulation to control for these factors. They sought to extend Moscovitch and Behrmann's study by assessing the participants' responses to single lateralised stimulation, and to determine the effect of hemispatial location on task performance. Mattingley and Bradshaw noted that the majority of research in this area requires space exploration, a task that may reflect kinaesthetic and/or exploratory deficits rather than pure tactile neglect. They suggested that previous findings may be best described as "tactile-kinaesthetic" or "exploratory-motor" neglect. They argued that a vibrotactile reaction time task could reduce the impact of kinaesthetic and/or exploratory deficits, and present a purer measure of neglect in the tactile modality. Eight patients with neglect (as assessed by line cancellation, circle cancellation, star cancellation, and line bisection tests), and eight neurologically healthy control participants were tested. With their eyes open and fixating directly ahead throughout the experiment, the participants' task was to detect vibrotactile stimulation delivered by a transducer attached to the upper surface of the index and middle fingers of the ipsilesional hand. Responses to demonstrate detection of vibrotactile stimulation were made by pressing one of two adjacent microswitches. The participants' ipsilesional hand was positioned 250 mm into the left or right side of space, or directly opposite the midline of the participant's body. The participants' eyes were open and they were required to fixate straight ahead. As in Moscovitch and Behrmann's study, participants were tested with the palm facing down or palm facing up. Mattingley and Bradshaw predicted that if patients exhibit impairments in responding to tactile stimulation located in a relative left position, then reaction time should be slower in response to stimulation delivered to the finger located furthest to the left in space irrespective of the hand posture and the location of the hand in space. If, in contrast, the patient's midline (viewer-centred coordinates) is more important, then the patients' performance will depend on the location of the responding hand relative to the body midline irrespective of the position of the fingers. More specifically, participants should be faster in responding to stimulation when the hand is located to the right of the body midline (right side of space) compared to when it is positioned to the left of the midline (left side of space). Results demonstrated that both patients with neglect and neurologically healthy controls were slower to detect stimulation delivered to the relative left finger irrespective of hand posture and hemispatial location of the hand. Although the overall reaction time results for patients and controls were the same (that is, not significantly different from each other), the magnitude of the left-to-right-finger reaction time difference was larger for the patients with neglect than it was for the neurologically healthy controls. Results also demonstrated that patients with neglect made more left- than right-finger errors, whereas there was no difference in error rates for the left and right fingers in controls. Mattingley and Bradshaw concluded that the results provide evidence that the relative positioning of tactile stimulation in space is more important in determining patient performance than hemifield. The results also illustrate the importance of including control participants, in tasks investigating neglect, to avoid misattributing normal attentional differences to hemispatial neglect.

A similar study was conducted by Tinazzi, Ferrari, Zampini, and Aglioti (2000). They sought to investigate the importance of multiple body anchors in determining 'left' and 'right'. The participant was a patient with right-hemisphere damage who exhibited tactile extinction in the absence of any somatic deficits. Extinction was again assessed by a standard confrontation technique in which single or double simultaneous stimulation was delivered to the patient. The patient accurately detected single stimulation but failed to detect stimulation delivered to the left in double simultaneous trials. This study extended previous research because they used single and double somatic stimulation to both hands, to the thumb or the little finger of a single hand, or to two sides of the index finger of a single hand (toward the thumb and toward the middle finger). The stimulated hand was positioned palm up or palm down, and hands were in an anatomically correct position or in a crossed position. The participant was required to have her eyes closed and her head facing straight ahead. Results demonstrated that tactile extinction was present in all conditions, but was more severe when stimulation was delivered to both hands than to a single hand. Although extinction was still present with stimulation delivered to positions on the right hand and the right index finger, it was less severe than when delivered to the left hand and index finger. Tinazzi et al. did not find evidence of a modulation of performance when the hands were in a crossed position. However, it is unclear whether the hands were in a crossed position when stimulation was delivered to both of the hands or *only* when stimulation was delivered to a single hand. The authors suggest that the lack of a change in performance in the crossed positions, when stimulation was delivered to a single hand or index finger, indicates that the participant used the body part stimulated as a reference point to code 'left' and 'right', rather than the left and right hemifield as defined in a viewer-centred frame of reference. Overall, findings were consistent with results provided by Mattingley and Bradshaw (1994) and Moscovitch and Behrmann (1994), suggesting that the relative positioning of tactile stimulation in space is more important in determining patient performance than hemifield.

Smania and Aglioti (1995) conducted a study to specifically investigate the accuracy of patients with extinction and/or neglect in detecting somatic stimulation according to the hemispace in which their hands were located. Their study sought to extend previous findings (Mattingley & Bradshaw, 1994; Moscovitch & Behrmann, 1994; Pierson-Savage et al., 1988) by exploring whether presenting somatic stimulation to the patients' ipsilesional and contralesional hands while they were in an anatomically correct position or crossed would have an effect on accuracy rates in detecting stimulation. In the first condition, the somatotopic and spatial frames of reference were aligned, whereas in the latter condition they were disambiguated. Participants consisted of 16 patients with damage to the right hemisphere, and with tactile/visual extinction and/or visual neglect. Tactile neglect and extinction was again assessed by a standard confrontation technique (see Tinazzi et al., 2000). The experimental method involved a double simultaneous stimulation procedure. Participants were presented with tactile stimulation to the dorsal surface of the right or left hand, or to both hands simultaneously. The patients were blindfolded during testing sessions, and stimulation was delivered in the following two conditions: (a) hands were in an anatomically correct position; (b) hands were in a crossed position. Responses to stimulation delivered to the participants' right hand were highly accurate both in the anatomically correct and crossed condition. In contrast, participants omitted a large number of responses delivered to the left hand. Participants detected significantly more stimulation delivered to the left hand in the single as compared to the double stimulation condition. Furthermore, they were more accurate in detecting stimulation delivered to the left hand in the crossed condition than in the anatomically correct condition both with single and double stimulation. Smania and Aglioti interpreted the advantage of stimulus detection to the left hand when it was located in the right hemispace as evidence that both somatotopic representations as well as higher-order spatial frames of reference influence the ability of patients with extinction and/or neglect to detect simple tactile stimulation.

Vaishnavi, Calhoun, and Chatterjee (1999) conducted a study replicating and extending Smania and Aglioti's (1995) experiment. Vaishnavi et al. suggested that the brain constructs multiple representations of space, and distinguished between personal space (the space occupied by the body) and peripersonal space (the space within reach encircling the body). They suggested that touch may be linked to personal space, whereas vision may be more closely linked to peripersonal space, and that integrating tactile and visual stimuli may help to bind personal and peripersonal space. They set out to investigate whether visual-tactile and tactile-motor integration would enhance contralateral awareness due to the integration binding personal and peripersonal space. Vaishnavi et al. delivered single and double simultaneous stimulation to patients' ipsilesional and contralesional hands while they were in an anatomically correct or crossed position. Participants, who were blindfolded during the experimental trials, included three patients with tactile extinction. Results demonstrated that patients were highly accurate in detecting single stimulation. But in contrast to the findings of Smania and Aglioti, Vaishnavi et al. (1999) found that hand location had no effect on accuracy in detecting stimulation. In a later replication of the same experiment, Vaishnavi, Calhoun, and Chatterjee (2001) found that their ten patients with tactile extinction were *less* accurate in detecting double simultaneous stimulation delivered to the contralesional hand in the crossed position than in the anatomically correct position, which is the opposite of what was found by Smania and Aglioti. Vaishnavi et al. (2001) distinguished between tactile extinction in personal and peripersonal space. They interpreted their results as evidence of extinction in personal space (the space occupied by the body) as opposed to Smania and Aglioti's findings of extinction in peripersonal space (the space within reach encircling the body).

In a separate experiment, Vaishnavi et al. (1999, 2001) required patients to detect double simultaneous stimulation whilst they looked at either the ipsilesional or their contralesional hand. The hands were always in an anatomically correct position. Results demonstrated that accuracy in detecting stimulation delivered to the contralesional hand improved when the patients' directed their gaze toward this hand. Vaishnavi et al. interpreted these results as evidence that visual input and direction of gaze may modulate tactile extinction. Although Vaishnavi et al. found an improvement in performance with visual input as opposed to deterioration in performance, this finding emphasises the importance of controlling for visual input in studies investigating tactile neglect.

Aglioti, Smania, and Peru (1999) conducted a further study to investigate the importance of the body-midline in the ability of patients with neglect to detect somatic stimulation. In addition, their study sought to extend previous findings by Moscovitch and Behrmann (1994), Mattingley and Bradshaw (1994), Smania and Aglioti (1995), and Vaishnavi et al. (1999, 2001) by exploring whether presenting somatic stimulation to the hands of a patient with neglect while the hands are crossed in *one* hemispace, would contribute to an amelioration of neglect symptoms. Participants consisted of 48 patients with left- or right-hemisphere damage, with or without visual neglect. Visual neglect was assessed by cancellation and reading tests. Participants were divided into five groups: (a) control participants; (b) patients with left-hemisphere damage; (c) patients with lesions to the right hemisphere who did not manifest tactile extinction; (d) patients with lesions to the right-hemisphere with tactile extinction; (e) patients with right-hemisphere lesions with severe tactile extinction. As in the work of Moscovitch and Behrmann, the experimental method involved a double simultaneous stimulation procedure. Participants were presented with somatic stimulation to the dorsal surface of their left or right hand, or to both hands simultaneously. Patients were blindfolded and tested in the following three experimental conditions: (a) one hand was in the left hemispace and the other hand was in the right hemispace, either in an anatomically correct position (not crossed) or crossed; (b) both hands were in the right hemispace, either in an anatomically correct position or crossed; (c) both hands were in the left hemispace, again either in an anatomically correct position or crossed. In each condition, ten single left, ten single right, and twenty double simultaneous stimulations were presented in a random sequence. The results from Aglioti et al.'s (1999) study indicated that control participants, left-hemisphere patients, and right-hemisphere patients without tactile extinction were highly accurate in detecting single stimulation. In double stimulation trials, these groups were more accurate when the hands were in an anatomically correct position as compared to when they were crossed, and this was true for all experimental conditions. This latter effect was not present in participants with damage to the right-hemisphere who also manifested tactile extinction. These participants were equally accurate in their detection of stimulation irrespective of the position of their hands. In contrast, those in the right-hemisphere group with severe tactile extinction omitted more stimulation delivered to their left hand compared to their right hand, and accuracy for detecting stimulation to the left hand was higher in the crossed as compared to the anatomically correct position in both single and double stimulation conditions. The reverse pattern was observed with stimulation delivered to the right hand. That is, the accuracy for detecting stimulation delivered to the right hand was lower in the crossed position than in the anatomically correct position. Aglioti et al.'s results complement Smania and Aglioti's results in that they demonstrate it is not only the body's somatosensory midline (egocentric coordinates) that is important in defining the left and right of what is to be neglected. They support Moscovitch and Behrmann's finding that the relative positioning within the left or right hemifield is also important. Aglioti et al.'s results provide further evidence that an object's relative position in space is also important. That is, they demonstrated that neglect can be ameliorated when the relative position of two objects changes.

Bartolomeo, Perri, and Gainotti (2004) conducted another study seeking to investigate the influence of limb crossing on tactile extinction. Bartolomeo et al. criticised Smania and Aglioti's (1995) interpretation of the advantage demonstrated in stimulus detection to the left hand when located in right hemispace. Bartolomeo et al. stated that if Smania and Aglioti's participants' performance were influenced by both somatotopic and a higher-order spatial frame of reference, then an impairment in the detection of stimulation delivered to the *right* hand should also be observed when the right hand was positioned in the left hemifield, as demonstrated by Aglioti et al. (1999). Bartolomeo et al. suggested that the above discrepancies between Smania and Aglioti's findings and Aglioti et al.'s results may be due to the possibility that crossing had a negative effect on stimulus detection in the right hand *only* for patients with more severe extinction and neglect. To investigate this, Bartolomeo et al. argued that an increase in the possible loci of stimulation in a double simultaneous tactile stimulation procedure should produce a more detrimental impairment in the detection of stimulation delivered to the right limb when the right limb is located in the left hemifield. This is due to the increased demands placed on already biased processing capacities in patients with right-hemisphere lesions. In contrast, Bartolomeo et al. suggested that if extinction is due to a representational impairment, then increasing the possible loci of stimulation should only lead to an improvement in detection of left-side stimulation and produce no change in right-side detection in the crossed condition, as was observed by Smania and Aglioti. Participants in Bartolomeo et al.'s study included 24 patients with right-hemisphere lesions and left tactile extinction and ten control participants without neurological impairment. Participants, who were blindfolded, were presented with single or double tactile stimulation on their cheeks, hands, or knees. Double stimulation was given to the same (homologous) or to different (non-homologous) body parts, and the participants' arms and knees were either in an anatomically correct position or crossed. Results demonstrated that the control participants, although highly accurate in all conditions, were more accurate in the anatomically correct position than in the crossed position when stimulation was delivered to homologous body parts. There was no effect of crossing in the non-homologous condition. Overall, the patients were more accurate in detecting stimulation delivered to the cheeks than to the hands and knees, and they detected more of the stimulations on the right side than on the left side. Results also demonstrated that the patients' accuracy decreased from single stimulation to double stimulation and to double non-homologous stimulation. Crossing decreased performance for *right* body parts *only* in patients with mild and more severe extinction, and this deterioration was much larger than the reduced accuracy rates observed for the control participants in the crossed condition. No change was observed in stimulus detection for left body parts for the patient group in the crossed condition. Bartolomeo et al. explained that what they found, a right-side disadvantage and no left-side advantage in the crossed condition, was a result of the increased attentional load associated with the increase in possible loci of stimulation. They suggested that attentional load produces different effects in terms of limb crossing, and indicated that a low attentional load may produce left-side improvements whereas a high attentional load leads to right-side disadvantages in crossed conditions.

Moro, Zampini, and Aglioti (2004) conducted another study investigating the impact of spatial position of hands on tactile neglect and extinction. The participants consisted of two patients (patients AF and SB) with right-hemisphere damage and evidence of visual and tactile neglect. Patient AF demonstrated neglect on several tests of neglect, including line cancellation, a reading test, a sentence-copying test, figure copying, and drawing tasks. Patient SB demonstrated neglect on all tests, except the line cancellation task. Both patients were required to detect single and double simultaneous stimulation delivered to their left and right hand. However, the two patients participated in different experimental conditions. Patient AF's right hand was positioned 5° to the right of her midline, whereas her left hand was positioned according to the following conditions: (a) 5° to the left of her midline; (b) 70° to the right of her midline; (c) 70° to the left of her midline. Moro et al. do not specify whether the patients were tested with their eyes open or blindfolded, but they stated their procedure follows the procedure used by Aglioti et al. (1999). It is therefore assumed that the patients were blindfolded.

Results indicated that she failed to detect stimulation delivered to her left hand during both single and double stimulation trials when her left hand was positioned in left hemispace. Accuracy increased to 100% when her left hand was located in the right side of space. Although the positioning of the right hand was unchanged, she was less accurate in detecting stimulation delivered to the right hand when the left hand was located in right hemispace. The above results are comparable with previous research and provide further evidence of the importance of the relative position of tactile stimulation in space in determining what is to be neglected or extinguished.

Patient SB underwent an identical procedure to that previously described by Aglioti et al. (1999). Patient SB was required to detect single and double stimulation in the following conditions: (a) one hand was in the left side of space and the other hand was in the right side of space, either in an anatomically correct position (not crossed or crossed; (b) both hands were in the right side of space, either in an anatomically correct position or crossed; (c) both hands were in the left side of space, either in an anatomically correct position or crossed. Results indicated that the spatial position of the hands affected SB's ability to accurately detect stimulation delivered to the left hand. In the first experimental condition, he was more accurate in detecting left-hand stimulation (both single and double) when his hands were in a crossed condition than when his hands were in an anatomically correct position. This result was replicated when both hands were located within the left side of space. When both hands were located within the right side of space, SB accurately detected stimulation delivered to both hands. Changes in the relative positioning of the hands also affected SB's ability to detect stimulation delivered to his right hand. More specifically, right-hand accuracy overall was higher when the hands were in an anatomically correct position than in a crossed position. These results were consistent with patient AF's results, and provide further evidence that an object's relative position in space is important in determining the 'left' and 'right' of what is to be neglected or extinguished (Moro et al., 2004).

Based on the observation that the manipulation of body posture can affect the manifestation of visual neglect, Peru, Moro, Sattibaldi, Morgant, and Aglioti (2006) conducted a study investigating the effect of spatial positioning of hands on the detection of tactile stimulation when participants were in upright or supine positions. Participants consisted of 18 patients with right-hemisphere damage with or without visual neglect. These participants were divided into two groups according to the presence or absence of tactile extinction, resulting in a group of 12 patients *with* tactile extinction and six patients *without* tactile extinction. The presence of tactile extinction was again assessed by a standard confrontation technique in which single or double simultaneous stimulation were delivered to the dorsal surface of the patients' hands. Twelve neurologically healthy participants also participated. The experimental procedure involved delivering single or double simultaneous stimulation to the participants' hands when participants were either in an upright (seated) position or in a supine (lying on their back) position. In both positions, stimulation were delivered when the spatial positioning of the participants' hands were either anatomically correct or crossed. Results demonstrated a higher accuracy in detection of left-side stimulation when patients were in a supine than in an upright position for patients in the tactile extinction group. Furthermore, the accuracy of left-side stimulus detection was higher when hands were in a crossed rather than in an anatomically correct position for patients in the tactile extinction group, but not for patients in the group without tactile extinction. The detection rate of right-side stimulation deteriorated in the crossed position as compared to the anatomically correct position. Control participants were highly accurate in the detection of both single and double stimulation. Peru et al.'s findings are consistent with previous reports of an advantage in the detection of left-side stimulation and deterioration in right-side stimulus detection when the hands are in a crossed position. Peru et al. further demonstrated that postural changes of the patients' bodies can affect the severity of tactile extinction, with an improved performance in the supine compared to the upright posture.

We previously emphasised that different experimental conditions may affect patient performance and results. It is important to note that some of the studies reviewed in the above section have blindfolded participants whereas others have allowed the patients' eyes to be open during the completion of the experimental task. Some studies do not specify whether eyes were open or closed (e.g., Valenza et al., 2004). Although Beschin et al. (1997) failed to find a gaze-centred component in their results, Vaishnavi et al. (1999, 2001) demonstrated that accuracy in the detection of stimuli delivered to the contralesional hand improved when gaze was directed toward this hand. This result indicates that it is important to control for gaze direction in studies investigating tactile neglect and extinction. Furthermore, as Bisiach et al. (1985) and Chokron and Imbert (1995) found that both the trunk and head midline affect the performance of patients with neglect on tactile exploration tasks and a straight-ahead pointing task, this may also indicate that trunk and head direction should be controlled. Although not specified in most of the studies outlined above, it is assumed that trunk direction would have been controlled due to the requirement in most of the tasks to sit opposite the experimenter. With the exception of the studies of Bisiach et al., Chokron and Imbert, Beschin et al., Mattingley and Bradshaw (1994), and Tinazzi et al. (2000), it is unclear whether head direction was controlled for. Although Pierson-Savage et al. (1988) required the participants to face straight ahead with their head and body, they were tested with their eyes open, and it is unclear whether gaze was fixated.

Stimulus-Centred Visual and Tactile Neglect

(Note: This paragraph is identical to that presented in Chapter 1, p. 23, and is repeated here for convenience to the Reader.) Ota, Fujii, Suzuki, Fukatsu, and Yamadori (2001) developed two new figure discriminative-cancellation tasks for the purpose of investigating whether viewer-centred (which the authors refer to as body-centred) and stimulus-centred neglect can be dissociated in patients with neglect. The circle discriminative-cancellation task included 20 complete circles and 40 incomplete circles that were evenly distributed on both sides of the vertical midline of a sheet of paper. Fifty percent of the incomplete circles had a missing segment on the right side, whereas the remaining incomplete circles had a missing segment on the left side. The second task, the triangle discriminative-cancellation task, was identical to the circle discriminative-cancellation task, except that the circles were substituted with equilateral triangles that were either complete or had a segment missing. Two participants with neglect were required to circle all complete stimuli and to cancel all incomplete stimuli. Errors on the left side of the page were interpreted as viewer-centred neglect, whereas incorrectly identifying stimuli, with a missing segment on the left side, as complete was interpreted as evidence for stimulus-centred neglect. The results indicated that one patient omitted more stimuli on the left side of the sheet of paper as compared to the right side of the paper. The accuracy for this patient's responses on the right side of the sheet was high. Ota et al. interpreted this as evidence for viewer-centred neglect. Contrary to Patient 1's results, Patient 2 responded to stimuli on both the left and the right side of the paper. Patient 2, however, made more mistakes when the object itself had a missing segment located on the left side than when it was a complete object or an object with a missing segment on the right side. That is, he erroneously identified stimuli with a missing segment on the left side as complete. Ota et al. interpreted this as evidence for stimulus-centred neglect.

The discriminative-cancellation task, as designed by Ota et al. (2001), has recently been used to test for neglect in the visual and tactile modality (Marsh & Hillis, 2008). Marsh and Hillis (2008) sought to determine whether the dissociation between viewer- and stimulus-centred neglect is modality-independent or modality-specific, and to investigate the incidence of the co-occurrence of visual *and* tactile viewer- and stimulus-centred neglect. The visual discriminative-cancellation task used was identical to that of Ota et al., with the exception that Marsh and Hillis used only the circle version of the task and the number of stimuli was reduced by half: 10 complete circles, 10 circles with a left gap, and 10 circles with a right gap. The participants consisted of 100 patients with acute right-hemisphere supratentorial ischemic stroke, who were required to circle the complete circles and to cross out all incomplete circles. (Two patients did not complete the visual task). Fifty-eight patients were also administered a tactile version of the task in which the stimuli consisted of raised circles on a board arranged in the same manner as in the visual version. With eyes closed, patients were asked to use the ipsilesional hand to determine whether the circles on the board were complete or incomplete. Omissions of circles on the contralesional side of the page were interpreted as viewer-centred neglect, whereas mistaking circles with a left-side gap as complete circles were interpreted as stimulus-centred neglect.

On the visual circle-cancellation task, 17 patients exhibited viewer-centred neglect and four demonstrated stimulus-centred neglect. Whereas, on the tactile version of the task, 19 patients exhibited viewer-centred neglect and only one demonstrated stimulus-centred neglect. The co-occurrence of viewer-centred and stimulus-centred neglect was observed in two patients on the visual task, but there were no co-occurrences of viewer-centred and stimulus-centred neglect on the tactile task. Of the 56 patients who were administered both the visual and tactile versions of the task, four patients demonstrated viewer-centred neglect in both modalities. Although no patients exhibited stimulus-centred neglect in both modalities, one patient who also had an old lesion to the left hemisphere, appeared to exhibit left viewer-centred *visual* neglect and right stimulus-centred *tactile* neglect. Results from this study suggest that egocentric and allocentric (specifically stimulus-centred) neglect can be dissociated in the tactile modality as well as in the visual modality (Marsh & Hillis, 2008). Distinct impairments are indicated, and these may dissociate. The findings also provide further evidence that neglect can be modality-specific in that it may be confined to either the visual or tactile modality.

Summary

The literature reviewed illustrates that the term 'tactile neglect' remains an ambiguous concept. The term has been defined in a number of different ways, which is reflected in the research performed in this area. Although results from research investigating the co-occurrence of neglect in the visual and tactile modalities are inconsistent, it is clear from the literature outlined above that tactile neglect (as defined by the various researchers) can indeed exist, and that it may also, but not necessarily, co-occur with visual neglect. While research initially focussed on establishing the existence of tactile neglect, studies have more recently started investigating whether tactile neglect can operate in different frames of reference, which have previously been demonstrated in the visual modality. In terms of viewer-centred coordinates, there is evidence to suggest that both the body- and the head- midline affect the performance of patients with neglect in tactile exploration tasks. Research have also demonstrated that tactile extinction and neglect can be ameliorated when the relative position of two objects change, even when these objects are located in the intact right visual field. Although Marsh and Hillis (2008) recently demonstrated that tactile neglect may occur in a stimulus-centred frame of reference, surprisingly little research has been conducted in this area. In future research it will be important to investigate whether tactile neglect can be demonstrated for objects with an intrinsic left and right side. No studies have to date examined this issue in the tactile domain. The literature on intrinsic object-centred neglect in the visual modality is inconsistent, and several researchers have argued that firm existence for intrinsic object-centred neglect in the visual domain has yet to be documented. Evidence for object-centred neglect both in the visual and tactile modalities will contribute to our understanding of the importance of an object-centred frame of reference in visual attention, not only in patients with neglect but also in neurologically healthy individuals.

Outline for Experiments

The goal of the final section of this thesis is specifically to investigate whether tactile neglect can occur in an object-centred frame of reference, and to introduce a *tactile* 'Æ' letter-identification task to disambiguate stimulus-centred from object-centred neglect in the tactile modality. We tested patient HT, who was one of five patients presented in Chapter 2: 'Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect'. As may be recalled, patient HT had previously been administered visual cancellation tasks, and demonstrated viewer-, stimulus, and object-centred neglect on the visual 'Æ' letter-cancellation task. No research to date has examined whether tactile neglect can be demonstrated for objects with an intrinsic left and right side. The task is simply to tactually identify letters presented individually. The viewer- and stimulus-centred frames of reference were indistinguishable in this task because the letter stimuli were presented on a board centred on the midline of the participant's body. The stimulus- and object-centred frames of reference were disambiguated by displaying the letters in normal and backward (mirror-reversed) parity, and in each of eight different angles of orientation (presented in 45° increments rotated clockwise from upright 0°). Errors in identification of the letter 'Æ' were interpreted as either stimulus- or object-centred neglect. Neglect in an object-centred frame of reference is neglect of the canonical left side of the letter 'Æ', the 'A' part of the letter, irrespective of parity and angle of orientation. In contrast, neglect in a stimulus-centred frame of reference is neglect of the 'A' part of the letter 'Æ' only when it is located on the left side as defined by a stimulus-centred frame of reference.

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Chapter 6

A Case of Object-Centred Neglect in the Tactile Modality

A Case of Object-Centred Neglect in the Tactile Modality

General Methods

Participants

Patient HT was the main participant for this study. She was recruited from St. Olavs Hospital in Trondheim (Norway). Patient HT is a 54-year old right-handed (*Laterality Quotient* = 100, where –100 indicates extreme left handedness and +100 indicates exclusive right handedness according to the Edinburgh Handedness Inventory; Oldfield, 1971) Norwegian woman with 12 years of education.[12] We also piloted the tasks on three neurologically healthy participants (two females and one male; aged 54, 58, and 62 years). The neurologically healthy participants were right-handed (M = 93.94; SD = 10.50) according to the Edinburgh Handedness Inventory, and they had not suffered previous neurological injury or illness. They were paid $5/hour for participation.

The study was approved by the Mid-Norway Regional Committee for Medical Research Ethics and the Human Research Ethics Committee at the Australian National University. Tests were conducted in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki. All participants read an explanatory statement containing information regarding the study and signed a consent form prior to their participation.

Norwegian was the first language of all participants.

[12] A full case description and neuropsychological test results for HT are presented in Chapter 2: 'Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect', and repeated briefly here for convenience.

Neuroimaging

This case description relating to brain damage for patient HT was provided by the neuroradiologist at St. Olavs hospital and is based on all available data, including previous clinical scans and the research scans acquired for this study. Overall, the findings showed evidence of a clipped right-side aneurysm, following an extensive right-side infarction. There was a shunt in the extracranial space on the right side. Substance-loss was found in areas of the temporal and frontal lobe, and there was gliosis of the surrounding brain mass. Secondary to substance-loss, there was atrophy of the right side of the crus cerebri and Wallerian degeneration of the brain stem. There was also marked enlargement of the right ventricle.

A research MRI was conducted for this study (Figure 1). Brain images were acquired using a 3T Intera MRI whole body scanner (Philips Medical Imaging, Best, Netherlands). After a scout-scan, AC-PC aligned axial, sagittal and coronal T2-weighted (TR=4540 ms, TE=97 ms, NEX=1, slice thickness = 5.91 mm, pixels = 0.60 x 0.60 mm, FOV = 336 x 384) or FLAIR (TR=9000 ms, TE=114 ms, NEX=1, slice thickness = 5.91 mm, pixels = 0.72 x 0.72 mm, FOV = 280 x 320) images were acquired followed by a 3D T1-weighted SPGR coronal sequence (TR=8.4644 ms, TE=3.8916 ms, NEX=1, slice thickness = 1.00 mm, pixels = 0.9375 x 0.9375 mm, FOV = 256 x 256), using a Philips 8-channel head coil. T1-weighted images were then converted to isotropic dimensions (1.00 mm^3). Acquisitions were repeated if the patient moved excessively creating image artifact. Total scanning time for patient HT was approximately 30 minutes.

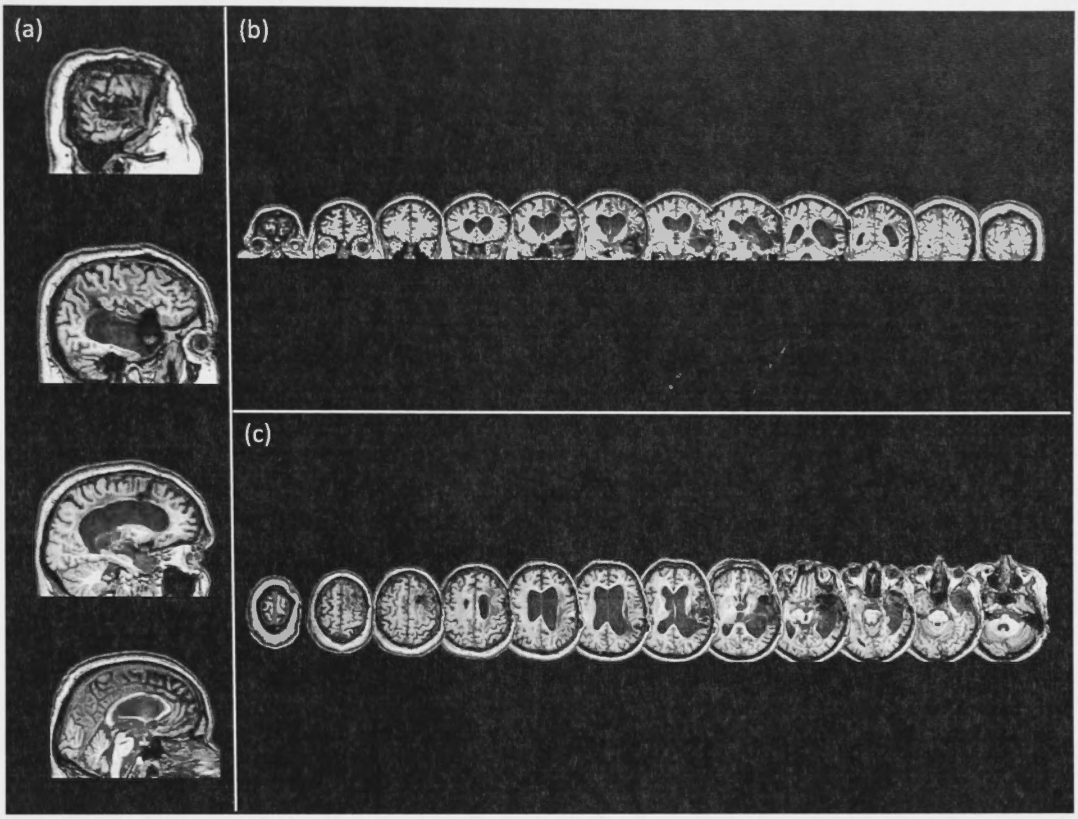


Figure 1. T1-weighted brain MR images of patient HT:

(a) Sagittal from right to midsagittal in steps of 21mm

(b) Coronal from frontal to occipital in steps of 10mm (from left of page)

(c) Axial from top to bottom in steps of 8mm (from left of page).

Neuropsychological Assessment of Neglect

Neglect was assessed with the following tests:

- Line Crossing, Letter Cancellation, Star Cancellation, Figure and Shape Copying, Line Bisection and Representational Drawing subtests from the Behavioural Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987);
- Schenkenberg Line Bisection (Schenkenberg, Bradford, & Ajax, 1980):
  % Deviation Score = (measured left half - true half) / true half x 100;
- Map Search subtest from the Test of Everyday Attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994);
- Bells Test (Gauthier, Dehaut, & Joanette, 1989);
- The Balloons Test (Edgeworth, Robertson, & McMillan, 1998);
- Ogden Scene Task (Ogden, 1985, p. 64):
  Score=5 no evidence of neglect
  Score=4 if only the chimney or the contralesional window of the house was missing
  Score=3 if the contralesional half of a tree or the house was missing
  Score=2 if the contralesional tree was completely missing
  Score=1 if the contralesional tree plus more of drawing on the same side was missing;
- Rey Complex Figure Test, Recognition Trial (RCFT; Meyers & Meyers, 1995) using a % Neglect Score (20 internal items on left side and 20 internal items on right side of Rey Figure (see Aimola, 1999, Appendix Manual, p. 27-30):
  Score=100% no evidence of neglect (items accurately drawn and correctly placed)
  Score=<50% neglect (items recognisable, even though they may not be accurately drawn, they are incorrectly placed)
  Score=0 neglect with severe visuospatial difficulties (items unrecognisable and incorrectly placed).

Patient HT demonstrated neglect on four BIT subtests (Star Cancellation, Figure and Shape Copying, Line Bisection, Representational Drawing), and on Map Search (subtest of TEA), Balloons Test, Ogden Scene Task, and Rey Complex Figure Test. All test results are presented in Table 1. Left-side information was either missing or distorted in copying and representational drawings (BIT), and in reproduction of the Ogden Scene Task and Rey Complex Figure (see Figure 2).

To ensure that patient performance was not confounded by directional hypokinesia, patient HT was also administered a task initially constructed by Tegnér and Levander (1991). Directional hypokinesia is the failure to initiate and perform motor activities toward and into the neglected hemispace, regardless of whether the ipsilesional or contralesional hand is used. The task decoupled arm movement and direction of attention with a simple assessment of line cancellation, presented on a stimulus sheet in (1) normal view and (2) mirror view (using a 90° angle mirror). Perceptual neglect leads to failure to cancel stimuli on the left side of the sheet in the normal view condition but leads to omissions of right-side stimuli in the mirror-view condition, since these stimuli are now displayed on the left side of the sheet as reflected in the mirror. Directional hypokinesia leads to failure to cancel stimuli on the left half of the sheet in both conditions, due to the inability to perform motor activities into the left side of space. Patient HT's performance indicated that her difficulties with responding to left side of stimuli on standard tests of neglect were due to perceptual neglect, and therefore could not be attributed to directional hypokinesia.

Table 1

Patient Performance on Neglect Tests

BIT Line Crossing	36 (36)	**Map Search**	**18 (80)**
- Left Side of Page	18	- **Left Side of Page**	**0**
- Right Side of Page	18	- **Right Side of Page**	**18**
BIT Letter Cancellation	26 (40)	**Balloons Test**	**50%**
- Left Side of Page	13	Schenkenberg Line Bisection	1.6%
- Right Side of Page	13	**BIT Line Bisection**	**4** (9)
BIT Star Cancellation	**36 (54)**	**BIT Figure/Shape Copying**	**3** (4)
- **Left Side of Page**	**10**	**BIT Representational Drawing**	**1** (3)
- **Right Side of Page**	**26**	**Ogden Scene Task**	**2** (5)
Bells Test	25 (30)	**Rey Complex Figure Test % Neglect**	
- Left Side of Page	12	- **Left Side of Rey**	**27.5%**
- Right Side of Page	13	- **Right Side of Rey**	**72.5%**

Bold indicates evidence of neglect.

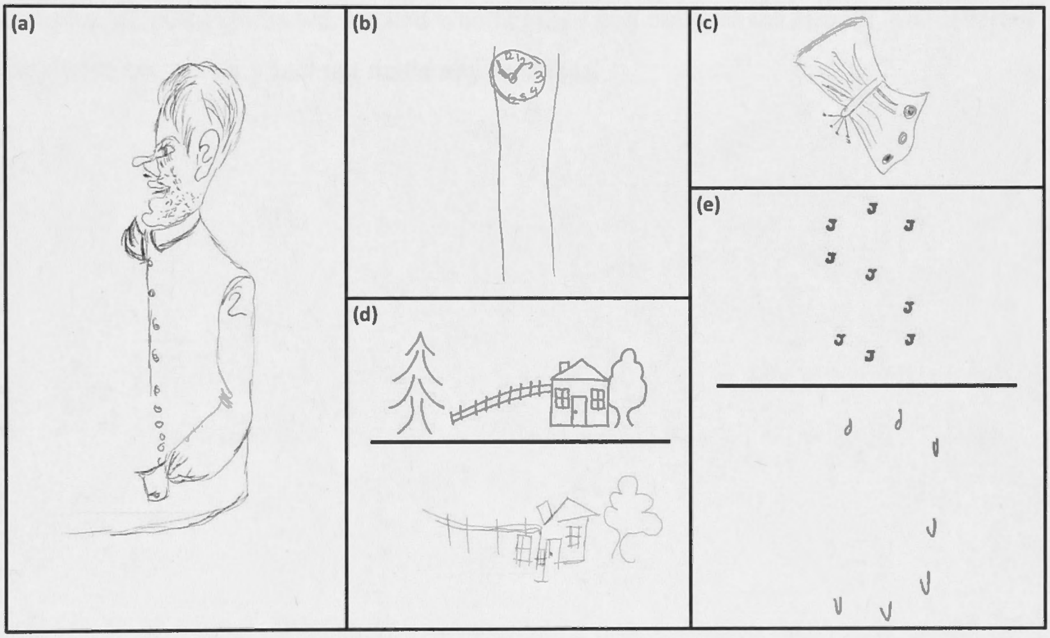


Figure 2. Patient HT: *Drawing* tasks (a) Draw a man or woman; (b) Draw a clock and set the time to 10 past 11; (c) Draw a butterfly; *Copying* tasks: (d) Ogden scene; (e) Hierarchical letter 'S'.

Experimental Procedure

Participants were tested individually in a distraction-free room. For all experiments, participants were seated at a desk with the stimulus sheet (visual tasks) or stimulus board (tactile task) centred on the desk at the participant's body midline. Participants used a pen held in their right hand to make responses for the visual tasks. No restrictions were imposed on head or eye movements, other than that the eyes were blindfolded for the tactile task. There was no time limit to complete the task. Upon completion, participants were asked whether they had checked the stimuli, and whether they were certain they had not made any mistakes.

Experiment 1. Visual Tasks

In Chapter 2 ('Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect'), patient HT was one of five patients administered the Ota, Fujii, Suzuki, Fukatsu, & Yamadori (2001) discriminative-cancellation task and our new 'Æ' letter-cancellation task. Here we present only an overview of patient HT's results on these visual tasks.

Experiment 1a. Visual Discriminative-Cancellation Task (Circles and Triangles)

Overall, the discriminative-cancellation task classified patient HT as having *neither* viewer- nor stimulus-centred neglect. Patient HT did not demonstrate a significant difference between stimuli responded to correctly on the left side side of page (83.06%) compared to the right side of page (83.61%). Patient HT did respond correctly to fewer stimuli with a gap than to stimuli with no gap (92.08%), but she did not demonstrate a significant difference between stimuli with a left gap (76.25%) compared to stimuli with a right gap (81.67%). (The neurologically healthy control participants were highly accurate (> 99.00%) in responding to all stimuli in the discriminative-cancellation task.)

Experiment 1b. Visual Norwegian 'Æ' Letter-Cancellation Task

Overall, the 'Æ' letter-cancellation task classified patient HT with viewer- and object-centred neglect, and with stimulus-centred neglect on the right side of page. There was no significant main effect or interaction with task. Patient HT responded correctly to fewer letters on the left side of page compared to the right side of page. Patient HT responded correctly to significantly more 'A' letters (91.07%) compared to A-right 'Æ' letters (87.20%), which indicated object-centred neglect. Patient HT responded correctly to significantly more A-right 'Æ' letters (92.26%) compared to A-left 'Æ' letters (79.76%) on the right side of page, which indicated stimulus-centred neglect but only on the right side of page. (The neurologically healthy control participants were highly accurate (> 99.45%) in responding to all stimuli in the 'Æ' letter-cancellation task.)

Experiment 2. Tactile Tasks

Experiment 2a. Tactile Circle-Identification Task

Stimuli, Apparatus and Procedure

The stimuli consisted of ten complete circles and twenty incomplete circles fixed to a wooden board (42cm x 30cm). Ten of the incomplete circles had a gap on the left side and the remaining ten incomplete circles had a gap on the right side. The circles were 3cm (height) x 2.3cm (width) x 0.8cm (depth) in size. The size of the gap on the incomplete circles was 1cm. The set-up of the circle-identification task was identical to the tactile circle-cancellation task used by Marsh and Hillis (2008). Half the number of stimuli was presented, in comparison to the Ota et al. (2001) *visual* discriminative-cancellation task, but the proportion of complete and incomplete stimuli remained the same. Although very similar to the Ota et al. discriminative-cancellation task, the task differed in terms of (1) stimulus size and (2) number of stimuli on the board. As in the Ota et al. discriminative-cancellation task, the circles were arranged in a random manner on the board but evenly on either side of the vertical midline.

Participants were shown examples of all stimuli prior to putting on a blindfold. The stimulus board was placed horizontally on the desk and centred on the desk at the participant's body midline. With eyes blindfolded, the participant's right hand was guided around the edge of the board, so that s/he became familiar with the size and positioning of the board. The right hand was then placed in the starting position, which was on the midpoint of the closest side of the board. Participants were asked to use the right hand to identify the stimuli tactually, but to report verbally whether the stimuli were complete circles or whether the stimuli had a gap. The participant's right hand was returned to the starting position at the beginning of each trial.

Testing was conducted in two sessions. Patient HT and the neurologically healthy participants were given two trials of the task in each session. The stimulus board was presented upside down in the second trial of the task in each session, for a total of four trials (Figure 3).

Results

The accuracy data was not formally analysed for the neurologically healthy participants because they were highly accurate in responding to the stimuli in the *tactile Circle-Identification task.* They correctly responded to a mean of 96.11% stimuli overall (left gap: 95.83%; right gap: 95.83%; no gap: 96.67%). And, they correctly responded to a mean of 95.00% of stimuli on the left side of the stimulus board and 97.22% on the right side of the board.

For patient HT, the full model containing all predictors failed to reach statistical significance (χ^2 (5) = 1.92, p = .86). As the side of page and gap main effects failed to reach significance, there was no evidence from the tactile circle-cancellation task to suggest that patient HT demonstrated viewer- or stimulus-centred tactile neglect.

			S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
VISUAL	Circle Task	Page Upside Up	*	*			*	*					
		Page Upside Down	*	*			*	*					
	Triangle Task	Page Upside Up	*	*									
		Page Upside Down	*	*									
	Æ Letter Task 1	Page Upside Up	*	*	*	*	*	*	*				
		Page Upside Down	*	*	*	*	*	*	*				
	Æ Letter Task 2	Page Upside Up	*	*	*	*	*	*	*				
		Page Upside Down	*	*	*	*	*	*	*				
	Æ Letter Task 3	Page Upside Up	*	*	*	*	*	*	*				
		Page Upside Down	*	*	*	*	*	*	*				
TACTILE	Circle Task	Upside Up					*	*					
		Upside Down					*	*					
	Æ Letter Task							*	*	*	*	*	*

Figure 3. Order of task administration: Visual Discriminative-Cancellation Task administered in Sessions 1, 2, 5, 6; Visual Norwegian 'Æ' Letter-Cancellation Task administered in Sessions 1 to 7; Tactile Circle-Identification Task administered in Sessions 5 and 6; Tactile Norwegian 'Æ' Letter-Identification Task administered in Sessions 6 to 11.

Experiment 2b: Tactile Norwegian 'Æ' Letter-Identification Task

Stimuli, Apparatus and Procedure

The stimuli consisted of the uppercase alphanumerical letters 'E' (3.1cm x 2.5cm), 'A' (3.1cm x 1.7cm), and 'Æ' (3.1cm x 3.6cm). All letters were 0.8cm in depth. The letter 'Æ' was the stimulus of most interest as it contained identifying information on both the left and the right side. All stimuli were presented individually, fixed with Velcro to a small rectangular board (26cm x 15cm), in each of six different angles of orientation (0, 45, 135, 180, 225, 315 degrees).[13] The letter 'Æ' was presented twice in normal and twice in backward (mirror-reversed) parity for each angle of orientation. The letters 'E' and 'A' were presented in normal parity *only* but twice at each angle of orientation. This yielded a total of 48 stimuli.

Participants were shown examples of the stimuli prior to blindfolding, and they were informed that the letters would be displayed in normal or backward parity and in different angles of orientation. The stimulus board was then centred on the desk at the participant's body midline. The participant's right hand was guided around the edge of the board so that s/he became familiar with the size and position of the board. The right hand was placed in the starting position, which was at the midpoint of the side of the board located closest to her (Figure 4). The participant was asked to use her right hand to identify the stimuli tactually, and to report verbally the identity of each of the letters ('E', 'A', or 'Æ') s/he tactually recognised. Following identification, the participant's hand was returned to the starting position and a different letter was attached to the board. This procedure was repeated until all letters had been displayed and identified.

Testing was conducted in six sessions (Figure 3). Patient HT and the neurologically healthy participants identified one set of letters (48 letters) in each session, for a total of 288 letters.

[13]Patient HT was originally administered a tactile equivalent of the visual Norwegian 'Æ' letter-cancellation task, and she was asked to use her ipsilesional (right) hand to identify the letters scattered across the stimulus board. She found this task extremely difficult, and she did not move her hand away from the rightmost side of the board. As the main aim of the study was to investigate neglect in an object-centred frame of reference, and to distinguish this from neglect in a stimulus-centred frame of reference, the task was modified to the present tactile 'Æ' letter-identification task, which involved presenting each letter individually.

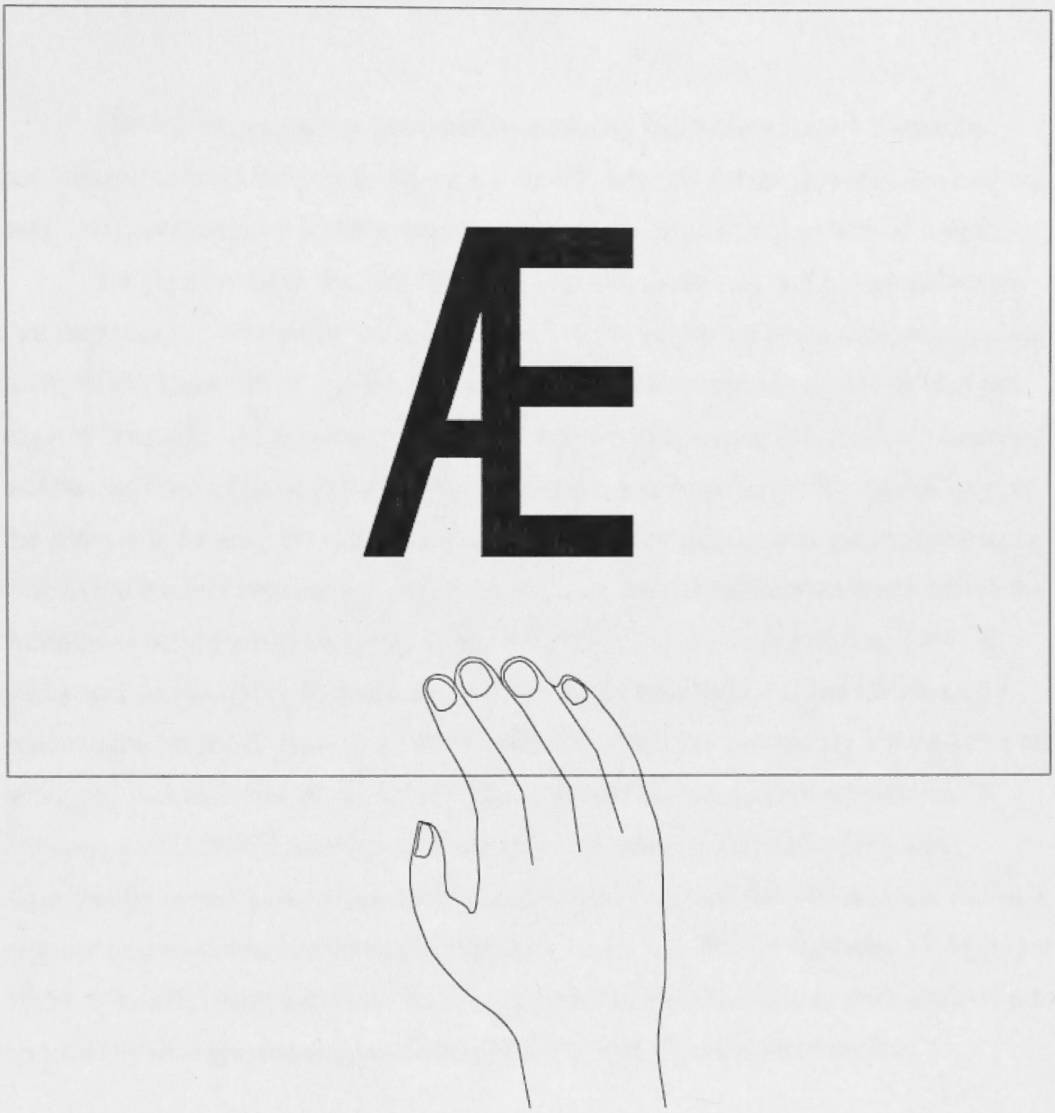


Figure 4. Hand-placement position for the *tactile Norwegian 'Æ' letter-identification task.*

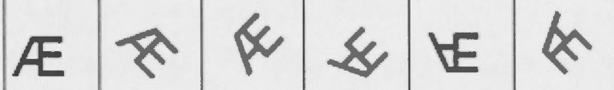
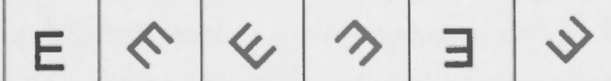
Results

The accuracy data was not formally analysed for the neurologically healthy participants because they found the *tactile Norwegian 'Æ' Letter-Identification task* was easy. All neurologically healthy participants correctly responded to 100% of stimuli.

We predicted that if patient HT demonstrated tactile neglect, she would report that the letter 'Æ' was either the letter 'E' or 'A', depending on angle of orientation and parity of the letter 'Æ'. If patient HT demonstrated either stimulus- or object-centred neglect, the letter 'Æ' presented in 'forward parity and upside-up' or 'backward parity and upside-down' (Table 2, Panel i) would be reported as the letter 'E'. The 'E' part of the letter falls on the right side of the letter 'Æ' in the object-centred frame of reference and, in these orientations and parity, it also falls on the right side of the letter 'Æ' in the stimulus-centred frame of reference. When the letter 'Æ' was presented in 'forward parity and upside-up' or in 'backward parity and upside-down', patient HT correctly reported the letter 'Æ' on only 12 of 72 trials (16.67%). She incorrectly reported that the letter 'Æ' was the letter 'E' on 59 of 72 trials (81.94%), and that it was the letter 'A' on only one trial (1.39%). Analysis with the *Q'* test confirmed that patient HT was significantly more likely to report that the letter 'Æ' was the letter 'E' than she was to report that it was either the letter 'Æ' ($Q'(1) = 10.42, p < .001$) or the letter 'A' ($Q'(1) = 16.59, p < .001$). Although these findings are consistent with tactile neglect, they do not specifically distinguish stimulus-centred neglect from object-centred neglect.

Table 2

Number of 'Æ', 'A' and 'E' Letter Stimuli Correctly (and Incorrectly) Identified as a Function of Angle of Orientation: Upside-Up (0˚, 45˚, 315˚) and Upside-Down (135˚, 180˚, 225˚)

		Upside-Up			Upside-Down			
		0°	45°	315°	135°	180°	225°	
	(i) 							TOTAL
Correct Æ		2	2	4	2	1	1	12
Incorrect A		0	0	1	0	0	0	1
Incorrect E		10	10	7	10	11	11	59
	(ii) 							TOTAL
Correct Æ		1	0	2	0	0	4	7
Incorrect A		0	0	0	0	0	0	0
Incorrect E		11	12	10	12	12	8	65
	(iii) 							TOTAL
Incorrect Æ		1	3	3	7	2	5	21
Correct A		9	7	5	4	9	5	39
Incorrect E		2	2	4	1	1	2	12
	(iv) 							TOTAL
Incorrect Æ		2	3	4	1	0	2	12
Incorrect A		0	0	0	1	0	0	1
Correct E		10	9	8	10	12	10	59

The second analysis distinguished neglect in the stimulus-centred frame of reference from neglect in the object-centred frame of reference. These frames of reference can be *disambiguated* when the letter 'Æ' is in 'forward parity and upside-down' or in 'backward parity and upside-up' (Table 2, Panel ii). Although the 'E' part of the letter always falls on the right side of the letter 'Æ' in the object-centred frame of reference, when the letter 'Æ' is presented in 'backward parity and upside-up' or in 'forward parity and upside-down', the 'A' part of the letter 'Æ' now falls on the right side of the letter 'Æ' in the stimulus-centred frame of reference. Thus, if patient HT demonstrated object-centred neglect, the letter 'Æ' presented in 'backward parity and upside-up' or in 'forward parity and upside-down' would continue to be reported as the letter 'E'. Whereas, if patient HT demonstrated stimulus-centred neglect, the letter 'Æ' presented in 'backward parity and upside-up' or in 'forward parity and upside-down' would be reported as the letter 'A'. When the letter 'Æ' was presented in 'backward parity and upside-up' or in 'forward parity and upside-down', patient HT correctly reported the letter 'Æ' on 7 of 72 trials (9.72%). She incorrectly reported that the letter 'Æ' was the letter 'E' on 65 of 72 trials (90.28%), and she never reported that the letter 'Æ' was the letter 'A' (0%). Analysis with the Q' test confirmed that patient HT was significantly more likely to report that the letter 'Æ' was the letter 'E' than she was to report that it was either the letter 'Æ' ($Q'(1) = 16.01$, $p < .001$) or the letter 'A' ($Q'(1) = 23.85$, $p < .001$). These findings indicate object-centred tactile neglect.

The reader may ask whether patient HT consistently reported that the letter 'Æ' was the letter 'E' because she had problems with identifying the letter 'A' by touch. We believe that this interpretation can be discounted because patient HT did correctly report the letter 'A' on 39 of 72 trials (54.17%). She incorrectly reported that it was the letter 'Æ' on 21 of 72 trials (29.17%), and she incorrectly reported that it was the letter 'E' on 12 of 72 trials (16.67%). Analysis with the Q' test confirmed that patient HT could identify the letter 'A' by touch, insofar as she was significantly more likely to correctly report the letter 'A' than she was to incorrectly report that the letter 'A' was either the letter 'Æ' ($Q'(1) = 3.22$, $p = .006$) or the letter 'E' ($Q'(1) = 5.21$, $p < .001$). It is noted that patient HT reported that the letter 'A' was the letter 'E' on only 16.67% of trials. Therefore, this also rules out the possibility that patient HT demonstrated a general reporting bias, that is, that *all* letters were the letter 'E'.

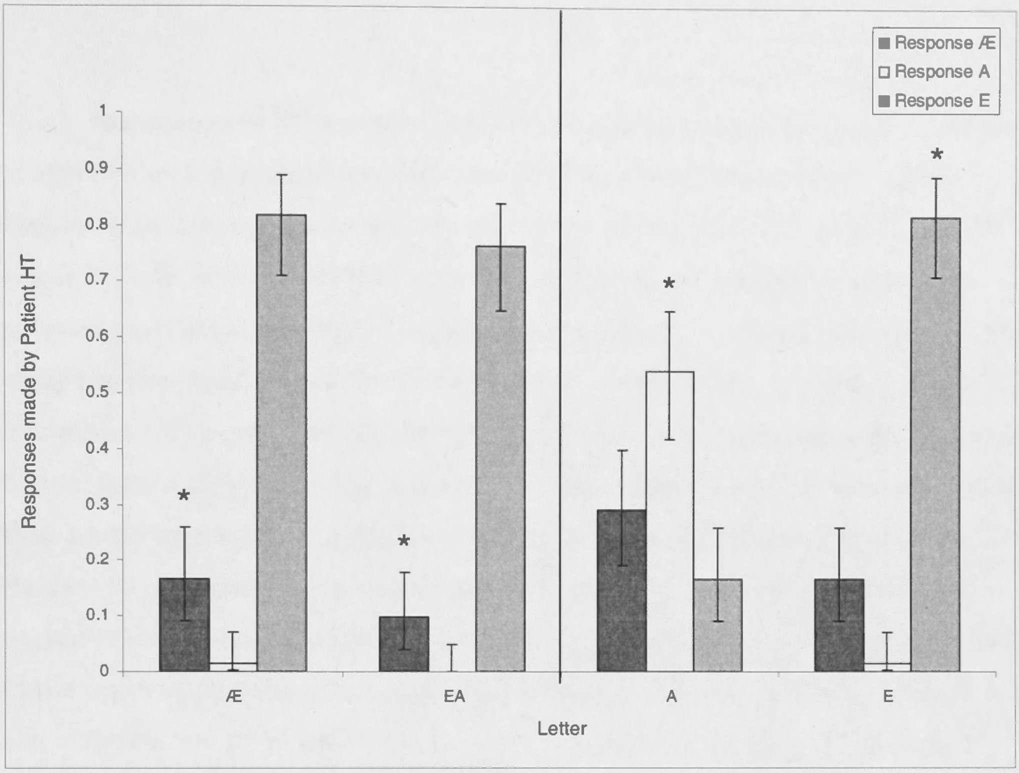


Figure 5. Responses to the letters 'E', 'A', and 'Æ': The *left panel* depicts the responses made by patient HT to the letter 'Æ', when the 'E' was on the left of the stimulus and when the 'E' was on the right of the stimulus. Overall, patient HT's responses to the letter 'Æ' were as if she were responding to the letter 'E'. The *right panel* depicts patient HT's responses to the letters 'A' and 'E'. The asterisk (*) above the bars indicates the correct response for each of the letters: 'Æ', 'EA', 'A', and 'E'. Error bars represent 95% confidence intervals for a single proportion (Wilson, 1927).

Discussion

Behrmann and Moscovitch (1994) found evidence to suggest that the allocation of attention within an object-centred frame of reference is unnecessary if object identification does not require specification of the left and right side of the particular object. In order to document firm evidence of object-centred neglect it is therefore necessary to provide evidence of neglect of the intrinsic left side of objects irrespective of the positioning of this side in relation to the environment and the viewer. The tactile Norwegian 'Æ' letter-identification task described in the current study takes account of Behrmann and Moscovitch's requirement of utilising objects with intrinsic left and right sides for the investigation of object-centred neglect. The current study extends previous findings by examining the co-occurrence of viewer-, stimulus-, and object-centred neglect in the visual *and* tactile modality. Research to date has not examined whether tactile neglect could occur for objects with an intrinsic left and right side. Thus the main aim of the current study was to investigate the occurrence of both visual and tactile object-centred neglect.

A review of patient HT's results on the visual tasks described in Chapter 2 ('Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect') was presented here for convenience and ease of comparison with her results on the tactile tasks described in the current chapter. Recall that the Ota et al. (2001) discriminative-cancellation task investigated viewer- and stimulus-centred neglect and participants were required to circle complete stimuli and to cross out incomplete stimuli. Poorer responses on the left side of page compared to the right side of page indicated viewer-centred neglect. Poorer responses to left-gap stimuli compared to right-gap stimuli indicated stimulus-centred neglect. Patient HT exhibited no neglect on this task. The aim of the visual 'Æ' letter-cancellation task was not only to distinguish viewer- from stimulus-centred neglect (left of viewer versus left of stimulus), but also to distinguish stimulus- from *object-centred neglect* (left of stimulus versus canonical left side of object). Omissions on the left side of page again indicated viewer-centred neglect while errors in following instructions with respect to the letter 'Æ' (e.g., either circling or failing to cross it out) due to inaccurate letter identification on both sides of the page were interpreted as either stimulus- or object-centred neglect. Comparisons were made between A-left 'Æ' and A-right 'Æ' and between the letter 'A' and A-right 'Æ'. Better responses to A-right 'Æ' compared to A-left 'Æ' indicated stimulus-centred neglect whereas better response to letter 'A' compared to A-right 'Æ' indicated object-centred neglect. On the visual 'Æ' letter-cancellation task, patient HT demonstrated neglect in viewer-, stimulus-, and object-centred frames of reference. She responded correctly to fewer stimuli on the left side of page than on the right side of page, a finding interpreted as viewer-centred neglect. She also responded correctly to fewer 'Æ' letters compared to 'E' letters or 'A' letters, suggesting the presence of either stimulus- or object-centred neglect. Patient HT responded correctly to fewer A-left 'Æ' letters compared to A-right 'Æ' letters on the right side of page but not on the left side of page, a finding interpreted as evidence of stimulus-centred neglect on the right side of page *only*. Patient HT also demonstrated object-centred neglect: She responded correctly to fewer A-right 'Æ' letters than 'A' letters.

We administered two tactile tasks in the current study: the tactile circle-identification task and the tactile 'Æ' letter-identification task. Both tasks were inspired by Ota et al.'s (2001) visual discriminative-cancellation task. The tactile circle-identification task was identical to the task administered by Marsh and Hillis (2008), and was used to distinguish viewer- from stimulus-centred neglect. This task was a tactile version of Ota et al.'s visual discriminative-cancellation task, and differed only in terms of the size and number of stimuli. Although the number of stimuli was halved, the proportion of stimuli with a left gap, right gap, or no gap remained the same as in the Ota et al. visual task. With eyes blindfolded, the participants were required to use their right hand to identify the stimuli tactually, and to report whether the stimuli were complete or had a gap. As with the visual discriminative-cancellation task, poorer responses on the left side of page compared to the right side of page indicated viewer-centred neglect and poorer responses to left-gap stimuli compared to right-gap stimuli indicated stimulus-centred neglect. There was no evidence of viewer- or stimulus-centred neglect on this task, a finding consistent with patient HT's results on the visual discriminative-cancellation task.

As with the visual 'Æ' letter-cancellation task, it was predicted that patient HT's pattern of responses to the letter 'Æ' in the tactile 'Æ' letter-identification task would provide a method for distinguishing stimulus-centred neglect from object-centred neglect. We predicted that if patient HT demonstrated tactile neglect, she would report that the letter 'Æ' was either the letter 'E' or 'A', depending on angle of orientation and parity of the letter 'Æ'. We suggested that if the letter 'Æ' was reported as the letter 'E' when displayed in 'forward parity and upside-up' and in 'backward parity and upside-down' (A-left 'Æ'), then this could reflect either stimulus- and/or object-centred neglect. Because the 'E' part falls on the right side of the letter 'Æ' in both stimulus-centred *and* object-centred coordinates when presented in these orientations, stimulus- and object-centred neglect cannot be distinguished. In these orientations ('forward parity and upside-up' and 'backward parity and upside-down'), patient HT incorrectly identified the letter 'Æ' as the letter 'E' on more than 80% of trials. Only once did she incorrectly identify the letter 'Æ' as the letter 'A'. To distinguish object-centred neglect from stimulus-centred neglect, we investigated responses to the letter 'Æ' when presented in 'backward parity and upside-up' or in 'forward parity and upside-down' (A-right 'Æ'). Although the 'E' part of the letter always falls on the right side of the letter 'Æ' in an object-centred frame of reference, the 'A' part of the letter 'Æ' now falls on the left side in a stimulus-centred frame of reference. If the findings were due to object-centred neglect, then patient HT should continue to report the letter 'Æ' to be the letter 'E'. If, however, the findings were due to stimulus-centred neglect, patient HT should now report the letter 'Æ' to be the letter 'A', given that the 'A' part of the letter 'Æ' now falls on the right (intact) side of the letter in a stimulus-centred frame of reference. When presented in 'backward parity and upside-up' or in 'forward parity and upside-down', patient HT continued to report the letter 'Æ' to be the letter 'E'. This finding was interpreted as evidence of object-centred neglect.

It is important to note that the new tactile 'Æ' letter-identification task could not demonstrate viewer-centred neglect because the stimuli were presented individually in the middle of a stimulus-board. Although the tactile circle-identification task tested for neglect in both viewer- and stimulus-centred frames of reference, patient HT did not demonstrate evidence of either viewer- or stimulus-centred neglect on this task. Patient HT did show clear evidence of object-centred neglect in the tactile Norwegian 'Æ' letter-identification task. She had significant difficulties with identification of the letter 'Æ', which she consistently identified as the letter 'E', irrespective of parity and angle of orientation. In addition, we provided evidence from a test originally constructed by Tegnér and Levander (1991) to show that patient HT's difficulties with responding to stimuli on the left side are due to perceptual neglect and could not be attributed to directional hypokinesia.

Patient HT incorrectly identified the letter 'A' on 33 of 72 trials, and she was significantly more likely to correctly report the letter 'A' than she was to incorrectly report that the letter 'A' was either the letter 'Æ' or the letter 'E'. We therefore discounted the possibility that patient HT consistently reported that the letter 'Æ' was the letter 'E' due to difficulties identifying the letter 'A' by touch. It is speculated, however, than the letter 'A' is somewhat more difficult to identify tactually than the letter 'E', leading to a slightly lower accuracy rate in identification of the letter 'A' than the letter 'E'. One can relatively easily identify the letter 'E' by confirming the presence of three horizontal lines on the intrinsic right side of the letter and a straight line on the intrinsic left side of the letter. It is speculated that the letter 'A' is somewhat more difficult to identify due to the requirement of disconfirming the presence of a third horizontal line in order to distinguish it from the letter 'E'. Therefore, with the letter 'A', the patients may locate the 'feet' of the letter and count these two feet. But in order to identify it as the letter 'A', the patients need to also disconfirm the presence of a third horizontal line. Given the finding that patients with neglect often return to previously indicated stimuli (e.g., Olk & Harvey, 2006), the patients may return to areas of the letter they have previously explored, before counting one of the 'feet' of the letter 'A' again. Given that they have now counted what may feel like three horizontal lines, the patients may inaccurately identify the letter 'A' as letter 'E'. If patients interpret the two 'legs' of the letter 'A' to be the letter 'E', and then return to the top of the letter 'A', this may lead to inaccurate identification of the letter 'A' as 'Æ'. It was evident in observations of patient HT completing the tactile 'Æ' letter-identification task that she took quite a long time to identify each letter. She also repeatedly returned to parts of the letter she had previously explored.

The pattern of repeatedly returning to parts of the letter previously explored is consistent with the findings of Olk and Harvey (2006). Olk and Harvey argued that although patients with neglect may fail to explore the contralesional side of space, they may also repeatedly return to stimuli in the ipsilesional side of space. They investigated exploration behaviour in a study that required patients with and without neglect to point to stimuli fixed on a cardboard. Stimuli consisted of twenty squares and twenty circles that were symmetrically distributed on the left and the right side of the board. The participants' task was to either point to all stimuli on the board, or point to the circles *only*. The tasks were first completed with the aid of vision, and were subsequently performed blindfolded. As expected, patients with neglect omitted more stimuli in the left half of space than control patients. Results also demonstrated that both patients with neglect, and control patients with lesions to the right hemisphere without neglect, more frequently returned to previously indicated stimuli. It is also interesting to note that when patient HT makes errors in the identification of the letter 'A', she more frequently reports that it is the letter 'Æ' (21 times) than the letter 'E' (12 times). This suggests that she for some reason assumes there is something more attached to the letter 'A'. She makes more errors when the letter 'A' is displayed upside-down in normal parity than when it is displayed upside-up, suggesting that she believes the letter 'E' is located on the stimulus-centred left side of the letter 'A'.

It is difficult to explain the reasons behind these errors, but we raise a question as to whether it is possible that she is using an internal image of the letter in these instances, and that these errors therefore may represent a stimulus-centred *representational* deficit. As initially pointed out by Beschin, Cazzani, Cubelli, Della Sala, and Spinazzola (1996), it is presumed that tactile identification or search tasks without the aid of vision will require the patient to form some kind of a mental image of the space or object to be explored or identified. If the patient is unable to form a mental image, or neglects the left half of the mental image, then it is unlikely that the patient will search on the side of the object that is non-existent in his or her internal representation. It is unclear whether neglect of a mental image of an object could occur in separate frames of reference, but Bisiach and Luzzatti (1978) described a patient with neglect of the left side of space. It is perhaps feasible to expect that representational neglect could also occur in separate frames of reference. It should be emphasised that these explanations are speculative, and given that we did not specifically test for representational neglect, we cannot make any claims in this regard. Future investigations of tactile neglect in different frames of reference should incorporate tests of representational neglect.

Patient HT was administered a range of standard tests of neglect (such as the Behavioural Inattention Test and the Bells Test), and demonstrated visual neglect on some, but not all, of these tests. Standard tests of neglect typically assess neglect in a viewer-centred frame of reference, and do not distinguish between viewer-, stimulus-, and object-centred neglect. Patient HT did not demonstrate neglect on the Line Crossing and Letter Cancellation subtests from the BIT, or on the Bells Test. These tests are perhaps some of the most widely used standard tests of visual neglect. This finding highlights the importance of administering several tests of neglect, as some tests may not reliably assess the presence of neglect even in patients who clearly demonstrate visual neglect on other tests. Collectively, the administration of a selection of standard tests of neglect demonstrated the presence of viewer-centred neglect in patient HT. The addition of tests that also investigate neglect in stimulus- and object-centred frames of reference provided additional important information regarding the nature of patient HT's deficits that may not have been identified with standard tests of neglect. By using our new Norwegian letter 'Æ' task (cancellation and identification version), we found evidence of the co-occurrence of viewer-, stimulus-, and object-centred neglect in the visual modality. We also documented evidence of object-centred neglect in *both* the visual and tactile modality. Although we were unable to find any evidence of neglect for patient HT, either visual or tactile, from the Ota et al. (2001) discriminative-cancellation tasks, results from Ota et al. and Marsh and Hillis (2008), as well as our own results documented in Chapter 2 ('Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect') suggest that this task is a useful inclusion in the investigation of viewer- and stimulus-centred neglect. The obvious advantage of both the visual and tactile Norwegian letter 'Æ' tasks is that they can also distinguish stimulus- from object-centred neglect. The current findings provide conclusive evidence that neglect can operate in an object-centred frame of reference, even in the *tactile* modality.

Patient HT demonstrated clear evidence of object-centred neglect on our tactile 'Æ' letter-identification task, but failed to demonstrate neglect in a stimulus-centred frame of reference on both the tactile circle-identification task and the tactile 'Æ' letter-identification task. The failure to find evidence of tactile stimulus-centred neglect with our patient HT is perhaps not unexpected given the findings that this form of neglect is particularly rare (Marsh & Hillis, 2008). We would, however, expect object-centred neglect to be even more infrequent than stimulus-centred neglect. Marsh and Hillis (2008) investigated the incidence of the co-occurrence of visual *and* tactile viewer- and stimulus-centred neglect. They administered the Ota et al. (2001) visual discriminative-cancellation task to one hundred patients with acute right-hemisphere supratentorial ischemic stroke. (Two patients did not complete the visual task). Fifty-eight patients were also administered a tactile version of the task identical to the circle-identification task used in the current study. Marsh and Hillis found that on the visual discriminative-cancellation task, seventeen patients demonstrated viewer-centred neglect and four demonstrated stimulus-centred neglect; whereas, on the tactile version of the task, nineteen patients demonstrated viewer-centred neglect, but only one patient demonstrated evidence of tactile stimulus-centred neglect. These findings indicate that stimulus-centred neglect is relatively infrequent both in the visual and tactile modalities, but particularly rare in the tactile modality. Given that this is the first study to investigate tactile object-centred neglect, we are not able to provide an estimate of the frequency of tactile neglect in an object-centred frame of reference. Although our data confirms the existence of tactile object-centred neglect, we suspect that this form of neglect is even more infrequent than stimulus-centred neglect.

Marsh and Hillis (2008) also sought to determine whether the dissociation between viewer- and stimulus-centred neglect is modality-independent or modality-specific. The co-occurrence of viewer-centred and stimulus-centred neglect was observed in two patients on the visual task, but there were no co-occurrences of viewer-centred and stimulus-centred neglect on the tactile task. This finding is consistent with patient HT's results in our investigations of viewer-, stimulus-, and object-centred neglect in the visual and tactile modalities. Patient HT demonstrated viewer-, stimulus-, *and* object-centred neglect on the visual 'Æ' letter-cancellation task, but displayed object-centred neglect *only* in the tactile 'Æ' letter-identification task. Of the fifty-six patients who were administered both the visual and tactile versions of the task in the study by Marsh and Hillis, four patients demonstrated viewer-centred neglect in both modalities. Although no patients exhibited stimulus-centred neglect in both modalities, one patient who also had an old lesion to the left hemisphere, appeared to exhibit left viewer-centred *visual* neglect and right stimulus-centred *tactile* neglect. Patient HT did not exhibit viewer-centred neglect in both modalities but she did demonstrate evidence of visual and tactile object-centred neglect, thus extending the findings of Marsh and Hillis. Results from the study by Marsh and Hillis suggest that viewer- and stimulus-centred neglect can be dissociated in the tactile modality as well as in the visual modality. Distinct impairments are indicated, and these may dissociate. The findings also provide further evidence that neglect can be modality-specific in that it may be confined to either the visual or tactile modality.

A possible explanation for the relative infrequency of stimulus-centred neglect observed in both visual and tactile modalities has been presented by Kleinman, Newhart, Davis, Heidler-Gary, Gottesman, and Hillis (2007). Although these comparisons are for the visual modality, they may explain why it has been difficult to document stimulus-centred neglect. Kleinman et al. used Ota et al.'s (2001) discriminative cancellation task to investigate the frequency of viewer- and stimulus-centred neglect in the *visual* modality following *left*-hemisphere damage, and found the distribution of neglect to be markedly different from that reported by Marsh and Hillis

(2008) in patients following right-hemisphere damage. In patients with left-hemisphere damage, Kleinman et al. found that stimulus-centred neglect was more common than viewer-centred neglect, with six of their forty-seven patients demonstrating stimulus-centred neglect *only* and one patient demonstrating viewer-centred neglect *only*. The co-occurrence of visual- and stimulus-centred neglect was evident in two patients. This is in contrast to the findings of Marsh and Hillis, who reported viewer-centred neglect to be more common than stimulus-centred neglect in their patients with acute *right*-hemisphere stroke. Future research should investigate whether the frequency of viewer- and stimulus-centred neglect in the tactile modality in patients with damage to the left hemisphere parallels Kleinman et al.'s results for the visual modality, where stimulus-centred neglect was observed to be much more common. No research has to date investigated the occurrence of tactile neglect in different frames of reference in patients with left-hemisphere damage.

The majority of research investigating frames of reference in unilateral neglect has examined neglect in the visual modality, and most researchers have failed to take the Behrmann and Moscovitch (1994) criteria of utilising objects with an intrinsic left and right side (for the investigation of object-centred neglect) into account. Instead, left and right have typically been defined according to an object's principal axis. For example, Driver and Halligan (1991) defined the handedness of an object relative to its principal axis of elongation. Their case-study participant, a patient with profound left neglect in the visual modality, was required to judge whether two nonsense shapes that were vertically elongated and bottom heavy were identical or different when presented one above the other. If dissimilar, they differed on one side only. The shapes were both presented either upright or tilted 45° left or right of upright. When the principal axis of each object was vertically upright, the viewer-, environment-, and object-centred frames of reference were aligned. In this condition, the patient failed to notice differences on the left. When the object was tilted, the object-centred frame of reference was disentangled from the other frames of reference. In this case, the patient continued to neglect disparities to the left of the objects' principal axes even when these differences were located to the right in other coordinate systems. Driver and Halligan interpreted this as clear evidence that neglect may occur for information appearing on the left of individual objects regardless of their spatial location. Here we argue that the division between left and right when based on an object's principal axis is dependent on viewpoint. In this regard, only the midline of the object that separates left from right is imparted by a property *specific* to the object itself (the object's principal axis). Handedness is imposed upon either side of this division in an egocentric manner. The imposition of handedness in these objects is therefore not independent from a viewer-centred representation, as the left and right side of the stimulus will depend on the side of the axis from *the viewer's perspective*.

Thus, previous findings from studies investigating object-centred neglect in the visual modality (e.g., Driver, Baylis, Goodrich, & Rafal, 1994; Driver & Halligan, 1991; Farah, Brunn, Wong, Wallace, & Carpenter, 1990) did not include objects with an intrinsic left and right side, and may have depended on which side of the objects' principal axes the letters or differences appeared from the viewer's perspective. For this reason, the majority of findings of so-called object-centred neglect in the *visual* modality may ultimately be explained by a viewer-centred representation, and therefore may not indicate firm evidence for the existence of neglect in an object-centred frame of reference. Most of the research on frames of reference in neglect to date can therefore be explained by neglect in either viewer- or stimulus-centred frames of reference and most of this research has been conducted in the visual modality. *Only* Marsh and Hillis (2008) have investigated viewer- and stimulus-centred neglect in the *tactile* modality, and no researchers have investigated tactile object-centred neglect. To the best of our knowledge, ours is the first study to provide evidence of object-centred *tactile* neglect, taking Behrmann and Moscovitch's (1994) criteria of utilising objects with intrinsic left and right sides into account.

Our study focused on a single-case, Norwegian patient HT, who has *persisting* neglect. Marsh and Hillis' (2008) findings suggest that stimulus-centred tactile neglect is particularly rare even in patients with *acute* neglect. As outlined previously, no research has previously investigated object-centred tactile neglect in acute or persisting neglect, but we would like to emphasise also that no study has to date investigated viewer- and stimulus-centred tactile neglect in patients with *persisting* neglect. It is therefore unclear whether the frequency and pattern of viewer- and stimulus-centred neglect in patients with persisting neglect follows the same pattern as patients with acute neglect. Acute neglect following stroke is relatively frequent but neglect persisting for more than three months is much less common (Aimola Davies, 2004; Samuelsson, Jensen, Ekholm, Naver, & Blomstrand, 1997). It is therefore more difficult to study patients with persisting neglect due to the rarity of this condition. Most investigations of tactile neglect have for this reason studied patients with acute neglect, and only a handful of these studies have incorporated patients with neglect persisting more than three months. Of the small number of studies that did include patients with persisting neglect (e.g., Beschin et al., 1996; Fujii, Fukatsu, Kimura, Saso, & Kogure, 1991; Gentilini, Barbieri, De Renzi, & Faglioni, 1989; Karnath & Perenin, 1998; Olk & Harvey, 2006; Schindler, Clavagnier, Karnath, Derex, & Perenin, 2006), the majority include a small number of patients with persisting neglect mixed with a larger number of patients with acute neglect, and it is therefore impossible to make inferences regarding differences in frequency and/or patterns of neglect. Only Cubelli, Nichelli, Bonito, De Tanti, and Inzaghi (1991) and Chokron and Imbert (1995) have tested patients with persisting neglect, and these researchers investigated single cases.

As with previous single-case research, patient HT's performance illustrates that single-case studies may be very valuable in the study of rare neurological disorders, such as persisting neglect, particularly when the form of neglect being investigated (stimulus- or object-centred neglect) is also particularly infrequent. Prior to the current study, there was no documentation in the existing literature of object-centred tactile neglect in either acute or persisting neglect patients. The simple tasks described in the current study illustrate the occurrences of neglect in different frames of reference in both the visual and tactile modalities in a single case. By using our simple Norwegian letter 'Æ' task (cancellation and identification version), we found evidence of viewer-, stimulus-, and object-centred neglect in the visual modality. Most importantly, we disambiguated stimulus- from object-centred frames of reference in a tactile-identification task and in so doing, we are able to present the first case ever of object-centred neglect in the tactile modality.

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Chapter 7

General Discussion

General Discussion

How does one define the 'left' and 'right' side of what a patient with neglect will fail to report? Research has pointed to the existence of different frames of reference to explain how the brain constructs representations of objects in space. A patient with viewer-centred neglect may fail to report stimuli located on the left side as defined by some landmark on themselves, whereas in an environment-centred frame of reference, 'left' and 'right' are defined with respect to some landmark in the environment. Spatial attention may also operate within a stimulus- or object-centred frame of reference. In this case, the patient with neglect fails to report the left side of individual objects in a scene, irrespective of their positioning relative to the viewer or the environment. The main distinction between stimulus- and object-centred neglect is that the canonical left and right of the object are maintained independently of the viewer-centred reference frame *only* in an object-centred representation.

A few researchers have provided evidence that visual neglect can occur in an object-centred frame of reference (e.g., Behrmann & Moscovitch, 1994), however, Buxbaum, Coslett, Montgomery, and Farah (1996) criticized findings of object-centred neglect, and suggested that these findings may be explained by mental rotation of stimuli to upright. Mental rotation of stimuli to upright realigns all spatial coordinate systems and thus makes a distinction between viewer-, stimulus-, and object-centred neglect impossible.

In contrast to the large amount of research on visual neglect, tactile neglect has been relatively unexplored. In the studies that do exist on neglect in the tactile modality, the different researchers have utilised a variety of definitions of tactile neglect. For example, some have defined tactile neglect in terms of a rightward bias in tactile search and exploration performance, with an associated impaired ability to search for, locate, and respond to targets positioned in the contralesional side of space (without the aid of vision). Other researchers have defined it according to a rightward bias in tactile line- and rod-bisection tasks. Additionally, tactile neglect has been described as the impaired ability to detect somatosensory stimuli delivered to locations (usually on the hand or arm) on the contralesional side of the body in the absence of somatosensory impairment. Although the literature documents that neglect *can* occur in the tactile modality, little research has been undertaken to investigate whether neglect in the tactile domain can occur in separate frames of reference. One study suggests that tactile neglect can be dissociated in the viewer-centred and stimulus-centred frames of reference (Marsh & Hillis, 2008), but to the author's knowledge, no previous researchers have attempted to disentangle the object-centred frame of reference in the tactile modality.

The series of studies reported set out to extend previous findings by examining the occurrence of viewer-, stimulus- *and* object-centred neglect in both the visual and tactile modalities. The main aim was to provide experimental evidence to indicate whether visual and tactile neglect can operate in an object-centred frame of reference. The visual discriminative-cancellation task originally designed by Ota, Fujii, Suzuki, Fukatsu, and Yamadori (2001), and the tactile version of the circle task later used by Marsh and Hillis (2008) were replicated with Norwegian patients who had persisting neglect. These tasks distinguish between viewer- and stimulus-neglect. Taking into account Behrmann and Moscovitch's (1994) criterion for utilising stimuli with an intrinsic left and right side to demonstrate 'true' object-centred neglect, three new tasks aimed to specifically distinguish between stimulus- and object-centred neglect were introduced. Although all three tasks investigated object-centred neglect, two examined neglect in the visual modality, and the third task examined neglect in the tactile modality. The stimuli in all three tasks included the letters 'E', 'A', and 'Æ'. In the Norwegian visual 'Æ' letter-*cancellation* task, the letters were scattered across a sheet of paper. The participants' task was to circle all 'E' letters and/or to cross out all letters except the letter 'E'. Omissions of stimuli on the left side of page were interpreted as viewer-centred neglect, and as with all three tasks, errors in following instructions with respect to the letter 'Æ' were interpreted as either stimulus- or object-centred neglect. In the visual 'Æ' letter-*identification* task, the letters 'E', 'A', and 'Æ' were displayed individually and centrally on a computer screen. The participants' task was to identify the letters presented by pressing clearly labelled keys on a computer keyboard. In addition to investigating stimulus- and object-centred neglect in the visual modality, the visual 'Æ' letter-*identification* task also set out to investigate the mental rotation hypothesis of object-centred neglect. The *tactile* 'Æ' letter-identification task required the patients to tactually identify individually presented letters without the aid of vision.

In all three new tasks, the stimulus- and object-centred frames of reference were disambiguated by displaying the letters in normal and backward (mirror-reversed) parity, and in each of six different angles of orientation (presented in 45-degree increments rotated clockwise from upright, excluding 90° and 270°). Errors in the identification of the letter 'Æ' were interpreted as either stimulus- or object-centred neglect. Specifically, object-centred neglect led to neglect of the 'A' part of the letter 'Æ' (the intrinsic left side) irrespective of parity and angle of orientation. In contrast, stimulus-centred neglect was demonstrated by neglect of the 'A' part of the 'Æ' *only* when it was located on the left side in a stimulus-centred frame of reference. In the presence of either stimulus- or object-neglect, the patient would respond incorrectly to the letter 'Æ' in all of the new tasks described. On the Norwegian visual 'Æ' letter-cancellation task, inaccurate identification of the letter 'Æ' as the letter 'E' would result in the patients circling the letter 'Æ' when asked to circle only 'E' letters. Omissions in the cancellation of the letter 'Æ' when asked to cancel all letters except the letter 'E' were also expected. In the visual or tactile 'Æ' letter-identification tasks, the presence of stimulus- or object-centred neglect would result in the inaccurate *identification* of the letter 'Æ' as either the letter 'E' or the letter 'A'. If errors were due to stimulus-centred neglect, it was expected that the patients would incorrectly identify the letter 'Æ' as the letter 'E' when presented as A-left 'Æ' ('normal parity and upside-up' or 'backward parity and upside-down'), but identify the 'Æ' as the letter 'A' when presented as A-right 'Æ' ('backward parity and upside-up' or 'normal parity and upside-down'). If errors were due to object-centred neglect, then it was expected that the patients would identify the letter 'Æ' as the letter 'E' irrespective of parity and angle of orientation. The findings are summarized in Table 1.

Table 1

Summary of Findings of Neglect in Viewer-, Stimulus-, and Object-Centred Frames of Reference as Assessed by Five Experimental Tasks[1]

	Visual Tasks			Tactile Tasks	
Patient	Discriminative -cancellation	Norwegian 'Æ' letter-cancellation	Norwegian 'Æ' letter-identification	Circle-identification	Norwegian 'Æ' letter-identification
Group	VCN, SCN	VCN, SCN, OCN			
Patient HH	VCN	VCN	No neglect		
Patient VR	No neglect	VCN	No neglect		
Patient BN	VCN, SCN	VCN	SCN		
Patient JF	VCN	VCN, SCN, OCN			
Patient HT	No neglect	VCN, SCN, OCN	No neglect	No neglect	OCN

[1] VCN = viewer-centred neglect; SCN = stimulus-centred neglect; OCN = object-centred neglect.

Responses to Research Questions

Section 1: Frames of Reference in Unilateral Neglect: Visual Modality

The first research question to be addressed by the current project sought to clarify whether visual neglect can operate in an object-centred frame of reference. Evidence of both viewer- and environment-centred neglect has been extensively documented in the visual domain (e.g., Calvanio, Petrone, & Levine, 1987; Farah, Brunn, Wong, Wallace, & Carpenter, 1990; Làvadas, 1987), and a number of studies have also demonstrated that visual neglect can arise in a stimulus-centred frame of reference (e.g., Baylis, Baylis, & Gore, 2004; Chatterjee, 1994; Grimsen, Hildebrandt, & Fahle, 2008; Marsh & Hillis, 2008; Marshall & Halligan, 1994; Ota et al., 2001). In the majority of studies investigating stimulus- and object-centred neglect, left and right of the object have typically been defined according to the object's principal axis. We argued that the separation of left and right when based on an object's principal axis is dependent on viewpoint. Only the separating line between left and right may therefore be imparted by allocentric co-ordinates of the object's principal axis. Handedness is imposed upon either side of this division in an egocentric manner. The imposition of handedness in these objects is therefore not independent from a viewer-centred representation, as the left and right side of the stimulus will depend on the side of the axis from *the viewer's perspective*. Results from most previous studies (e.g., Di Pellegrino et al., 1995; Driver, Baylis, Goodrich, & Rafal, 1994; Driver & Halligan, 1991; Farah et al., 1990; Ota et al., 2001; Pavlovskaya, Glass, Soroker, Blum, & Groswasser, 1997; Savazzi, Neppi-Mòdona, Zettin, Gindri, & Posteraro, 2004) may therefore have depended on which side of the objects' principal axes the letters or differences appeared from the viewer's perspective, reflecting viewer- or stimulus-centred neglect rather than object-centred neglect.

Consistent with the above argument, Behrmann and Moscovitch (1994) claimed that the allocation of attention within an object-centred frame of reference is not required *unless* object identification necessitates the specification of the left and right side of that particular object. In objects with an intrinsic handedness, an object's left and right side are specifically marked and maintained to ensure its accurate representation. Behrmann and Moscovitch therefore argued that one cannot truly conclude that attention can be allocated within an object-centred frame of reference without demonstrating neglect for objects with an intrinsic handedness independent of the spatial location of the left side of these objects as defined by viewer-, environment-, and stimulus-centred coordinates. In other words, Behrmann and Moscovitch predicted attention to be distributed within an object-centred frame of reference *only* in inherently asymmetrical objects with an intrinsic left and right side. We took Behrmann and Moscovitch's criteria for utilising objects with an intrinsic left and right side into account in our visual 'Æ' letter-cancellation task introduced in Chapter 2: 'Disambiguating viewer-, stimulus-, and object-centred neglect: Five patients with visuospatial neglect'. This task investigated whether visual neglect can operate in an object-centred frame of reference in a group of five patients with neglect, while simultaneously examining for the presence of viewer- and stimulus-centred neglect. We separated the object-centred frame of reference from the viewer- and stimulus-centred reference frames by displaying the upper-case letters 'E', 'A', and 'Æ' in normal and backward parity and in eight different angles of orientation. Omissions on the left side of page indicated viewer-centred neglect, while errors in following instructions with respect to the letter 'Æ' on both sides of the page were interpreted as either stimulus- or object-centred neglect. Comparisons were made between A-right 'Æ' and A-left 'Æ' and between A-right 'Æ' and the letter 'A'. Poorer responses to A-left 'Æ' compared to A-right 'Æ' indicated stimulus-centred neglect whereas better response to the letter 'A' compared to A-right 'Æ' indicated object-centred neglect. With our visual Norwegian 'Æ' letter-cancellation task we were able to provide conclusive experimental evidence that neglect can occur in an object-centred frame of reference.

The second research question to be addressed in the current project concerns the possibility that object-centred visual neglect can co-occur with visual neglect in other frames of reference. Behrmann and Moscovitch (1994) provided tentative evidence that neglect can arise in an object-centred frame of reference by requesting patients with neglect to report outline colours of objects. The objects were rotated 90° to the left and right of upright to disambiguate the object-centred frame of reference from the viewer-centred frame of reference. Results demonstrated that patients reported fewer outline colours on the intrinsic left side of asymmetrical letters. Although their findings provide an indication that neglect can operate in an object-centred frame of reference, they do not provide any indication as to whether neglect in other frames of reference may co-occur with object-centred neglect. Behrmann and Moscovitch's design precluded the detection of neglect in other reference frames because the stimuli were individually and centrally presented. Marsh and Hillis (2008) later provided evidence that viewer- and stimulus-centred neglect can co-occur in the visual modality. Only two of the 98 patients administered the Ota et al. (2001) discriminative-cancellation task by Marsh and Hillis demonstrated neglect in viewer- *and* stimulus-centred frames of reference, suggesting that the co-occurrence of neglect in these two frames of reference may be relatively rare. With the design of our 'Æ' letter-cancellation task, we were able to provide affirmative evidence that visual neglect may operate in viewer-, stimulus-, and object-centred frames of reference simultaneously within the same individual.

Section 2: A Mental Rotation Hypothesis of Object-Centred Neglect?

The aim of the second section of the thesis was to investigate the mental rotation hypothesis of object-centred neglect. As mentioned previously, Buxbaum et al. (1996) suggested that findings of object-centred neglect may be due to mental rotation of stimuli to upright. Mental rotation to upright realigns the viewer-, stimulus-, and object-centred frames of reference and thus makes differentiation impossible. We designed a new 'Æ' letter-*identification* task to investigate the mental rotation hypothesis, and specifically to examine whether there is evidence for mental rotation of stimuli to upright in the process of identification and report of asymmetrical upper-case letters. The task again examined the distinction between stimulus- and object-centred neglect, but also took advantage of the known fact that mental rotation of misoriented stimuli has an established time course. We were able to provide conclusive experimental evidence that mental rotation is not required in the identification of the letters presented, suggesting that our findings of stimulus-centred neglect in patient BN could not be due to mental rotation to upright. This finding also provides evidence that our findings from the visual 'Æ' letter-*cancellation* task represents evidence of 'true' stimulus- and object-centred neglect.

Our findings are consistent with earlier research suggesting that the identification of misoriented asymmetric letters does *not* normally require mental rotation (Corballis, 1982). The lack of a mental rotation curve in the reaction time data of neurologically healthy participants and patients with neglect has an important implication for previous interpretations of findings of object-centred neglect. Our results argue against Buxbaum et al.'s (1996) suggestion that previous findings of object-centred neglect are due to mental rotation of stimuli to upright. Given that the stimuli included in the current studies consist of asymmetrical letters, it also disconfirms Buxbaum et al.'s suggestion that the participants in Behrmann and Moscovitch's (1994) study mentally rotated only the asymmetrical letters included in their experiment. The findings of Behrmann and Moscovitch are therefore likely to indicate neglect in an object-centred frame of reference.

Section 3: Frames of Reference in Unilateral Neglect: Tactile Modality

The final research question to be addressed by the current project concerned the existence of a separate object-centred frame of reference in the tactile modality. In contrast to the large amount of research on neglect in the visual modality, tactile neglect has been relatively unexplored. Only one study has investigated whether tactile stimulus-centred neglect can be dissociated from viewer-centred tactile neglect (Marsh & Hillis, 2008). To the author's knowledge, no previous researchers have attempted to disentangle the object-centred frame of reference in the tactile modality. The new tactile 'Æ' letter-identification task took into account Behrmann and Moscovitch's (1994) criteria of utilising asymmetrical stimuli with a canonical left and right side in the investigation of object-centred neglect, and extended the investigation of object-centred neglect to the tactile modality. The object-centred frame of reference was again disentangled from the stimulus-centred frame of reference by individually displaying letters in normal and backward parity and in eight different orientations in a simple tactile letter-identification task. We excluded directional hypokinesia as a factor by administering the test originally constructed by Tegnér and Levander (1991).

The first important finding relating to the experimental design of our tactile 'Æ' letter-identification task is that we were able to provide firm evidence that neglect of the intrinsic left side of individual objects can occur in the tactile modality. This is the *first* study to document the existence of tactile object-centred neglect. The second important finding with respect to our investigation of tactile neglect concerns the possibility that visual and tactile object-centred neglect may co-occur. Marsh and Hillis (2008) previously investigated viewer- and stimulus-centred tactile neglect, and found evidence of stimulus-centred neglect on a tactile version of Ota et al.'s (2001) circle-cancellation task. Four of 56 patients in their study demonstrated the co-occurrence of visual and tactile viewer-centred neglect, but there was no evidence to suggest that stimulus-centred neglect may co-occur in the visual and tactile modalities. Patient HT's performance on our visual 'Æ' letter-cancellation task and the tactile 'Æ' letter-identification task extends previous findings, and is the first to provide experimental evidence documenting that object-centred neglect indeed may co-occur in both modalities. Furthermore, for patient HT we demonstrated that not only does object-centred neglect co-occur in both the visual and tactile modalities, but viewer- and stimulus-centred neglect in the visual modality may also be present *at the same time.*

The Role of Representational Neglect in Findings of Tactile Neglect

Beschin, Cazzani, Cubelli, Della Sala, and Spinazzola (1996) noted that a confounding factor in relation to findings of tactile neglect includes the possibility that patient performance can be attributed to a representational deficit or "general inability to explore a self-generated mental image" (p. 46). Beschin et al. identified tactile neglect in this regard as a rightward bias in tactile search and exploration performance, with an associated impaired ability to search for, locate, and respond to targets positioned in the contralesional side of space without the aid of vision. It is presumed that any space exploration tasks without the aid of vision will require the patient to form some kind of a mental image of the space to be explored. If the patient is unable to form a mental image, or neglects the left half of the mental image, then it is unlikely that the patient will search in the side of space that is non-existent in his or her internal representation of the space to be searched. Thus, impaired searching performance may be attributed to tactile neglect *or* to representational neglect.

Representational neglect was first illustrated by Bisiach and Luzzatti (1978) who in their famous experiment demonstrated a patient with neglect failing to describe information located on the left side of space when imagining a familiar place, the Piazza del Duomo in Milan. When subsequently asked to imagine the same place from the opposite end of the square (from a reverse perspective), the patient was able to describe features that were previously omitted. Features that were previously located in the neglected side of space were now located in the intact right side of space.

Palermo, Piccardi, Nori, Giusberti, and Guariglia (2010) have subsequently demonstrated evidence of a relationsip between visuospatial neglect and deficits in visual mental imagery in a task testing navigational imagery ability. Participants in this study consisted of a total of 21 patients with lesions to the right hemisphere. Of these, four demonstrated evidence of visuospatial neglect on the 'Standardized Battery for the

Evaluation of Hemineglect', seven patients demonstrated either representational neglect *only* or both representational and visuospatial neglect, and 10 patients showed no signs of neglect. Representational neglect was assessed by the Grossi, Modafferi, Pelosi, and Trojano (1989) o'Clock Test and the Familiar Squares Description Test by Bisiach and Luzzatti (1978). Seven patients with lesions to the left hemisphere without neglect and a group of age-matched neurologically healthy individuals also participated. Although Palermo et al. investigated multiple deficits in imagery processes, the deficit of relevance to the current discussion concerns their finding in the egocentric navigation-questions task. In this task, the participants were required to follow a pathway through a hospital with landmarks that the patients had not previously explored. Patients were subsequently asked to imagine being on the path and to answer questions regarding whether landmarks were on their left or their right. Results demonstrated that only patients with representational neglect performed worse than neurologically healthy controls in this task, a finding interpreted as evidence that the presence of representational neglect has a detrimental effect on general imagery tasks.

As suggested by Beschin et al. (1996), it therefore seems important to incorporate imagery tasks to establish the presence of representational neglect in tasks investigating viewer-centred neglect. The ability to form a mental image of immediate surroundings is expected to be beneficial, if not a prerequisite, to forming a response to a tactile task without the aid of vision. That is, a deficit in this ability with respect to one side of space could manifest itself as tactile neglect. Furthermore, the presence of visual neglect may also inhibit an individual's inclination to search the left side of space. If the left side of space does 'not exist' in the visual modality, why would the patient search this side of space? It is likely that the patient would concentrate his or her efforts in the non-neglected side of space. Perhaps a better way of establishing neglect in the tactile modality then is to explore the patient's ability to make *judgments* about stimuli located in space by tactile exploration. This is what we did with our tactile 'Æ' letter-identification task. Given the absence of viewer-centred neglect on the tactile circle-identification task, it is unlikely that representational neglect contributed to findings of tactile neglect in the 'Æ' letter-identification task for patient HT. It does, however, raise the question as to whether it is possible that representational neglect could also occur in different frames of reference. Given that it has been established that both visual and tactile neglect can be demonstrated in different frames of reference, it is perhaps not unreasonable to expect that representational neglect may also occur in separate frames of reference.

Grossi et al. (1989) conducted an elegant experiment that we speculate may have unintentionally illustrated that representational neglect can occur in separate frames of reference. Grossi et al. investigated the different roles of the left and right hemispheres in mental imagery. They sought to provide evidence that left posterior lesions lead to deficits in mental imagery, whereas right posterior lesions are associated with both perceptual neglect *and* representational neglect. The patients consisted of two single cases: (a) patient LG, a patient with a right posterior lesion involving the temporal and parietal lobes and thalamus; (b) patient AP, a patient with a left posterior lesion. Patient LG demonstrated evidence of severe visuospatial neglect, as tested with line cancellation, copying, and drawing tasks. Patient LG showed a selective imagery deficit as evidenced by the ability to correctly copy a visual model and an inability to draw from a mental image (without a model) or describe places he was familiar with. Grossi et al. designed a test they called the o'Clock Test to demonstrate the differential roles of the left and right hemispheres. The test consisted of a preliminary task, a perceptual task, and an imaginal task. The preliminary task was conducted to establish that the patients were familiar with the analog clock. The perceptual task required the patients to make a comparison between two clock drawings set to different times. The clocks were set so that one arm was along the vertical midline and the other arm was either in the right half (right condition) or the left half (left condition) of the clockface, and the task was to indicate in which of the two clocks the arms formed the larger angle. The clocks were presented one above the other, aligned with the midline of the patient's body. The imaginal task was identical to the percentual task, except that instead of viewing the clocks, the patients were asked to *imagine* a pair of clock faces set to different times as proposed verbally by the experimenter. Grossi et al. predicted: patient LG would make more errors in the left condition than in the right condition and thereby demonstrate left neglect in both the perceptual and imaginal task; patient AP would make more errors in the imaginal task *only.* Consistent with predictions, patient AP performed better in the perceptual task than in the imaginal task. Of particular relevance to the currect discussion is patient LG's performance. Patient LG performed better in the right condition than in the left condition in both tasks, a finding interpreted as evidence of both perceptual and representational neglect. This task did not distinguish between viewer- and stimulus-centred representational neglect, so it is unclear whether the findings of representational neglect are due to neglect in a viewer- or stimulus-centred frame of reference. It should be noted, however, that patient LG did not demonstrate representational neglect on the Familiar Squares Description Test described by Bisiach and Luzzatti (1978), a test that investigates representational neglect in a viewer-/environment-centred frame of reference. Grossi et al. interpreted this discrepancy as evidence that their o'Clock Test was a more sensitive measure of representational neglect. An alternative explanation of this discrepancy includes the possibility that patient LG experiences representational neglect in a stimulus-centred frame of reference *only.* Due to stimulus-centred neglect, he makes errors on the left side of the imagined clockfaces (left side of the stimuli), but does not demonstrate neglect on Bisiach and Luzzatti's test of viewer-centred representational neglect.

If our findings of tactile object-centred neglect in patient HT were due to an *object*-centred representational deficit, it would be expected that patient HT would have tactually identified the letter 'Æ' in order to then neglect the intrinsic left side of its mental image. An important question to raise is therefore whether tactile letter-identification requires comparison to a stored mental representation of the letter. Given that the stored mental representation is most likely in the orientation we usually see the letter (i.e., upside-up and normal parity), this would not necessarily match the orientation of the tactile letters displayed in our tactile 'Æ' letter-identification task. A comparison to the stored mental representation of the letter would therefore require mental rotation to upright. We argue that given that mental rotation to upright is not required for identification of visually presented letters it is unlikely that identification of tactile stimuli requires mental rotation to upright, a claim that of course requires further investigation. For these reasons, however, we believe our findings reflect tactile neglect in an object-centred frame of reference.

Informational Asymmetry and Findings of Object-Centred Neglect

Previous research has indicated that attentional allocation within an object-centred frame of reference may be confounded with several other factors. Our new visual 'Æ' letter-identification task investigated Buxbaum et al.'s (1996) mental rotation hypothesis of neglect, which is *one* of the alternative explanations for previous findings of object-centred neglect. Informational asymmetry is a second explanation for the findings of object-centred neglect reported by Behrmann and Moscovitch (1994). That is, informational asymmetry could favour the allocation of attention to one side over the other. As the reader may wonder how this explanation fits with our reported findings, we will provide a brief overview of relevant research investigating the informational asymmetry hypothesis before discussing whether this is relevant to our findings of object-centred neglect.

Aimola Davies and Corballis (under review) conducted a study that investigated the mental rotation hypothesis of object-centred neglect by utilising the letter 'R', which has its distinguishing features located on the intrinsic right side. In this study, TMA, a patient with left-side neglect, was shown the letter 'R' in normal and backward parities and in eight different angles of orientation (ranging from 0 to 315 degrees). A small dot was positioned to the left or right side of the letter in two thirds of the trials, and there was no dot present in the remaining third of the trials. Patient TMA was required to indicate the presence of a dot in Experiment 1, but her task in Experiment 2 was, first to make a parity judgment for the letter (normal or backward) presented on each trial, and then to indicate whether a dot was present. Experiment 3 was a parity-judgment task, a task known to demand mental rotation. In this way, mental rotation of the letter to make the parity judgment could be investigated, by way of a mental rotation curve in the reaction time data; as is typical in mental rotation experiments of letter parity (e.g., Cooper & Shepard, 1973; Corballis & McMaster, 1996; Corballis, Nagourney, Shetzer, & Stefanatos, 1978; Corballis, Zbrodoff, & Roldan, 1976). In the first two experiments, TMA performed significantly worse when the dot was located on the intrinsic left side of the letter, regardless of parity and orientation. And, there was evidence of a mental rotation curve in both the second and third experiments, indicating that patient TMA could (when needed) mentally rotate the letter to make an accurate parity discrimination. These findings were interpreted as evidence for intrinsic object-centred neglect.

An alternative explanation of the results obtained by Behrmann and Moscovitch (1994) and Aimola Davies and Corballis (under review) includes the possibility that visual attention is allocated to the more informative features of a letter. As the left side of many asymmetrical letters can be confused with each other (the left side is often a straight line, such as with the letters 'B', 'D', 'E'), attention may be allocated more optimally to the regions of the letters that contain unique or distinguishing features that aid identification. Drain and Reuter-Lorenz (1997) suggested that a bias in attentional allocation may give rise to the object-based effects obtained in previous studies, and devised a study aiming to test this possibility. They argued that a right bias in the allocation of attention in neurologically healthy participants should produce the same qualitative pattern of results as observed in patients with neglect. In their experiment, participants were required to report the colours outlining symmetrical and asymmetrical letters presented for 150ms either upright (0°) or rotated (90°, 180°, 270°) following letter identification. Results demonstrated an apparent rightward object-centred bias in neurologically healthy participants. Although no bias was observed when letters were upright, a rightward bias in the distribution of attention was evident for asymmetrical letters (and not for symmetrical letters) in the rotated conditions when the object-centred frame of reference was decoupled from viewer/environment-centred coordinates. This pattern of results is indistinguishable from the findings obtained by Behrmann and Moscovitch. Rather than attributing this object-centred effect to representational disparities between symmetrical and asymmetrical letters, Drain and Reuter-Lorenz raised the possibility that the distribution of attention could be influenced by the task of letter identification in the presence of informational asymmetries (as is evident for asymmetrical letters). That is, neurologically healthy participants, and possibly patients with neglect in previous studies, may have allocated more attention to features that facilitated letter identification, resulting in a relative rightward bias and a tendency for less regard to the left of asymmetrical letters. It should be noted that Drain and Reuter-Lorenz' findings were based on an experiment that used time-restricted stimulus exposure, and the majority of experiments on neglect use unrestricted viewing time of the stimuli. The results therefore may not easily generalise to results with patients with neglect and should not affect the interpretation of our results. We established that neurologically healthy individuals were highly accurate on all tasks, and thereby ruled out the possibility that the findings were a reflection of 'normal' biases in the allocation of visual attention, confirming that the results were due to object-centred neglect. The findings of Drain and Reuter-Lorenz do, however, highlight the importance of testing neurologically healthy participants to ensure that normal biases in the distribution of attention is not misattributed to findings of neglect.

In the study by Drain and Reuter-Lorenz (1997), the effects of informational asymmetry following letter identification cannot be disentangled from a general rightward bias in attentional allocation since the letters tested had informational features located to the right, and not to the left of the letter. It is thus unclear whether the rightward bias is due to informational asymmetry or a general tendency to direct attention to the right independent of the location of informative features. Research has provided evidence to indicate that neurologically healthy individuals display a tendency to direct attention rightward under certain task conditions (Kinsbourne, 1987, 1994; Bultitude & Aimola Davies, 2006; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990). The rightward attentional bias observed by Drain and Reuter-Lorenz could therefore reflect the manifestation of 'normal' hemispheric asymmetries in lateral orienting.

Maguire, Bates, Boycott, and Corballis (2002) have since examined how neurologically healthy participants distribute attention to asymmetrical letters with the distinguishing information located to either the right side ('R') or the left side ('J'). In Maguire at al.'s experiment, the stimuli ('R' and 'J') were presented individually in normal or backward parity and in six different angles of orientation (0°, 45°, 135°, 180°, 225°, 315°). In fifty percent of the trials, a dot was present equally often to the left or right of the stimuli, whereas in the remaining fifty percent of trials the dot was absent. Participants were required to make two responses for each trial. First, they were instructed to indicate the parity of the letter, and second, they were required to specify whether a dot was present. Maguire et al. predicted that dot reaction times would be faster when the dot was located at the informative side of the letter as a result of attention being more optimally directed to this side. Contrary to what was expected, there were no differences in dot reaction times with regard to which side the dots were positioned. However, parity-judgment reaction times were faster when the dot was located on the distinguishing side of the letter. Maguire et al. interpreted the latter result as support for Drain and Reuter-Lorenz's (1997) theory that attention can be directed more optimally to the informative side of a letter. It is unlikely that the findings from our new 'Æ' letter tasks are due to 'normal' biases in the identification of misoriented letters, as results from the control participants demonstrated that the tasks described are not difficult for neurologically healthy participants, a finding which applies to the tactile letter-identification task as well. Although it is possible that informational asymmetries, or other stimulus-related characteristics, have favoured the allocation of attention to one side over the other in objects utilised in previous studies, the high accuracy rates demonstrated by neurologically healthy participants in all tasks described in this thesis indicates that it would be an inadequate explanation of the current results. Again, we emphasise the importance of incorporating neurologically healthy individuals in experiments investigating neglect to prevent the potential misinterpretation of results.

As it is possible that more complex tasks than the ones described here may be susceptible to 'normal' biases in the allocation of attention, we have been conducting a new series of experiments to examine how visual attention is distributed in neurologically healthy individuals. These experiments replicate and extend the study by Maguire et al. (2002). As with Maguire et al., we have investigated the time taken to detect a dot placed on the intrinsic left or right side of the asymmetrical uppercase letters 'R' and 'J'. We have also designed a separate experiment to investigate the effect of including a letter with distinguishing features on both the intrinsic left *and* right side on the allocation of visual attention in neurologically healthy participants.

Implications for Single-Case Research

We investigated the presence of viewer-, stimulus-, and object-centred neglect in a group of patients with neglect, both as group data and as single-case data. In both the visual discriminative-cancellation task and the 'Æ' letter-cancellation task there was evidence of neglect in multiple frames of reference in the group analysis. For both tasks, the single-case analysis provided a range of different results. We therefore found that the group analysis failed to find individual differences in performance in either of the two tasks. This finding highlights the importance of analysing data from rare neurological disorders as single cases. It is possible that reduced power in the single-case analysis precluded the detection of either stimulus- or object-centred neglect for some of the patients. For at least patient HH, however, the single-case analysis accurately identified him with viewer-centred neglect *only,* and highlighted a pattern of results that was different from the results of the group analysis. Our results emphasise the importance of single-case research in the study of rare neurological disorders. We suggest that grouping of the data produces overall results that do not reflect individual patient data, and valuable information regarding individual results may be lost as a consequence. Due to our speculation that the failure to find statistical differences in data may be due to lack of power in the single-case research, we suggest that researchers consider analysing data from rare disorders both individually and as a group.

Implications for Bedside Tests

Our findings emphasise the importance of utilising multiple instruments in the investigation of neglect in different frames of reference. We would like to highlight two examples to illustrate the importance of using more than one test. The first example concerns patient JF. Patient JF demonstrated viewer-centred neglect *only* on the visual Ota et al. (2001) discriminative-cancellation task, whereas his performance on the visual 'Æ' letter-cancellation task indicated neglect in three frames of reference (viewer-, stimulus-, and object-centred neglect). In contrast, patient BN demonstrated both viewer- and stimulus-centred neglect on the visual discriminative-cancellation task, but only viewer-centred neglect on the 'Æ' letter-cancellation task. It is unclear why patient BN failed to demonstrate stimulus-centred neglect on the visual 'Æ' letter-cancellation task, given that he subsequently demonstrated stimulus-centred neglect on the visual 'Æ' letter-*identification* task. Baylis, Baylis, and Gore (2004) documented that the frame of reference of neglect may change depending on task requirements. It is possible that differences in task requirements elicited neglect in different frames of reference for patients JF and BN, and that this is why their results were not consistent across the discriminative-cancellation task and the 'Æ' letter-cancellation and letter-identification tasks. The above points highlight the importance of administering multiple tests in the investigation of visuospatial neglect, as the pattern of responses may change depending on the task and the associated task requirements. Based on the above findings, we suggest that both the Ota et al. discriminative-cancellation task and the 'Æ' letter-cancellation task could be administered together in research or clinical investigations of reference frames in neglect. If time permits the administration of only one of these tasks, we suggest the 'Æ' letter-cancellation task. Even though it failed to detect stimulus-centred neglect in patient BN, it provided evidence of stimulus-centred neglect in both patients JF and HT, who failed to demonstrate evidence of this in the discriminative-cancellation task. In addition to its obvious advantage of also assessing object-centred neglect, it has an increased detection rate for demonstrating stimulus-centred neglect.

We administered the 'Æ' letter-cancellation task in seven separate sessions for patients JF and HT. Although we speculated that the increase in power associated with the increased number of trials contributed to the higher detection rate of neglect in the different frames of reference for patients JF and HT, we have since found, in a separate analysis for patients JF and HT, that the findings of viewer-, stimulus-, and object-centred neglect hold true even if we analyse the data from the first four sessions *only*. The question that then arises is, how many sessions are necessary to reliably investigate the presence of neglect in the three separate frames of reference? Based on the findings for patients JF and HT, we suggest that no more than four sessions are necessary for this investigation, which should take no more than 30 minutes per session. Both the Ota et al. (2001) discriminative cancellation task and the 'Æ' letter-cancellation task are easy to administer and we found the patients to enjoy the tasks. These tasks could also be interspersed with other activities or routine tests if necessary.

Our investigations also included the administration of standard tests of neglect. Although these tests are designed to detect viewer-centred neglect, we found that only a small number of these tests produced evidence of viewer-centred neglect in *all* five patients described in the current thesis. Even the Line Crossing subtest from the Behavioural Inattention Test, which is perhaps one of the most commonly administered standard tests of neglect, produced evidence of viewer-centred neglect in only one of the five patients. Patient HH, who reliably demonstrated viewer-centred neglect on the visual discriminative-cancellation task and the 'Æ' letter-cancellation task, failed to demonstrate viewer-centred neglect on several of the standard tests of neglect. This highlights the importance of administering several tests of neglect as some tests may not reliably detect the presence of neglect even in patients with clear evidence of viewer-centred neglect. If time permits the administration of only a few standard tests of neglect, then some of the more sensitive tests should be administered. We found the more reliable standard tests of neglect to be BIT Star Cancellation, BIT Representational Drawing, Schenkenberg Line Bisection, Balloons Test, Ogden Scene Task, and Rey Complex Figure.

Suggestions for Future Research

The new 'Æ' letter tasks introduced to distinguish between stimulus- and object-centred neglect provide an important contribution to the existing literature, and provide a useful new method to distinguish between these two forms of neglect. The visual 'Æ' letter-identification task additionally controls for mental rotation by gathering reaction time data. Although we provided evidence of the co-occurrence of visual neglect in viewer-, stimulus-, and object-centred frames of reference in patients whose first language is Norwegian, it will be important to investigate whether these findings can be replicated irrespective of the patient being familiar with the stimuli (the letter 'Æ'). If the findings cannot be replicated, it will be important to develop tasks that can investigate neglect in different frames of reference irrespective of cultural background.

To the author's knowledge, no research has to date investigated the occurrence of object-centred neglect after left-hemisphere damage, although there is evidence to suggest that stimulus-centred neglect is more frequent than egocentric neglect following damage to the left-hemisphere (Kleinman, Newhart, Davis, Heidler-Gary, Gottesman, & Hillis, 2007). Kleinman, Newhart, Davis, Heidler-Gary, Gottesman, and Hillis investigated the occurrence of viewer- and stimulus-centred neglect after left-hemisphere injury, utilising tasks such as the circle-cancellation task originally designed by Ota et al. (2001). They found that out of the nine patients with neglect, six manifested stimulus-centred neglect. But only three demonstrated evidence of viewer-centred neglect. Given that standard tests for neglect typically assess neglect in a viewer-centred frame of reference, it is (according to Kleinman et al.'s results) possible that the incidence of neglect associated with lesions to the left hemisphere may be underestimated. Future research should therefore also investigate whether neglect following lesions to the left-hemisphere can exist in an object-centred frame of reference. It may be important to consider including tests to assess both stimulus- and object-centred neglect in standard assessment batteries to minimize the potential underestimation of neglect. Ota et al.'s tasks are quick and easy to administer, and perhaps more importantly, patients do not seem to mind completing these tests. This could therefore serve as a screening measure for stimulus-centred neglect.

Although our understanding of neglect gradually improves, there is still limited evidence to support the efficacy of any rehabilitation strategy, and most patients remain impaired following clinical rehabilitation (see Aimola Davies, 2004). One problem, of course, is that neglect is such a diverse syndrome, which is manifested by deficits in various frames of reference and across modalities. A sound understanding of the various deficits accompanying neglect is a prerequisite for the development of any rehabilitation program. The development of tests to accurately assess the various deficits associated with neglect is also important in this regard. Further research in the area is therefore of particular importance, with the overall goal of developing effective treatment techniques in order to minimize the potential disability associated with neglect. An increased understanding of the anatomical, neuropsychological, and other cognitive aspects of the disorder is also likely to contribute to our knowledge and understanding of spatial processing and object recognition in the neurologically healthy brain.

It may appear as an obvious disadvantage that in the letter-cancellation task there is a requirement to be familiar with the letter 'Æ'. A challenge for future research is to design a task that can be used irrespective of the patients' linguistic background. We have begun this task by first testing patients with neglect who are not familiar with the letter 'Æ' to investigate whether this letter can be used with patients who are not familiar with the Norwegian language. Inspiration for this possibility comes from the work of Savazzi, Neppi-Mòdona, Zettin, Gindri, and Posteraro (2004), who demonstrated that the viewer-centred left-right orientation of an object in a particular orientation can be experimentally determined by repeatedly displaying the object to patients with neglect. The eleven patients in their study were required to bisect 20cm-long line drawings of a basset hound individually presented on a sheet of paper that was positioned aligned with the midline of the patient. The patients completed twenty trials repeated in five separate sessions. In fifteen trials, the basset hound was oriented with its head on the right side of space and its tail on the left side of space. In the last trial the stimulus orientation was reversed so that the basset hound now had its head in the left side of space. The results demonstrated a reversal or reduction in the direction of the bisection error in the final reversed stimulus presentation for four of the patients. Savazzi et al. interpreted this finding as evidence that reversal of the left-right canonical orientation of a stimulus may induce a reversal from contralesional to ipsilesional neglect. Given Savazzi et al.'s findings, one may expect that it is possible to determine the left-right orientation of the letter 'Æ' in individuals unfamiliar with this letter. It would be interesting to investigate whether the new 'Æ' letter-cancellation task would elicit both stimulus- and object-centred neglect in individuals unfamiliar with this letter following learning of its left-right orientation. It is possible that the task would elicit stimulus-centred neglect *only*, since maintaining the left-right orientation of the letter is not required to complete the task of circling all of the 'E' letters and/or crossing out all other letters.

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Appendices

Appendix A

Appendix A

Sessions 1-4, All Tasks

Patient HH's correct responses on the left and right side of the page for the Discriminative Cancellation Task and the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
Discriminative Cancellation	Left Gap	0/40	0.00%	20/40	50.00%	20/80	25.00%
	Right Gap	0/40	0.00%	21/40	52.50%	21/80	26.25%
	No Gap	0/40	0.00%	24/40	60.00%	24/80	30.00%
	Total	0/120	0.00%	65/120	54.17%	65/240	27.08%
'Æ' Letter-Cancellation	Letter 'E'	18/64	28.13%	56/64	87.50%	74/128	57.81%
	Letter 'A'	13/64	20.31%	48/64	75.00%	61/128	47.66%
	Letter 'Æ'	38/128	29.69%	97/128	75.78%	135/256	52.73%
	Total	69/256	26.95%	201/256	78.52%	270/512	52.73%
	A-left Letter 'Æ'*	13/48	27.08%	35/48	72.92%	48/96	50.00%
	A-right Letter 'Æ'*	13/48	27.08%	36/48	75.00%	49/96	51.04%
	Letter 'Æ'*	26/96	27.08%	71/96	73.96%	97/192	50.52%
	SumTop'A'+'Æ'*	39/160	24.38%	119/160	74.38%	158/320	49.38%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, Task 2

Patient HH's correct responses on the left and right side of the page for the

'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-	Letter 'E'						
Cancellation	Letter 'A'	5/32	15.63	24/32	75.00%	29/64	45.31%
	Letter 'Æ'	28/64	43.75%	59/64	92.19%	87/128	67.97%
	A-left Letter 'Æ'*	8/24	33.33%	21/24	87.50%	29/48	60.42%
	A-right Letter 'Æ'*	11/24	45.83%	22/24	91.67%	33/48	68.75%
	Letter 'Æ'*	19/48	39.58%	43/48	89.58%	62/96	64.58%
	SumTop'A'+'Æ'*	24/80	30.00%	67/80	83.75%	91/160	56.88%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, Task 3

Patient HH's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-	Letter 'E'	7/32	21.88%	26/32	81.25%	33/64	51.56%
Cancellation	Letter 'A'	8/32	25.00%	24/32	75.00%	32/64	50.00%
	Letter 'Æ'	10/64	15.63%	38/64	59.38%	48/128	37.50%
	Total	25/128	19.53%	88/128	68.75%	113/256	44.14%
	A-left Letter 'Æ'*	5/24	20.83%	14/24	58.33%	19/48	39.58%
	A-right Letter 'Æ'*	2/24	8.33%	14/24	58.33%	16/48	33.33%
	Letter 'Æ'*	7/48	14.58%	28/48	58.33%	35/96	36.46%
	SumTop'A'+'Æ'*	15/80	18.75%	52/80	65.00%	67/160	41.88%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, All Tasks

Patient VR's correct responses on the left and right side of the page for the Discriminative Cancellation Task and the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
Discriminative Cancellation	Left Gap	72/80	90.00%	69/80	86.25%	141/160	88.13%
	Right Gap	73/80	91.25%	69/80	86.25%	142/160	88.75%
	No Gap	80/80	100.00%	78/80	97.50%	158/160	98.75%
	Total	225/240	93.75%	216/240	90.00%	441/480	91.88%
'Æ' Letter-Cancellation	Letter 'E'	126/128	98.44%	127/128	99.22%	253/256	98.83%
	Letter 'A'	81/128	63.28%	111/128	86.72%	192/256	75.00%
	Letter 'Æ'	224/256	87.50%	241/256	94.14%	465/512	90.82%
	Total	431/512	84.18%	479/512	93.55%	910/1024	88.87%
	A-left Letter 'Æ'*	83/96	86.46%	87/96	90.63%	170/192	88.54%
	A-right Letter 'Æ'*	85/96	88.54%	91/96	94.79%	176/192	91.67%
	Letter 'Æ'*	168/192	87.50%	178/192	92.71%	346/384	90.10%
	SumTop'A'+'Æ'*	249/320	77.81%	289/320	90.31%	538/640	84.06%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, Task 2

Patient VR's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'						
	Letter 'A'	20/64	31.25%	49/64	76.56%	69/128	53.91%
	Letter 'Æ'	108/128	84.38%	123/128	96.09%	231/256	90.23%
	A-left Letter 'Æ'*	40/48	83.33%	44/48	91.67%	84/96	87.50%
	A-right Letter 'Æ'*	41/48	85.42%	47/48	97.92%	88/96	91.67%
	Letter 'Æ'*	81/96	84.38%	91/96	94.79%	172/192	89.58%
	SumTop'A'+'Æ'*	101/160	63.13%	140/160	87.50%	241/320	75.31%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, Task 3

Patient VR's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'	63/64	98.44%	63/64	98.44%	126/128	98.44%
	Letter 'A'	61/64	95.31%	62/64	96.88%	123/128	96.09%
	Letter 'Æ'	116/128	90.63%	118/128	92.19%	234/256	91.41%
	Total	240/256	93.75%	243/256	94.92%	483/512	94.34%
	A-left Letter 'Æ'*	43/48	89.58%	43/48	89.58	86/96	89.58%
	A-right Letter 'Æ'*	44/48	91.67%	44/48	91.67%	88/96	91.67%
	Letter 'Æ'*	87/96	90.63%	87/96	90.63%	174/192	90.63%
	SumTop'A'+'Æ'*	148/160	92.50%	149/160	93.13%	297/320	92.81%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, All Tasks

Patient BN's correct responses on the left and right side of the page for the Discriminative Cancellation Task and the 'Æ' Letter-Cancellation Task

Task	Stimulus	Left Side of Page		Right Side of Page		Both Sides of Page	
		Proportion	%	Proportion	%	Proportion	%
Discriminative Cancellation	Left Gap	71/80	88.75%	72/80	90%	143/160	89.38%
	Right Gap	74/80	92.5%	80/80	100%	154/160	96.25%
	No Gap	76/80	95%	79/80	98.75%	155/160	96.88%
	Total	221/240	92.08%	231/240	96.25%	452/480	94.17%
'Æ' Letter-Cancellation	Letter 'E'	93/128	72.66%	126/128	98.44%	219/256	85.55%
	Letter 'A'	96/128	75%	119/128	92.97%	215/256	83.98%
	Letter 'Æ'	206/256	80.47%	248/256	96.88%	454/512	88.67%
	Total	395/512	77.15%	493/512	96.29%	888/1024	86.72%
	A-left Letter 'Æ'*	73/96	76.04%	91/96	94.79%	164/192	85.42%
	A-right Letter 'Æ'*	79/96	82.29%	94/96	97.92%	173/192	90.10%
	Letter 'Æ'*	152/192	79.17%	185/192	96.35%	337/384	87.76%
	SumTop'A'+'Æ'*	248/320	77.50%	304/320	95.00%	552/640	86.25%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, Task 2

Patient BN's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task.

Task	Stimulus	Left Side of Page Proportion	Left Side of Page %	Right Side of Page Proportion	Right Side of Page %	Both Sides of Page Proportion	Both Sides of Page %
'Æ' Letter-Cancellation	Letter 'E'						
	Letter 'A'	41/64	64.06%	55/64	85.94%	96/128	75.00%
	Letter 'Æ'	96/128	75.00%	122/128	95.31%	218/256	85.16%
	A-left Letter 'Æ'*	33/48	68.75%	44/48	91.67%	77/96	80.21%
	A-right Letter 'Æ'*	38/48	79.17%	47/48	97.92%	85/96	88.54%
	Letter 'Æ'*	71/96	73.96%	91/96	94.79%	162/192	84.38%
	SumTop'A'+'Æ'*	112/160	70.00%	146/160	91.25%	258/320	80.63%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4, Task 3

Patient BN's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task.

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'	54/64	84.38%	64/64	100.00%	118/128	92.19%
	Letter 'A'	55/64	85.94%	64/64	100%	119/128	92.97%
	Letter 'Æ'	110/128	85.94%	126/128	98.44%	236/256	92.19%
	Total	219/256	85.55%	254/256	99.22%	473/512	92.38%
	A-left Letter 'Æ'*	40/48	83.33%	47/48	97.92%	87/96	90.63%
	A-right Letter 'Æ'*	41/48	85.42%	47/48	97.92%	88/96	91.67%
	Letter 'Æ'*	81/96	84.38%	94/96	97.92%	175/192	91.15%
	SumTop'A'+'Æ'*	136/160	85.00%	158/160	98.75%	294/320	91.88%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4 Ota and Sessions 1-7 Letter 'Æ', All Tasks

Patient JF's correct responses on the left and right side of the page for the Discriminative Cancellation Task and the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
Discriminative Cancellation	Left Gap	47/120	39.17%	92/120	76.67%	139/240	57.92%
	Right Gap	42/120	35%	98/120	81.67%	140/240	58.33%
	No Gap	49/120	40.83%	106/120	88.33%	155/240	64.58%
	Total	138/360	38.33%	296/360	82.22%	434/720	60.28%
'Æ' Letter-Cancellation	Letter 'E'	130/224	58.04%	210/224	93.75%	340/448	75.89%
	Letter 'A'	133/224	59.38%	201/224	89.73%	334/448	74.55%
	Letter 'Æ'	214/448	47.77%	289/448	64.51%	503/896	56.14%
	Total	477/896	53.24%	700/896	78.13%	1177/1792	65.68%
	A-left Letter 'Æ'*	68/168	40.48%	95/168	56.55%	163/336	48.51%
	A-right Letter 'Æ'*	90/168	53.57%	118/168	70.24%	208/336	61.90%
	Letter 'Æ'*	158/336	47.02%	213/336	63.39%	371/672	55.21%
	SumTop'A'+'Æ'*	291/560	51.96%	414/560	73.93%	705/1120	62.95%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-7 Letter 'Æ', Task 2

Patient JF's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'						
	Letter 'A'	81/112	72.32%	99/112	88.39%	180/224	80.36%
	Letter 'Æ'	127/224	56.70%	141/224	62.95%	268/448	59.82%
	A-left Letter 'Æ'*	36/84	42.86%	44/84	91.67%	80/168	47.62%
	A-right Letter 'Æ'*	58/84	69.05%	60/84	71.43%	118/168	70.24%
	Letter 'Æ'*	94/168	55.95%	104/168	61.90%	198/336	58.93%
	SumTop'A'+'Æ'*	175/280	62.50%	203/280	72.50%	378//560	67.50%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-7 Letter 'Æ', Task 3

Patient JF's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'	60/112	53.57%	104/112	92.86%	164/224	73.21%
	Letter 'A'	52/112	46.43%	102/112	91.07%	154/224	68.75%
	Letter 'Æ'	87/224	38.84%	148/224	66.07%	235/448	52.46%
	Total	199/448	44.42%	354/448	79.02%	553/896	61.72%
	A-left Letter 'Æ'*	32/84	38.10%	51/84	60.71%	83/168	49.40%
	A-right Letter 'Æ'*	32/84	38.10%	58/84	69.05%	90/168	53.57%
	Letter 'Æ'*	64/168	38.10%	109/168	64.88%	173/336	51.49%
	SumTop'A'+'Æ'*	116/280	41.43%	211/280	75.36%	327/560	58.39%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-4 Ota and Sessions 1-7 Letter 'Æ', All Tasks

Patient HT's correct responses on the left and right side of the page for the Discriminative Cancellation Task and the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
Discriminative Cancellation	Left Gap	91/120	75.83%	92/120	76.67%	183/240	76.25%
	Right Gap	99/120	82.50%	97/120	80.83%	196/240	81.67%
	No Gap	109/120	90.83%	112/120	93.33%	221/240	92.08%
	Total	299/360	83.06%	301/360	83.61%	600/720	83.33%
'Æ' Letter-Cancellation	Letter 'E'	213/224	95.09%	215/224	95.98%	428/448	95.54%
	Letter 'A'	197/224	87.95%	211/224	94.20%	408/448	91.07%
	Letter 'Æ'	377/448	84.15%	386/448	86.16%	763/896	85.16%
	Total	787/896	87.83%	812/896	90.63%	1599/1792	89.23%
	A-left Letter 'Æ'*	147/168	87.50%	134/168	79.76%	281/336	83.63%
	A-right Letter 'Æ'*	138/168	82.14%	155/168	92.26%	293/336	87.20%
	Letter 'Æ'*	285/336	84.82%	289/336	86.01%	574/672	85.42%
	SumTop'A'+'Æ'*	482/560	86.07%	500/560	89.29%	982/1120	87.68%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-7 Letter 'Æ', Task 2

Patient HT's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'						
	Letter 'A'	99/112	88.39%	108/112	96.43%	207/224	92.41%
	Letter 'Æ'	191/224	85.27%	196/224	87.50%	387/448	86.38%
	Total	290/336	86.31%	304/336	90.48%	594/672	88.39%
	A-left Letter 'Æ'*	73/84	86.90%	65/84	77.38%	138/168	82.14%
	A-right Letter 'Æ'*	71/84	84.52%	79/84	94.05%	150/168	89.29%
	Letter 'Æ'*	144/168	85.71%	144/168	85.71%	288/336	85.71%
	SumTop'A'+'Æ'*	243/280	86.79%	252/280	90.00%	495/560	88.39%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.

Sessions 1-7 Letter 'Æ', Task 3

Patient HT's correct responses on the left and right side of the page for the 'Æ' Letter-Cancellation Task

		Left Side of Page		Right Side of Page		Both Sides of Page	
Task	Stimulus	Proportion	%	Proportion	%	Proportion	%
'Æ' Letter-Cancellation	Letter 'E'	105/112	93.75%	109/112	97.32%	214/224	95.54%
	Letter 'A'	98/112	87.50%	103/112	91.96%	201/224	89.73%
	Letter 'Æ'	186/224	83.04%	190/224	84.82%	376/448	83.93%
	Total	389/448	86.83%	402/448	89.73%	791/896	88.28%
	A-left Letter 'Æ'*	74/84	88.10%	69/84	82.14%	143/168	85.12%
	A-right Letter 'Æ'*	67/84	79.76%	76/84	90.48%	143/168	85.12%
	Letter 'Æ'*	141/168	83.93%	145/168	86.31%	286/336	85.12%
	SumTop'A'+'Æ'*	239/280	85.36%	248/280	88.57%	487/560	86.96%

*Letter 'Æ' at the 90° and 270° angle of rotation are not included in the results.