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UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL AND HUMAN SCIENCES

Psychology

Visual and Cognitive Processing in Hemispatial Neglect

by

Louise-Ann Leyland

Thesis for the degree of doctor of philosophy

March 2014

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This thesis is dedicated to my parents,

Patricia June Leyland

and the late Bryan Edward Leyland

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ABSTRACT

FACULTY OF SOCIAL AND HUMAN SCIENCES

Psychology

Doctor of Philosophy

Visual and Cognitive Processing in Hemispatial Neglect

Louise-Ann Leyland

A number of theoretical issues can be investigated by examining patterns of eye movements in hemispatial neglect. For example, how the brain codes spatial information, how oculomotor behaviour relates to perception and awareness and what affects the allocation of spatial attention. These interesting questions will be outlined and discussed in a literature review presented in Chapter 1. Experiment 1 involved collection of behavioural and eye movement data obtained from a chronic neglect patient (SS), stroke controls and older adult controls during completion of the three cancellation tasks from the Behavioural Inattention Test (Wilson, Cockburn, & Halligan, 1987). This revealed underlying deficits that were contributing to neglect. Not only was SS's visual sampling of the neglected information limited, she also exhibited deficient and delayed processing of contralesional information when it was sampled. Experiments 2 and 3, through newly developed cancellation tasks, examined whether different frames of reference for the coding of spatial information operate in neglect. The findings indicated that an allocentric (object-based) reference frame was not exhibited by patients with neglect when searching for specific targets letters, or clocks displaying specific times. Importantly, an egocentric reference frame based upon the position of gaze was able to account for the neglect behaviour exhibited. This suggests that many findings interpreted as evidence for allocentric neglect may be explained by the left side of the object falling to the left of the point of fixation, and therefore results from egocentric neglect. Experiment 4 determined that the reference frame operating in neglect could be affected by task demands. As a processing deficit for contralesional information was shown in all the previous experiments reported in this thesis, Experiment 4 also aimed to investigate the stages of visual and cognitive processing that may be disrupted in neglect for contralesional information. The final chapter summarises the main findings and discussion of the main theoretical questions that have been outlined is presented. Conclusions are drawn with regards to these issues, which have previously been considered elusive functions of the brain (Buxbaum, 2006).

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Abbreviations

AGD Average Gaze Duration

BIT Behavioural Inattention Test

CT Computed Tomography

ERP Event Related Potential

FES Functional Electrical Stimulation

FL Far Left

fMRI functional Magnetic Resonance Imaging

FR Far Right

ICA Internal Carotid Artery

LED Light-Emitting Diode

LH Left Hemianopia

LVF Left Visual Field

RVF Right Visual Field

MCA Middle Cerebral Artery

NL Near Left

NP Neglect Patient

NR Near Right

OAC Older Adult Control

R Right

SC Stroke Control

SEAN Simultaneously investigating Egocentric and Allocentric Neglect

SS Neglect patient included in Experiment 1

PACs Partial Anterior Circulation infarct

PET Positron Emission Tomography

TACs Total Anterior Circulation infarct

TIA Target Identification Accuracy

Chapter 1. Literature Review of Visual and Cognitive Processing in Hemispatial Neglect

In this literature review, firstly hemispatial neglect will be defined and characterised. The tests used to diagnose and determine the severity of this disorder will be described and evaluated in terms of their sensitivity in identifying the presence of neglect. It is important to note that this disorder is distinguished from another, hemianopia, by a fundamental difference with regard to the visual and attentional mechanisms underlying the disorders (Walker, Findlay, Young, & Welch, 1991).

Frames of reference that may operate in neglect are outlined and evidence is presented for and against the existence of two main types of neglect: egocentric and allocentric. This leads to a discussion of the underlying mechanisms that may be deficient in neglect and introduces the value of eye movement recording and analyses for enhanced understanding of factors contributing to neglect of information and spatial processing. Factors that affect both eye movements and the frames of reference operating in neglect will also be considered. Finally, the chapters presented in this thesis will be outlined and the theoretical questions that the experiments address will be specified.

1. Hemispatial Neglect: Characterisation, Incidence and Effect

Strokes are, unfortunately, frequent and devastating, with around 150,000 people a year in the UK suffering from a stroke resulting in brain damage (The Stroke Association, 2011). Lesions can result from ischemia (lack of blood to an area) or haemorrhage (ruptured blood vessels leading to a bleed inside the brain). Most stroke survivors experience severe cognitive and physical disabilities resulting from brain damage which can persist for the remainder of their lives (The Stroke Association, 2011). Stroke is the most common cause of chronic physical disability in adults (Feigin, Barker-Collo, McNaughton, Brown, & Kerse, 2008).

Hemispatial neglect is an acquired neuropsychological condition that frequently results from stroke (Stone et al., 1991). This disorder involves decreased awareness of an area of space. The area of space most frequently neglected is contralateral (opposite) to the lesioned hemisphere (contralesional). Often patients with hemispatial neglect fail to eat food on the contralesional side of their plate, do not apply make-up to/shave that side of their face, and do not respond to people on the neglected side (e.g. Bisiach, 1996). It is as if that side of space has vanished from their representation of the world.

Chapter 1.

Hemispatial neglect is a debilitating disorder which is a strong predictor of hampered functional recovery and a major disruptive factor impeding rehabilitative success following stroke (Denes, Semenza, Stoppa, & Lis, 1982; Jehkonen et al., 2000; Kinsella & Ford, 1984; Smith, Akhtar, & Garraway, 1983; Sunderland, Wade, & Langton-Hewer, 1987). Patients with neglect show reduced independence, with extensive and more demanding motoric rehabilitation compared to stroke survivors without neglect (Denes et al., 1982). The effectiveness of rehabilitative techniques for motoric and cognitive deficits may also be reduced in neglect due to a high proportion of neglect patients experiencing anosognosia, a condition whereby patients do not acknowledge their deficit (e.g. Stone, Halligan, & Greenwood, 1993) or anosodiaphoria (indifference to their deficits; Gainotti, 1972, as cited in Denes et al., 1982). These additional complications can lead to a failure in neglect patients adopting compensatory responses and behaviours to aid attention to the usually neglected side of space.

It is important to note that the failure to report information on the neglected side of space is not due to a sensory and/or motor loss, although these aspects may be implicated (e.g. the motor intention hypothesis, Karnath, Milner, & Vallar, 2002), but due to a deficit of attention (Behrmann, Ghiselli-Crippa, Sweeney, Di Matteo, & Kass, 2002). It has been suggested that neglect reflects a fundamental failure in allocating attention to the contralesional side of space, and it is that which causes the perceptual deficit (e.g. Rizzolatti & Carmada, 1987). It has been demonstrated that patients are able to accurately perceive information on the neglected side if they are prompted to attend to it (e.g. Grabowecky, Robertson, & Treisman, 1993); although there is evidence that this is not always the case, as they mat not perceive information even if they do look at it (Forti, Humphreys, & Watson, 2005; Walker, Findlay, Young, & Lincoln, 1996; see *Eye Movements in Hemispatial Neglect*, below). There is also suggestion that there is no ocular deficiency in neglect (e.g. Van der Stigchel & Nijboar, 2010).

Even though it is often assumed that patients fail to report information because they do not look to the contralesional area, participants can saccade (make an eye movement) to the contralateral side of space if a target is presented there (Van der Stigchel & Nijboar, 2010). However, whether they then can sufficiently, and efficiently, process that information in order to accurately report it once they have fixated it is not entirely clear. This is the main question outlined in the section entitled *Mechanisms Underlying Neglect: The Value of Eye Movement Analyses.* The reason that the attentional deficit is contralesional is due to the anatomy of the visual system. The visual field is split vertically into left and right visual fields for each eye (Buser & Imbert, 1992). The external environment is processed contralaterally, such that information presented to the left visual field (LVF) is predominantly processed by the right hemisphere, and vice-versa (Michael-Titus, Revest, & Shortland, 2007). Therefore, the area of space predominantly ignored in hemispatial neglect is contralesional to the damage. However, bilateral inattention can occur in neglect (see Bisiach & Vallar, 1988), with contralesional and ipsilesional information (information on the same side of the lesion) being missed, depending on the reference frame that is operating for the task (see the section on *Spatial Frames of Reference* in Neglect). Nevertheless, typically patients fail to attend to the area of space contralateral to the lesion, as well as information falling within the LVF. This is an important distinction and there is an on-going debate with regard to the spatial frames of reference that are operating in neglect.

Hemispatial neglect is observed with greater frequency and severity after lesions to the right hemisphere compared to when there are left hemisphere lesions, resulting in the left side of space being neglected (e.g. Denes et al., 1982; Halligan, Marshall, & Wade, 1990; Stone et al., 1993). Up to 85% of patients suffering from right hemisphere stroke demonstrate neglect, if only for a short period of time (e.g. Denes et al., 1982; Stone et al., 1993). Additionally, hemispatial neglect is more likely to result after right parietotemporal lesions (Brain, 1941), which may be a result of the right hemisphere serving many spatial functions (Coull & Nobre, 1998; Corbetta, Miezin, Shulman, & Peterson, 1993; Nobre et al., 1997) which damage to this area disrupts. Therefore, throughout this review, where appropriate, the neglected side of space will be referred to as the left side.

Even though sometimes neglect recovers after the acute phase has passed (Kinsella & Ford, 1985; Stone et al., 1993), 10% of stroke patients still present with neglect three months after the stroke occurred (Hurwitz & Adams, 1972; Stone, Patel, Greenwood, & Halligan, 1992). Thus, given that individuals suffering from visual neglect have a hindered rehabilitation, it is important to understand the underlying deficits involved in this disorder in order to develop effective rehabilitative techniques (see *Mechanisms Underlying Neglect: The Value of Eye Movement Analyses* section). Neglect is also of scientific interest, due to the insight gained regarding elusive functions of the brain, such as how the brain codes spatial information, allocates attention and processes visual information (Buxbaum, 2006), and how these factors may interact. These will be considered in detail later in the review. First, the various ways in which neglect is currently measured and neglect patients' typical performance on the tasks will be discussed.

1.2 The Behavioural Inattention Test

The Behavioural Inattention Test (BIT) was developed to diagnose and determine the severity of neglect (Wilson, Cockburn, & Halligan, 1987). This battery is composed of six different conventional tests and nine behavioural tasks. The conventional tests are the line, star and letter cancellation tasks; figure and shape copying; representational drawing; and line bisection. The behavioural tests are menu reading; picture scanning; telephone dialling; article reading; telling and setting the time; coin sorting; address and sentence copying; map navigation; and card sorting. Two of the most commonly used sub-tests to diagnose and determine the severity of neglect are the cancellation and figure copying tasks (Black et al., 1994; Parton, Malhotra, & Husain, 2009), which are employed in experiments reported in this thesis. Cancellation tasks require the patient to find and cross through all target items that are displayed amongst distractor items on a piece of paper presented in front of them (e.g. crossing through all the lines in the line cancellation task, see *Figure 1*). Neglect patients often fail to cross through target items lying on the left side of the stimulus, which corresponds to information on the patients' left side. Figure copying tasks require the patient to draw an image placed in front of them, with patients routinely failing to produce information presented on the left side of the picture (Black et al., 1994; see *2.2 The Value of Figure Copying Tasks in Revealing Frames of Reference Operating in Neglect* for further information).

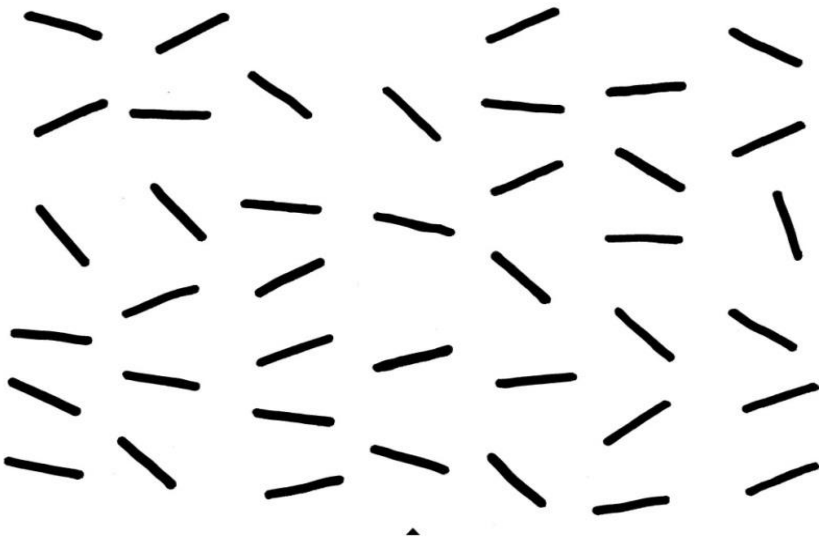

Figure 1. The line cancellation task from the Behavioural Inattention Test. This, along with the letter and star cancellation tasks, was employed in Experiment 1 reported in Chapter 2. The participants were instructed to use a pen to 'cancel' all the lines that they could see on the page.

The three cancellation tasks included in the BIT are the line, letter and star cancellation tasks. The line cancellation task is composed of 40 short lines of varying orientations arranged in seven columns each containing six or four lines (see *Figure 1*). This is a detection task only, as patients are required to cross through all the lines presented on the page and therefore do not have to discriminate between targets and distractors (as there are no distractors present). The letter cancellation task contains 5 lines of 34 random capital letters, containing 40 target letters to be identified by the participant (‘E’s and ‘R’s [see *Figure 2*]). The star cancellation task is composed of small and large stars, along with short words and capital letters (see *Figure 3*). The participant is required to ‘cancel’ the 54 small stars with a pen. Frequently, neglect patients fail to cross through targets that lie to the left (the contralesional side) of the page and will also start the task on the right (the ipsilesional side), which is unusual for control participants (e.g. Forti et al., 2005; Behrmann, Watt, Black & Barton, 1997).

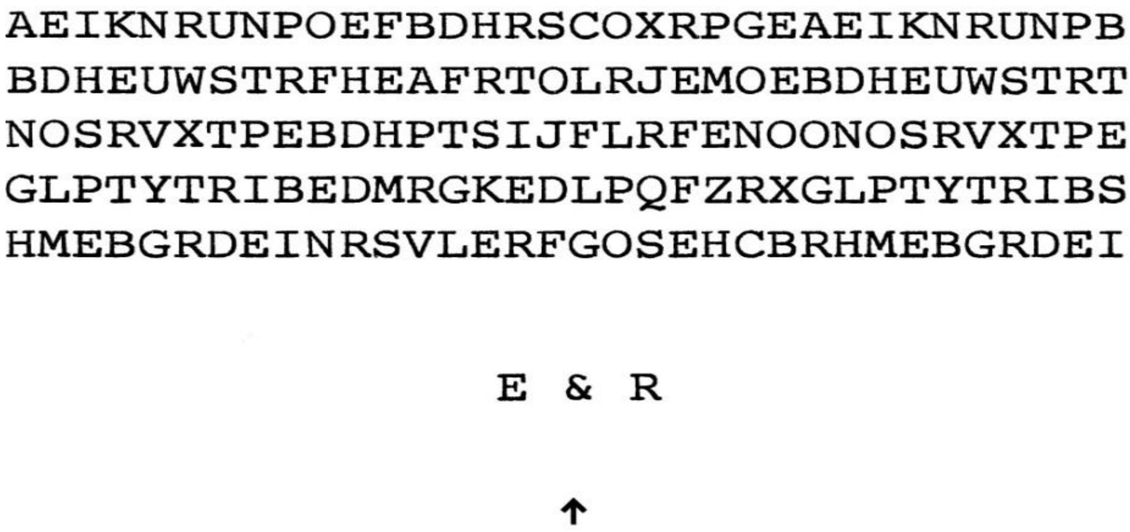

Figure 2. The letter cancellation task from the Behavioural Inattention Test. The participants were instructed to cross through the letters ‘E’ and ‘R’ in the stimulus.

Figure 3. The star cancellation task from the Behavioural Inattention Test. Patients are instructed to mark all the small stars on the page with a pen after the experimenter demonstrates the difference between the large and small stars in the task and crosses through two of the central small stars.

1.2.1 Sensitivity and Reliability. The cancellation tasks are widely used in clinical settings due to the fact that they are simple and easy to administer at the bedside, and are also scored objectively. These tests are regarded as sensitive pen-and-paper measures (Azouvi et al., 2002) for demonstrating whether neglect is present. A limited number of investigations have been conducted to determine the sensitivity of the sub-tests included in the BIT. For a test to be sensitive, the task should place demands on underlying deficits experienced by neglect patients and, therefore, reveal whether a patient has neglect through their failure to successfully complete the task. Studies have demonstrated that increasing demands on visual selective attention, for example presenting targets amongst distractors that are required to be distinguished from one another, decreases performance in visual search tasks in patients with neglect (Ferber & Karnath, 2001). For example, it has been established that cancellation tasks requiring search for target elements, like the letter and star cancellation tasks in the BIT, are more sensitive than the simple line bisection tests (Ferber & Karnath, 2001) that involves participants placing a vertical line at the midpoint of a horizontal line, outlined next. The main sub-tests that are used in isolation to diagnose neglect within the clinical setting will now be outlined with regards to the underlying deficit(s) they reveal and the sensitivity of the test in indicating neglect is present will be considered.

Line bisection. In the line bisection task from the BIT the participant is required to place a vertical line at the midpoint of three horizontal lines that are presented at different positions on the page. Typically patients with neglect bisect the line further to the right. Some researchers have postulated neglect patients bisect the line further to the right because they have failed to perceive the left side of the line or underestimated its extent. This has been supported by research that has demonstrated that patients failed to fixate to the left of the centre of the line and, therefore, may not have been able to encode it (Ishiai, Furukawa, & Tsukagoshi, 1989).

An alternative explanation has been offered by McIntosh, Schindler, Birchall, and Milner (2005). They provided evidence that line bisection error was due to the patients being unable to concurrently represent both sides of the line, which would occur even if the left side were to have been fixated. However, eye movements were not recorded during this task, and therefore, it is not clear whether the left side of the line was neglected because it was not fixated, or because it was fixated but not represented by the neglect patients. This is an important theoretical issue that will be outlined later in this review and investigated by the experiments conducted on neglect patients using eye movement methodology reported in Experiments 1-4 in this thesis. The contribution of eye movement research to the understanding of neglect will be outlined in the section entitled *Mechanisms Underlying Neglect: The Value of Eye Movement Analyses.*

In an investigation conducted by Ferber and Karnath (2001) on the sensitivity of tasks in revealing neglect, they compared neglect patients performance on the line bisection and cancellation tasks. They found that when the patient's accuracy on the line bisection task was taken into consideration in isolation (i.e. without performance measures from any other test of neglect), almost 40% of the patients were not identified as having neglect. This raises the question of the sensitivity of this test in revealing neglect or even whether this test reflects a specific type of deficit of neglect. Milner and McIntosh (2005) note that double dissociations between performance on line bisection tasks and other tests of neglect, such as cancellation tasks, occur in neglect. This means that these tests cannot be measuring the same unitary disturbance.

Cancellation tasks. The BIT includes the line, letter and star cancellation tasks, which are regularly used in isolation to identify neglect and have been suggested to be more sensitive measures of neglect than the line bisection task (Ferber & Karnath, 2001).

Additionally, differences in the sensitivity of the cancellation tasks in revealing neglect have been established. Ferber and Karnath (2001) compared accuracy on three cancellation tasks that were similar to the line, letter and star cancellation tasks included in the BIT for 35 neglect patients. The letter cancellation, which included 60 target items (the letter ‘A’) pseudo-randomly interspersed with distractors, was found to have the highest sensitivity of all the tasks employed. This was indexed by 94% of patients with neglect being accurately diagnosed when the letter cancellation task results were considered in isolation. Furthermore, this test had the highest percentage of omitted targets overall in the neglect group (62%) than any of the tests administered.

The star cancellation task was the next most sensitive task, with 87% of stroke patients being correctly identified compared with only 71% when the line cancellation task was used. The line cancellation task is relatively less complex, as all the items on the page are required to be crossed through (as such this is a detection-task only). The line cancellation task includes fewer target items than the letter and star cancellation tasks. Therefore, it appears that the sensitivity of the tasks relate to the physical properties of the stimulus (e.g. density of the information presented, number of targets and distractors, size of the targets) and task demands. As tasks get more complex, they become more visually and cognitively demanding, resulting in poorer performance in neglect. For example, when conducting search for two items (as in the letter cancellation task) as opposed to one (as in the star), extent of neglect is exacerbated, as patients find it harder to identify targets overall in the letter cancellation task. It seems likely that this is due to the increased cognitive load in this task. Tasks with fewer cognitive demands may be less sensitive to neglect. This will be considered further in Experiment 1.

Physical properties of the letter cancellation task that may affect the task’s difficulty are, firstly, the similarity of the distractors to the target items and the systematicity of search that is required for this task. To expand on the first difference, in the letter cancellation task other letters were employed as distractors for the target letter, ‘A’, so the distractors were highly similar to the target and harder to distinguish than the distractors and targets were in the star cancellation task. When targets and distractors are more difficult to distinguish, this may place higher demands on cognitive processing when searching for targets (Ferber & Karnath, 2001), as no ‘pop out’ effect occurs (Treisman & Gelade, 1980) for the target items. Targets that do not ‘pop-out’ fail to be salient items as they do not possess any features that can be detected (and distinguished from distractors) pre-attentively (i.e. without an eye movement being made to that target). The star cancellation task included many different distractors (e.g. words, letters, large stars), and these, arguably, can be more easily discriminated from the targets (due to size and shape). The more similar a target is to a distractor, the less salient that target item is (Aglioti, Smania, Barbieri, & Corbetta, 1997). Aglioti et al. (1997) found that neglect patients' performance on a visual search task was exacerbated when the target was low in salience. Aglioti and colleagues believed that the processing of targets with low salience engaged higher focal attention so that it could be distinguished from the distractors. As mentioned earlier, the line cancellation task does not require the patient to distinguish between targets and distractors as it is a detection task, and therefore is the least cognitively demanding of the three tasks and the least likely to identify neglect in isolation.

The second possible explanation for the increased sensitivity of the letter cancellation task is that reading may induce more systematic (left-to-right, line-by-line searching) and focused search. That is to say, reading starts on the left of a line in English and therefore there is likely to be an inherent tendency, when searching for target items in a letter cancellation task, to look at each letter along the horizontal extent of that line from left-to-right. Any disruption to this systematicity, likely experienced in neglect due to disinclination to explore the left side of space, could adversely affect performance.

Azouvi et al. (2002), like Ferber and Karnath (2001), also found that tests with a strong visual component were more likely to reveal neglect. A reading task, composed of 12 lines (of which 5 were to be read by the participant) was the most sensitive measure compared to the other tests included in the battery. The bells test, in which participants are required to search a vast visual array composed of target items (bells) and distractors (a number of different objects) presented pseudorandomly on an A4 sheet of was deemed as the second most sensitive test. Furthermore, neglect appeared to be exacerbated by the following: increased density of the elements comprising the stimulus (i.e. targets and distractors being heavily concentrated), random distribution of targets amongst distractors and increased numbers of distractors (Azouvi et al., 2002).

In summary, there appear to be two main aspects contributing to cancellation tasks' sensitivity in identifying neglect. The first is the physical properties of the stimulus and the second is the level of task difficulty; the latter relates to the number of cognitive demands the test requires in order to be successfully completed. The physical properties of the stimulus (such as density of the information presented in the task) affect the task difficulty (i.e. the task is harder to complete when the stimulus has a high density of targets and distractors). It is currently not known *why* these aspects affect test sensitivity and modulate the extent of information that is neglected on a test. The fact that different cognitive demands affect the extent of neglect exhibited, suggests that the more information there is to process (e.g. many targets and distractors being present), or the harder it is to process information (e.g. similar targets and distractors being present in the task), the poorer a neglect patients' performance will be. This in turn would imply that a processing deficit of contralesional information may be contributing to poor performance in visual search tasks. This is another main theoretical issue that will be considered later in this review under the *Mechanisms Underlying Neglect: The Value of Eye Movement Analyses* section. The offline measures these tasks provide are not informative with regards to *how* attention is allocated in neglect. The measurement of eye movements is now widely recognised within cognitive science as a valuable experimental technique to investigate human visual and cognitive and attentional processing (Liversedge & Findlay, 2000; Rayner, 1998). No empirical investigations have been conducted measuring neglect patients' eye movements as they complete cancellation tasks, that are similar to those incorporated in the BIT. The letter, star and line cancellation tasks were employed as experimental stimuli in Experiment 1, reported in Chapter 2, in order to investigate visual, cognitive and attentional processing in neglect during these visual-motor tasks that vary in complexity.

Figure copying. Figure copying it is also a conventional test contained in the BIT. It is the second most used test for identifying neglect (Bowen, McKenna, & Tallis, 1999) and it is easy to administer and is sensitive to the underlying deficits in neglect (Halligan, Marshall, & Wade, 1990; Halligan & Robertson, 1992). The task provokes a strong engagement of focal attention due to requiring encoding of visual information to be copied, if an attentional deficit exists then the task is likely to expose deficits, such as omissions of elements on the contralateral side (Ishiai, Seki, Koyama, & Yokota, 1996), and should reflect the dysfunctional spatial representations that exist in neglect. Additionally, the task is cognitively challenging as it requires complex and resource demanding visual-motor responses in the contralateral hemispace (Azouvi et al., 2002). Azouvi et al. (2002) found that figure copying was the third most sensitive test of visual neglect from a battery of tests, following the BIT letter cancellation task and the Bells test.

However, the stimuli have to be designed appropriately in order to maximise the sensitivity of the test and minimise subjectivity in scoring the behavioural assessment. For example, copying of a single item has been shown to have low sensitivity and high subjectivity (Bailey, Riddoch, & Crome, 2006; Johannsen & Karnath, 2004). Johannsen and Karnath (2004) investigated figure copying in acute and chronic patients with severe spatial neglect. Initially, 35 patients were identified and assessed on copying a multi-object scene consisting of four figures: a house, a tree, a car, and a fence. Twenty-five of the patients were reassessed more than 1 year post-stroke, of which 40% were still showing neglect. All patients showed neglect for contralesionally located objects in the acute phase, indicating that this test was sensitive to the deficits experienced in neglect. At follow up, 60% of the patients with chronic neglect still failed to copy elements on the left. In four of the patients' data that were selectively reported by the authors, two of the patients showed the same amount of deficit in this task as during the acute phase, despite being above the cut-off for diagnosis of neglect using other standard tests. This shows that, on occasions, picture copying of a multi-element scene can provide a more sensitive measure of persistence of neglect in chronic cases than other tests that are used to diagnose the disorder. The reasons for this will be considered further in the section entitled *2.2 The Value of Figure Copying Tasks in Revealing Frames of Reference Operating in Neglect*.

Johannsen and Karnath (2004) concluded that the demands of copying tasks were sensitive enough to determine residual neglect in a considerable proportion of chronic patients, an observation that had not previously been made. Furthermore, the authors argued that these results demonstrated that exploratory abilities of the patients with severe spatial neglect directly affected their performance in multi-object copying. However, they had no direct measure of the exploratory behaviour of patients during the task. In order to directly determine the oculomotor behaviour of neglect patients during the copying task, eye movements need to be examined. Furthermore, eye movements during such tasks could provide a more sensitive measure of how attention is allocated during completion of these tasks and the underlying deficits involved in neglect. For example, eye movement experiments can determine whether information is neglected on the left side of space because it was not visually sampled, or whether information is fixated in that region but still not processed sufficiently in order for the patient to respond accurately (see the section on *Mechanisms Underlying Neglect: The Value of Eye Movement Analyses*). No experimental investigations have been carried out to investigate the eye movements that neglect patients make when they are copying and reproducing a picture.

1.3 Hemispatial Neglect and Hemianopia

It is important to distinguish between hemispatial neglect, which is a failure to respond or report stimuli in the contralateral hemispace, and hemianopia, where the individual has visual field loss on one side (homonymous hemianopia). The latter is not a result of an attentional deficit but occurs due to a visual field defect caused by brain damage, usually, to the occipital lobe. The underlying deficits in these two disorders are very different but can be hard to disentangle (Walker, Findlay, Young, & Welch, 1991). Hemispatial neglect and hemianopia can occur in isolation or simultaneously in an individual who has suffered brain damage. Patients failing to report stimuli in the LVF if eye movements are not allowed could be due to either neglect or hemianopia. Failure to detect LVF stimuli in hemianopia is due to the patient being blind in that visual field. Neglect results in LVF information not being reported to the failure in attending to that region of space.

Differences between neglect and hemianopia in performance on standard neuropsychological tests of neglect have been demonstrated. Hemianopic patients tend to misplace the midpoint of a line in line bisection tasks towards the (contralesional) blind visual field, whereas the bisection error of a patient with neglect more often than not is away from the neglected visual field (i.e. ipsilesional; Barton, Behrmann, & Black, 1998). It seems counterintuitive for hemianopic patients to place a line on a point that is within the area of defective vision but this behaviour is likely to be a result of compensatory strategies employed by these patients to try and overcome their deficits (e.g. Pambakian, Mannan, Hodgson, & Kennar, 2004; Parton, Malhotra, & Husain, 2009). It has been determined that compensatory eye movements are made by hemianopic patients in order to bring information into their intact RVF (e.g. Behrmann et al., 1997). Such compensatory strategies are rarely present in neglect.

An easy and effective way to determine visual field defects in patients is to use Confrontation Visual Field Testing (Johnson & Baloh, 1991). This is a clinical bedside examination where the examiner evaluates the extent of the patient’s visual field by asking them to report when they can see points that are presented to them within each quadrant of their visual field, whilst viewing monoculary. This has been shown to be as reliable as other instruments, such as automated perimetry (Johnson & Baloh, 1991), which requires specialist equipment and a considerable amount of time to conduct and can over-estimate apparent visual field defects. However, if a patient presents with neglect, the patient is likely to perform poorly on confrontation visual field testing even if they do not have a visual field defect. To be clear, not only would the patient fail to report a stimulus presented to their LVF if they were blind in that region (i.e. had a visual field defect), they may also fail to report the stimulus due to their neglect and neglect has been demonstrated to exacerbate visual field defects (Halligan, Marshall, & Wade, 1990). However, if a patient reports a stimulus on the left when presented in isolation and not when simultaneously presented with an ipsilesional stimulus, this would indicate that they did not have a visual field defect (as they can detect the stimulus on the left when presented in isolation). This relates to extinction of stimuli, which is often experienced by neglect patients (Geeraerts, Lafosse, Vandenbussche, & Verfaille, 2005) but can dissociate from neglect suggesting there may be different underlying mechanisms (Vossell, 2014). Confrontation visual field testing can determine whether a patient exhibits extinction. Extinction is the inability to detect contralesional stimuli during simultaneous presentation with ipsilesional stimuli but an ability to detect contralesional stimuli in isolation. If a patient was unable to detect LVF stimuli in isolation and during presentation of simultaneous ipsilesional stimuli, this may be due to a visual field defect (hemianopia or quadrantanopia, with the latter being a blind quarter of the visual field). This would be a conservative report as this pattern of behaviour may be due to neglect and not a result of a visual field defect. If a patient accurately detected LVF stimuli when it was presented in isolation but could not accurately detect LVF stimuli during bilateral stimulation, the inability to report that information could be interpreted as likely to be a result of extinction and/or neglect.

It can be deduced from the studies outlined above that hemispatial neglect is a heterogeneous disorder, and is often difficult to distinguish from hemianopia. A critical element involved in the disorder of neglect, which does not exist in hemianopia, is that the operation of different frames of reference affects the information that is or is not attended to. This is an important point that will be returned to several times during the course of the thesis. Frames of reference do not change similarly in patients with hemianopia. Thus, insight can be gained with regard to how space is normally represented by the brain by examining which areas of space are not attended to in neglect.

2. Spatial Frames of Reference in Neglect

A fundamental issue that researchers have investigated is the nature of the spatial representational mechanisms underlying neglect. One important question concerns how spatial information in the visual array is coded and represented by the brain. A further question relates to a patient neglecting the left side of space, what the neglect is left of. ‘Left’ can refer to a number of different spatial locations. For example, it can denote the patient’s left (with reference to their body, head and/or eye vertical midline), the left of the scene at which they are looking, or even the left of individual objects within that scene. Spatial information is coded by the brain in relation to a set of coordinates with which left and right are defined, and this depends upon the frame of reference that is operating (Halligan, Fink, Marshall, & Vallar, 2003). In the next section possible frames of reference will be considered.

2.1 Frames of Reference for the Coding of Spatial Information

Two main spatial reference frames have been emphasised in research into neglect, namely, egocentric and allocentric frames of reference. Egocentric reference frames involve coding of spatial information with respect to the viewer's position. 'Left' is defined in relation to the midpoint of the viewer (with this midpoint potentially relating to a number of body parts). If this reference frame was operating in neglect then everything to the patient's left would be ignored. Egocentric reference frames may be based upon eye, head and/or body position (Behrmann et al., 2002). The midpoint of the egocentric reference frame (with which left and right are defined) may lie at the vertical midline of any one of these parts. Evidence that has arisen from investigations into egocentric reference frames indicates that spatial information is coded relative to the position of gaze (e.g. Behrmann et al., 2002; Colby, & Goldberg, 1999). Egocentric reference frames based on eye positioning would result in information falling in the LVF being neglected. However, the true extent to which these different egocentric reference frames are independent is still contentious in the field (Behrmann et al., 2002).

In contrast to egocentric reference frames, allocentric reference frames emphasise each individual object within the visual field. Left and right are defined by the left and right of the object, regardless of the object's orientation or its position in relation to the viewer (Behrmann & Moscovitch, 1994). For example, allocentric reference frames would result in the numbers seven to eleven on an upright analogue clock being coded as the left side (which, if the clock was presented centrally to the individual, would also be left of the egocentric midpoint). The allocentric left remains the same even when the clock is inverted (and therefore is no longer aligned with the egocentric frame of reference, as the left side of the clock would now be on the right side of the individual). In this case, the left of the egocentric midpoint would now incorporate the numbers from one to five (see *Figure 4*). This type of neglect is often referred to as 'object-centred' neglect, as information to the left of the object's centre is neglected. This is what will be referred to as allocentric neglect throughout this thesis. Object-centred neglect is differentiated from 'object-based' neglect, which refers to the neglect of the left side of an object regardless of its position in relation to the viewer, but not irrespective of its orientation. This would result in the left side of an object being neglected even if that information was to the right of an egocentric midline. However, it does not necessarily mean that the same information within the object would be neglected if the orientation of the object was manipulated (i.e., the midline of the object does not rotate with the object as is implied with object-centred neglect).

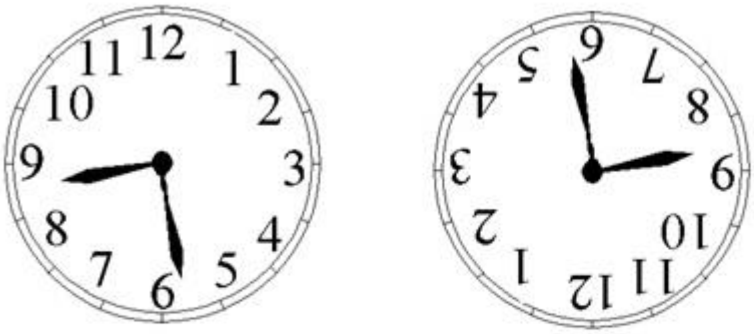

Figure 4. An analogue clock presented upright and inverted. The operation of allocentric and egocentric reference frames would result in differential neglect of these clocks. Allocentric (object-centred) neglect would result in the numbers 7-11 being neglected, regardless of orientation or position of the clock relative to the viewer. However, with egocentric neglect, the numbers 7-11 would be neglected when the clock is upright and presented centrally to the viewer, but numbers 1-5 would be neglected when the clock was inverted.

It is not yet clear which of these spatial reference frames operates in neglect or if multiple frames of reference may operate simultaneously (Chatterjee, 1994). In normal viewing conditions they are often confounded, with stimuli being presented centrally to the patient. The midline of the egocentric (viewer-centred) reference frame is thus aligned with the midpoint of the allocentric (object-centred) reference frame. One way to investigate the influence each reference frame has on neglect is to manipulate these midpoints, presenting them out of alignment with each other. For example, placing the object within the intact (non-neglected) side of space, so that the left half of the object is no longer on the left side of the individual. However, if patients are free to move their head and/or eyes to inspect the object presented on their right, the left of the object may still be neglected due to falling, once again, to the left of the egocentric midline if this is defined with respect to the head or eyes. Altering the orientation is one way to overcome this problem (e.g. rotating the object by 90^{o} or 180^{o}), as the left side of the object (allocentric reference frame) would no longer fall on the left side of the individual (egocentric reference frame; as in the clock example, above), even if a patient oriented their eyes/head to the centre of that object.

Predominantly, studies that have investigated reference frames have reported neglect of stimuli in the left side of space relative to the egocentric position (e.g. Behrmann & Moscovitch, 1994). Behrmann and Moscovitch (1994) presented line drawings (such as a cow) to neglect patients, which were surrounded by four colour coded regions (see *Figure 5*). Patients failed to report the colours on the left side relative to egocentric frames of reference (yellow and blue). Additionally, those colours left of the egocentric midpoint were still neglected even when the picture was rotated by 90^{o}. If an allocentric reference frame was operating, patients would neglect colours on the left of the *object* when it was rotated (blue and red). However, the neglect behaviour was dependent on the egocentric reference frame, with information on the patient's left continuing to be ignored.

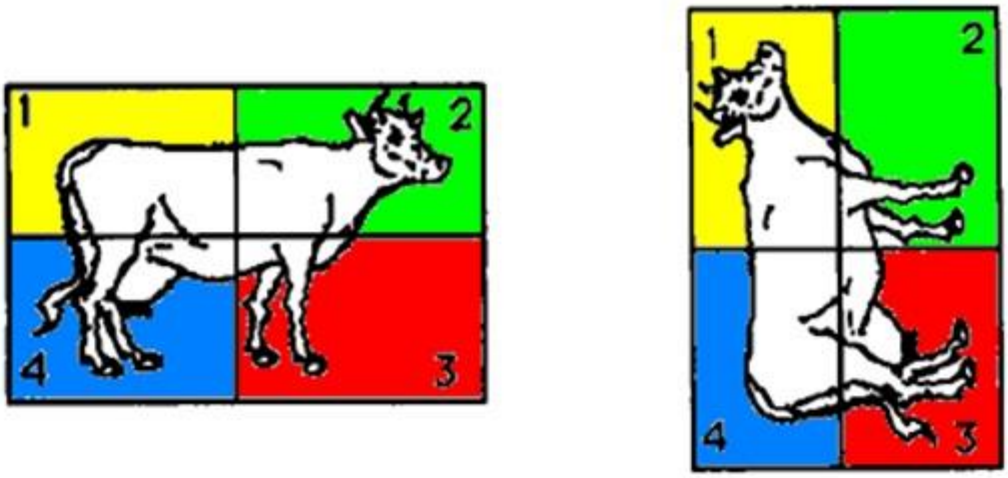

Figure 5. An image of a cow, either upright or rotated by 90^{o}, surrounded by four sections presented in different colours. These were the stimuli employed in the study conducted by Behrmann and Moscovitch (1994).

Nevertheless, as Behrmann and Moscovitch (1994) acknowledged, the task did not necessarily involve processing of the object as it required colours surrounding the picture to be identified, not the image itself. Consequently, it is possible that object-based representations of the cow were not activated, leading to the apparent lack of allocentric neglect. This highlights the possibility that the tasks employed in such experiments may influence the operation of reference frames. This will be considered again in all experimental chapters.

Another point to note is that in this example, the line drawing did not have intrinsic left and right sides (see *The importance of canonical handedness in investigating allocentric neglect* section next). The left and right sides are defined by the egocentric reference frame (i.e. the ‘left side’ of the cow, the hind legs, is defined as such because that information falls on the left of the egocentric position when presented upright). If the cow were to be flipped along the horizontal axis, the previous left side, the hind legs, would now be the right side, due to its placement relative to the egocentric frames of reference). This issue refers to the ‘canonical handedness’ of an object, which this stimulus lacks. Thus, pure allocentric neglect, where the left side of the object is neglected, without any influence from egocentric reference frames, cannot be determined using this stimulus since the left side relative to the allocentric frame of reference is also the left as defined by an egocentric frame of reference; these two aspects are not differentiated.

The role of allocentric reference frames in neglect has been highly debated (e.g. Driver & Pouget, 2000). Despite this, some evidence supports the influence of such reference frames on hemispatial neglect (e.g. Young, Hellawell, & Welch, 1992). Young et al. (1992) investigated allocentric neglect by utilising chimeric faces as stimuli. Chimeric faces are composed of two different faces split vertically down the middle; the left half is one face and the right half another. Typically the two sides of the face vary in identity, emotional expression or gender. Young et al. presented chimeric faces to one individual with neglect, and found that even when the entire face was presented in the patient’s RVF (the non-neglected side), target items that were presented on the left side of the face were neglected. Clearly, in this situation, neglect was not purely egocentric, otherwise none of the face would have been neglected. Nevertheless, when centrally presented faces were inverted, the patient still neglected the left side of the face relative to her egocentric position, suggesting also that neglect did not operate exclusively within allocentric coordinates.

The importance of canonical handedness in investigating allocentric neglect. Typically, stimuli used in studies investigating frames of reference do not have canonical handedness (intrinsic left and right sides; e.g. Behrmann & Moscovitch, 1994). In order to reveal whether the left sides of objects are neglected regardless of their position relative to egocentric co-ordinates (pure allocentric neglect), stimuli with intrinsic left and right sides need to be used. For example, asymmetrical capital letters, such as 'B' and 'F', possessing canonical handedness due to having a midpoint with which left and right can be coded (independent of egocentric perspective) which are necessary for accurate identification of the letter. Thus, these letters can be presented inverted and the intrinsic left side of the letter remains the same part as it was when it was presented upright but is now presented on the right relative to an egocentric perspective. Caramazza and Hillis (1990) presented words to patient NG who, uncommonly, suffered from right neglect. Words have canonical handedness, as the first part of the word remains the left portion of the word regardless of its orientation (i.e. the initial part of the word remains the left part in relation to allocentric coding even when the word is presented in a mirrored-reversed format). When words were presented normally to patient NG, the end part (right side) of the word was neglected. However, when the word was presented in a mirrored-reversed format (flipped horizontally), presented backwards or vertically, NG still neglected the end part of the word, even though this side of the word now fell within the non-neglected LVF. This demonstrates object-centred neglect, where the canonical left side of the word is neglected regardless of where that information falls with respect to an egocentric reference frame.

Thus, when an object (in this case a word) has an intrinsic left/right distinction, the right side (in NG's case) may be neglected regardless of its position relative to the viewer. The fact that the intrinsic right side of a rotated object was neglected (object-centred neglect) suggests that the stimulus was first mentally rotated to its canonical view during the process of object recognition, and the left side of that representation was subsequently neglected (Koriat & Norman, 1984, as cited in Buxbaum, 2006), demonstrating damage to the word-centred (object-centred) grapheme representation. However, as NG suffered damage to his left hemisphere, an area linked to language processing (and one that is likely to be involved in accessing stored representations of words; Young & Ellis, 1985), this may have resulted in this apparent object-based neglect. It may be that this in fact is a phenomenon related to functions of the independent hemispheres and, therefore, may be limited to right hemispatial neglect (Walker, 1995). Furthermore, the way in which we represent and access words may be different to that of objects. Another reference frame may operate in neglect based on word-centred representations (Monk, 1985; Driver, Baylis, Goodrich, & Rafal, 1994) which is independent of object-based reference frames. Driver et al. (1994) stated that 'pure allocentric neglect' (i.e. neglect of the intrinsic left side of an object regardless of its orientation) still needs investigation to determine whether allocentric neglect is dependent on the operation of an egocentric frame of reference or can occur independently of egocentric coordinates.

Is allocentric neglect related to the coding of egocentric coordinates? Evidence that both egocentric and allocentric reference frames can operate, even though the latter is still somewhat controversial, has led researchers to postulate that both frames of reference work together in neglect. Behrmann and Moscovitch (1994) suggest that neglect is a fully encompassing disruption of spatial representation and therefore it is not surprising that numerous reference frames are implicated in this disorder. It has been suggested that egocentric and allocentric neglect can occur simultaneously and interactively (Driver & Pouget, 2000).

Evidence for this view of co-existing frames of reference that have been disrupted in neglect comes from a second experiment reported by Behrmann and Moscovitch (1994), where asymmetric capital letters were used as stimuli with four regions behind the letter being colour coded (similar to *Figure 4*). They found that patients neglected colours on the left relative to egocentric coordinates, even when the stimulus was rotated. Moreover, all seven subjects failed to report colours on the intrinsic left side of the letter demonstrating object-centred neglect. This demonstrates that both egocentric and allocentric neglect occurred simultaneously. Consequently, Behrmann and Moscovitch (1994) proposed that allocentric frames of reference depend upon egocentric frames of reference, as they observed egocentric neglect without allocentric neglect, but not vice-versa. Furthermore, Driver and Pouget (2000) have argued that allocentric neglect is in fact 'relative egocentric neglect'. This is the idea that the left part of an object is neglected because the neural response to that side of the object is lower than that of the right side. The activation of stimuli within the visual field in neglect is under a gradient that monotonically decreases from right to left. This would mean that the left side of the object would produce less activation than the right side of the object, regardless of the absolute position of that object with regards to an egocentric reference frame (see *Figure 6*). So, when an object is presented upright, both the absolute egocentric position and the relative egocentric position of parts within the visual field are important in the spatial coding of information, and, therefore, which spatial information is neglected. Furthermore, often the allocentric representation is based on how that object was initially presented, and therefore is likely to be coded in egocentric coordinates and this could result in the neglect of the intrinsic left side of an object (demonstrating a pattern of object-centred neglect).

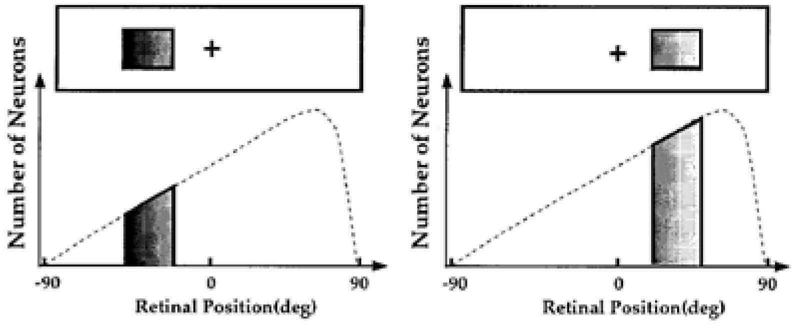

Figure 6. A graphical depiction of relative egocentric neglect. The grey boxes above the graphs represent an object being positioned at that point in the visual field, with 0 aligning with the midline of the patients' egocentric reference frame. The left side of an object receives a reduction in the neural response compared to the right side of the object, regardless of the objects' position in relation to an absolute egocentric midline. Adapted from Driver and Pouget (2000).

More recently, this dependence of allocentric neglect on egocentric frames of reference has been questioned. Ota, Fujii, Suzuki, Fukatsu, and Yamadori (2001) established a double dissociation between the two reference frames. A double dissociation in this case is defined as one patient suffering exclusively from one deficit (such as egocentric neglect) and another solely experiencing a different deficit (such as allocentric neglect). Ota et al. (2001) employed a task specifically developed to distinguish between egocentric and allocentric neglect. Two patients were presented with a sheet of paper containing both normal circles and 'pseudo-circles'. The pseudo-circles had a portion of the loop missing, so that the circle was incomplete. This gap was either on the left or right side of the circle. The patients were required to circle every complete circle and cross out every incomplete circle.

Ota et al. (2001) found that Patient 1 ignored the circles on the left side of the page (left of their egocentric position), but accurately identified incomplete circles on the right side of the stimulus, regardless of which side the gap was on. This demonstrates that this patient did not neglect the left side of each object on the page, as they could discriminate when there was a gap on the left side of the circles that were presented on the right side of the page. However, Patient 2 marked every circle on the page, showing that they did not neglect the left of their egocentric position, but they deemed those circles that had a gap on the left to be complete circles. Thus, this patient was neglecting the left side of the objects across the horizontal extent of the stimulus. The independence of the two reference frames underlying neglect is clearly determined in this study, as there was no interaction or relationship between egocentric- and object-centred neglect. This is contrary to Behrmann and Moscovitch's (1994) view that allocentric neglect only occurs alongside or as a result of egocentric neglect.

However, the allocentric neglect demonstrated in this task may be linked to the effect of sequential eye fixations (e.g. Gainotti, D'Erme, Monteleone, & Silveri, 1986) and the operation of egocentric neglect. This idea, postulated within this thesis, relates to allocentric neglect occurring as a result of eye fixations being made to the centre of each object (which is the usual landing position of the eyes during search; Henderson, 1993). Every time an object is fixated, the left side of that object falls within the LVF, which means that it is likely to be neglected. Ota et al.'s (2001) task is likely to involve each of the circles on the page being individually fixated (in order to determine whether they are complete or not). This is the case regardless of where the circle is placed in relation to the viewer. An eye movement being made to the centre of that object would result in the circle's midpoint becoming aligned with the midpoint of the viewer's eye positioning (i.e. an egocentric reference frame). This would mean that neglect of information within the LVF (egocentric neglect) would be manifesting in a way that appears to be neglect of the left half of an object (allocentric neglect). The influence of allocentric and egocentric frames of reference on neglect and the nature of allocentric neglect will be determined by Experiment 2-4 reported in Chapters 3-5 in this thesis.

Manipulating the orientation of an object should allow meaningful conclusions to be drawn with regard to the operation of different frames of reference. The left half of an object may be neglected due to falling on the patient's left side (egocentric reference frame operating) or due to being the left side of the object (allocentric neglect). However, it may also be a result of the patient making an eye movement to the centre of that object to inspect it, therefore it cannot be determined whether it is allocentric neglect or egocentric neglect resulting in the left side being neglected, unless the object is rotated. This is to ensure that the intrinsic left side of the object does not fall on the left of the egocentric reference frame (as defined by the position of gaze) when the object is centrally fixated. To be sure that Patient 2 in Ota et al.'s (2001) study demonstrated allocentric neglect, objects in the cancellation task would have had to have canonical handedness and vary in orientation, so that when the circle was directly fixated, the egocentric and allocentric midpoints were not aligned. This is not achievable with circle stimuli as they do not have intrinsic left and right sides that remain as such, when the object is rotated.

Driver, Baylis, Goodrich, and Rafal (1994) also provided evidence for object-centred neglect and suggested that the role of eye movements in this type of allocentric neglect was minimal in three neglect patients included in their study. The authors employed triangle stimuli that remained physically identical across trials but could differ in the perceived direction in which they were pointing. This allowed manipulation of whether a gap, which was the participants' task to detect, was on the left or right of one of the triangles in the stimuli according to the perceived viewpoint. The stimuli were presented for 200ms to prevent an eye movement being made to the centre of the triangle. They demonstrated that the neglect patients missed more gaps when the gaps were on the left side of the triangle compared to the right, even though the only difference between the stimuli was the direction in which the triangles were perceived to be pointing. Even though this demonstrated the operation of allocentric frames of reference in neglect, the authors concluded that egocentric frames of reference were important as well, as assigning one side of the object as left and one side as right relies on the viewpoint, and an egocentric reference frame, and therefore the behaviour exhibited by the neglect patients could not be interpreted as *pure* allocentric neglect but involved an interplay between egocentric and allocentric reference frames.

Do multiple frames of reference operate simultaneously in neglect? Karnath and Niemeier (2002) investigated whether the task imposed on three patients with left neglect would affect the area to which they allocated attention during spontaneous search of their surroundings, which would provide evidence of multiple frames of reference operating for coding of spatial information. The conditions varied in the experiment according to the instructions given to the participants. The colour of the letters in the array either segmented the visual scene into vertical bands (where there were six segments of different coloured letters) or was a homogeneous stimulus in a visual search task. They found that when the participant was searching a homogeneous array (where all the letters were the same colour and the stimulus appeared as one whole section), the whole left half of the array was neglected.

However, when the participants were informed that a target would only appear in a region denoted by a specific colour that was one sixth of the array (and a boundary was placed around this region; the segmented condition), participants now failed to inspect the left side of that region, which was previously attended to in the homogenous condition.

This demonstrated that different frames of reference operate over an array depending on the area of space that is deemed imperative for that specific task. Thus, frames of reference in neglect and patterns of eye movements exhibited can be influenced by the task at hand and the visual properties of the stimulus. This is an interesting area to investigate as it reveals that underlying spatial representations in the disorder can be manipulated and potentially neglect moderated. However, theoretical reasons for task related effects on neglect remain largely unresolved (Ferber & Karnath, 2001). This will be investigated in the experiment reported in Experiment 4.

2.2 The Value of Figure Copying Tasks in Revealing Frames of Reference Operating in Neglect

As discussed in the section entitled *1.2 The Behavioural Inattention Test*, figure copying has been shown to be sensitive to the deficits experienced in neglect as accurate performance relies heavily on the visual information provided in the visual field to have been sufficiently encoded and represented by the participant (Halligan & Robertson, 1992). As the task provokes a strong engagement of focal attention, if an attentional deficit exists, then the task is likely to expose omissions of elements on the contralateral side (Ishiai, Seki, Koyama, & Yokota, 1996). Thus, many researchers have employed figure copying as a task to identify the spatial frames of reference that are operating in neglect and to investigate both egocentric and allocentric reference frames.

Copying tasks involve encoding of the object to be copied in terms of a variety of characteristics (Tchalenko & Miall, 2009), such as size, shape and spatial location, and therefore require direct processing of objects and activation of allocentric reference frames would be required by the task. Hillis, Rapp, Benzing, and Caramazza (1998) found that neglect patients failed to copy objects on the left side of the 'Ogden scene' (see *Figure 7*), but copied entire objects on their right (which were also on the right side of the scene). The results clearly demonstrated the influence of egocentric coordinates in neglect, even when object-based representations should be important, i.e. object based representations are activated due to the task requiring each object to be encoded, represented and stored in short-term memory during task completion.

Figure 7. Classic 'Ogden scene' used by Hillis et al. (1998).

The dysfunctional spatial representations that do or do not exist in neglect can be investigated by manipulating the properties of the objects in a stimulus to be copied. This can allow investigation of whether the left side of the object is being neglected, or information that falls on the individuals' left is neglected. In a study that investigated reference frames operating during figure copying in neglect, Behrmann and Plaut (2001) report results from two neglect patients. The patients were required to copy a daisy, which was presented in four different orientations: upright, head of the daisy to the left, head to the right, or inverted. Both patients often failed to copy the left side of the daisy, regardless of its orientation demonstrating object-centred neglect. So, even when the daisy was rotated 90^{o} to the left (head of the daisy pointing towards the left), parts to the right of the egocentric reference frame midline, but on the left of the object, were not drawn. This suggests that allocentric neglect was occurring without the relative influence of egocentric neglect, as these two frames of reference in this task were placed out of alignment with one another by rotating the object.

However, as a daisy (like the circles of Ota et al., 2001) does not have canonical handedness, the left side is only defined as such due to the coding of spatial co-ordinates during its original, and usual, presentation form (i.e. that side is deemed the left side of the daisy as it fell to the left of the individual, and the egocentric midline, when presented upright). Thus, egocentric frames of reference may still influence whether this type of neglect is apparent, due to egocentric reference frames defining the allocentric left and right of the object initially. Behrmann and Plaut (2001) concluded that neither of the patients reported in the paper had exclusive allocentric neglect. Either patients presented exclusively with egocentric neglect or demonstrated a combination of allocentric and egocentric neglect. Thus, this is evidence that allocentric neglect often relies on the operation of egocentric reference frames in neglect.

In the second experiment reported by Behrmann and Plaut (2001), the patients were required to copy a more complex image. This image was either two separate daisies that were not joined together (separate pots for each daisy) or two daisies that were joined at the stem (originating from one pot). If pure allocentric neglect was occurring, then one would expect that in the joined case the whole left daisy would be neglected as this would be the left side of the object. On the contrary, allocentric neglect in the non-joined case would manifest with both daisies being copied but with the left side of each being neglected. However, egocentric neglect would result in the left daisy being neglected in the joined and non-joined case. They found that all four patients neglected information to the left of their midline but also some information was missed to the left of each daisy, demonstrating that a combination of allocentric and egocentric reference frames were contributing to the neglect exhibited by the four patients examined in this experiment.

However, copying is a sequential task, thus each object would be the sole focus of attention for some period of time during the copying process. This may result in patients aligning their head and/or eye positions with the centre of the object currently being copied (thus aligning egocentric and allocentric frames of reference). Therefore, the left half of individual parts of the object may be neglected due to the left side of the currently fixated object falling on the left side of the participant (with regards to head and/or eye position), rather than reflecting neglect of the left side of the object. This results in a pattern of behaviour whereby elements on the left side of each daisy are not copied but the right sides are copied accurately, which has been provided as evidence for allocentric neglect. However, this may be a result of the egocentric midpoint shifting during progression of the copying task (i.e. the egocentric midpoint [relating to the eyes/head] is aligned with the allocentric midpoint of the right daisy when this object is being copied but the egocentric midpoint shifts to the centre of the left daisy when this object is being copied).

Another explanation for the appearance of allocentric neglect in this task could be ‘relative egocentric neglect’ (Driver & Pouget, 2000). The left side of an object receiving less activation than the right side, as it lies more to the left relative to the egocentric midline, would also results in a pattern of behaviour whereby elements on the left side of each daisy are not copied but the right sides are copied accurately. For example, the left side of the daisy that is presented on the right side of the viewer receives relatively less activation than the right side of that daisy, and therefore this part of the figure is neglected when the patient is focusing on that object. The same principle (relative activation) also applied for the daisy presented on the left when the patient is copying that object. Why the task demands affect the spatial aspects, and therefore the effect of relative activation, of the visual information that is neglected is still not clear. This issue is the main focus of Experiment 4.

In summary, the complexity of the disorder of hemispatial neglect is illustrated by the inconsistency in the literature regarding frames of reference. What is clear is that the definition and characterisation of hemispatial neglect cannot be accurately determined without considering reference frames underlying the deficit of attention. Even though the majority of studies investigating hemispatial neglect argue that neglect occurs on an egocentric level (e.g. Beschin, Cubelli, Della Sala, & Spinazzola, 1997; Driver & Pouget, 2000), neglect does appear to operate on an allocentric level under some circumstances (e.g. Caramazza & Hillis, 1990; Behrmann & Moscovitch, 1994; Ota et al., 2001; Walker et al, 1996). Even so, the extent to which allocentric neglect is a manifestation of egocentric neglect and why allocentric neglect is demonstrated on some occasions have not been determined. Whether allocentric neglect is dependent upon egocentric frames of reference is still to be determined.

In order to minimise inconsistencies in the literature, future studies need to carefully consider the stimuli used in experimentation in order to differentiate allocentric neglect from that which is based on egocentric co-ordinates. To establish whether sequential eye fixations result in the apparent operation of allocentric reference frames, stimuli with canonical handedness that are presented at different orientations need to be contained within tasks employed. This is to ensure that the midlines of allocentric and egocentric reference frames are not aligned when the object is directly fixated during the course of the task progression. Furthermore, detailed eye movement analyses of neglect patients' visual exploration whilst copying complex figures would be informative with regards to the information that is visually sampled and processed in neglect, which will be expanded on in the following section. Tracking eye movements during completion of the BIT, namely cancellation tasks and figure copying, has not been conducted before for neglect patients. This experimentation will be outlined in the empirical chapters of this thesis.

3. Mechanisms Underlying Neglect: The Value of Eye Movement Analyses

At the end of the section entitled *1.2 The Behavioural Inattention Test*, it was suggested that eye movements may offer a more sensitive measure of neglect than the standard off-line measures of accuracy (e.g. cancellation tasks) because eye movements provide detailed information with regard to the patient's exploration of space. Eye movements may also offer insight into the underlying deficits involved in the disorder and disclose information about the underlying spatial representations that are operating in neglect across a range of tasks. In this section, the value of eye movement analyses in investigating these factors will be discussed and studies that have examined eye movements in this patient group will be outlined and evaluated.

The primary behavioural means by which humans sample their visual environment is through saccadic eye movements (Findlay & Gilchrist, 2003). Saccades are very rapid, ballistic rotations of the eyeball that serve to orient the eyes to different points in the visual array in order to allow light from objects under fixation to fall directly onto the high acuity area of the retina (the fovea). We make a saccade about 3-4 times a second, and between saccades, we make fixations (Liversedge & Findlay, 2000). Fixations are short periods when the eye is comparatively still, during which visual information is extracted and processed by the brain (Liversedge & Findlay, 2000).

The measurement of saccadic eye movements is now widely recognised within cognitive science as a valuable experimental technique to investigate human visual and cognitive processing (see Liversedge & Findlay, 2000; Rayner, 1998). Eye movements have been strongly associated with attentional processing (e.g. Liversedge & Findlay, 2000; Shepherd, Findlay, & Hockey, 1986) and, therefore, as hemispatial neglect is a disorder of dysfunctional attention allocation, one would expect that eye movements could potentially provide great insight into the deficits involved in this disorder.

3.1 Eye Movements in Hemispatial Neglect

A number of researchers have recognised the value of examining patterns of eye movements in neglect to reveal the impairment of space exploration (e.g. Barton et al., 1998; Behrmann et al., 1997; Forti et al., 2005; Walker, Findlay, Young, & Lincoln, 1996; Walker & Young, 1996). Eye movements have also been demonstrated to indicate the extent of neglect recovery (e.g. Olk, Harvey, & Gilchrist, 2002), which is important if pen-and-paper tasks' sensitivity is low and no longer indicates that a deficit still exists. Given the advantages that would be gained by recording patterns of eye movements in neglect patients, there have been a surprisingly limited number of eye movement experiments conducted (e.g. on visual search, line bisection, chimeric faces; Behrmann, et al., 1997; Behrmann, Ebert, & Black, 2004; Forti et al., 2005; Fruhmann-Berger & Karnath, 2005; Walker & Findlay, 1996; Walker, Findlay, Young & Lincoln, 1996).

3.1.1 Sampling and Processing of Contralesional Information in Visual Neglect

An important question that has not been fully addressed by studies investigating neglect of visual information, is whether inattention to the left side of space results in patients failing to sample that information, which leads to the neglect that is manifest (e.g. a sampling deficit of the contralesional side of space; Chédru, Leblanc, & Lhermitte, 1973; Karnath, Neimeire, & Dichgans, 1998) or whether they fixate that information but fail to process it sufficiently in order to accurately respond to it (e.g. Forti et al., 2005; Walker et al., 1996). Eye movement methodology can reveal whether information is not reported due to the patients presenting with a sampling deficiency (i.e. they failed to fixate the area that was neglected) or a processing deficiency (i.e. they fixate the left side of space but failed to process information there adequately in order to report it accurately). This issue is critical in order to understand the underlying mechanisms that are deficient in neglect to better characterise the disorder, and in the future, to aid development of effective rehabilitative methods, which to date show limited success in ameliorating neglect (Manly, 2002).

Kinsbourne (1970; 1977; 1987) postulated that neglect was due to an imbalance in oculomotor mechanisms. Furthermore, Kinsbourne believed that increased arousal of the ipsilesional hemispace caused an exaggerated attention to that region, and consequential preferential responding to the right (Kinsbourne, 1977). This has been suggested to be due to the non-damaged (left) hemisphere having a higher activation overall compared to the damaged (right) hemisphere (Kinsbourne, 1970) and, therefore, there being increased inhibition of the damaged hemisphere. In this way, neglect of the left occurs due to over attention to the right, rather than inattention to the left (Ládavas, Petronio, Umiltá, 1990; Marshall & Halligan, 1989). The contribution of hyper-attention to the right in neglect can be examined by patterns of eye movements produced by neglect patients. Findings from studies that have investigated eye movements whilst neglect patients complete a variety of tasks have suggested that neglect patients saccade to the left less frequently, and spend more time fixating the right side of a stimulus compared to controls (e.g. Behrmann et al., 1997; Barton et al., 1998; Walker & Young, 1996).

Behrmann et al. (1997) tested nine left hemispatial neglect patients and two control groups (hemianopic and non-brain damaged controls) on a letter detection task. Participants were asked to search for a target ‘A’ amongst an array of randomly distributed letters. Search for targets was performed whilst participants’ eye movements were recorded, through the search coil technique. Participants were asked to report the number of letter ‘A’s that they found at the end of their search for which there was no time limit.

Not only did Behrmann et al. find that the neglect patients performed significantly worse on the task than the hemianopic patients and the controls, they also found that neglect patients made significantly fewer fixations on the contralesional side of the stimulus and spent less time fixating that region. This demonstrated that there is evidence for a sampling deficit contributing to hemispatial neglect. Additionally, the neglect patients made more fixations on the ipsilesional side and had longer fixation durations in this region compared to the other two groups, and they predominantly started their search on the right side of the stimulus. These findings provided support that hyper-attention to the right side of space occurs in neglect. Hemianopic patients showed the reverse pattern of eye movements. Patients with hemianopia spent longer on the far left region than the controls and neglect patients (Behrmann et al., 1997). This is suggested to be due to a compensatory strategy hemianopic patients develop to bring information within their intact visual field that would otherwise fall within the blind LVF.

Since the neglect patients were able to fixate the left side on occasions (and they were able to do this during calibration of the eye tracker), Behrmann et al. (1997) concluded that there was no evidence of a fundamental oculomotor deficit underling the disorder. Therefore, neglect patients were able to fixate the usually neglected region of space but possessed an inherent bias to fixate the neglected side less frequently than controls, supporting the sampling deficit account of neglect. As the quantitative measure of neglect that the researchers obtained in Behrmann et al.'s (1997) study was the number of targets found overall, information with regard to accuracy within different regions of space was not accessible. This means that the eye movement measures (which were divided into areas of interest on the stimulus) could not be associated with accuracy within that region. Thus, the relationship between sampling and target identification accuracy in neglect could not be determined. Even though restricted sampling of the contralesional region of space has been associated with neglect, the extent to which this sampling deficit is linked with poor contralesional target identification is unknown, as is whether or not poor sampling of the left is a cause of neglect or a result of it. If the object has not been fixated, it is unlikely to be accurately identified. The value of using eye movements to investigate this theoretical issue is evident, with Behrmann et al. (1997) concluding that oculographic analysis is a 'robust' method for examining underlying deficits in visual neglect.

Evidence exists demonstrating that scanning training, encouraging sampling of the contralesional region in neglect, aids responding to information in the usually neglected region of space. This suggests that a sampling deficit may be a factor contributing to neglect, as if a sampling deficit is mitigated, so is neglect. Pizzamiglio et al. (1992) offered patients approximately 40 hours of scanning training via highly salient cues presented within the contralesional region and therapist encouragement to look to the left using a variety of tasks (including reading, naming objects in spatial arrays, following leftward moving lights projected over a wide area). The cues were progressively reduced in use as awareness of the left side of space increased in the neglect patients. As would be expected if a sampling deficit was contributing to the neglect exhibited, neglect patients' performance on the tasks showed significant gains after scanning training. Bailey Riddoch, and Crome, (2002) also demonstrated that three of the five neglect patients who received scanning and cueing showed a reduction in neglect in one or more tests. Furthermore, this improvement was maintained during the treatment withdrawal phase. These studies indicated that if visual sampling of the left is increased, then information can be reported in the usually neglected region. This suggests that a sampling deficit of contralesional regions being present before treatment was likely to be contributing to targets not being identified within that area of space. Interestingly, scanning training has also been demonstrated to mitigate neglect in tasks that do not involve the visual modality. To be clear, this suggests that a sampling deficit of the left is strongly associated with visual neglect and contributes to target items not being identified in that area.

However, scanning training treatment tends to have only a short-lived effect on neglect and often fails to generalise to tasks outside that employed in the training situation. Thus, simply encouraging patients to sample the usually neglected information, does not necessarily result in that information being processed sufficiently in order for the patient to respond accurately. This is further demonstrated by a study investigating the effect of prismatic adaptation on neglect, which involves recoding visual-motor coordination. Ferber, Danckert, Joanisse, Goltz, and Goodale (2003) provided evidence that prismatic adaptation shifted neglect patients eye movements to the left. However, this increased sampling of the left following treatment failed to improve detection of contralesional information. Thus, these results appear to suggest that, in neglect, overt eye movements and covert attention may be decoupled (Benson, Ietswaart, & Milner, 2012). This is to say that, even when a neglect patient directly fixates a target or an object on the left, they still may fail to process it sufficiently in order to accurately identify that information. This same conclusion was reached by Benson et al. (2012) when investigating the eye movements of a single neglect patient (MB). In this single case study, MB demonstrated a dissociation between an intact ability to make appropriate reflexive eye movements to targets in the contralesional regions of space and the ability to accurately report targets presented in that area. Therefore, the tight coupling that is normally demonstrated between attention and eye movements appears to be disrupted for certain tasks in neglect (Benson et al. 2012; Liversedge & Findlay, 2000).

Emerging eye movement evidence suggests that limited sampling of contralesional information is not the only factor contributing to decreased awareness of contralesional stimuli. A number of studies have demonstrated that information on the neglected side is insufficiently processed by neglect patients or that more time is required to process the information (e.g. Forti et al., 2005; Walker & Young, 1996). Chimeric stimuli are useful to investigate neglect patients' processing and perception of information. It has been shown that neglect patients often fail to notice that a chimeric face presented to them was composed of two different faces; one face on the left and another on the right, the faces either differing in identity or emotion (Walker et al., 1996). Neglect patients' perceptions of a chimeric face are predominantly based on the information provided in the right part of the image (Walker et al., 1996). Walker et al. (1996) investigated the eye movements of one patient (RR) with visual neglect whilst he viewed and reported on chimeric stimuli. RR was required to either report the identity of the face was presented (which belonged to a famous person), which building was displayed (which was famous, e.g. the Eiffel Tower), or which two faces or buildings comprised the image when a chimeric face or building was shown.

When the stimuli were presented centrally (i.e. the midline of the stimulus lined up with the sagittal midplain of RR's trunk), the participant failed to report the left side of the chimeric faces, whereas he was 100% accurate for the face on the right side. This corresponded with a lack of visual sampling of the left side of the face, i.e. no saccades were made to the left side of the face. The findings were similar for the chimeric buildings, with only 2% of the total trial time spent fixating the neglected side on trials where the left side was not identified. In experiment two of this investigation into RR's eye movements, faces and buildings were either presented centrally (as in experiment one) or to the right of the patient. Walker et al. (1996) found that when the chimeric face was presented on the right of the participant, accuracy in reporting the left side of the face improved (increasing by 21% compared to when it aligned with RR's trunk midline). However, on occasions where the left side was not reported, RR still spent 26% of the total trial time fixating that side. This demonstrates that a significant proportion of fixation time was allocated to visual inspection of that area; however, this did not result in that information being reported. This provides clear evidence for a processing deficit associated with visual information that is fixated on the neglected side of space. These results imply that either the information on the left side was not encoded by RR during fixation, resulting in him failing to report it, or that the information was visually encoded but a problem associated with representing the information correctly was causing the processing deficit. This issue will be returned to in Experiment 4.

Forti et al. (2005) also demonstrated that a processing deficit may account for neglect in another neglect patient (MP). The authors presented a case study of MP's eye movements whilst he searched for a target object on a table. The target was present amongst other distractor objects, which were equally distributed in a random order across the area of space. Despite MP directly fixating all objects presented within the contralesional visual field, he still failed to report 28% of the targets on the left. This suggests that impaired scanning of the neglected area was not the primary cause of the evident neglect exhibited by this patient.

These studies appear to be suggesting that a processing deficit contributes to neglect. Further investigations are required to verify these findings in a group of neglect patients to establish whether this is an underlying deficit in the disorder of neglect and not just these individual patients that are experiencing these difficulties. The previous studies provided evidence that sampling and processing deficits contribute to *visual* neglect. However, neglect can occur in other modalities. It has been demonstrated that some neglect patients fail to respond tactically to information on the left, even when they have their eyes closed. Therefore, it is unlikely in this situation that the failure to sample the left side of space would be contributing to poor performance as no visual input is available. Bartolomeo (2002) investigated the relationship between visual neglect and neglect of visual mental images (imaginal neglect) by comparing performance of neglect patients on tasks which were visually mediated and those that were not (i.e. the patients' eyes were closed). Performance in a task that required information to be visually encoded and represented was poorer than in the task where participants were asked to respond tactically to information they could not see. Bartolomeo concluded from this that there are different underlying mechanisms which are deficient in these types of neglect, suggesting there is not a common neural mechanism for visual perception and mental imagery (Halligan, Fink, Marshall, & Vallar, 2003). Furthermore, visual neglect may be exacerbated compared to other forms of neglect due to the reliance on visual encoding and representation of visual information, which have been suggested to be deficient in neglect (Denny-Brown, Meyer & Horenstein, 1952; Bisiach & Luzzatti, 1978). Given the evidence outlined above and the fact that not all patients with visual neglect experience neglect in other modalities (whether that be tactile or imaginal), it is expected that sampling and processing deficits would contribute to neglect of visual information and this will be one main focus of this thesis.

In conclusion, it appears that often there is a sampling deficit exhibited by patients with visual neglect, whereby they spend less time fixating the neglected side, make fewer eye movements to that region and spend more time fixating the ipsilesional side. This was not the case in hemianopia (Behrmann et al., 1997), confirming that the attentional deficit was the factor influencing inhibited visual sampling of contralesional space in neglect. A few empirical findings have indicated that even when contralesional information was directly fixated by the neglect patient, it was still not reported. This may indicate that a processing deficit of contralesional information contributes to neglect. This issue needs further investigation to determine whether a contralesional processing deficit occurs for a group of neglect patients as well as for those reported in the case studies described here. Furthermore, establishing whether a processing deficit occurs in a large group of neglect patients will reveal whether this is an underlying mechanism in the disorder of neglect and not simply limited to specific lesions in a sub-set of neglect patients. It is often assumed that the main factor causing neglect of information is that patients fail to fixate the left (as been demonstrated by Behrmann et al., 1997; Barton et al., 1998; Chédru, Leblanc, & Lhermitte, 1973; Karnath, Niemeier, & Dichgans, 1998; Walker & Young, 1996) and thus rehabilitative methods often focus on encouraging neglect patients to fixate the left side of space. If emerging evidence suggests that a sampling deficit is not the sole factor contributing to neglect, this may provide insight into why those rehabilitative methods, involving encouraging increased sampling of the usually neglected region of space, have had limited success in aiding responding to the left in neglect (Manly, 2002).

4. Theories of Hemispatial Neglect

There are many theories of neglect which implicate different underlying deficits in the disorder. This section will include an outline of the neuroanatomy of neglect and the main models that have been proposed to explain the neglect, specifically those focused on spatial and non-spatial attentional deficits, low vigilance/arousal, working-memory difficulties and how these theories can account for different types of neglect (e.g., egocentric and allocentric neglect) and inform rehabilitation of the disorder.

4.1 The Neuroanatomy of Neglect

When an individual suffers from an ischemic stroke, the Middle Cerebral Artery (MCA) is the vessel most commonly affected by cerebrovascular accident. The MCA is the largest cerebral artery supplying the brain and supplies most of the outer convex of the brain surface, nearly all the basal ganglia, and the posterior and anterior internal capsules. Furthermore, the parietal and sometimes frontal and temporal lobes are likely to be damaged if blood from this artery is restricted due to a clot or a haemorrhage. Clinical reports suggest that those with neglect often had a stroke originating with the right MCA territory. Many different regions of the brain that are supplied by this area and that often have been damaged from an MCA infarct have been causally related to neglect and its symptomatology.

The reason for left neglect being more common has been attributed to the spatial functions that the right hemisphere serves that has been damaged in neglect patients. Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) studies have demonstrated that the right inferior parietal lobule and intraparietal sulcus regions were activated when participants were cued to orient their attention to a specific spatial location in the visual array (Corbetta, Miezin, Shulman, & Peterson, 1993; Coull & Nobre, 1998; Nobre et al., 1997). Furthermore, recovery of neglect has been demonstrated to be associated with a restoration and rebalancing of activity within the parietal regions in the right hemisphere (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005). This association between the right hemisphere and neglect has been explained as a result of ipsilesinal attentional orienting of the right hemisphere (e.g., Heilman & Valenstein, 1979).

It was proposed by Heilman and Valenstein (1979) that a simple model of neglect involving right-hemisphere specialisation for spatial attention can account for the clinically observed higher incidence of left neglect. This model includes the prepositions that, whereas the left hemisphere predominantly directs attention to the right side of space, the right hemisphere directs attention to both the left (contralesional orienting) and right regions (ipsilesional orienting) of space. Therefore, when the left hemisphere is damaged, the right hemisphere still serves orienting of attention to the right side of space, making right neglect less likely to occur. However, when the right hemisphere is damaged, the left hemisphere only directs attention to the right and, therefore, left neglect is apparent.

Experiments using a wide range of techniques with human participants have provided evidence for this model of spatial attention and its ability to explain neglect (e.g., Corbetta et al., 1993; Oyachi & Ohtsuka, 1995; Gitelman et al., 1999).

The brain regions within the right hemisphere that are involved in neglect have become intensely disputed (Mort et al., 2003). It has been demonstrated that the superior temporal gyrus is associated with neglect (STG; Karnath, Ferber, & Himmelbach, 2001), the posterior parietal lobe is important in orienting of attention, specifically the inferior parietal lobe (IPL; Mort et al., 2003) as well as the medial temporal lobe region being involved in neglect (Mort et l., 2003). Mort et al. claimed the role of the STG was negligible as mapping the lesions of 35 right-hemisphere damaged neglect patients in their study revealed half of them did not have damaged within that region. This would suggest that the main function of the IPL is one of contralesional orienting of spatial attention. However, recent imaging and lesion studies have revealed that inferior parietal regions have non-spatial functions, such as in sustaining attention, detecting salient events embedded in a sequence of events and controlling attention over time (Husain & Nachev, 2007) casting doubt on whether the involvement of the IPL in neglect is due to its spatial processing function. The underlying deficits in the disorder are extremely important to understand as this has an impact in the way in which the disorder is rehabilitated, which will be considered in more detail at the end of this section.

4.2 Spatial Accounts of Neglect

There are three different frameworks for neglect that are based on the premise that neglect is a result of a spatial attentional impairment/bias. The first is that there is impaired orienting of attention to the neglected side (e.g., Riddoch & Humphreys, 1983). This idea links to the sampling deficit account of neglect outlined in Section 3.1.1. Evidence for this contributing to neglect comes from studies demonstrating that neglect patients can respond to stimuli if they are prompted to attend to it (e.g., Halligan, Manning & Marshal, 1991; Riddoch & Humphreys; 1983).

The second spatial attentional bias hypothesis is that those with neglect have a propensity to orient to the ipsilesional region of space. As explained previously, Kinsbourne (1977) proposed the inter-hemisphere rivalry hypothesis. This is the concept that left neglect results from the damaged (right) hemisphere no longer inhibiting the intact (left) hemisphere and therefore not enabling attention to be transferred to the left side of space. Therefore, an overactive left hemisphere causes preferential responding to the ipsilesional region of space, i.e. hyper-attention to the right (Kinsbourne, 1977). According to this theory, neglect of the left occurs due to over attention to the right, rather than inattention to the left (Ládavas, Petronio, Umiltá, 1990; Marshall & Halligan, 1989). Evidence for an ipsilesional attentional bias is provided from studies that have demonstrated faster reaction times for neglect patients compared to control for ipsilesionally presented stimuli (Ládavas, 1990; Ládavas, Menghini, & Umilta, 1994).

A final account of neglect based on impairment in spatial attention is that there is the inability to disengage attention from the ipsilesional side of space once attention has been oriented there (e.g., Posner, Cohen, & Rafal, 1982). It has been demonstrated that when neglect patients were prompted to attend to the ipsilesional region of space, subjects were more impaired in responding to contralesional stimuli if they have been prompted to attend to the contralesional region or centrally (Posner, 1980). This, in combination with the inter-hemisphere rivalry hypothesis, could account for neglect of the left. Whether these different factors are contributing to neglect can be determined by investigating the pattern of eye movements exhibited by neglect patients whilst they conduct search for target items during completion of cancellation or search tasks. This will be discussed further in Chapter 2.

In addition to spatial attentional biases/impairments in neglect, representational models of neglect exist. Representation models of neglect stipulate that the representation of space in neglect is disturbed (e.g. Bisiach et al., 1979). Bisiach and Luzzatti (1978) first proposed that a representational deficit could account for neglect when they documented two neglect patients neglected the left side of an imagined scene. The patients were asked to describe a familiar place, the Piazza del Duomo in Milan, according to definite perspectives. First, they were requested to imagine themselves looking at the front of the cathedral from the opposite side of the square; then the reverse perspective had to be described, i.e. the perspective seen from the front doors of the cathedral. In both situations the patients failed to recall details that were on the left side of the scene in relation to the viewpoint taken. This suggested that the patients were not neglecting that part of the scene due to not orienting to it (as there was nothing to orient to) and therefore an attentional account could not explain neglect of the left side of imagined scenes. Furthermore, it is unlikely in this situation that the failure to sample the left side of space would be contributing to poor performance as no visual input is available. Therefore, the representation of the left side of space was suggested to be deficient.

Evidence against the representational account of neglect exists. Bartolomeo (2002) investigated the relationship between visual neglect and neglect of visual mental images (imaginal neglect) by comparing performance of neglect patients on tasks which were visually mediated and those that were not (i.e. the patients' eyes were closed). Performance in a task that required information to be visually encoded and represented was poorer than in the task where participants were asked to respond tactically to information they could not see. Bartolomeo concluded from this that there are different underlying mechanisms which are deficient in these types of neglect, suggesting there is not a common neural mechanism for visual perception and mental imagery (Halligan, Fink, Marshall, & Vallar, 2003). Furthermore, visual neglect may be exacerbated compared to other forms of neglect due to the reliance on visual encoding and representation of visual information, which have been suggested to be deficient in neglect (Denny-Brown, Meyer & Horenstein, 1952; Bisiach & Luzzatti, 1978). It may be that the two neglect patients investigated in Bisiach and Luzzatti's (1978) study possessed both visual and imaginal neglect and that representational deficits are only present in a sub-group of the neglect population. Another explanation for Bisiach and Luzzati's (1978) results is that the representation of space is intact but the deficit in attending to that region of space, even for the mental representation, resulted in that information not being activated and accessed for the neglect patient to respond to (Rizzolatti & Berti, 1993).

4.3 Non-Spatial Models of Neglect

There are also theories for neglect that do not implicate spatial processing deficits, such as those including working memory problems as a key impairment resulting in neglect of information (e.g. Gaffan, & Hornak, 1997; Husain et al., 2001) and general decreases in vigilance/arousal. Husain et al. (2001) tracked the eye movements of a neglect patient (G.K.) in order to determine whether he demonstrated working memory deficits during visual search for target items on a computer screen. When a target was found G.K. was required to click it with the mouse cursor. They found that G.K. often failed to remember the locations of the targets he had already clicked, with his re-fixation rate on targets being 13 times higher than control participants and re-clicking (on targets that had already been identified) rate 34 times higher. These results indicate that G.K. presented with a deficit in retaining the locations of previously identified targets. However, this may not be due to a working memory deficit but perseveration. Perseveration is the tendency, which is extremely common in neglect, to repeatedly respond to ipsilesional targets (Rusconi, Maravita, Bottini, & Vallar, 2002). This is believed to be due to be due to an ipsilesional attentional bias (or hyper-attention to ipsilesional regions; Na et al., 1999). However, Husain et al. (2001) provide some evidence that G.K. did not demonstrate perseveration, as this would result in successive clicks on a target. They found that there was an average interval of 15 s between clicks on the target, suggesting that G.K. had made a saccade away from the target, searched another area and then re-fixated that target later. This is indicative of working memory problems associated with searching for targets. Nevertheless, it is not clear why performance would be poorer on the left in neglect when the deficit is also apparent within ipsilesional regions of space.

Pisella, Berberovic, and Mattingley (2004) also proposed that working memory for location is selectively impaired. They compared the performance of right hemisphere neglect patients with parietal and non-parietal lesions on a change detection task. Patients were presented with four objects in different positions on the screen, and were required to detect a change in the location, colour or shape of one of the objects following presentation of a brief visual mask. Neglect patients with parietal lesions were selectively impaired in detecting location changes, regardless of the horizontal position of the object on the screen, relative to colour and shape changes. They concluded that the human parietal cortex is crucially involved in the updating and maintenance of spatial representations across saccades, and that neglect arising from parietal damage causes impairment in these re-mapping mechanisms. However, some of the neglect patients (those whose lesions spared the parietal lobe) did not demonstrate this inability and therefore this cannot be a sole explanation for the neglect syndrome. Other theories that are based on non-spatial deficits in neglect relate to the level of vigilance and arousal in neglect patients. An explanation that has been proposed for the predominance of left neglect is that the right hemisphere is heavily involved in the regulation of vigilance (e.g., Rizzolatti & Berti, 1993; Rizzolatti & Camarda 1987; Robertson, 1993). This theory has been supported by studies that show increasing demands on selective attention exacerbate inaccuracy in reporting targets in the left region of space in neglect (e.g., Robertson & Frasca, 1992; Ferber & Karnath, 2001). Furthermore, increasing the patients' alertness has been demonstrated to ameliorate neglect. In Robertson, Mattingley, Rorden, and Driver's (1998) study investigating the effects of phasic alerting in neglect, on average, in the baseline condition neglect patients became aware of left visual stimuli half a second later than right stimuli. This spatial imbalance in the time course of visual awareness was corrected when a warning sound alerted the patients phasically. Importantly, even a warning sound presented on the right side of space accelerated the perception of left visual stimuli. It has not been established whether this could explain neglect in isolation, or contributes to poor contralesional performance alongside impaired orienting (Robertson, 1993).

4.4 Rehabilitation of neglect

It is important to understand underlying causes of hemispatial neglect in order to develop appropriate and effective therapies for neglect. Currently most therapies focus on increasing sampling of the affected side of space. As mentioned previously in Section 3, some studies indicate that if visual sampling of the left is increased, then information can be reported in the usually neglected region (e.g. Bailey Riddoch, & Crome, 2002). However, scanning training treatment tends to have only a short-lived effect on neglect and often fails to generalise to tasks outside that employed in the training situation (Manly, 2002). Thus, simply encouraging patients to sample the usually neglected information does not necessarily result in that information being processed sufficiently in order for the patient to respond accurately.

The lack of amelioration of neglect from correcting an orienting, or sampling, deficit is further demonstrated by a study investigating the effect of prismatic adaptation on neglect, another common treatment for neglect. This involves the patients' wearing prismatic lenses which cause an optical shift of, usually, 10^{o} to the right. A visuo-motor adaptation process (the patient reaching to targets presented in front of them and adapting the movement in order to make the correct response) results in a corresponding shift of attention to the left when the lenses are removed due to the remapping of motor responses towards the left when the target appears to be more rightward (e.g., Ferber, Danckert, Joanisse, Goltz, and Goodale (2003). The success of this type of intervention for reducing neglect relates to the premise that orienting to the left is disturbed and this increases orienting to the left through the adaptation procedure causing an involuntary shidt in eye movements to the left.

Ferber et al. (2003) provided evidence that prismatic adaptation shifted neglect patients' eye movements to the left. However, this increased sampling of the left following treatment failed to improve detection of contralesional information. This suggests that neglect is not simply a result of a sampling deficit, as even if the information is sampled, it is still not reported. This has implications for the orienting accounts of neglect and suggests that other factors may also be contributing. This will be investigated in the empirical studies reported in this thesis. In order to determine which theories can accurately account for neglect symptoms still needs investigation and the interventions that are successful in treating neglect requires further empirical support as recent randomised control trials have demonstrated that some treatments of neglect do not cause lasting changes for these patients.

5. Summary of Hemispatial Neglect, Frames of Reference Operating and Pattern of Eye Movements Exhibited

In summary, hemispatial neglect is a disorder involving resulting in a failure to respond to information presented within the contralesional side of space. This is distinct from the visual deficit of hemianopia, which involves a blind region of the visual field. There is an on-going debate with regard to the frames of reference operating in neglect, and therefore which spatial aspects of the visual environment are not attended to, with evidence for both egocentric and allocentric neglect operating under different conditions. Controversy remains with regards to the extent that allocentric neglect operates independently of egocentric neglect. Furthermore, it is not clear how and why visual and physical properties of the stimulus affect the extent of neglect and the operation of different frames of reference in various tasks. One prominent question, which has not been directly addressed in previous studies that were designed to focus on other aspects of neglect, is the defective mechanisms that are contributing to neglect, namely the extent of sampling and processing deficits underlying this disorder.

It is apparent that eye movements can provide valuable insight into these issues and reveal in-depth information regarding the deficits that exist, particularly with regard to sampling and processing deficiencies and spatial frames of reference operating. However, further investigation is required in order to verify the patterns of eye movements that are exhibited in neglect, the frames of reference operating and whether these relate to the pattern of eye movements displayed during visual sampling of information. Many of these issues will be considered in the first empirical chapter presented in this report (see Chapter 2) and the following experiments reported in Chapters 3-5 were designed to specifically investigate these issues. There are many theories of neglect that implicate different disrupted processes in neglect including spatial and non-spatial impairments. It is important to understand underlying causes of hemispatial neglect in order to develop appropriate and effective therapies for neglect. Investigation of the underlying deficits in neglect is still required in order to determine which theoretic accounts can be verified or not and provide insight into which treatments may be most effective in rehabilitating the disorder.

6. Outline of Thesis

Throughout this thesis, empirical investigations that have been designed to establish whether sampling and/or processing deficits are contributing to the neglect exhibited by patients will be reported. Due to emerging evidence that both sampling and processing deficits contribute to neglect (Forti et al., 2005; Walker et al., 1996), the primary focus will be on assessing the extent of these disruptions by examining patterns of eye movements exhibited by those with neglect in a number of different tasks. For all the experiments included in this thesis, neglect patients' eye movements have been recorded for the first time in the tasks employed, making this an entirely novel set of experiments. Chapter 2 contains findings from behavioural and eye movement measures obtained from a chronic neglect patient (patient SS) whilst completing three cancellation tasks from the Behavioural Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987). These findings directly pertained to the deficits contributing to the manifest neglect. Also, insight regarding factors affecting the extent of neglect and the pattern of eye movements produced by neglect patients is provided by the empirical results obtained in this experiment. Furthermore, whether an intervention that aims to increase attention to the contralesional side of space can affect the neglect patients' sampling and/or processing of information in those regions was investigated.

However, as the BIT tasks do not distinguish between allocentric and egocentric neglect, it is not determined through these tasks whether a patient exclusively presents with allocentric neglect. Therefore, the stimuli employed in Experiments 2 and 3, reported in Chapter 3 and Chapter 4 respectively, were designed specifically to investigate egocentric and allocentric neglect simultaneously and obtain detailed oculomotor analysis from a group of neglect patients whilst they completed the newly developed cancellation tasks. Conclusions were drawn as to the existence of different frames of reference operating in neglect and the underlying mechanisms contributing to the deficit.

One of the main experimental questions directly assessed by the experiments reported in Chapters 2, 3 and 4 is whether a processing deficit of contralesional information is present in neglect, as well as limited sampling of that information. However, an important issue, if there is a processing deficit contributing to neglect, is during which stage of visual processing disruption in processing of contralesional information arises.

Deficient processing of contralesional information may be due to the visual information that is presented in the affected region of space not being encoded sufficiently in neglect in order for that information to be represented and accurately responded to. An alternative explanation could be that the information was encoded sufficiently but the representation of that information was deficient, thus resulting in the manifest neglect. These factors will be considered in Experiment 4, reported in Chapter 5, along with investigation of how task demands may affect the operation of different frames of reference in neglect.

The final chapter summarises the main findings and interprets the results in a broader perspective, looking at how these results inform us about the underlying deficits in neglect, the nature of spatial information processing in the human brain, how oculomotor behaviour relates to perception and awareness and what affects the allocation of spatial attention. Additionally, the main findings regarding the underlying deficits in neglect will be considered in relation to theories of this disorder.

Chapter 2. Patterns of Eye Movements in Hemispatial Neglect during Completion of the Behavioural Inattention Test Cancellation Tasks.

This experiment involved tracking the eye movements of a stroke patient with chronic neglect (SS), as well as stroke controls (SCs) and older adult controls (OACs), during completion of the Behavioural Inattention Test (BIT) cancellation tasks (the letter, star and line cancellation tasks). One aim of this study was to evaluate the viability of tracking participants' eye movements during visual-motor actions made during completion of cancellation tasks. When participants cancel targets during these tasks, they are required to make arm and body/head movements. For this reason, in order to measure participants' eye movements as they conduct these tasks, it was necessary to employ a head-mounted eye tracker that allowed relatively free movement of the body, head and arms. Additionally, and because eye movements during cancellation tasks have not been recorded before, even in healthy control participants, the aim was also to use, test and refine the eye tracking paradigm prior to engaging in larger scale projects. Specifically, it was imperative to establish that calibration of the head-mounted eye tracker could be achieved with a neglect participant (who may fail to fixate contralesional calibration points) and stroke patients who often experience fatigue and difficulty sustaining attention and therefore may be difficult to calibrate with this set-up. Furthermore, evaluation of the different eye movement measures was required in relation to the extent that they allowed quantification of any sampling or processing deficit that might be present in neglect (see section on *1.1 Sampling and Processing Deficits in Hemispatial Neglect* below).

In addition to testing the eye-tracking paradigm, Experiment 1 aimed to investigate three of the theoretical issues raised in the Literature Review. These issues relate to: (1) whether sampling and/or processing deficits contribute to visual neglect; (2) whether differences in task demands affect the extent of neglect exhibited; and (3) whether neglect is a result of hypo-attention to the left and/or hyper-attention to the right. Furthermore, the effect of limb stimulation (via functional electrical stimulation; FES) on sampling and processing of contralesional information in neglect was considered. Limb stimulation as an effective treatment for neglect relies on the assumption of the premotor theory of attention (Rizzolatti & Carmarda, 1987), which stipulates that neural circuits involved in the coding of representation of space are linked to the control of motor responses. Therefore, a motor response made by a contralesional limb is suggested to activate the neural circuits involved in the representation of space in the contralesional hemisphere and therefore aid attention to the usually neglected side in neglect patients (Eskes, Butler, McDonald, Harrison, & Phillips, 2003; Harding & Riddoch, 2009; Polanowska, Seniów, Paprot, Leśniak, & Członkowska, 2009; Robertson, Hogg, & McMillan, 1998).

1.1 Sampling and Processing Deficits in Hemispatial Neglect

The first issue that will be considered is whether sampling and/or processing deficits contribute to neglect of information. The former is the idea that was initially introduced and discussed in Chapter 1, namely, that neglect may result from patients failing to sample (i.e. make saccades to) the left regions of space. Therefore, a failure to report the contralesional information would occur because it had not been visually inspected (i.e. a sampling deficit caused neglect of information). Few eye movements being made to, and little time being spent fixating, the neglected region of space would support the idea that a sampling deficit contributed to neglect of contralesional information. Research on patterns of eye movements in neglect during detection tasks and search tasks have indicated that few saccades are made to the left regions of space and less time is spent fixating contralesional regions of space than ipsilesional regions by neglect patients (e.g. Barton et al., 1998; Behrmann et al., 1997; Forti et al., 2005; Walker et al., 1996; Walker & Young, 1996; refer back to *Literature Review: Eye Movements in Hemispatial Neglect*). Even though it has been established that neglect patients often fail to saccade to the left, a question that remains unanswered is whether, when neglect patients fixate the left, they can identify fixated targets, or instead whether they fail to visually and cognitively process contralesional information during fixation.

Some studies have revealed that neglect patients still fail to accurately identify contralesional information even when it has been directly fixated (Forti et al., 2005; Walker et al., 1996; Walker & Young, 1996). This would appear to support the suggestion that a processing deficit contributes to neglect of contralesional information. That is, during fixation, neglect patients fail to adequately encode contralesional information in order to accurately respond to it, or that successfully encoded information was not integrated and represented sufficiently for an accurate response to be made. Many researchers have postulated that neglect may be a result of information processing deficits (Birch, Belmont & Karp, 1967; Denny-Brown, Meyer & Horenstein, 1952; Riddoch & Humphreys, 1987a; see *3.1 Eye Movements in Hemispatial Neglect*) but this, to-date, has undergone very little empirical investigation with regard to its contribution to visual neglect. Eye movements provide a sensitive method to investigate cognitive processing

(Liversedge & Findlay, 2000) and reveal any deficits that may arise in neglect during processing of contralesional visual stimuli.

In this experiment, the letter, star and line cancellation tasks from the BIT were employed to investigate target identification accuracy (TIA) in both ipsilesional and contralesional regions. Eye movements were tracked during completion of all three cancellation tasks to enable direct investigation of whether sampling and/or processing deficits contributed to poor TIA in neglect. These tasks were selected as they are the most common conventional tests that are used within clinical settings to diagnose and determine the severity of neglect (Bowen, McKenna, & Tallis, 1999) and therefore these tests should be sensitive to the deficits experienced by neglect patients.

1.2 Sensitivity of the Letter, Star and Line Cancellation Tasks included in the BIT

The second issue that this experiment was designed to investigate pertains to the sensitivity of each of the letter, star and line cancellation tasks in revealing neglect. The sensitivity of these individual BIT tasks has been subject to limited investigation (e.g. Ferber & Karnath, 2001). There is evidence that the tasks differ in the extent to which they reveal neglect (and the severity of the neglect exhibited). As discussed in Chapter 1, Ferber and Karnath (2001) found that the letter cancellation task from the BIT was more sensitive in revealing the presence of neglect than other tasks employed in the experiment. The next sensitive test was the star cancellation task. This was followed by the line cancellation task, which failed to indicate nearly one third of the neglect patients presented with neglect, when accuracy in the line cancellation task was only taken into account (Ferber & Karnath, 2001).

These findings are likely to be due to physical properties of the stimulus and task difficulty. The visual properties of the letter cancellation task, namely a higher density of items included in the task compared to the other tasks, makes searching for targets more difficult compared to the other tasks. It has been demonstrated that the absolute number of targets (Chatterjee, Mennemeier & Heilman, 1992; Mennemeier, Rapcsak, Dillon, & Vezey, 1998) and the ratio of targets to distractors (Kaplan et al., 1991) can affect target identification performance within contralesional regions in neglect. Furthermore, the target items included (E and R; see *Figure 2* on page 5) are arguably more similar to the distractors, which are other letters, than is the case in the line cancellation task (in which there are no distractors), and in the star cancellation task (where there are various distractor items). Additionally, the letter cancellation task from the BIT requires participants to search for two target items (dual-target search), as opposed to one target item, in the other cancellation tasks, increasing cognitive load experienced when conducting the task. All these factors make the letter cancellation task more cognitively demanding than the star and line cancellation tasks. The star cancellation task contains less similar distractors, is a less dense array than the letter cancellation task and only involves single-target search. The reduced sensitivity of the line cancellation task compared to the star and letter cancellation tasks is likely to be a result of the task being less cognitively demanding. In this task patients were required to cancel all items present, and therefore, this task is likely to be the least complex of the cancellation tasks as cognitive processing required for distinguishing targets from distractors was not necessary.

It is not completely understood why there are often large differences in the extent of neglect on different tasks (Ferber & Karnath, 2001). Thus, reasons behind why there are differences in sensitivity between the BIT tasks require elucidation. The discussion above and in Chapter 1 suggest that task properties, both physical aspects of the stimulus (such as stimulus density, target-to-distractor ratio) and aspects affecting cognitive processing engaged in by the participant (task demands, task difficulty) impact on the extent of neglect exhibited. Recording patterns of eye movements produced during completion of these three tasks allows assessment of whether increasing cognitive difficulty in conducting a task influences the extent of contralesional sampling and the processing of contralesional targets, which may be contributing to poor performance in neglect.

1.3 Hypo-attention to the Left and Hyper-attention to the Right in Hemispatial Neglect

The third issue that this experiment investigated was whether neglect of the left side of the stimulus arose exclusively due to failure to attend to that area of the stimulus, or instead whether neglect also occurred due to preferential responding, i.e. hyper-attention, to the right side of the stimulus. Neglect of visual information on the left side of a stimulus arising solely as a result of inattention to the left has been termed hypo-attention to the contralesional side (e.g. Bartolomeo & Chokron, 1999). This is the idea that left neglect reflects an attentional deficit to contralesional space (Behrmann et al., 2002). This would result in fewer fixations, and therefore, less time being spent on the left, and the neglect participant taking longer to make a gaze on this area (i.e. it would take longer for this area to capture the neglect participant’s attention).

Other researchers have postulated that increased arousal of the ipsilesional hemispace causes exaggerated attention to that region, and consequential preferential responding to the right (Kinsbourne, 1977). This has been suggested to be due to the non-damaged (left) hemisphere having a higher activation overall compared to the damaged (right) hemisphere (Kinsbourne, 1970) and, therefore, there being increased inhibition of the damaged hemisphere. In this way, neglect of the left occurs due to over attention to the right, rather than inattention to the left (Ládavas, Petronio, & Umiltá, 1990; Marshall & Halligan, 1989). These two explanations are hard to disentangle as both possibilities result in the same pattern of behaviour. Hypo-attention to the left is likely to result in target items being missed within the left regions of space. However, hyper-attention to the right may also result in information being missed on the left due to the difficulty for a patient to disengage attention from the right regions of space once attention has been captured by that region (Posner, Walker, Friedrich, & Rafal, 1984). Recording participants eye movements' as they engage in a task may enable insight into which is the main cause of neglect. If neglect was due to hypo-attention, then there would be restricted sampling of the left, with fewer eye movements being made to the contralesional regions and less time being spent fixating there than the ipsilesional regions. If neglect was due to hyper-attention to the right, then not only would it be expected that there would be fewer eye movements made to, and less time spent fixating the contralesional regions, but additionally, a disproportionately increased amount of time would also be spent fixating ipsilesionally and more eye movements would be made to that region compared to control participants.

1.4 Limb Stimulation in the Treatment of Hemispatial Neglect

An additional issue that this experiment investigated was whether the extent of neglect could be reduced by an intervention aimed to increase attention to the left side of space through increasing activation in the damaged hemisphere. It has been argued that neglect results from imbalanced competition between the left and right hemispheres (Duncan, Humphreys, & Ward, 1997). Damage to one hemisphere (e.g. the right) results in the non-damaged hemisphere, which has higher activation, failing to be inhibited. Inhibition of one hemisphere is required in order for attention to be shifted from the ipsilesional to contralesional region of space (Kinsbourne, 1977). Upper limb activation and stimulation have been put forward as possible effective treatments for neglect due to increasing the activation of the damaged hemisphere, and therefore its ability to inhibit the non-damaged hemisphere (Bailey et al., 2002; Robertson, Hogg, & McMillan, 1998;

Robertson & North, 1992). The underlying mechanism(s) believed to be accounting for the effectiveness of limb activation as a treatment for neglect relies on the assumption of the premotor theory of attention (Rizzolatti & Carmarda, 1987). It is stipulated in the premotor theory of attention that neural circuits involved in representing space are linked to the control of motor responses (Rizzolatti & Carmarda, 1987). Therefore, making a motoric response within the contralesional region activates regions of damaged hemisphere that represent contralesional space. Therefore, the activation of the damaged hemisphere, particularly the right parietal regions, through contralesional limb activation, increases inhibition of the non-damaged hemisphere, and enables attention to the usually neglected side in neglect (Eskes, Butler, McDonald, Harrison, & Phillips, 2003; Harding & Riddoch, 2009; Polanowska, Seniów, Paprot, Leśniak, & Członkowska, 2009; Robertson, Hogg, & McMillan, 1998; Robertson & North, 1992).

The right parietal region has been suggested to have an important role in directing attention to the left side of space. Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) studies have demonstrated that the right inferior parietal lobule and intraparietal sulcus regions were activated when participants were cued to orient their attention to a specific spatial location in the visual array (Corbetta, Miezin, Shulman, & Peterson, 1993; Coull & Nobre, 1998; Nobre et al., 1997). Furthermore, recovery of neglect has been demonstrated to be associated with a restoration and rebalancing of activity within the parietal regions in the right hemisphere (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005). Therefore, activation of the right parietal region through left limb movements may enable allocation of attention to the left.

Attention being allocated to the left during treatment may result in a saccade being made to that area in order to extract detailed visual information from stimuli presented in that region (see Liversedge & Findlay, 2000). It has been demonstrated that attention is first allocated to a spatial location before a saccade is planned and initiated to that area (Bartolomeo & Chokron, 2001; Shepherd et al., 1986). Therefore, if a neglect patients' attention is increased to the left through stimulation to their affected arm, it is likely that corresponding eye movements will be made to that region to extract detailed information from stimuli there (Liversedge & Findlay, 2000; Shepherd et al., 1986). Brown, Walker, Gray and Findlay (1999) suggested that limb activation may improve the patient's ability to make leftward saccades in tasks that are under higher level voluntary control (such as in search tasks and reading). The present study aimed to investigate whether limb activation had an impact on the sampling behaviour of a neglect patient during cancellation tasks.

Specifically, to investigate whether there was an increase in sampling of the contralesional region after treatment and whether this was associated with an improvement in contralesional TIA. On the contrary, the neglect patient may have still exhibited poor TIA within contralesional regions even if sampling of that region had increased. This would suggest that the patient exhibited a processing deficit of fixated information within contralesional regions of space.

Limb activation treatment usually involves patients making functional movements with their affected arm. Often stroke patients suffer from hemiparesis and have very little functional movement in their affected arm (Harding & Riddoch, 2009). One clinically applicable tool used to stimulate the upper limb when there is little or no functional movement is Functional Electrical Stimulation (FES), which was employed in this study. This involves applying electrodes to an area on the upper arm and passing an electrical current, usually 40 Hz, to the muscles to provide sensory stimulation and muscle contraction and joint movement in the affected limb (Harding & Riddoch, 2009). FES is a new technique to aid limb activation and treat neglect. The underlying mechanism(s) for the effect of limb stimulation (e.g. FES) on neglect are not established (Eskes et al., 2003; Polanowska et al., 2009) but are based on the explanations for limb activations' affect on improving neglect through activating shared brain regions for motor responses and attention (Harding & Riddoch, 2009). Limb stimulation, similar to the effect of limb activation, results in a movement of the upper arm and this initiates activation of the right parietal lobe and attention to the left side of space (e.g. Robertson, Tegnér, Goodrich, & Wilson, 1994; Kinsbourne, 1993).

Treatment involving FES has been shown to be effective in rehabilitating functional movement in the affected arm (e.g. Meadmore et al., 2012) and mitigating neglect in stroke survivors, with this being shown to last 6 months or more (e.g. Eskes et al., 2003; Harding & Riddoch, 2008). Functional Electrical Stimulation applied to a paretic limb has been demonstrated to activate certain cortical areas, specifically the secondary motor and somatosensory areas and the contralateral inferior parietal lobule, which is strongly associated with spatial attention and which is often found to be lesioned in neglect (Golaszewski et al., 1998). Harding and Riddoch (2009) applied FES (at 40 Hz) to the forearm muscles of four neglect patients for a three week period. Three patients made a good physical and functional recovery in their upper arm. Additionally, their neglect ameliorated following treatment. Harding and Riddoch (2009) suggested that the improved performance was a result of the sensory stimulation activating the proprioceptive map in the parietal lobe of the damaged hemisphere, which is then able to inhibit the non-affected hemisphere. This inhibition, in turn, increases the detection and recognition of stimuli in the usually neglected area of space.

Polanowska et al. (2009) employed left hand stimulation alongside visual scanning training to investigate the effect of these rehabilitative techniques in mitigating neglect. Some of their patients received scanning training for one month alongside sham stimulation (placebo condition). The experimental group received both scanning training and limb stimulation treatment for one month. Polanowska et al. believed that this approach would activate the right hemisphere attention system and thus increase visual exploration of the contralesional space. Neglect severity was measured pre-treatment, immediately following sham or real stimulation and after one month of the intervention. It was found that after one month of limb stimulation and visual scanning training there was a pronounced increase in the number of targets identified contralesionally by neglect patients, with significantly higher scores obtained after treatment for those that received both treatments as opposed to scanning training on its own. As large somatosensory fields for the hand are localised in the parietal region, the somatosensory stimulation elicited may have contributed to an increase in the activation level in these cerebral areas, something that is crucial for spatial attention (Polanowska et al., 2009).

One of the aims of Polanowska et al. (2009) was to evaluate the effect of limb stimulation on visual scanning. This was not directly measured but inferred from task performance on the star and line cancellation tasks. It is argued here, given that it is unknown the extent to which processing deficits occur for contralesional information even when information has been sampled, that the performance on the task cannot represent a direct measure of the extent and area of the stimulus that was visually explored. The present experiment involved tracking participants eye movements whilst they completed these standardised tasks from the BIT before (on two separate occasions) and after limb stimulation treatment in order to directly assess the extent to which the treatment influenced sampling and processing of information on the left side of space.

1.5 The Present Study and Hypotheses

This study was conducted as a part of a collaborative project between a team of researchers from Psychology, the Faculty of Health Sciences and the Electronics and Computer Science Departments at the University of Southampton. The intervention was designed to test the effect of upper limb stimulation on motoric function of the arm that was affected by the stroke (the efficacy of the iterative treatment on motoric function is reported elsewhere; see Meadmore et al., [2012]) and neglect. Involvement in this study provided access to a chronic neglect patient (referred to as SS throughout) and two stroke controls (SCs). The opportunity was provided to measure their eye movements during completion of the three BIT cancellation tasks on three separate occasions; the first two sessions before the treatment commenced (baseline assessments) and the final session after limb activation treatment had been applied. During each session, the three cancellation tasks were completed whilst participants' eye movements were tracked. The eye movements of three older adult controls (OACs) were also measured over three sessions in order to obtain a measure of normal performance and to assess the extent of any change (e.g. practice effects) in healthy participants who did not undertake the intervention.

The head-mounted eye tracking equipment that was required to measure participants' eye movements during completion of cancellation tasks was a video-based eye tracking device. Due to the data being acquired during a video based system which had lower spatial and temporal accuracy compared to desk mounted eye trackers (e.g. the EyeLink 1000), the data did not include individual fixations. Hence, the present study also provided an opportunity to develop and evaluate processing time measures based on a 60 Hz frame by frame video recording of eye movement behaviour. The eye movements were manually scored enabling the following measures to be obtained: the amount of time spent fixating a region before transgressing a region boundary (average gaze duration); the total amount of time spent fixating each region; and the number of eye movements made to each region. Again, this preliminary investigation was necessary in order to establish that the sample rate was sufficiently high to allow meaningful (and sensitive) measures of eye movement behaviour to be obtained. It was anticipated that these measures would provide detailed information as to whether a region of space was sampled to the same extent as other regions by SS, and the amount of time that was required on average in order for SS to process the visual information presented. The effect of upper limb stimulation on these measures was also analysed.

Upper limb stimulation treatment was administered over a period of 6-8 weeks, between the second and third eye movement recording sessions of this experiment. The treatment involved patients having 18 1-hour limb activation sessions during which the patient used their arm that had been affected by the stroke (their left arm). The affected arm was electrically stimulated via 40 Hz FES to their triceps brachii and anterior deltoid muscles and was supported by a robotic arm that assisted movement. The patients' aim was to track a slowly moving sphere on a computer screen in front of them that travelled along a pre-determined trajectory. The trajectory extended across the visual field and visual sampling of the usually neglected area was therefore encouraged by the activity during these trials, and this was expected to increase sampling of the left regions after treatment.

1.5.1 Sampling and Processing Deficits contributing to Neglect: Hypotheses

Based on the literature outlined in Chapter 1 (e.g. Behrmann et al., 1997; Barton et al., 1998; Walker & Young, 1996) and the findings from studies summarised in this chapter, it was anticipated that SS would primarily exhibit a sampling deficit, spending less time fixating the left side of the stimulus and making saccades into that region on fewer occasions (fewer gazes made on that region). However, based on Forti et al. (2005) and Walker et al. (1996) and the hypotheses that an information processing deficit contributes to neglect of contralesional information (Denny-Brown et al., 1952; Birch et al., 1967), it was also anticipated that a sampling deficit would not be the sole cause of neglect. On some occasions SS would make fixations on the left, but on these occasions, inadequate processing of information would still result in targets failing to be identified by SS. Furthermore, when SS achieved high TIA within contralesional regions, it was predicted that more time would be spent fixating those regions (compared to ipsilesional fixation time) by SS. This is proposed to reflect difficulty in accurately processing contralesional targets.

1.5.2 Sensitivity: Hypotheses

The second set of hypotheses relate to the sensitivity of the individual BIT cancellation tasks in revealing whether neglect of contralesional information was present. For the letter cancellation task, it was expected that TIA would be poorer, especially within contralesional regions, compared to the star and line cancellation tasks, due to this task being more cognitively demanding. This suggestion is in line with the findings of Ferber and Karnath (2001). Poorer TIA for SS in the letter cancellation task was predicted due to search for two different target items being required along with increased processing for discriminating between highly similar targets and distractors being necessitated. Higher accuracy on the star cancellation task was expected to be obtained by SS compared to her performance on the letter cancellation task. This would be due to the star cancellation task only requiring search for one target item (small stars) amongst distractors that were less similar to the targets than the ones included in the letter cancellation task. Finally, accuracy in the line cancellation task was expected to be the highest for SS since this task was the least cognitively demanding of the three. Recall, that in this task participants were simply required to cancel every item within the entire stimulus and did not have to distinguish between targets and distractors. Eye movements produced during these tasks were expected to provide insight into the factors affecting performance in neglect.

1.5.3 Hypo-attention and Hyper-attention: Hypotheses

Hypo-attention would be indicated by restricted sampling of the left, i.e. less eye movements being made to, and less time spent fixating, the left regions of the stimulus. Such behaviour was predicted for SS. Additionally, a similar amount of fixation time, and a similar number of gazes, would be made on the right regions by SS as the control participants. However, if hyper-attention to the right was occurring as well, this would be indicated by an exaggerated tendency for SS to spend more time fixating the right regions of interest, inflated gaze durations (time spent fixating) on those regions (demonstrating difficulty disengaging attention from that region), and more gazes being made on that region compared to controls. It was expected that inattention to the left and hyper-attention to the right would both be shown to be contributing to the neglect of information on the left for SS, as evidenced by the pattern of eye movements produced during the tasks.

1.5.4 Limb Activation: Hypotheses

It was anticipated that the intervention would increase the extent to which SS sampled left space. This could arise for two reasons. Firstly, it may be due to increased activation in the lesioned hemisphere through FES facilitating left arm movement and, therefore, areas involved in aiding attention to contralesional space in the right parietal regions (e.g. Harding & Riddoch, 2009; Robertson et al., 1998). Sampling of contralesional regions may also be increased after treatment by implicit scanning training of the neglected region of space during treatment as SS was required to fixate the contralesional regions during training sessions when guiding movements made by her arm in that region. It may also be the case that, due to FES increasing activation of the damaged hemisphere and, thus, weightings of information presented contralesionally, that processing of contralesional space may be improved. This would be indicated by treatment enabling accurate target identification on the left side of space when SS fixated that region. If processing was not affected by the treatment, then sampling of contralesional regions would increase during completion of the cancellation tasks in the session after treatment but TIA would still be poor for SS.

In summary, this experiment recorded eye movements during completion of the letter, star and line cancellation tasks in a chronic neglect patient (SS), two SCs and three OACs. The main aims were to test the eye tracking paradigm, to investigate sampling and processing deficits contributing to neglect, to determine the extent to which hypo-attention to the left side of space and hyper-attention to the right side of space occurred and the effect of task difficulty on the extent of neglect exhibited by patient SS. The effect of limb activation treatment on sampling and processing of contralesional regions and the extent of neglect exhibited was also examined.

2. Method

2.1 Participants

A chronic neglect patient was assessed (SS), along with two SCs and three OACs. SS was a 58 year old female, who had experienced a right hemisphere stroke 11 months prior to the assessment for the current study. A Computed Tomography (CT) report for SS indicated she suffered a hemorrhagic infarct in the right Middle Cerebral Artery (MCA) territory. The lesion involved the right lateral anterior frontal lobe and extended from the internal capsule, including both grey and white matter, continuing all the way to the cortical surface. The two SCs, one male and one female, had right hemisphere lesions resulting from ischemic or hemorrhagic strokes[1], 33 and 52 months pre-assessment and were aged 40 and 65, respectively. All patients were right handed. The chronic neglect patient and SCs were recruited through a collaborative project being conducted by Psychology, Electronics and Computer Science and Faculty of Health Sciences Departments. Patient SS had spent 11 years in education, which was similar to that of the two SCs, with 10 and 12 years being spent in education by these participants.

The presence of neglect was ascertained from SS’s performance on the three cancellation tasks from the BIT. SS was below the cut-off value for normal performance on the star and letter cancellation tasks, i.e. SS demonstrated clinical neglect on these tasks, but not for the line cancellation task. Azouvi et al. (2002) concluded that due to the poor sensitivity of some tests in revealing neglect (i.e. the line cancellation task, as was discussed in the introduction of this chapter), one must not rule out the presence of neglect in a patient, based on normal performance on one task. It is important to note that SS was nearly a year post-stroke and therefore the neglect exhibited was chronic and was highly unlikely to spontaneously recover (i.e. without intervention) at this stage (Wilson et al., 1987; Kinsella & Ford, 1984). The other two SCs were above the clinical cut-off value for inattention as determined by the three BIT cancellation tasks, demonstrating normal performance on all the tasks.

The three OACs were recruited through a participant pool for older adult volunteers held in the Psychology Department at the University of Southampton. Two females and one male were all right handed with an age range of 67-75 years (M = 71 years; SD = 4 years). They had normal or corrected to normal vision and no history of stroke or brain damage. On average, OACs had spent 14 years in education. These participants were included to investigate how older, non-brain damaged individuals performed on cancellation tasks, and to examine the pattern of eye movements produced, and whether there were any changes over the three sessions. The OACs did not receive limb activation treatment. This study received Psychology Department, University of Southampton, ethical approval.

2.2 Stimuli

Three sub-tests from the BIT were included in the experiment: the letter, the star and the line cancellation tasks. The line cancellation task (see *Figure 1* on page 4) consisted of seven columns of short lines (each 2.5 cm in length) differing in orientation. The central column contained four lines and the remaining six columns contained six lines each. There were 36 lines to be cancelled in total, of which 18 were to the left of the midline and 18 to the right. The central four lines were discounted from the overall score (according to the BIT manual) as two were crossed through by the examiner during instruction to the participant. The letter cancellation task (see *Figure 2* on page 5) consisted of 5 horizontal lines of 34 capital letters. The letters were approximately 1 cm in width and height and the five lines of letters were spaced 1 cm apart from one another. The targets in the task were the letters ‘E’ and ‘R’ of which there were 40 in total (20 on the left of the midline and 20 on the right). The star cancellation task (see *Figure 3* on page 6) consisted of small and large stars, single letters and letter strings forming meaningful words (i.e. leg, ten, her). The targets in this task were the small stars of which there were 54 in total (27 appeared on the left of the midline and 27 on the right). All of the tasks were printed on an A4 piece of paper of landscape orientation, constituting approximately 21.6^{o} x 30.1^{o} of the visual angle.

2.3 Apparatus

An easel, 76.2 cm x 59.9 cm at a slant of 67^{o}, was used to display the stimuli. This was placed on a desk in front of the participant and was located at an average viewing distance of 55 cm. The participants were seated in an adjustable chair with their heads resting on a chin rest in order to minimise head movements and to ensure the stimulus was centred on the sagittal mid-plane of the participants' head and trunk.

The eye-tracking data were gathered using an Applied Science Laboratories E5000 eye-tracker, running at 60 Hz. This was a video-based infrared tracker, which monitored fixation positions by tracking the centre of the pupil, as well as the first-surface corneal reflection. The eye-tracking video cameras were mounted onto a set of spectacle frames (acquisition device), which were worn by the participants during the experiment. There were two cameras involved: the eye camera and the scene camera. The eye camera was directed towards the right eye and recorded the movements made by the eye (including the pupil and corneal reflection). The corneal reflection was illuminated via a light-emitting diode (LED) located underneath the eye camera. Participants viewed the scene binocularly but only the movement of the right eye was recorded. The scene camera recorded the scene in front of the participant as the trial progressed. The two video feeds were recorded by a JVC GR-DF4SOV camcorder operating at 30 frames per second, housed in a backpack. The backpack also contained a power supply for the camera and a multiplexer for the eye-tracking equipment.

2.4 Design

All participants were tested on three different occasions (these will be referred to as the testing sessions: Session 1; Session 2; Session 3). Each testing session involved administering all three of the cancellation tasks (counterbalanced for order of presentation across participants and sessions) whilst the participants' eye movements were tracked. Sessions 1 and 2 were approximately 4 weeks apart, and Sessions 2 and 3 had a 6-8 week interim during which treatment sessions were undertaken. Two baseline sessions (before treatment) were included in order to get a measure of variability in SS's perform across testing sessions. The last testing session was included in order to assess the effect of the treatment compared to performance in Sessions 1 and 2. The treatment sessions between Session 2 and 3 involved iterative limb stimulation treatment being administered to SS and the SCs during 18 1-hour sessions. See *Figure 8* for a pictorial representation of the design of the study.

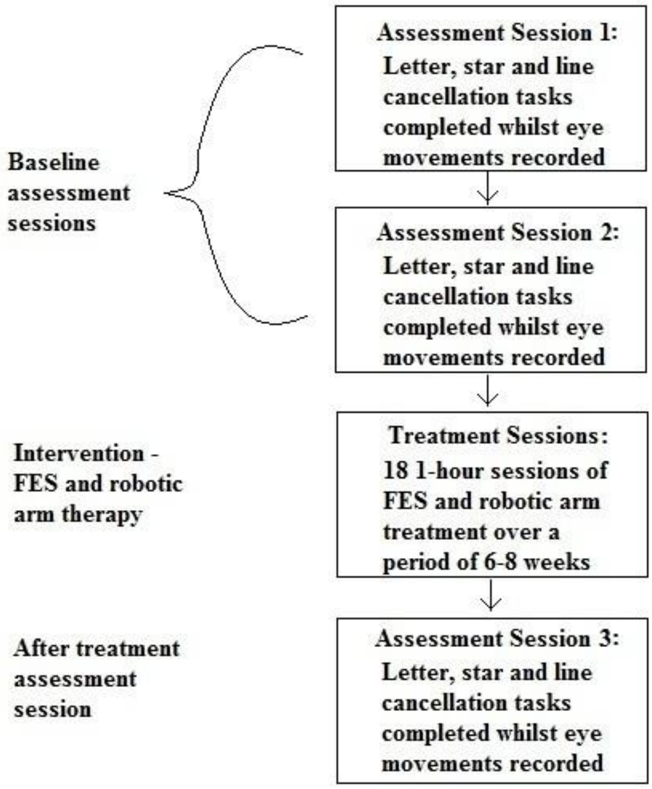

Figure 8. Consort diagram demonstrating the design of Experiment 1, including all assessment and treatment sessions.

2.5 Procedure

For the testing sessions, the participants were run individually in a quiet and well-lit room in the Faculty of Health Sciences or Psychology Department at the University of Southampton. The participant was seated in a chair (or their wheelchair if required) in front of a desk on which the easel was placed. The participant was asked to wear the head-mounted eye tracker acquisition device like a pair of spectacles. When the experimenter was satisfied that the positioning of the cameras would obtain high-quality recordings of the eye movements and the scene, recording of the video feeds commenced.

Calibration procedures were undertaken before the experiment began. During calibration, participants were required to follow a laser-pointer that guided the participants to the centre of five points presented in the scene (subtending approximately 2^o x 2^o of visual angle) sequentially. One calibration point was placed at each of the corners, and at the centre, of an A4 piece of paper, which was located at the centre of the easel. A stimulus (the line, star or letter cancellation task) was then placed onto the centre of the easel. If required, the participant was able to take a break following completion of one task, after which another calibration was undertaken before the next task was administered. When the stimulus was placed in front of the participant, the experimenter explained the cancellation task, as instructed in the BIT manual, directing the participant's attention to the stimulus and indicating to them which elements were required to be searched for and crossed through during the task. The participant was given a marker pen and asked to cross through all of the targets that they could find in the stimulus and to place the pen down when they had finished. No time limit was imposed on the task to ensure that if contralesional targets were not identified that this was due to neglect and not a result of SS running out of time to find targets on the left. The order in which the stimuli were administered was counterbalanced across participants and sessions.

The treatment sessions involved the participants using their affected arm to track a slowly moving sphere along a trajectory, which was displayed on a computer monitor in front of them. Assistance in moving the affected (left) arm was provided from FES to their triceps brachii and anterior deltoid muscles and a robot which supported the arm during tracking. The trajectory extended across the visual field and into the contralesional side of space. The same trajectory was repeated 6 times during the treatment session and 3-6 different trajectories were administered in each session (the number of trials administered being determined by the fatigue experienced by the participant).

Important feedback was provided in these sessions. A real-time image of the participant's arm was displayed as it moved to follow the sphere and the colour of the sphere changed depending on the accuracy of the tracking movement. Green represented there was less than 5 cm error in the participant's tracking movement and red indicated greater than 5 cm error. This encouraged sampling of the contralesional region of space and allowed the participant to correct their tracking behaviour if the movement was inaccurate.

2.6 Data Analysis

Using specialised software held within the Psychology Department, the fixation position of the eye in the scene (obtained from the eye camera) was superimposed onto the scene footage (obtained from the scene camera). This was achieved by calibrating the position of the eye at each of the five calibration points that were present in the scene footage during the calibration procedure. A verification procedure (a second calibration) was included to ensure that the fixation cross was in the correct position within the scene following calibration (i.e. that the fixation cross fell on each of the calibration points during the second procedure). If this was not achieved, calibration was attempted again and if it was not possible to accurately calibrate the data, the trial was excluded from the analyses. One of the SC's trials was excluded (for the line cancellation task during Session 3) as it could not be accurately calibrated due to a failure of the LED to consistently illuminate the first surface corneal reflection during testing.

An .avi file was saved incorporating the point of fixation within the scene for each frame in the video (approximately 2,000 frames per trial). There were 53 trials included in total, three cancellation tasks for each of the three sessions for six participants (excluding one of the SC's trials). Using video analysis software (VirtualDub) to step through the .avi footage frame-by-frame, the position of the fixation with respect to regions of interest imposed on the stimuli (described in the next section) was hand-scored for each frame. Frames were scored for the period of the trial in which the task was being completed (i.e. not for eye movements made during instruction to the participants). When the fixation cross was not available in a frame due to an eye-blink or tracker loss, these frames were not included in the data. The temporal accuracy was determined by the rate of recording on the camcorder, which was one frame every 33 ms. All of the trials were hand-scored by two individuals in order to achieve scoring reliability. The two individuals' scoring sheets were compared to one another. This was to identify any discrepancies in which an individual had coded the fixation cross to be in one region, and the other individual had coded it as in another region for each of the video frames during the trial. Where discrepancies were identified, the frames were re-scored with both reviewers present to achieve the most objective scoring of the eye movement data.

For analysis of behavioural responses, the BIT cancellation tasks were divided into four regions of interest. This was in order to determine accuracy for target identification with regard to different areas of space (i.e. far left [FL], near left [NL], near right [NR], far right [FR]). However, the regions employed by the BIT are not equal in size and do not have distinct region boundaries (e.g. letters within the same column are included in different regions along the horizontal extent of the stimulus). The authors (Wilson, Cockburn, & Halligan, 1987) divided the stimulus into regions based on the placement of targets within the stimulus and aimed to equate the regions for target numbers, not size. For the eye movement measures in the study reported here, it was important that the regions of interest were equivalent in size (or a specific proportion of the stimulus) in order to meaningfully compare the amount of time and number of gazes made across the regions during analysis so that a sampling deficit could be identified if present in neglect. Also, these boundaries needed to be clearly defined (straight down a column of letters) to be easily identifiable within the stimulus when scoring of the eye movements was conducted based on the scene footage. Therefore, the letter and star cancellation tasks were divided into equal quarters for the behavioural and eye movement analyses: FL; NL; NR; and FR (see *Figure 9* and *Figure 10*). The design of the line cancellation task meant that it could not be divided into four quadrants, as this would result in the majority of the targets falling into two different regions of interest. Therefore, for analysis of behavioural and eye movement measures on the line cancellation task, this stimulus was divided into three meaningful regions of interest: left; centre; and right (see *Figure 11*), with the central region comprising 40% of the stimulus and left and right 30% each. As the letter, star and line cancellation tasks were not designed with equal sized regions for the BIT, the regions employed in this experiment meant that different numbers of targets were located in the four regions. Thus, the percentage accuracy was reported for each region of the cancellation tasks.

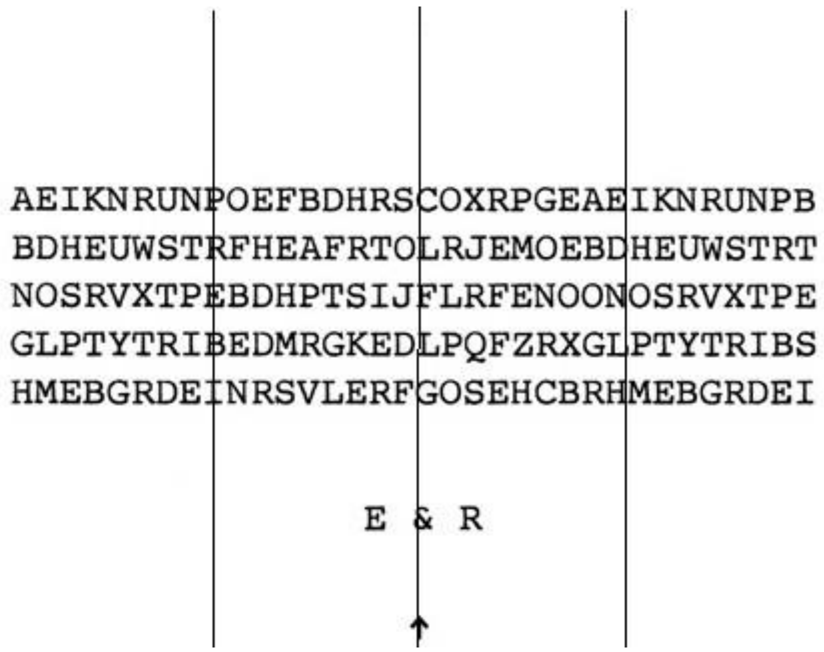

Figure 9. Regions of interest, denoted by the vertical lines, imposed on the letter cancellation task for the behavioural and eye movement measures. From left to right: far left (FL), near left (NL), near right (NR), far right (FR). The vertical lines were not present when the participant was completing the task. The arrow at the bottom of the stimulus was aligned with the sagittal midplain of the participants' trunk.

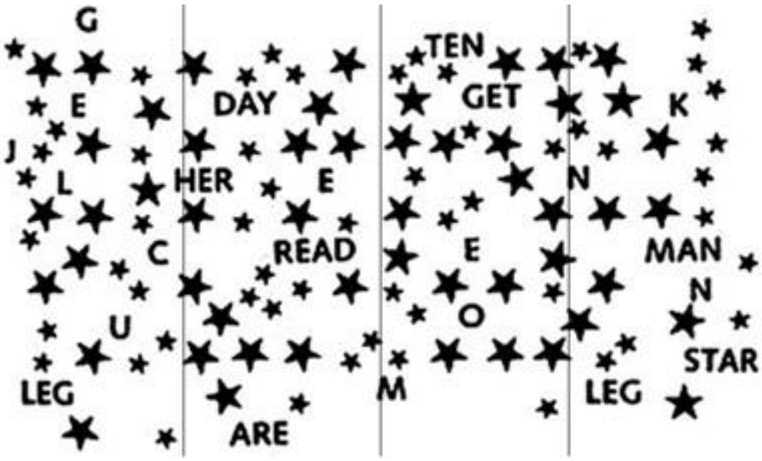

Figure 10. Regions of interest, denoted by the vertical lines, imposed on the star cancellation task for the behavioural and eye movement measures. From left to right: far left (FL), near left (NL), near right (NR), far right (FR). The vertical lines were not present when the participant was completing the task.

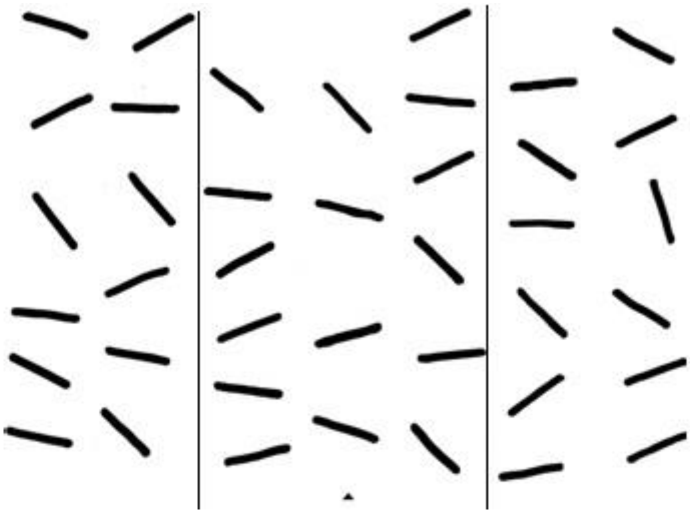

Figure 11. Regions of interest, denoted by vertical lines, imposed on the line cancellation task for the behavioural and eye movement analyses. From left to right: left, centre, right. The arrow at the bottom of the stimulus was aligned with the sagittal midplain of the participants' trunk. The vertical lines were not present when the participant was completing the task.

In the letter cancellation task for the regions of interest employed in this study, there were 8 targets in the FL region, 12 in the NL region, 11 in the NR region, and 9 in the FR region. In the star cancellation task, there were 16 targets in the FL region, 14 in the NL region (2 of which are not included in the score as these are cancelled by the experimenter during instruction to the participant, as per the BIT manual), 13 in the NR region and 13 in the FR region. In the line cancellation task, there were 12 targets in the left region, 16 in the central region (of which four were not included in the behavioural scoring, as per the BIT manual), and 12 on the right.

3. Results and Discussion

In this section, descriptive statistics for both behavioural and eye movement data were reported for the three cancellation tasks in the three testing sessions and, where appropriate, inferential statistical tests were conducted.

3.1 Eye Movement Measures

In order to obtain meaningful measures from the hand-scored eye movement data, a code was developed in RStudio™ by Dr. Hayward Godwin and myself to process the raw data. This involved integrating all the consecutive fixations within a region (to remove breaks in the fixation due to blinks or tracker loss and therefore eliminate artificial gaze durations) before an eye movement was initiated to another region. Eye movement measures were extracted via algorithms developed.

To establish whether there was a difference in SS's sampling of the different regions, the proportion of overall gazes made and the proportion of the total trial time spent fixating each region was calculated and analysed. A gaze commenced with a saccade being made to a region. The end of the gaze occurred when the eye transgressed a region boundary, i.e. made a saccade to another region. Proportion of gazes and proportion of fixation time for each region were reported as, for the letter, star and line cancellation task, SS took more time to complete the task and made more gazes overall than the control participants. Thus, as the amount of time overall spent fixating a region would be affected by the increase in overall time spent conducting the task, proportions of time spent fixating each region were deemed to be more informative when comparing SS's allocation of attention across the stimulus as a whole to that of the control participants. To be clear, if a sampling deficit was contributing to neglect, one would expect that SS would spend less time fixating the left regions. However, as she spent more time completing the task than the control participants, fixation time on the FL may be greater than that of the control participants. However, the time spent fixating the FL region may be far less than the time she spent fixating the FR. Therefore, in order to capture the attention allocation over the stimulus as a whole in neglect, the proportion of the total trial time spent fixating, and the proportion of overall gazes made, were reported for each region.

Average gaze durations were also calculated as this measure allowed investigation of whether there was a delay associated with processing targets that were identified during contralesional gazes made on the left by SS. This measure was defined as the average amount of time spent fixating a region before transgression of the region boundary. As this measure reflects the amount of time spent fixating during each gaze (i.e. time spent searching a region before moving on to another region), the total trial time would be highly unlikely to have had an impact on this measure and therefore the raw data here (instead of proportions of total trial time) were used to reveal whether processing deficits arose during contralesional fixations. Inflated average gaze durations would indicate more time was required to process the information in that region.

3.2 Statistical Analyses

When it was appropriate, the Crawford and Howell (1998) method was employed to compare single-case study data (from SS) to the small group of controls. This test is essentially a modified *t*-test. It was considered more appropriate to use the Crawford and Howell method than *z*-tests due to the likelihood of inflating a Type I error as a small control sample (≤ 5) was used and therefore over-estimation of the abnormality of SS's score was likely to occur.

3.3 Letter Cancellation Task Results

3.3.1 Behavioural measure: Target Identification Accuracy (TIA)

SS's performance in all the sessions of the letter cancellation task was below the cut-off score (34/36 targets identified) as determined by the BIT from normative data and thus demonstrates she was consistently outside of the normal range of performance for this task, indicating clinical inattention (see Table 1). As expected, the SCs and OACs did not fall below this cut-off point on the task, being within the normal range for target identification. On average 96.7% of targets were found by the SCs, and 98.5% by OACs.

As expected, in Sessions 1 and 2, SS exhibited reduced accuracy for target identification in the FL and the NL regions (see Table 1) compared to control participants (Session 1, $t(4) = 8.09$, $p = .001$; Session 2, $t(4) = 8.09$, $p < .001$). SS's accuracy was highest for the target items contained in the right (ipsilesional) regions in Session 1. The limb stimulation treatment did not have an impact on the extent of neglect exhibited by SS in the letter cancellation task, as measured by TIA. Patient SS's TIA in the FL region in Session 3 remained the same as in Sessions 1 and 2 (50%) and was significantly lower than controls, $t(4) = 45.64$, $p < .001$. In Sessions 2 and 3, the neglect of information was not limited to the contralesional side; with SS identifying fewer target items in the NR region than the NL region (see Table 1). Poor target identification of items on the right in neglect has been documented previously (e.g. Azouvi et al., 2002; Bisiach & Vallar, 1988; Forti et al., 2005) and reasons for this will be considered next.

Ipsilesional targets (in the NR region) that SS failed to identify in Sessions 2 and 3 may have occurred due to an emphasis on representing the left occurring in these sessions compared to previously. It appears that neglect is a dynamic disorder, and different areas of space may be neglected based on how the space was represented (i.e. which frame of reference was operating) during the task. Neglect patients representing the visual array differently for different task demands has been demonstrated by Karnath and Niemeier (2002). They found that when the participant was searching a homogeneous array (where all the letters were the same colour and the stimulus appeared as one whole section), the whole left side of the array was neglected. However, when the participants were informed that a target would only appear in one sixth of the array in a region denoted by a specific colour and that was surrounded by a boundary (the segmented condition), participants failed to inspect the left side of that region. The area that was neglected in the segmented condition was previously attended to in the homogenous conditions. This demonstrates that the area neglected was determined by which parts of the stimulus were deemed important for SS to attend to in order to conduct the task. Thus, the importance of different regions of space can be affected by the task demands and this can affect how the external environment is represented (i.e. whether one region is focused on or a larger area of space is represented). This can directly impact on the area that is subsequently neglected and may account for the unusual pattern of TIA in SS for Sessions 2 and 3. It may have been that SS was representing the stimulus as two halves – the left side and the right side of the stimulus – in the later sessions. This may have occurred if SS was trying to compensate for inattention to the left and assigned the left side of the stimulus as an important area of interest. Therefore, neglect of the left side of each of those parts that have been deemed to be important for completion of the task may occur, i.e. the FL region (the left side of the left half) and the NR region (the left side of the right half). This will be investigated further in Experiment 4. Reasons as to why SS may have changed her representation of the stimulus in Session 2 (i.e. before the treatment) may be linked to the heterogeneity of neglect, awareness of the deficit, and also to practice effects, which will all be considered further in the General Discussion.

3.3.2 Eye movement measures: Proportion of gaze and total trial time fixating regions on the stimulus

The proportion of total gazes made on each region and the proportion of the total trial time spent fixating each region are measures of how attention was allocated across the stimulus during the cancellation task. These allowed quantification of any sampling deficit present in SS that may be causing neglect of contralesional information, and also, along with TIA, determination of whether deficient processing during fixation of contralesional information was contributing to neglect.

Firstly, the pattern of eye movements exhibited by the control participants will be outlined before describing the pattern of eye movements SS produced. In all sessions, control participants tended to make more gazes on the NL and NR (internal) regions than the FL and FR (external) regions, $t(14) = 6.74$, $p < .001$ (see Table 1). If the size of the region determined how many gazes were made, then it would be expected that all regions would attract the same number of gazes, as each region was equivalent in terms of size. However, as this was not the case, it appears that other factors may have been affecting the number of gazes a region received. There are three main reasons why the control participants may have made more gazes on the internal regions.

The first explanation relates to the fact that the internal regions in the letter cancellation task are flanked by two regions, one on either side. This may result in more transgressions between region boundaries for the internal regions compared to the external regions, where there is only one region, either to the left or right. To be clear, when the participant was fixating the FL or FR (external) regions, they were more likely to stay in the region due to there being little incentive to exit the region to the left or right, respectively, as these regions were beyond the extent of the stimulus (which were not relevant for completion of the task). Therefore, being less likely to exit, and subsequently re-enter, those regions than the internal regions, may have resulted in fewer overall gazes being made on the external regions. For the internal regions participants were likely to exit and re-enter those regions (i.e. transgress the region boundaries) due to the areas outside those regions containing task-relevant information (i.e. more potential targets).

A second reason for internal regions having received more gazes is that participants exhibit a ‘general tendency’ to fixate central regions of stimuli during search tasks (e.g. Henderson, Brockmole, Castelhano, & Mack, 2007). This tendency to fixate central regions was suggested by Henderson et al. to be more influential than the effect of saliency on the pattern of eye movements exhibited. For example, even if a salient area was present in the external regions of the stimulus, participants would still make more fixations on the central regions due to this intrinsic predisposition.

Thirdly, in the letter cancellation task, the internal regions contained more targets (NL = 12; NR = 11) than the external regions (FR = 9; FL = 8) and therefore these regions may have attracted more gazes. More gazes being made due to more targets being present within those regions is likely to occur due to the necessity to increase visual sampling of those regions in order to accurately identify all of the target items there. Despite making more gazes to the internal regions, the control participants spent an equivalent proportion of fixation time in each region during all sessions (see *Figure 12* for a graphical depiction of this pattern). This suggests that they did not need increased fixation time to identify more targets that were present in the internal regions.

Table 1

Target Identification Accuracy (TIA; % of Targets Found), Proportion of Gazes (Gazes), and Proportion of Trial Time spent Fixating (Time) the Four Regions (far left [FL], near left [NL], near right [NR], far right [FR]) of the Letter Cancellation Task Stimulus across Three Sessions for SS (presented in bold), Stroke Controls (SCs) and Older Adult Controls (OACs).

Measure	Group	Session 1				Session 2				Session 3			
		FL	NL	NR	FR	FL	NL	NR	FR	FL	NL	NR	FR
TIA	**SS**	**50**	**67**	**91**	**100**	**50**	**83**	**55**	**87**	**50**	**83**	**64**	**89**
	SCs	94	96	100	100	94	92	100	100	100	100	100	100
	OACs	100	100	97	96	100	100	97	100	100	97	94	100
Gazes	**SS**	**.12**	**.27**	**.37**	**.24**	**.15**	**.35**	**.29**	**.21**	**.18**	**.30**	**.32**	**.20**
	SCs	.20	.31	.30	.20	.13	.32	.37	.18	.16	.37	.32	.16
	OACs	.21	.27	.28	.24	.19	.30	.32	.19	.18	.28	.33	.21
Time	**SS**	**.08**	**.28**	**.29**	**.35**	**.22**	**.41**	**.20**	**.17**	**.22**	**.24**	**.26**	**.28**
	SCs	.26	.26	.27	.23	.24	.23	.29	.24	.25	.25	.27	.24
	OACs	.26	.25	.28	.22	.25	.25	.27	.22	.25	.25	.26	.24

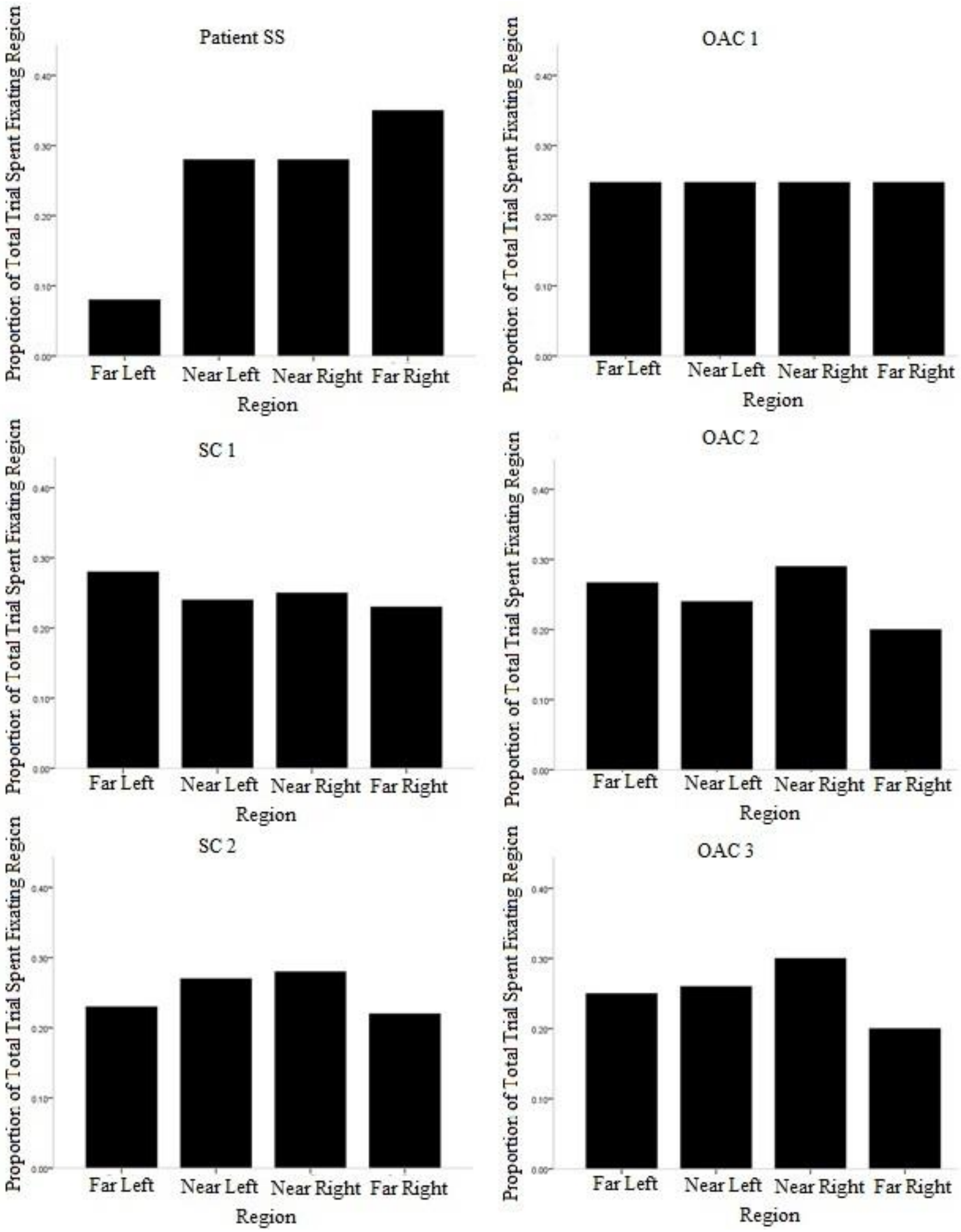

Figure 12. The proportion of the total trial time spent fixating each region (Far Left, Near Left, Near Right, Far Right) of the letter cancellation task in Session 1, for SS, Stroke Controls (SCs) and Older Adult Controls (OACs). Whereas control participants spent a similar proportion of time fixating each region, SS spent less time fixating regions further to the left of the stimulus.

In summary, control participants made more gazes on the internal regions than the external regions but spent a proportional amount of the total trial time fixating each of the regions. This pattern of eye movements was associated with high target identification for each region of the letter cancellation task for control participants. Thus, these eye movement measures could provide insight into why SS failed to identify targets contained within contralesional regions when comparing her pattern of eye movements to that of the controls. This will be considered next.

In Session 1, SS made a significantly smaller proportion of gazes on (12% of the total gazes), and spent significantly less of the total trial time (8%) fixating, the FL region than the control participants, $t(4) = 2.73$, $p = .026$; $t(4) = 8.17$, $p = .001$ (see *Figure 12* for proportion of time spent fixating the regions of the stimulus). This demonstrated that SS's allocation of attention via eye movements to contralesional regions in this session was very limited. These findings provide evidence for a sampling deficit contributing to the neglect of information on the left.

Additionally, SS made twice as many gazes on, and spent 27% more time fixating, the FR region compared to the FL region in this session. This may suggest that SS was hyper-attending to the ipsilesional regions. However, the measures reported here were proportions and, therefore, these proportions reported for the different regions are dependent on one another. This means that the proportion of time or gazes on the ipsilesional regions would be inflated by a decrease in time spent fixating, or gazes made on, the contralesional regions, which may be due to hypo-attention to the left. Whether neglect patients do present with hyper-attention to ipsilesional regions will be considered in subsequent chapters of this thesis, where, due to the nature of the research questions and trial time being equivalent across participant groups, proportional measures were not reported.

In Session 2, before treatment was administered, unexpectedly, there was no longer a significant difference in the proportion of gazes made on, and the amount of time SS spent fixating, the FL region compared to controls, $ts(4) = 0.46$, $p = 0.336$; $t(4) = .83$, $p = .227$. Additionally, SS produced a pattern of gazes, and proportions of fixation time, that were more comparable for the FL and FR regions in this session, although the proportion of gazes was still slightly higher on the FR. Recall, however, that SS, as in Session 1, still failed to identify 50% of the target items in the FL region. This demonstrates that a sampling deficit was not contributing to SS's poor contralesional TIA in Session 2, as she was sampling the contralesional regions to a similar extent as control participants. It seems likely, therefore, that a processing deficit of contralesional information occurred, and to a significant degree, this contributed to poor contralesional target identification in this session. To be clear, SS made saccades to the left and spent a proportional amount of time in those regions but still failed to process many target items within that period. Even though sampling of contralesional regions improved in this session, contralesional TIA did not. There are two main reasons why sampling of the left may have improved in Session 2 for the letter cancellation task.

Firstly, differential performance across assessment sessions in neglect has been demonstrated to occur, with this being explained by the variability associated with the manifestation of neglect within and across participants (e.g. Buxbaum, 2006; Walker et al., 1996). The pattern of eye movements in Session 2 of the letter cancellation task may have changed due to SS representing the stimulus differently to the way it was represented in the previous session. Task demands may affect the operation of different frames of reference (Karnath & Niemeier, 2002) and consequently can result in different parts of the stimulus being neglected, as explained previously. In Session 2, if the importance that SS attached to the left part of the stimulus (i.e. a compensatory strategy employed to attend to the left side of space in this session) may have been different to that assigned in the previous session and more eye movements may have been made to the left because of this.

A second reason for the increased sampling of the contralesional regions in Session 2 of the letter cancellation task could be the effect of practice on performance. As the patient was completing the task for the second time, it may be that familiarity with the task reduced the cognitive load associated with its completion and this may have resulted in increased sampling of usually neglected information. This reasoning would also be able to explain any improvement in Session 3. The effect of tasks being completed multiple times on the extent of neglect exhibited and the stability of neglect over different assessment sessions has undergone little empirical investigation; therefore it is unknown whether familiarity with a test may improve neglect performance. The important finding to note is that the increase in fixating the left region did not affect the extent of neglect exhibited. This means that neglect cannot, fundamentally, be entirely caused by a sampling deficit. This is an important finding and one that will be considered in more detail later in this thesis.

Eye movement measures from Session 3, after treatment had been completed, demonstrated that there was also no significant difference between SS's and the control participants' proportion of gazes on the FL region, $t(4) = 0.46$, $p = 0.336$. Furthermore, the proportion of gazes made by SS on the FL and FR regions in this session was almost equivalent. The increase in proportion of gazes made on, and time fixating, the left for SS may have been a result of the intervention or practice effects. Further discussion of these possible explanations will be deferred until the General Discussion. Patient SS's fixation time on the FL was still significantly lower than the control participants', $t(4) = 10.14$, $p < .001$. However, this was likely to be a result of the small amount of variability observed in the control participants ($SD = .27\%$) during this session. Note that SS only spent 3% less time fixating the FL than the control participants.

In summary, SS tended to make fewer gazes on, and spent 18% less of the total trial time fixating, the FL region than the controls in Session 1, indicating that SS exhibited a primary sampling deficit of contralesional information. In contrast, in the later sessions (Sessions 2 and 3), SS spent a similar amount of time fixating, and made a similar proportion of gazes on, the FL as the control participants but, interestingly, as in Session 1, SS identified 50% less target items in that region than the control participants. Importantly, this increase in sampling did not have an impact on neglect, thereby implying that a processing deficit contributed to neglect in these sessions.

3.4 Star Cancellation Task Results

3.4.1 Behavioural measure: Target Identification Accuracy (TIA)

As expected, SS had poorer TIA within the left regions on the star cancellation task in Session 1 than the controls (see Table 2), $t(4) = 5.53$, $p = .003$. Furthermore, SS's accuracy for the right regions was higher than the left regions. In Session 2, SS had higher accuracy in the left regions and slightly lower accuracy in the NR region compared to Session 1. However, SS still obtained lower TIA within the left regions of the stimulus compared to controls, $t(4) = 2.43$, $p = .036$. This was in line with SS's performance on the letter cancellation task. Patient SS's performance on the star cancellation task in both pre-treatment sessions was below the clinical cut-off value determined by the BIT.

Table 2

Target Identification Accuracy (TIA; % of Targets Found), Proportion of Gazes (Gazes), and Proportion of Trial Time spent Fixating (Time) in the Star Cancellation Task in the Four Regions (FL, NL, NR, FR) across Three Sessions for SS (presented in bold), SCs and OACs

Measure	Group	Session 1				Session 2				Session 3			
		FL	NL	NR	FR	FL	NL	NR	FR	FL	NL	NR	FR
TIA	**SS**	**69**	**58**	**93**	**100**	**81**	**92**	**85**	**92**	**94**	**92**	**100**	**100**
	SCs	100	100	100	100	100	96	100	100	100	96	100	100
	OACs	96	94	100	100	96	100	95	100	100	100	100	100
Gazes	**SS**	**.22**	**.35**	**.26**	**.17**	**.16**	**.31**	**.31**	**.22**	**.13**	**.26**	**.30**	**.30**
	SCs	.23	.30	.30	.19	.20	.32	.34	.16	.17	.31	.35	.18
	OACs	.17	.36	.32	.15	.19	.34	.31	.16	.19	.28	.33	.20
Time	**SS**	**.15**	**.21**	**.23**	**.41**	**.17**	**.31**	**.20**	**.32**	**.25**	**.17**	**.25**	**.33**
	SCs	.38	.20	.23	.20	.32	.23	.22	.24	.32	.23	.25	.21
	OACs	.29	.17	.27	.24	.29	.21	.25	.25	.29	.20	.28	.23

In Session 3, SS's accuracy was considerably higher with only a few targets being missed in the FL and NL regions. SS's performance in this session was no longer demonstrating clinical inattention, as her overall score in this session was above the clinical cut-off point. Patient SS only failed to identify 6% of the target items in the FL region compared to controls. This performance is substantially higher than that exhibited in Sessions 1 and 2 for the star cancellation task and all sessions of the letter cancellation task (where SS consistently failed to identify 50% of the target items in the FL region). This improved accuracy was likely to be a result of the treatment, or possible practice effects. The treatment, however, did not appear to have an impact on TIA for the letter cancellation task. As explained in the introduction, a number of factors vary between the letter and star cancellation tasks that result in the star cancellation task being less cognitively demanding. The improved performance of SS on the star relative to the letter cancellation task likely arises due to a combination of these factors. Further discussion of this issue will be deferred until the General Discussion.

3.4.2 Eye movement measures: Proportion of total gazes and total trial time spent fixating each region on the stimulus

Once again, the control participants' pattern of eye movements produced during the star cancellation task will be outlined before describing SS's eye movements. As can be seen from Table 2, the control participants fixated the central regions more often than the external regions, as was also found for the letter cancellation task. The explanations for this effect are the same as were suggested for the letter cancellation task. The control participants' spent a larger proportion of the trial time fixating the FL region than the other regions on the stimulus. Recall that the star cancellation task had more target items in the FL region than in any other region (16 compared to 12 in the NL and 13 in both the NR and FR regions), therefore, it appears that the control participants' fixation time was influenced heavily by the number of targets in the regions.

Contrary to expectations, there was no significant difference found between the proportion of gazes that were made on the FL region by SS and controls in Session 1, $t(4) = .637$, $p = .279$, or Session 2, $t(4) = .883$, $p = .213$. This is extremely interesting when taking into account SS's TIA in the FL region; only 50% of the targets were identified there. This demonstrates that SS was fixating the contralesional side of space and that, in this case, it was not a sampling deficit that resulted in the neglect of targets on the left side of the stimulus. This is evidence, again, that a processing deficit of contralesional information can result even when information on the left is sampled in neglect. The pattern of gazes produced by SS in this task is in stark contrast with those produced in Session 1 of the letter cancellation task, where there was a marked sampling deficit. Note that in the letter cancellation task only 8% of the total trial time was spent fixating the FL, whereas for the star cancellation task this time was nearly double (15%). The difference in sampling across these two tasks may be due to physical properties of the stimulus and differential complexity of the tasks. The effect that these factors have on attention and sampling for SS will be outlined in the General Discussion of this chapter.

In contrast to the control participants, SS's proportion of fixation time was not influenced by the fact that there were more targets on the FL of the stimulus. In Session 1 and 2 the least amount of time was spent fixating the FL, with this being significantly less than the controls, $t(4) = 2.99$, $p = .020$; $t(4) = 2.42$, $p = .036$, respectively. Considered together, the proportion of gazes measure demonstrates that SS fixated the left to the same extent as controls, but the proportion of time measure indicates that time spent fixating the left is shorter in duration compared to the control participants. Limited time spent fixating the regions may explain why fewer targets were identified there by SS.

The pattern of eye movements SS produced was slightly different in Session 3, with SS making a similar number of gazes on, and spending a higher proportion of time fixating, the FL region than previously (these were not significantly different from that of the controls, $t(4) = 1.47$, $p = .107$, $t(4) = 1.43$, $p = .113$). This demonstrates that compensatory eye movements were made to the FL of the stimulus, with the result of higher accuracy than reported in the previous sessions for this region (25% higher accuracy than in Session 1 and 13% more than in Session 2). The change in the pattern of eye movements produced during this task by SS may have been a direct result of the treatment. However, recall that this was not the case in the letter cancellation task. It appears that the treatment may only result in eye movements being made to contralesional regions when the cognitive demands of the task are low (as in the star compared to the letter). High cognitive demands being imposed by a task (e.g. dual-target search in the letter cancellation task) may mean that attention is still restricted to the left even after treatment and may be due to limited resources being available to conduct more difficult tasks within contralesional space.

Brown, Walker, Gray and Findlay (1999) suggested that their limb activation treatment was not effective due to the dual-tasking interference effects of the neglect patients conducting two tasks simultaneously. They believed this to be a factor decreasing performance in some conditions after limb activation treatment. The dual-search required for completion of the letter cancellation task reported in the current experiment may act in the same way as dual-tasking, reducing the effectiveness of the treatment in that condition. The absence of a dual-search component in the star cancellation task may have meant that the FES treatment was successful in aiding sampling of the usually neglected regions of space. It appears that this increased sampling of left space in the star cancellation task improved contralesional TIA, which indicates that there was no processing deficit during fixation in this session, but this deficit was apparent in Sessions 1 and 2. This suggests that limb stimulation did not only have an impact on sampling of the left in the star cancellation task, it also aided processing of information that was fixated on the left, which was not the case in the letter cancellation task. Task difficulty, again, is likely to be a factor moderating the effectiveness of the treatment in aiding attention to the left side of space. Differential complexity of the tasks moderating the effectiveness of treatments in ameliorating neglect may be a reason why some rehabilitative methods for neglect have not been found to generalise to more complex tasks than those used within the intervention (e.g. Bonato, 2012; Manly, 2002; Robertson, Halligan, Marshall, 1993).

3.5 Line Cancellation Task Results

3.5.1 Behavioural measure: Target Identification Accuracy (TIA)

In contrast to the behavioural results from the letter and star cancellation tasks, the line cancellation task assessment indicated that in all sessions SS scored above the cut-off value for clinical inattention. Only in one session was a target missed (97.7% accuracy in Session 2) and this target was in the centre of the stimulus (recall that there are three regions of interest for this stimulus: left, centre and right). This demonstrates that this task was not as sensitive as the letter and star cancellation tasks in revealing the presence of neglect, as has been demonstrated previously (Ferber & Karnath, 2001). As has been explained previously, it was not necessary to distinguish targets from distractors in the line cancellation task (as every item that was present in the task was required to be cancelled). Furthermore, the line cancellation stimulus had a less dense array of target items than the star and letter cancellation tasks, which may also make it less cognitively demanding to complete. Fewer cognitive demands required to complete the line cancellation task (for example, participants not being required to distinguish between targets and distractors) may have enabled allocation of attention to the usually neglected side of space for SS.

3.5.2 Eye movement measures: Proportion of total gazes and total trial time spent fixating each region on the stimulus

SS had poor TIA in the letter and star cancellation tasks. These tasks, therefore, allowed investigation of factors that were contributing to neglect in the task, specifically whether sampling and/or processing deficits were causing information to be neglected. The line cancellation task, due to SS's high TIA, was informative as it enabled determination of potential patterns of eye movements that were required for optimal task performance. Once again, the eye movement patterns that control participants produced will be outlined first. As in the letter and star cancellation tasks, control participants made more gazes on the central region (see Table 3). It is suggested that this is likely to result from the central region being the largest region in the line cancellation task and contained slightly more target items (two more than the left and right regions). Furthermore, the proportion of time spent in each region for the controls was greatest for the central region, which was in accordance with the size of the region and number of targets present.

As shown in Table 3, in Sessions 1 and 2, SS appeared to exhibit reduced sampling of the left region compared to the right, with smaller proportions of the total gazes being made to that region. However, SS's sampling of the left, represented in proportion of gazes or fixation time, was not significantly lower than that of the controls for Session 1, $ts(4) < 1.86$, $p > .05$, although there was a trend towards fewer gazes and less time being spent by SS on the left region in Session 2, $t\ (4) = 1.862$, $p = .068$; $t\ (4) = 1.580$, $p = .095$. This trend suggests that SS's reduced proportion of gazes on the left did not represent a defect in sampling in Session 1. In Session 2, it appears that there was a reduction in proportion of gazes and time on the left and that may have been due to SS hyper-attending to the right. This is to say that, the proportion of time spent fixating the left was significantly reduced in Session 2 due to a tendency for SS to spend a disproportionate amount of time fixating the right region.

Table 3

Target Identification Accuracy (TIA; % of Targets Found), Proportion of Gazes (Gazes), Proportion of Trial Time spent Fixating (Time) and Average Gaze Durations (AGD; ms) on the Three Regions of the Line Cancellation Task Stimulus for the Three Regions (Left, Centre, Right) across Three Sessions for SS (presented in bold), SCs and OACs.

Measure	Group	Session 1			Session 2			Session 3		
		Left	Centre	Right	Left	Centre	Right	Left	Centre	Right
Gazes	**SS**	**.10**	**.50**	**.40**	**.07**	**.47**	**.47**	**.24**	**.47**	**.29**
	SCs	.23	.50	.28	.26	.47	.28	.33	.50	.17
	OACs	.23	.49	.28	.19	.50	.31	.25	.50	.25
Time	**SS**	**.29**	**.42**	**.29**	**.26**	**.40**	**.34**	**.31**	**.40**	**.29**
	SCs	.33	.39	.29	.31	.41	.29	.34	.37	.30
	OACs	.32	.40	.29	.29	.41	.30	.33	.38	.29
AGD	**SS**	**9570**	**2878**	**2401**	**9834**	**2140**	**1862**	**2401**	**1572**	**1841**
	SCs	3732	2074	3075	2588	1709	2007	3003	2090	4373
	OACs	3443	1991	2930	3826	2007	2550	2544	1474	2884

In Session 2, SS made a significantly higher proportion of gazes on the right than the controls, $t(4) = 3.22$, $p = .016$. This is particularly noteworthy considering that the proportion of gazes on the right was equivalent to that of the centre, which was a larger region (and one would expect it to receive more gazes overall on the task). Re-visits made to the right (and central) regions were unlikely to be required to complete the task, as the ease of the task meant that often all the targets within one region were often cancelled during the first gaze. This demonstrates that SS was more likely to make unnecessary gazes on the right region, providing support for that region capturing neglect patients' attention and that hyper-attention to the ipsilesional side was occurring. Hyper-attention to the right, however, did not result in neglect of targets on the left in the line cancellation task. This suggests that hyper-attention, on its own, may not be a factor contributing to neglect of information on the left, and therefore neglect is likely to be a result of hypo-attention to the left, in conjunction with hyper-attention to the right occurring.

In Session 3, there was no significant difference between the proportion of gazes SS spent on the left region compared to the controls, $t(4) = .57$, $p = .301$. The hyper-attention that was present in Sessions 1 and 2 (with a similar proportion of gazes being made to the right region as the larger central region) had completely dissipated, with SS not having significantly higher proportion of gazes and time on the right than the controls, $ts(4) < 1.02$, $p > .05$. Additionally, as can be seen in Table 3, SS spent a slightly higher proportion of the total trial time fixating the left compared to the right. This demonstrates that there was a reduction in hyper-attention to the right in this session which may be a result of the treatment.

An additional measure is reported for this task due to SS's high TIA. Analyses of average gaze durations for each region were completed to investigate whether there was a delay in processing contralesional targets by SS when accurate identification was achieved. It appears that more time was required in order for SS to process information on the left side. As shown in Table 3, average gaze durations were inflated on the left region, indicating processing difficulty. In Session 1, SS spent 3.3 times longer, on average, in a gaze made on the left region than the right region and had significantly longer gaze durations than the control participants on the left, $t(4) = 2.86$, $p = .023$. In Session 2, AGD were also increased. Patient SS's AGD were 4.2 times longer on the left compared to the region with next highest average gaze duration (the centre) and was significantly longer than the control participants spent fixating during a gaze on that region, $t(4) = 5.51$, $p = .003$. Therefore, a delay in processing contralesional information was apparent when all targets items were identified within that region. This suggests that eye movements may be a more sensitive measure of neglect when offline behavioural measures indicate normal performance. Interestingly, average gaze durations on the left were no longer inflated in Session 3, $t(3) = .341$, $p > .05$, indicating there was no longer a delay in processing contralesional targets. It appears that the treatment may not only have reduced hyper-attention to the right for SS in the line cancellation task (as indicated by the reduction in the proportion of the total trial time spent fixating the right), but also appeared to aid the processing of contralesional information, as was apparent in Session 3 of the star cancellation task.

In summary, the line cancellation task was less sensitive than the letter and star cancellation tasks, failing to reveal that SS exhibited neglect in any of the sessions, as has been demonstrated previously (Ferber & Karnath, 2001). Due to the high accuracy in this task, there was an opportunity to investigate the pattern of eye movements exhibited when SS performed optimally. The eye movement measures demonstrated that SS fixated the left to the same extent as the control participants and spent as much time overall exploring that region. The proportion of gazes on the right region was similar to that made on the central region, which was 10% larger in size. These results provide evidence that SS exhibited hyper-attention to the ipsilesional side. However, importantly, during each gaze made on the left, SS required more processing time in order to accurately identify the targets within the contralesional side. This indicates that eye movements may be a more sensitive measure of neglect than behavioural measures for less complex search tasks included in the BIT. Importantly, inflated processing time and hyper-attention to the right mitigated after treatment, suggesting that limb stimulation may aid attention to, and processing of, contralesional information during completion of more simple tasks.

4. General Discussion

4.1 Summary

Experiment 1 investigated the pattern of eye movements exhibited by a stroke patient with chronic neglect (SS), two SCs and three OACs during completion of the three cancellation tasks included in the Behavioural Inattention Test (BIT; Wilson et al., 1987). Data were obtained on three separate occasions, with the last testing session ensuing after limb activation treatment had been administered, in order to assess whether this treatment could ameliorate underlying deficits in neglect. One aim of this study was to evaluate the viability of tracking stroke patients’ eye movements with a head-mounted eye tracker during enactment of visual-motor actions that must be made during cancellation tasks. This had not been conducted before, even in adult control participants. This case study demonstrated that calibrating and measuring neglect and stroke patients' eye movements during cancellation tasks was feasible and that insight into sampling and processing deficits in neglect can be gained via employing this paradigm. The SCs and OACs exhibited similar patterns of eye movements during the cancellation tasks. In contrast, SS often made fewer eye movements to the left and spent less time fixating there. On occasions, SS exhibited a similar pattern of eye movements as the controls during completion of tasks but still exhibited a marked deficit in identifying contralesional targets.

The results will be discussed in relation to the three main theoretical issues that were outlined in the introduction: (1) the extent to which sampling and/or processing deficits of contralesional information contribute to neglect; (2) the effect of task demands on the sensitivity of the cancellation tasks in revealing whether neglect is present, and the extent of neglect if present; and (3) the contribution of hyper-attention to ipsilesional regions in causing neglect of contralesional information. Finally, a section was dedicated to a review of the effectiveness of limb stimulation as a treatment for neglect and a discussion as to how task demands can affect the evaluation of this rehabilitative technique. Recording eye movements provided a way in which to investigate these issues and directly quantify the extent of any sampling and/or processing deficits, contribution of hyper-attention to neglect, the influence of task demands on attention allocation and efficacy of limb stimulation as a treatment.

4.2 The Mechanisms Underlying Neglect: Sampling Deficit and Processing Deficits for Contralesional Information

The first issue that will be considered is whether a sampling deficit and/or processing deficit contributed to the neglect of information in SS. It is important to understand the underlying deficits in neglect in order to accurately characterise the disorder and develop appropriate and effective treatments to directly target, and attempt to ameliorate, these deficits. The eye movement measures from Session 1 of the letter cancellation task indicated that SS demonstrated a sampling deficit of contralesional information, with few saccades being made into left regions of the stimulus and a small proportion of the trial time spent fixating the left. These findings are consistent with those from other investigations of neglect patients' eye movements during search tasks (e.g. Barton et al., 1998; Behrmann et al., 1997; Forti et al., 2005) and viewing of chimeric stimuli (Walker et al., 1996; Walker & Young, 1996). Importantly, the pattern of eye movements exhibited by SS during these tasks was related to the neglect exhibited with poor accuracy often being linked with little visual sampling of the neglected side of space. Therefore, and as predicted, it appeared that SS's failure to sample the contralesional regions of the stimulus contributed to an inability to accurately identify targets within those regions. Distinguishing targets from distractors and detecting contralesional stimuli are likely to require direct fixation in order for the items to be scrutinised under the high acuity area of the fovea (Shepherd et al., 1986) and, therefore, eye movements would need to be made to each item on the left for accurate target identification to be made. It is unlikely that without direct fixations made on the left that target items would be able to be accurately identified. Therefore, a sampling deficit was contributing to the neglect of targets presented within contralesional regions of space. However, this was not the only factor contributing to the failure of SS to identify contralesional targets.

Additionally, there were occasions when SS fixated the left, and sessions in which SS exhibited a similar pattern of eye movements to the control participants. However, it was also shown that when SS sampled contralesional regions in the letter and star cancellation tasks, target items were not processed sufficiently during fixation for an accurate response to be made (i.e. cancelling the target). This demonstrated a processing deficiency, whereby targets were not encoded or represented accurately in order for an appropriate response to be made during fixation. A processing deficit during fixation of contralesional targets was indicated by Forti et al. (2005). It was demonstrated that a neglect patient was able to scan objects presented within the contralesional visual field, but still failed to report 28% of the targets on the left, despite all targets having been directly fixated. This suggests that impaired scanning of the neglected area was not the primary cause of the evident neglect exhibited by this patient. Furthermore, Walker et al. (1996) investigated the eye movements of one patient (RR) with visual neglect whilst he viewed and reported on chimeric stimuli. Patient RR was required to either report the identity of a face that was presented (belonging to a famous person), the name of the building that was displayed (which was famous, e.g. the Eiffel Tower) or which two faces or buildings comprised the image when a chimeric face or building was shown. The findings showed that on occasions where the left side of a chimeric image was not reported, RR had spent 26% of the total trial time fixating that region. This demonstrates that a significant proportion of time was allocated to visual inspection of the left region; however, this did not result in that information being reported. This indicates that processing of contralesional information is deficient.

There was evidence that a processing delay for contralesional information was present in SS. During the line cancellation task of Experiment 1, SS required more processing time to identify and respond to target items accurately during a gaze (compared to the controls and the time she required to accurately identify targets in the right region). Despite TIA indicating normal performance on the line cancellation task, the pattern of eye movements revealed that SS experienced a delay in processing the contralesional information. Collectively these findings support other studies that have suggested that even when information on the left has been fixated, it may still not be processed in neglect (e.g. Forti et al., 2005; Walker et al., 1996). A processing deficit, as well as a sampling deficit, was, therefore, contributing to neglect of contralesional information in SS.

4.3 The Effect of Task Demands on Eye Movements and Hemispatial Neglect

Interestingly, sampling of the left in SS was more restricted in the letter cancellation task than in the star cancellation task. The far left region received nearly twice the amount of fixation time by SS during completion of the star cancellation task. Therefore, sampling and processing of the left regions varied across the different cancellation tasks. Based on Ferber and Karnath's (2001) study that investigated test sensitivity in revealing neglect, it was predicted that the letter cancellation task would be the most sensitive test of neglect and the extent of neglect on this task would be greater than that shown for the other two cancellation tasks. This was the case in the current study, as demonstrated by SS's TIA in the letter cancellation task being poorer than that on the other tasks (being consistently below the cut-off point in this task), and in the sampling of the left being more restricted (as indicated by proportion of gazes and fixation time). Possible reasons for the letter cancellation task restricting sampling of the left, and TIA within contralesional regions being lower for SS, were as follows: (1) the physical properties of the stimulus and (2) differential complexity and cognitive demands imposed by the task.

The physical properties of the stimulus, such as similarity of targets to distractors and density of targets and distractors, can impact on the extent of neglect that is demonstrated. It has been demonstrated that search is more difficult and less efficient when targets and distractors have similar physical properties (Treisman & Gelade, 1980). It has also been suggested that when targets do not have unique physical properties and are highly similar to the distractors present that serial search is likely to occur (Duncan & Humphreys, 1989).

Serial search means that each item within the visual array is identified separately which requires focused attention (Treisman & Gelade, 1980). In order for a decision to be made with regard to whether an item is a target or not in the letter cancellation task, where there is increased difficulty in distinguishing between targets and distractors compared to the star cancellation task, means each letter (or a limited number of letters) may need to be attended to (and, therefore, possibly directly fixated). However, in the star cancellation task, a number of different distractors are present (letters, words, and large stars) which are visually distinct from the target items making the search for target items easier than in the letter cancellation task. This increased local cognitive processing during the letter cancellation task may restrict global attention to the stimulus as a whole, and to the left in neglect (Gainotti, D'erme, Monteleone, & Silveri, 1986). It has been determined by Gainotti and colleagues (Gainotti et al., 1986), when investigating the possible interactions between hemisphere laterality and task type, that tasks necessitating focal attention on a small section of space (for example, a letter in the letter cancellation task), resulted in an increase of the extent of neglect of the stimulus for right hemisphere lesioned patients. Furthermore, this restriction in attention to the left during tasks requiring local processing is likely to result in fewer eye movements being made to that region of space (Shepherd et al., 1986).

The letter cancellation task also required search for two different target items. This is likely to have amplified the cognitive demands. Searching for two targets as compared with one has been demonstrated to hinder TIA, even in control participants who have not suffered from brain damage (e.g. Menneer, Barrett, Phillips, Donnelly, & Cave, 2007). Furthermore, this has also been shown to affect neglect patients' performance, with more omissions made by neglect patients in a conjunction task than in a feature detection task (Aglioti et al., 1997). Some researchers have concluded that making neglect tasks more resource demanding by any means increases the spatial bias in responding (Mennemeir, Morris, & Heilman, 2004).

In contrast, the star cancellation task imposed fewer cognitive demands than the letter cancellation task. The star cancellation task was a less dense visual array, contained distractors that were not as similar to the target items as in the letter cancellation task and only required search for one target item. The findings of the current study demonstrated that this reduction in cognitive demands due to the physical properties of the stimulus and lower task difficulty meant that SS sampled the FL region twice as much as in the letter cancellation task. The physical properties and task demands of the line cancellation task enabled attention to be allocated to the usually neglected side of space, with more eye movements being made to, and increased fixation time spent, on the left region in this task. The line cancellation task target items (small, straight lines) would appear to have been easier to encode and represent (i.e. process) than small stars and ‘E’s and ‘R’s in the other tasks. Furthermore, the lines in the line cancellation task were not densely presented on the piece of paper, making them easier to detect. Therefore, when target items were easy to detect, and required limited processing (e.g. distinguishing between target and distractors not being required), SS could accurately identify contralesional targets (even though this processing was delayed).

In summary, it appeared that the demands that were required when completing the different cancellation tasks impacted upon their sensitivity in revealing neglect. The factors that exacerbated neglect and restricted sampling of the left related to the physical properties of the stimulus and the cognitive demands of the task. It is postulated that the letter cancellation task induced serial search. With attention having to be allocated more locally to each letter (or a limited number of letters), this subsequently restricted attention to the stimulus as a whole, and resulted in limiting the sampling of the left side of space in neglect.

4.4 Hyper-attention to the Right?

The current experiment also revealed that SS exhibited a pattern of eye movements that suggested over-attending to the right regions of space. This provides support for the inter-hemisphere rivalry hypothesis (Kinsbourne, 1977). This is the concept that left neglect results from the damaged (right) hemisphere no longer inhibiting the intact (left) hemisphere and therefore not enabling attention to be transferred to the left side of space. Therefore, an overactive left hemisphere causes preferential responding to the ipsilesional region of space, i.e. hyper-attention to the right (Kinsbourne, 1977). This issue will also be investigated in Experiment 2 and Experiment 3 reported in the next Chapters. The effectiveness of limb activation as a treatment for neglect relies on the assumption that if the over-activation of the non-damaged (left) hemisphere, is inhibited by increasing the activation of the damage (right) hemisphere through initiating contralesional limb movements, then attention to the usually neglected side should be promoted. This will be the focus of the next section.

4.5 Did Limb Stimulation Treatment affect the Pattern of Eye Movements and Extent of Neglect Exhibited in SS?

It has been argued that targets within contralesional regions may not be detected in neglect due to competition from stimuli in the ipsilesional space being stronger. The balance of inter-hemisphere competition is off-set towards the non-damaged hemisphere and therefore the ipsilesional region of space (Harding & Riddoch; Kinsbourne, 1977; Polanowska et al., 2009; Sparing et al., 2009). It has been proposed that the activation of the damaged hemisphere through FES increases the weighting of contralesional space and this can result in an improvement in the detection and recognition of stimuli in the left hemispace (Harding and Riddoch, 2009).

It was predicted that if there was a sampling deficit present in neglect that limb stimulation treatment would reduce its extent. This prediction was based on previous research demonstrating that limb activation, due to increasing contralesional attention through activating the right parietal regions, improves scanning of the contralesional side of space (Eskes et al., 2003). Increased sampling of the left by SS was apparent in Session 3 for all the tasks (either demonstrated in the proportion of gazes and/or fixation time), although to a lesser extent in the letter cancellation task, partly due to there being an increase in eye movements made to the left in Session 2 of this task.

The treatment appeared to increase contralesional target identification in the star and line cancellation tasks. In the star cancellation task, increased sampling of the left after treatment resulted in more contralesional targets being identified in this session than previously. Thus, for the star cancellation task, the treatment not only aided sampling of the left region but also processing of information in the left region, which was shown to be deficient in the first two sessions. Additionally, inflated processing time on the left and hyper-attention to the right mitigated after treatment in the line cancellation task. These findings together suggest that limb stimulation may aid attention to, and processing of, contralesional information.

In contrast to performance in the star and line cancellation tasks, treatment did not affect contralesional TIA in the letter cancellation task. For this task, even though the sampling deficit was alleviated in Session 3, neglect remained to the same extent as in the previous sessions. It has been suggested that the effectiveness of treatment in ameliorating neglect depends upon the measures used to assess the extent of neglect recovery (Bowen & Lincoln, 2007; Bonato, 2012). Brown et al. (1999) also found that limb activation had an impact on performance in neglect in particular tasks. Fewer errors were made for reading words presented on the left of a sentence by the neglect patients during a limb activation condition compared to a neutral condition. However, limb activation did not improve detection of briefly presented contralesional stimuli or on contralesional saccadic eye movements. They concluded that limb activation improved performance on tasks that required voluntary eye movements to be made to the left but not for those tasks that required initiation of reflexive eye movements to be made. Therefore, voluntary eye movements may be improved by limb activation in neglect. However, as all of the tasks that were used in the present study required voluntary eye movements to be made into contralesional space, this cannot explain the differences found for the effectiveness of the treatment on performance for the different tasks. As the letter cancellation task was the most difficult task and neglect of contralesional targets during completion of this task in neglect persisted, it is likely that the factor that is moderating the effect of the treatment is related to task complexity, which has been discussed earlier in great detail.

It has been suggested that in order for FES treatment to have long term effects in neglect it would appear that cortical reorganisation of the damaged hemisphere is promoted (Polanowska et al., 2009; Rushton, 2003). It has, however, so far only been established that FES improves performance in neglect patients who are in their acute phase of stroke recovery (Eskes et al., 2003; Harding & Riddoch, 2009; Polanowska, 2009). The present study demonstrated that FES treatment can aid contralesional target identification in a chronic neglect patient, which means that some cortical reorganisation may still be enabled by FES treatment a year post-stroke.

It is important to note that the treatment effects of the present study cannot solely be related to the effect of FES. Due to the inclusion of iterative sessions of tracking a moving sphere within the contralesional field and the use of the robotic arm to support movements within that region of space, these factors could have also affected performance. It may be that SS was, albeit implicitly, trained to scan the contralesional side of space during the training trials where she was required to guide her affected arm within the contralesional regions of space. Therefore, any relief in the sampling deficit apparent in the initial sessions may not be a direct result of FES but also that of implicit scanning training. However, Polanowska et al. (2009) found that one-month of scanning training alone was far less effective in ameliorating neglect than the combination of this training alongside FES treatment. It may be that scanning training needs to be combined with other treatments in order for any processing deficit of contralesional information to be alleviated so that increased sampling can improve contralesional target identification.

Unfortunately no follow up assessment was obtained for patient SS. It would have been beneficial to determine whether the effects of the FES treatment on sampling and processing were maintained 3 and 6 months after the treatment was completed. This is required to assess the effectiveness of the treatment in mitigating neglect and determining whether this type of treatment affects the underlying causes of neglect and not just symptomology (which may demonstrate improvement in the short term). Both scanning training and prismatic adaption have demonstrated mitigation of neglect after treatment but often neglect is present again on testing 3 or 6 months later. Follow up after FES requires further investigation to establish whether it targets the underlying causes of neglect. Harding and Riddoch's (2009) study suggested that this was the case, as the patients whose neglect had mitigated after treatment was still diminished at 6 month follow up (Harding & Riddoch, 2009).

In summary, it seems as though the underlying deficits in neglect can be revealed by detailed inspection of measures of eye movements exhibited during cancellation tasks. It was clear that initially the neglect participant displayed a sampling deficit, not fixating the contralesional side less often or for less time as the ipsilesional regions. It was also apparent, though, that SS did sample the left side of the stimulus and, on some occasions, to the same extent as the control participants. Importantly, this did not always result in that information being processed, or there was an associated delay in processing contralesional targets before treatment was administered. The task demands also affected sampling and processing of contralesional information and moderated the effect of limb stimulation treatment on these factors. Given that many patients present with hemiplegia (and therefore cannot move their affected arm), it would appear that FES, which enables passive movement of the arm, could be a clinically applicable tool, even in chronic cases of neglect, to aid sampling and processing of contralesional space during completion of simple tasks.

Chapter 3. Eye Movements in Hemispatial Neglect: Simultaneously investigating Egocentric and Allocentric Neglect

The behavioural and eye movement findings for patient SS reported in Chapter 2 demonstrated that insight into the underlying deficits exhibited by those with neglect can be gained by considering patterns of eye movements exhibited during cancellation tasks. These results suggested that SS exhibited a sampling deficit in the first session of the letter and star cancellation tasks, whereby less time was spent fixating the contralesional side of the stimulus and fewer saccades were made into that region. Importantly, this was not the only factor contributing to the neglect exhibited by SS. Even when contralesional regions were sampled to the same extent as controls, targets were still not reported there, or more time was required to identify targets when performance was optimal, suggesting a processing deficit as well as sampling deficit.

The focus of Experiment 2 was to investigate whether different types of neglect, namely egocentric and allocentric neglect, can operate in a single task, as well as examining patterns of eye movements produced during cancellation tasks by a large group of neglect patients. As the BIT cancellation tasks do not examine allocentric (object-based) neglect, there is on-going development of tasks designed to accurately assess allocentric neglect, but these are yet to be normalised and applied clinically (e.g. ‘The Apples Test’; Bickerton, Samson, Williamson, & Humphreys, 2011; ‘Defect Detection Task’; Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001). The existence of exclusive allocentric neglect is still fundamentally disputed and whether it relies on the activation of egocentric reference frames has not yet been fully determined (e.g. Driver & Pouget, 2000; as discussed in Chapter 1 under the section entitled *Spatial Frames of Reference in Neglect*).

1. The Present Study

For Experiment 2 a new letter cancellation task was developed. A letter task was employed due to the increased sensitivity of this type of task compared to non-letter based tasks (Ferber & Karnath, 2001; refer back to Chapter 2 results). The main aim of this task was to enable the simultaneous investigation of the operation of egocentric and allocentric frames of reference in a group of neglect patients. For brevity this task will be referred to as the ‘SEAN’ task: Simultaneously investigating Egocentric and Allocentric Neglect. Developing this task also provided the opportunity to control stimulus properties (e.g. number of targets in each region of the stimulus), which was not done in the BIT tasks.

Furthermore, maximising the sensitivity of the test to identify the presence of neglect was attempted. This was done by employing letters as targets and distractors in the task, as the letter cancellation task has been found to be the most sensitive BIT cancellation task (as discussed in Chapters 1 & 2; Ferber & Karnath, 2001). This is likely to be due to the similarity of the targets and distractors when both are letters. This similarity of the items included in the task may induce serial search in order to determine whether each item is a target or not, as discussed in the previous chapter. Additionally, high numbers of targets and distractors were included (i.e. the stimulus was a dense array) and distractors that were highly similar to targets were also incorporated. Finally, dual-target search was required to increase the cognitive demands of the task.

The eye movements of Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs) were recorded whilst they completed the SEAN task. The SEAN task required participants to find and cross through two different target items that appeared multiple times in the stimulus. A target-type manipulation was employed to investigate both egocentric and allocentric neglect. This relied on target items possessing canonical handedness (recall the section in Chapter 1 on canonical handedness under *2.1 Frames of Reference for the Coding of Spatial Information*) and therefore asymmetrical letters were employed as targets. Asymmetrical letters have canonical handedness because there is a canonical (usual) view in which the letter is presented, which is important for correct identification of the letter, and left and right of the letter can be defined in relation to that presentation form. Thus, even if the letter is not presented in its canonical view (i.e. is rotated or flipped horizontally), the canonical left side may still be represented as the left side of the object without being left of an egocentric position. For example, the canonical left side of the letter ‘h’, the ascending part, may still be represented as the left side of the letter, even if that side of the letter was presented within the RVF. Previously it has been demonstrated that object-centred neglect of the left side of letters can occur and this would provide evidence for allocentric neglect (Behrmann & Moscovitch, 1994). Behrmann and Moscovitch presented NPs with asymmetrical letters in different orientations with four different coloured region presented behind the letter (refer back to *Figure 5*). They found that all seven subjects failed to report colours on the intrinsic left side of the letter, which was interpreted as providing evidence for the existence of object-centred neglect. Therefore, based on this previous research, if allocentric neglect was present it is likely that the left side of individual letters would be neglected.

One of the target letters included in the SEAN task had critical information necessary for accurate letter identification on the canonical left side of the letter (left sided target) and the other target had this critical information on the canonical right side of the letter (right sided target). The left sided target letter employed in the SEAN task was a lowercase ‘h’. If the canonical left side of the letter ‘h’ was neglected it would no longer be distinguishable from the letter ‘n’, or even ‘m’ (highly similar distractors used in the task, as can be seen from *Figure 13*). The information remaining on the right of the letter ‘h’ would not be different from that of the highly similar distractors. Therefore, the distractors may be perceived as the target letter ‘h’ by NPs or they could fail to identify this target due to not perceiving the intrinsic left side, indicating allocentric neglect. The letter ‘q’ was employed as a right sided target, as if the left side was neglected due to a patient presenting with allocentric neglect, then critical information necessary for correctly identifying the letter should be preserved (and therefore would be distinguishable from the highly similar distractors, that were included in the task, ‘g’ and ‘d’). Therefore, if a patient presented with left allocentric neglect they still should be able to identify right sided target items. This enabled the SEAN task to assess egocentric neglect in conjunction with allocentric neglect, as if a patient experienced both allocentric and egocentric neglect, then they should still be able to identify right sided targets that were present within the regions of the stimulus that were located on the right of their midline. The two main aims of this experiment were (1) to investigate whether patients demonstrated egocentric and/or allocentric neglect on the same task, and (2) further verify that sampling and processing deficits contribute to neglect, as Experiment 1 indicated, in a large group of NPs.

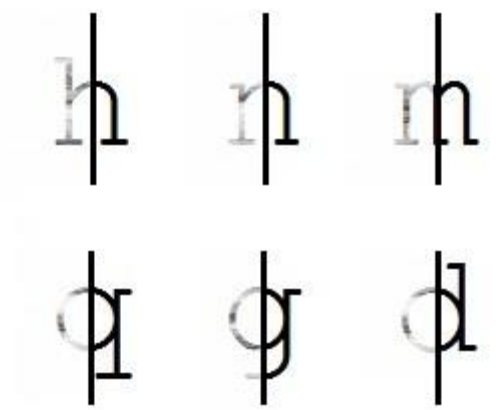

Figure 13. The target letters included in the SEAN task are presented on the far left. The faded sections demonstrate the parts of the letters that may be neglected if a patient presented with left allocentric neglect. Patients with left allocentric neglect would find it more difficult to distinguish between the left sided target 'h' and its distractors than the right sided target letter 'q' and its distractors. The 'n' and 'm' were highly similar distractors for the left sided target and 'g' and 'd' for the right sided target.

1.1 Target Identification Accuracy (TIA): Hypotheses

For the behavioural and eye movement analyses, the SEAN task was divided into four regions of interest (Far Left [FL], Near Left [NL], Near Right [NR], and Far Right [FR]). These regions were the same size and contained the same number of targets and distractors. If the patient exhibited egocentric neglect only, then they would be able to accurately identify both left and right sided targets in the right regions (NR and FR) of the stimulus only, as they would be neglecting information to the left of their head/trunk midline (aligned with the centre of the stimulus), in the FL and NL regions. In contrast, if allocentric neglect was exhibited in isolation, then the patient would be able to identify right sided targets along the full extent of the horizontal axis of the stimulus but fail to cross through left sided targets. If egocentric and allocentric neglect were experienced in conjunction, patients would only be able to identify the right sided targets in the right regions of the stimulus, neglecting targets in the left regions of the stimulus and the left sided target items across the whole stimulus. Based on previous research and the suggested low prevalence of allocentric neglect (e.g. Bickerton et al., 2011; Hillis et al., 2005), it was expected that egocentric neglect would be the most common type of neglect presented, as indicated by low target identification accuracy within the left regions of the stimulus. Furthermore, egocentric neglect would be evident in the pattern of eye movements produced by the NPs, with less sampling of the NL and FL regions, as demonstrated in Experiment 1.

1.2 Sampling and processing deficits contributing to neglect: Hypotheses

Based on the findings from Experiment 1 and research on eye movements in neglect (Behrmann et al., 1997; Barton et al., 1998; Walker & Young, 1996), a sampling deficit of contralesional information was expected to be associated with poor contralesional target identification accuracy. Therefore, for patients with egocentric neglect, it was predicted that fewer gazes would be made overall to the left of the stimulus and less total time would be spent fixating that area and that this would be associated with low TIA within those regions. This would indicate that a sampling deficit was contributing to neglect. Patients exclusively with allocentric neglect only would be expected to sample the left regions of the stimulus. Control participants were expected to make more saccades into internal regions compared to external regions, as demonstrated in Experiment 1, resulting from controls being more likely to transgress a region boundary when fixating those regions and there being a general tendency to fixate central regions more often in normal populations (Henderson, Brockmole, Castelhano, & Mack, 2007). Equivalent proportions of time spent fixating each region was expected for the control participants; reflecting that the same amount of time was required to search each region as these were the same size and contained the same number of target items to be identified.

Furthermore, based on Experiment 1's findings and a small number of case studies investigating eye movements in neglect (e.g. Forti et al., 2005; Walker et al., 1996), it was predicted that NPs would occasionally fixate the left but still fail to identify target items positioned at those locations. This would demonstrate a processing deficit of contralesional information during fixation, and provide evidence that neglect cannot, fundamentally, be entirely caused by a sampling deficit. Furthermore, as a processing deficit of contralesional information was expected, it was predicted that inflated average gaze durations would result when NPs fixated the left due to increased processing time being required to identify contralesional targets. This would not be the case for controls, where, due to increased number of fixations on the central regions (due to these regions having more boundaries and there being a general tendency to fixate central regions more often; Henderson et al., 2007) and equivalent time spent fixating each region, there would be slightly longer average gaze durations on the external regions. This would be equivalent for both the FL and FR regions for control participants. In contrast, average gaze durations would be higher on the FL region than the FR region for NPs due to increased processing difficulty experienced in contralesional regions.

2. Method

2.1 Participants

In total there were 33 participants in this experiment. Thirteen patients with left hemispatial neglect who had right hemisphere damage (neglect patients; NPs), eight patients who had suffered from a right ischemic or haemorrhagic stroke but did not exhibit neglect (stroke controls; SCs) and twelve healthy older adult controls (OACs) were included (see demographic information in Table 4). Lesion information from NPs and SCs was obtained from the admitting hospital's medical records relating to Computed Tomography (CT) scans and reports (see Table 5).

There were 25 females and 8 males. All were right handed. NPs had an age range of 46-82 years (*M* = 70.21 years, *SD* = 10.61 years), SCs 62-84 years (*M* = 70.88 years, *SD* = 8.11 years) and OACs 52-82 years (*M* = 68.33 years, *SD* = 8.73 years). All NPs were in the acute phase (prior to 3-months post stroke), with the number of days post-stroke at the time of participating in the experiment, ranging from 2-59 (*M* = 29.07, *SD* = 16.92) for NPs and 2-100 for the SCs (*M* = 34.25, *SD* = 32.56). Three months post-stroke is considered within the field to be the acute stage of stroke recovery, after which patients are either likely to have recovered (Hurwitz & Adams, 1972; Stone, Patel, Greenwood, & Halligan, 1992) or have developed compensatory strategies to overcome their deficits (Krakauer, Carmichael, Corbett, & Wittenberg, 2012; Kwakkel, Kollen, & Lindeman, 2004; Nijboer, Kollen, & Kwakkel, 2012). The NPs did not significantly differ in number of days post-stroke at the time of participating in the experiment compared to the SCs included (see Table 5), $t(20) = .50$, $p > .05$. This suggests that if NPs had poorer performance compared to SCs on the SEAN task, this is unlikely to be due to the more acute nature of their condition.

Lesion location information was obtained from the available CT head/brain scan reports (and additional Magnetic Resonance Imaging [MRI] scan report for Case 3) contained within the patients' medical notes at the admitting hospital. The majority of the NPs had an infarct within the right middle cerebral artery (RMCA) territory lesioning the right frontoparietal or temporal lobes and for some patients including the right internal capsule, lentiform nucleus and insula (see Table 5 for lesion location information for each stroke patient). One NP (Case 12) also had damage to the lateral aspect of the right occipital lobe but, note, that this participant did not demonstrate visual field loss. The SCs, similarly, tended to have RMCA initiated infarcts resulting in damage to the right caudate nucleus, insula, external capsule, putamen, sylvian fissure, lacunar and precentral gyrus.

This study received Psychology Department, University of Southampton, and NHS Southampton REC National Research Ethics Service ethical approval and was adopted by the UK Stroke Research Network (SRN) portfolio. The patients were recruited from the following sites included in this project: Southampton General Hospital, Royal Hampshire County Hospital, Royal Bournemouth Hospital, Poole General Hospital and Lymington New Forest Hospital. NPs were referred to the researcher from the stroke team at the hospitals if they had clinically demonstrated neglect (NPs) or had suffered a right hemisphere stroke but exhibited no neglect (SCs). All patients provided informed written consent according to the protocols established for ethical approval.

The presence or absence of neglect was quantified from the performance on a sub-set of the BIT (Wilson, Cockburn, & Halligam, 1987; see *2.3 Screening Tests*). Using the clinical diagnosis, the BIT score and observation of behaviours during the tasks indicative of neglect (e.g. immediately orienting to the right and repeatedly crossing through ipsilesional targets) the presence of neglect was confirmed. As determined by the BIT, obtaining less than 90% accuracy overall in the tasks included in the screening (see Screening Tests) indicated neglect was present (see Table 4 for NPs' BIT scores).

All of the SCs scored above 92% on the assessments and OACs above 96%. The OACs were recruited through a voluntary participant pool for older adult controls held in the School of Psychology at the University of Southampton.

2.2 Stimuli

The SEAN task was developed and designed based on the results of the exploratory BIT experiment reported in Chapter 2 and the empirical results of other studies that have been outlined. The SEAN task (*Figure 14*) was composed of eight rows of forty letters. Each letter was presented in lowercase Courier New font (size 34.5) and subtended the same degree of visual angle. This stimulus, printed on an A4 piece of paper of landscape orientation and constituting approximately 21.6^o x 30.1^o of the visual angle, was divided into four regions of interest for analysis (Far Left [FL], Near Left [NL], Near Right [NR], Far Right [FR]; see *Figure 14* for regions of interest imposed on the stimulus).

As mentioned in the Introduction of this chapter, targets employed were lowercase letters 'h' and 'q', which were presented at the very bottom of the stimulus for the participant to refer to (as in the letter cancellation stimulus of the BIT). If the patient exhibited left allocentric neglect, the target letter 'h' (left sided target) would be harder to identify than the right sided targets. In contrast, a patient with left allocentric neglect should be able to identify 'q' (right sided target) as the right part of the letter (the descender) is informative in isolation. High numbers of targets and distractors were incorporated into the stimulus in order to create a high density array to maximise the difficulty of the task and, therefore, its sensitivity. Each of the four regions of the stimulus included 16 targets, 8 of which were left sided targets 'h' and 8 of which were right sided targets 'q'. Distractors were also included, with 64 in each region, 16 of which had similar features to the left and right sided targets (high similarity distractors; shown previously in *Figure 13*).

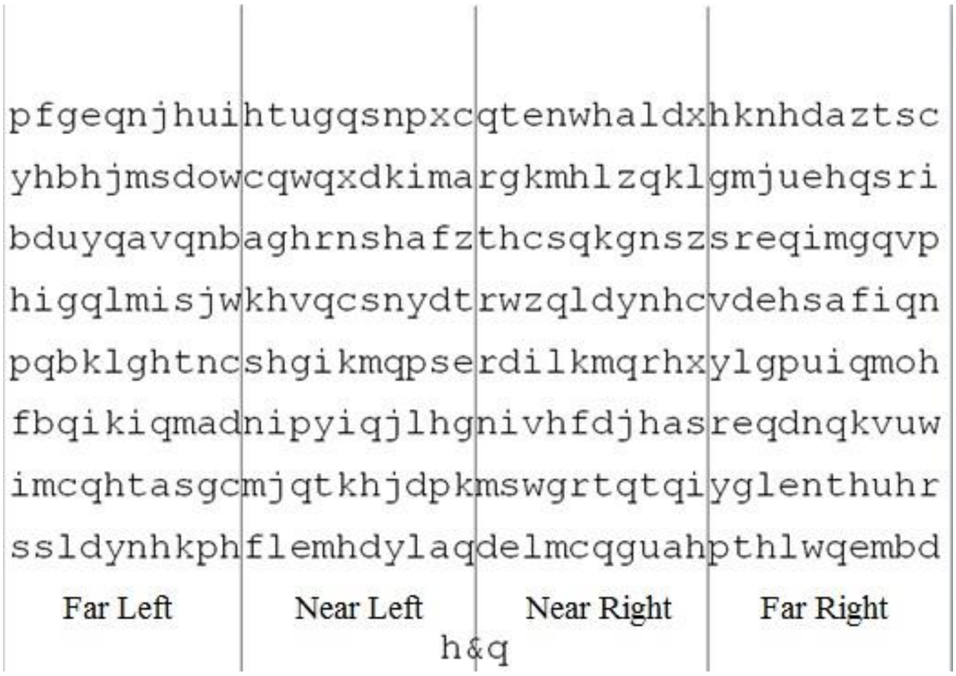

Figure 14. The SEAN task developed for and employed as the task in this experiment, with the four regions of interest indicated by the vertical lines (Far Left; Near Left; Near Right; Far Right). These lines were not presented on the stimulus. The participant was required to search for and cross through all of the ‘h’s and ‘q’s they could find and place the pen down when they had completed the task.

The targets were placed in a pseudo-random order within the stimulus. The placing of targets amongst distractors within the first four rows of the stimulus from left-to-right (starting from the top FL) was mirrored in the placing of targets in the four bottom rows from right-to-left (starting from the bottom FR). This was to ensure the left and right regions were equivalent for the placing of targets amongst distractors, as this may affect the difficulty in identifying targets. For example, if two targets were presented in close proximity on a row within one of the left regions of the stimulus this would also occur within the corresponding right region of the stimulus.

2.3 Screening Tests

Tests were conducted to obtain measures of IQ, memory, visual acuity, visual fields, inattention and demographic information was also collected (age, handedness, gender and lesion location) for patients (see Table 4 and Table 5). The Snellen Visual Acuity Test (see Appendix A, Snellen, 1862) was used to determine the participants’ visual acuity with and without glasses. The nominator reported in Table 4 represented the viewing distance in inches (16) for the test. The denominator reported is the last line of letters (out of nine lines) on the test that the participant managed to read correctly (for which a maximum of one error was made) with this number representing the distance (inches) at which someone with 20/20 vision could read a letter of that size. The larger the denominator relative to the numerator; the poorer the visual acuity. Visual Acuity comparisons indicated there was a marginal difference across groups, $F(2, 30) = 2.78$, $p = .078$. *T*-tests demonstrated that NPs and SCs did not differ on this measure, $t(20) = .99$, $p = .333$, but NPs had significantly poorer visual acuity than OACs, $t(23) = 2.23$, $p = .036$. If poor visual acuity resulted in poorer performance on the tasks, then this would be evident for SCs as well as NPs.

The Mini-Mental State Examination (MMSE; see Appendix B; Cummings, 1993) was used to compare groups on their memory performance to check whether this was a factor contributing to poor performance in the cancellation tasks. This consisted of 30 questions assessing orientation, encoding and recall of new auditory information, attention and calculation, language skills, ability to follow verbal instructions, writing, and figure copying. The NPs did not have significantly poorer memory performance on the MMSE than SCs and OACs, $F(2, 30) = 1.22$, $p > .05$. Therefore, poorer performance on the SEAN task that was limited to NPs would be unlikely to be a result of poor memory.

The National Adult Reading Test (NART) was employed to assess pre-stroke IQ in order to determine that IQ was not contributing to potential differential performance on the experimental tasks. There was an overall difference in groups on the NART, $F(2, 30) = 7.15$, $p = .003$. Further tests indicated that both NPs and SCs were poorer in this test than OACs, $t(23) = 4.21$, $p < .001$; $t(18) = 2.36$, $p = .043$, but NPs and SCs did not differ significantly, $t(20) = .26$, $p = .672$, demonstrating any reduction in performance that was shown exclusively by NPs was unlikely to be a result of lower IQ.

In order to determine whether the stroke participants presented with visual field deficits or not, including hemianopia and quadrantanopia, Confrontational Visual Field Testing was conducted (see Kodsi & Younge, 1992; Johnson & Baloh, 1991). This involved the examiner presenting a moving probe (e.g. finger, pen tip) in each quadrant of the visual field whilst the patient fixated the experimenter's nose monocularly. This was conducted twice, with the first test composing of the probe moving further into the centre of the visual field and the second with a number of fingers presented statically. The patient was required to state within which visual quadrant the probe appeared in and for the second test, the number of fingers that they saw, without moving their gaze from the central position. Although poor performance on this test may reflect the patient's neglect and not a visual field defect, a conservative approach was taken. This involved reporting a visual field defect being present if the patient failed to report a stimulus presented in isolation *and* simultaneously with an ipsilesional stimulus as evidence for a visual field defect, despite this pattern possibly arising due to neglect. It was interpreted that if a patient could report a left stimulus presented in isolation but not when a concurrent ipsilesional stimulus was presented, that the patient did not have a visual field defect (as they could report the left stimulus in isolation) and this pattern resulted from neglect and/or extinction. This information is reported in Table 5. Four of the NPs demonstrated some degree of visual field loss. Case 2 demonstrated left hemianopia with macular sparing (as documented in the medical records), Case 6 had left hemianopia, as did Case 9. Case 10 presented with lower left quadrantanopia. Additional information was sought from the patients and their medical notes retained on the stroke wards at the admitting hospital. The information obtained included currently administered medication, comorbidity of other physical and mental health disorders and number of years in education (see Appendix C; Acquired Patient Information).

A sub-set of the BIT was conducted to confirm the diagnosis of neglect and quantify the severity based on the score obtained. The tasks used for this were as follows: letter, star, and line cancellation tasks (as used in Experiment 1 reported in Chapter 2), the line bisection task (where the participant is required to place a vertical line at the point where they believed the centre of a horizontal line to be), figure copying tasks (copying line drawings of a star, cuboid and flower), representational drawing (drawing a clock, man and butterfly from memory) and setting and telling the time on a large analogue clock and from photos of digital clocks. These were scored in accordance with the guidelines presented in the BIT and converted into an overall percentage score (shown in Table 4). To assess whether allocentric neglect was present, the classic 'Ogden scene' was also presented to participants to copy, with a maximum score of eight points, one point for each half of an object accurately copied. None of the patients presented with allocentric neglect on this task (omitting the left side of each object but copying the right side of each object presented across the full extent of the page).

Table 4

Age, Gender, Handedness, Years of Education, Mini-Mental State Examination (MMSE), National Adult Reading Test (NART), Behavioural Inattention Test (BIT) and Visual Acuity Information for Participants involved in Experiment 2. An Additional Column is Included to Denote the Participant Number for those Participants that were Included in a Subsequent Experiment (reported in Chapter 4).

Participant Number	Group	Age	Gender	Handedness	Years of Education	MMSE	NART	BIT (%)	Visual Acuity	Participant Number in Experiment 3
Case 1	NP	68	F	R	24	27/30	45/50	64.90	80/16	Case 1
Case 2	NP	63	F	R	11	27/30	40/50	78.57	32/16	Case 2
Case 3	NP	46	M	R	11	29/30	20/50	89.61	40/16	Case 3
Case 4	NP	79	F	R	19	22/30	27/50	77.27	48/16	Case 4
Case 5	NP	82	F	R	10	25/30	46/50	75.53	40/16	Case 5
Case 6	NP	75	F	R	10	17/30	30/50	26.97	24/16	--
Case 7	NP	80	F	R	10	21/30	38/50	75.93	80/16	Case 6
Case 8	NP	75	F	R	10	26/30	33/50	88.89	80/16	Case 7
Case 9	NP	63	F	R	11	27/30	32/50	81.05	32/16	Case 8
Case 10	NP	78	F	R	10	18/30	17/50	67.28	56/16	Case 9
Case 11	NP	62	F	R	12	29/30	29/50	83.36	54/80	Case 10
Case 12	NP	78	F	R	10	18/30	30/50	66.67	40/16	Case 11
Case 13	NP	57	F	R	12	27/30	34/50	87.04	48/16	--
SC1	SC	70	F	R	16	28/30	46/50	98.05	40/16	SC1

SC2	SC	67	M	R	14	28/30	48/50	97.40	40/16	SC2
SC3	SC	66	M	R	10	29/30	21/50	95.39	48/16	SC3
SC4	SC	68	F	R	10	27/30	20/50	92.21	32/16	SC4
SC5	SC	62	M	R	16	28/30	45/50	100.00	32/16	--
SC6	SC	67	M	R	10	27/30	35/50	98.15	56/16	SC5
SC7	SC	84	M	R	10	29/30	33/50	96.10	48/16	--
SC8	SC	83	F	R	10	25/30	26/50	96.30	40/16	SC6
OAC1	OAC	74	M	R	13	29/30	50/50	99.35	56/16	OAC1
OAC2	OAC	71	F	R	12	27/30	46/50	98.70	40/16	OAC2
OAC3	OAC	67	F	R	16	27/30	48/50	99.35	32/16	OAC3
OAC4	OAC	82	F	R	16	24/30	44/50	100.00	24/16	OAC4
OAC5	OAC	66	F	R	8	29/30	43/50	96.30	32/16	OAC5
OAC6	OAC	73	F	R	10	29/30	44/50	100.00	56/16	OAC6
OAC7	OAC	52	F	R	16	27/30	47/50	100.00	20/16	OAC7
OAC8	OAC	54	M	R	16	30/30	43/50	98.69	16/16	OAC8
OAC9	OAC	76	F	R	23	30/30	50/50	100.00	32/16	OAC9
OAC10	OAC	64	F	R	16	28/30	33/50	99.35	16/16	OAC10
OAC11	OAC	74	F	R	16	30/30	45/50	98.77	24/16	OAC11
OAC12	OAC	67	F	R	16	29/30	38/50	99.35	16/16	OAC12

NP = Neglect Patients; SC = Stroke Controls; OAC = Older Adult Controls; R = Right; M = Male; F = Female

Table 5

Number of Days Post-Stroke, Aetiology and Lesion Area of Stroke and Hemianopic Status of the Neglect Patients (NPs) and Stroke Controls (SCs) included in Experiment 2.

Participant Number	Group	Days Post-Stroke	Aetiology	Lesion Area	Hemianopia	Participant Number in Experiment 3
Case 1	NP	16	Thrombosis	R MCA territory; R frontoparietal	None	Case 1
Case 2	NP	47	Haemorrhage	R temporal lobe	LH; macular sparing	Case 2
Case 3	NP	27	Thrombosis from R ICA	R basal ganglia; genu of the internal capsule; medial aspect of the R temporal lobe	None	Case 3
Case 4	NP	38	Infarct	R MCA territory; R frontparietal	None	Case 4
Case 5	NP	31	Infarct	R MCA territory; R frontoparietal	None	Case 5
Case 6	NP	25	Infarct	R MCA territory; R frontoparietal	LH	--
Case 7	NP	48	Infarct	R MCA territory; R frontoparietal; R lentiform nucleus	None	Case 6
Case 8	NP	7	Infarct	R PACs	None	Case 7
Case 9	NP	59	Infarct	R MCA territory	LH	Case 8
Case 10	NP	28	Infarct	R MCA territory; R TACs	LLQ	Case 9
Case 11	NP	25	Infarct	R MCA territory	None	Case 10
Case 12	NP	2	Infarct	R parietal and lateral occipital lobe	None	Case 11

Case 13	NP	10	Infarct	R MCA territory; R frontoparietal, frontal operculum and insula	None	--
SC 1	SC	62	Infarct	R caudate head	None	SC1
SC 2	SC	2	Infarct	R MCA territory	None	SC2
SC 3	SC	38	Infarct	R insula; R external capsule; lateral limit of the R putamen; R sylvian fissure	None	SC3
SC 4	SC	23	Infarct	R PAC	None	SC4
SC 5	SC	18	Infarct	R caudate nucleas; R lacunar	None	--
SC 6	SC	25	Infarct	Basal ganglia; R globus pallidus/putamen; R lacunar	None	SC5
SC 7	SC	100	Infarct	R precentral gyrus	None	--
SC8	SC	6	Infarct	R lacunar	None	SC6

R = Right; MCA = Middle Cerebral Artery; ICA = Internal Carotid Artery; PAC = Partial Anterior Circulation infarct; TAC = Total Anterior Circulation infarct; LH = Left Hemianopia, LLQ = Lower Left Quadrantanopia

2.4 Apparatus

The equipment used (a head-mounted Applied Science Laboratories eye-tracker) and the experimental set-up (stimuli presented on an easel) was the same as that employed in Experiment 1 reported in Chapter 2 (see 2.3 *Apparatus* section on page 56).

2.5 Design

All NPs, SCs and OACs were assessed on the SEAN task once whilst their eye movements were recorded. The between participant variable included was group, which had three levels (NPs, SCs, OACs). Two within participant variables were included: region (FL, NL, NR, FR) and target type (left and right sided targets).

2.6 Procedure

The stroke patients (NPs and SCs) were run individually in a well-lit, quiet room within the admitting hospital or within their own homes if they had been discharged. The OACs were all tested in the same environment in the School of Psychology at the University of Southampton. The first stage involved completion of the screening tests and obtaining of any additional information, which lasted approximately 30-45 minutes. Once this stage was completed, the participant was given a break before the experiment commenced. On some occasions, due to chronic fatigue that stroke patients often experience, the experiment was run on a separate occasion, usually the next day. If the experiment was not conducted within a week of screening, the participants were reassessed and those measures were reported in this section.

For the experiment, the eye tracking equipment was set up. The participant was seated at a desk in front of the easel, with the sagittal mid-plain of their trunk aligned with the centre of the easel. The backpack housing the equipment for the eye-tracker was placed on the desk to the right of the participant (as the cord from the head-gear protruded from the right hand side of the tracker). This was out of sight of the participant. The participant was asked to wear the eye-tracking glasses like a normal pair of spectacles. The cameras were adjusted in order to obtain the most accurate recordings. When the position of the cameras was suitable, recording of the video feeds commenced.

Both five and nine point calibrations were conducted, as described in Experiment 1 (see section 2.5 *Procedure* on page 59). Three tasks (the letter cancellation and two clock cancellation tasks, the latter reported in Experiment 3 in Chapter 4) were completed and the order was counterbalanced across participants. The participants were free to take a break between trials, after which another calibration procedure was undertaken before commencement of the next trial.

The stimulus, obscured by a cover, was placed on the easel whilst the experimenter explained the task and ensured the participants understood the instructions. The participants were instructed to search the stimulus and place a single line through (i.e. cross through) all target items 'h' and 'q'. Just before the trial began, the participant was asked to fixate a central fixation cross beneath the stimulus so that all participants started from the same central fixation position. The trial commenced once the cover was removed from the stimulus. Participants were asked to indicate when they had finished the task by placing the pen on the table and looking at it (so that the end of the trial could also be identified within the eye movement recording). No time limit was imposed.

2.7 Data Analysis

Using specialised software within the School of Psychology, the fixation position of the eye was superimposed onto the scene footage, as reported in Experiment 1 in Chapter 2. This was done through calibrating the position of the eye at five or nine points in the scene. The second calibration was used to verify that the position of the fixation cross was accurate at different points in the scene. Using software to step through the footage frame-by-frame (30 frames/second), the position of the fixation with respect to regions of interest imposed on the stimulus was hand-scored for each frame. Region boundaries were easily identifiable in the video footage, denoted by markers on a border presented around the stimulus. Frames where no fixation cross was available due to blinks were not included. A sub-set of the trials were also hand scored by an independent assessor to ensure there was inter-rater reliability for the eye movement data[2].

3. Results and Discussion

Both behavioural (target identification accuracy; TIA) and eye movement results are presented in this section. Omnibus 4 (region: far left, near left, near right, far right) x 2 (target-type: left side target, right sided target) x 3 (group: NPs, SCs, OACs) mixed model ANOVAs were conducted to determine initial effects and, where appropriate, post-hoc *t*-tests were conducted to investigate main effects and interactions. If SCs and OACs did not significantly differ on a measure, the two groups were combined to form one control group to compare to the NPs. Additionally, when the Mauchly's test of severity was violated when conducting an ANOVA, Greenhouse-Geisser *F* values and degrees of freedom are reported. Tables of means (*M*s) and standard deviations (*SD*s) are presented in Appendix D.

3.1 Eye Movement Measures

Eye movement measures were extracted via the algorithms that were developed as reported in Experiment 1. The measures reported for this experiment were as follows: total number of gazes (a gaze was defined as a saccade being made to a region; a new gaze commencing when the eyes transgressed a region boundary, i.e. made a saccade to another region), proportion of total trial time (the proportion of the total trial time spent fixating that region) and average gaze duration (the average amount of time spent fixating the region before saccading to another region, i.e. sum of fixation durations on a region before saccading to another region, averaged for the regions). Furthermore, a qualitative analysis of the scanning behaviour during completion of the trial will be outlined.

3.2 Target Identification Accuracy (TIA) in the SEAN Task

If targets and distractors were harder to distinguish when the critical information necessary for letter identification was presented on the left side of the letter, then one might expect that the highly similar distractors ('n' and 'm') would be cancelled in error. This would indicate that the participant mistook the distractors for the target item ('h'), which would likely to be due to the information being perceived on the right side not differing across the letters. In contrast to what would be expected if NPs were presenting with allocentric neglect, participants made very few errors in cancelling distractor items during completion of the task, i.e. errors in cancelling distractor items. These will be briefly outlined for the different participant groups. Due to these types of errors being low, the remainder of this section will focus on accuracy in correctly detecting targets (target identification accuracy; TIA) within different regions of the stimulus. The NP group made seven errors in total cancelling distractor items. All errors, apart from one, were made by NPs cancelling one of the highly similar distractors to the left and right sided targets (i.e. 'n' and 'm'; 'g' and 'd', respectively) that were specifically included in the task. For NPs, cancelling the distractors that had high similarity to the right sided target (i.e. 'g' and 'd') occurred more frequently than cancellation of distractors that had high similarity with the left sided target (i.e. 'n' and 'm'). This suggests that left allocentric neglect was not operating, otherwise NPs would have neglected the left side of each letter and, therefore, would have been more likely to cancel distractors highly similar to the left sided target, i.e. 'n' and 'm'. Whether allocentric neglect was supported in the results of this experiment will be considered further by comparing the difference in TIA for left and right sided targets. The SCs made three errors in total, two cancellations of the distractors with high similarity to the right sided target and one distractor with high similarity to the left sided target. The OACs made two errors in total, both errors in cancelling distractors to the right sided target. These errors demonstrate that the high similarity distractors included in the task were mistaken for target items more than any other letter included as distractors in the task.

For TIA, there was a main effect of group, $F(2, 31) = 37.30$, $p < .001$, $\eta_p^2 = .71$, with NPs, as predicted, obtaining lower TIA overall than the SCs and OACs. There was also an effect of region on TIA, $F(1.8, 57.03) = 11.37$, $p < .001$, $\eta_p^2 = .27$, with TIA for the right regions being higher overall compared to the left regions. As predicted, there was a significant region by group interaction, $F(3.68, 31) = 8.42$, $p < .001$, $\eta_p^2 = .35$ (see *Table 10* for *M*s and *SD*s). As can be seen in *Figure 15*, SCs and OACs had equivalent TIA across regions. In contrast, the NPs' accuracy decreased monotonically from right to left.

One-way ANOVAs with three levels (group: NPs, SCs, OACs) for each region (FL, NL, NR, FR) were conducted to determine for which regions of the stimulus the groups differed in accuracy. There was a significant difference between groups for TIA in all regions, FL $F(2, 65) = 93.55$, $p < .001$, $\eta_p^2 = .74$; NL $F(2, 65) = 33.99$, $p < .001$, $\eta_p^2 = .51$; NR $F(2, 65) = 17.63$, $p < .001$, $\eta_p^2 = .35$; FR $F(2, 65) = 8.79$, $p < .001$, $\eta_p^2 = .21$. The NPs had significantly lower TIA for the FL region than SCs and OACs, $t(38) = 10.32$, $p < .001$; $t(38) = 12.21$, $p < .001$, respectively. For the NL and NR regions, NPs also had significantly poorer TIA than the control participants, $t(38) = 7.03$, $p < .001$, $t(38) = 5.10$, $p < .001$. However, accuracy in the FR region was not significantly different for NPs compared to SCs, $t(38) = 1.71$, $p = .095$, but was significantly lower than OACs' TIA (95%), $t(38) = 3.43$, $p = .002$. This is consistent with the pattern of TIA predicted for NPs, with more accurate responses being made to stimuli located in more ipsilesional regions and NPs not differing from SCs in the most ipsilesional region. These findings demonstrate that statistically there was no difference in NPs' and SCs' search for two targets in the FR region, suggesting that NPs could conduct search for two target items ('h' and 'q') to a similar extent as the SCs in the most ipsilesional region. Specifically, it is likely that neglect resulted in poor accuracy within more contralesional regions and not that the NPs performed poorly overall due to another factor.

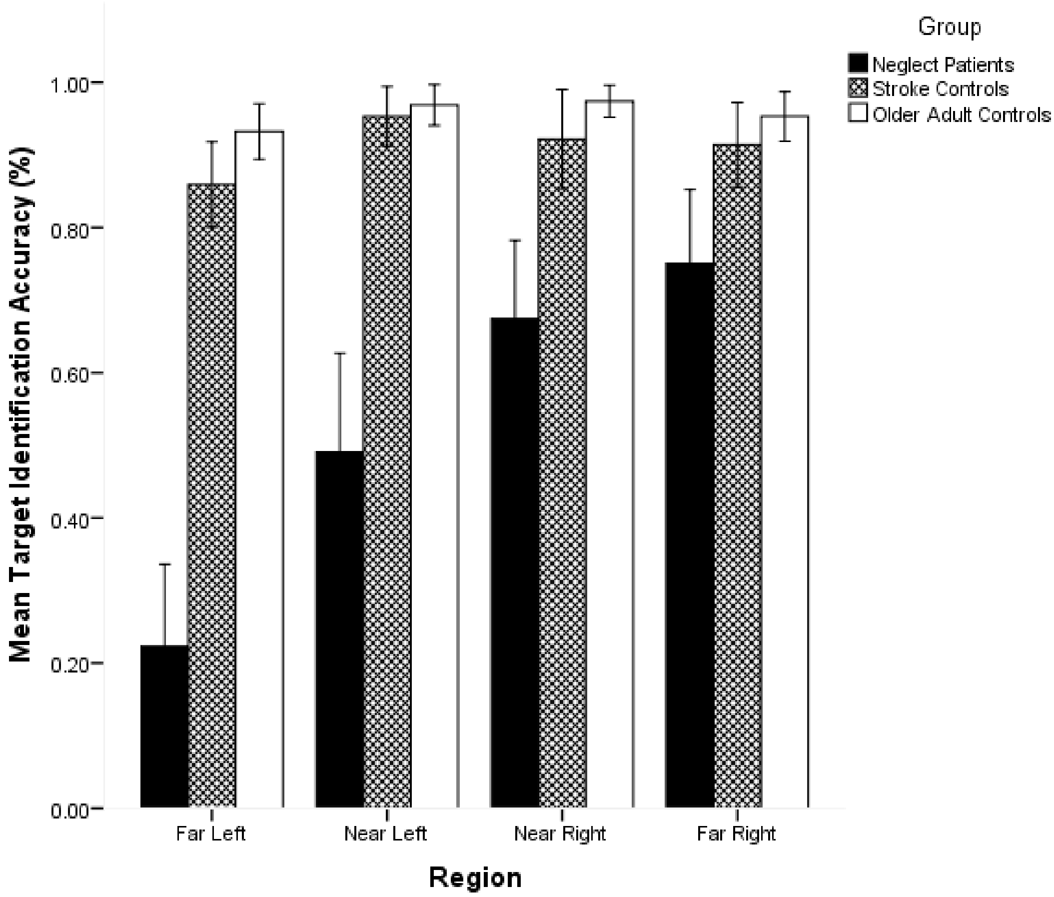

Figure 15. Target Identification Accuracy (TIA; %) on the SEAN task for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs) for each region on the stimulus (Far Left; Near Left; Near Right; Far Right). Error bars represent 95% confidence intervals around the mean.

There was no main effect of target-type, $F(1, 31) = 1.67$, $p = .206$, signifying that there was no overall difference in accuracy for identifying left and right sided targets ('h' and 'q', respectively). Interestingly, there was a significant target-type by group interaction, $F(2, 31) = 7.79$, $p = .002$, $\eta_p^2 = .33$. The target-type by group effect was investigated by comparing TIA for left and right sided targets within each group. NPs, contrary to predictions, marginally identified more left sided targets (57.58%) than right sided targets (49.38%), $t(55) = 1.86$, $p = .068$. This indicates that allocentric neglect was unlikely to be occurring during this task (otherwise NPs would have obtained lower TIA for left sided targets than the right sided targets). The NPs obtaining higher accuracy for one target item compared to the other may be due to NPs prioritising one target item over the other to enable efficient search. As the left sided target, 'h', was the first target item presented (at the bottom of the SEAN task, see *Figure 14*), this may have resulted in NPs preferentially responding to that target item (even if implicitly).

There was no significant difference between left (M = 91%) and right sided (M = 89%) TIA for SCs, $t(55) < 1$, $p = .385$. However, unexpectedly, OACs had significantly higher TIA for right (98%) than left sided targets (94%), $t(48) = 2.41$, $p = .020$. This was a small difference but may have resulted from the right sided target item, ‘q’, being slightly easier to identify due to the unique physical characteristics (e.g. the descender). Target items possessing unique physical properties have been demonstrated to aid the efficiency and accuracy of search in control participants previously (Treisman & Gelade, 1980). However, the left sided target also possessed a unique (and salient) property (the ascender) and the distractor (‘g’) also possessed a descender, and therefore should have been equally as salient as the target letter ‘q’.

These results indicate that object-based, allocentric neglect, was not observed in the NPs for this task. However, this may be because the NPs as a group did not exhibit allocentric neglect. Individual NPs may have exhibited this form of neglect and, thus, this will be considered next. All NPs, except one, obtained higher accuracy for the left sided targets compared to the right sided targets. Case 2, demonstrated lower accuracy for left compared to right sided targets. Using the Crawford and Howell’s (1998) method to compare single case study data to a control group (as in Experiment 1; Chapter 2), it was demonstrated that Case 2’s difference in TIA between left and right sided targets was not significantly different from control participants who demonstrated the same pattern, $t(10) = 0.64$, $p = .541$. Thus, it seems reasonable to conclude that none of the patients exhibited allocentric neglect. Potential reasons for this will be considered in the General Discussion of this chapter.

3.3 Scanning Patterns

Before considering the detailed eye movement measures, a qualitative analysis of the scanning behaviour exhibited by participants during completion of the SEAN cancellation task will be outlined. The majority of the control participants (OACs and SCs) started scanning the task from the top left corner of the stimulus and worked along the line towards the right side of the stimulus, fixating the FL, NL, NR and then FR region. The NPs demonstrated a distinctly different pattern of scanning behaviour during completion of the SEAN task. One pattern NPs appeared to exhibit was starting from fixating the NR or FR region and attempting to work across those regions from left to right, going down the regions from one line to another. Another pattern that emerged, when NPs started fixating the FR region, was working towards the left regions from the FR, often failing to reach the FL region (or NL region, depending on severity) of the stimulus. The NPs demonstrated consistent re-scanning of the right regions of the stimulus and as a consequence for the remainder of the trial the patient would search these regions only, making upward and downward saccades to fixate different lines of letters within these regions. The propensity for NPs to re-fixate the right regions will be discussed in the measure capturing the number of gazes made on different regions of the stimulus, outlined next.

3.4 Number of Gazes made on each Region

The next issue that was investigated was whether poor spatial sampling of contralesional information occurred in neglect alongside poor contralesional TIA, by comparing the number of gazes made to each region by the different participant groups. As anticipated, there was a significant effect of region, $F(1.45, 44.79) = 24.30$, $p < .001$, $\eta_p^2 = .44$, demonstrating that, as in Experiment 1, more gazes were made to the internal regions than the external regions overall. There was no effect of group, $F(2, 31) = 1.07$, $p = .355$, showing that the groups did not differ in the overall number of gazes made on the stimulus. This suggests that NPs did not need to make more gazes on the stimulus overall whilst conducting search for target items, unlike SS in Experiment 1. The overall number of gazes being equivalent across groups on this task meant that meaningful comparisons across groups and regions on the stimulus could be made using the raw data. Thus, number of gazes was reported in this section (as opposed to proportion of overall gazes reported in Experiment 1).

As predicted, there was a significant region by group interaction for number of gazes made on the stimulus, $F(2.89, 44.79) = 9.50$, $p < .001$, $\eta_p^2 = .38$ (*M*s and *SD*s reported in *Table 11* in Appendix D). It is clear from *Figure 16* that there is a marked decrease in the number of gazes being made on the left regions compared to the right for the NPs, which is not the case for the control participants, with more gazes made to the internal (NL and NR) regions than the external ones (FL and FR). In support of a contralesional sampling deficit contributing to poor TIA, NPs made significantly fewer gazes on the FL region than control participants, $t(32) = 5.15$, $p < .001$. This demonstrates that NPs were saccading to the left on fewer occasions and this reflects a deficiency in the sampling of information contralesionally[4].

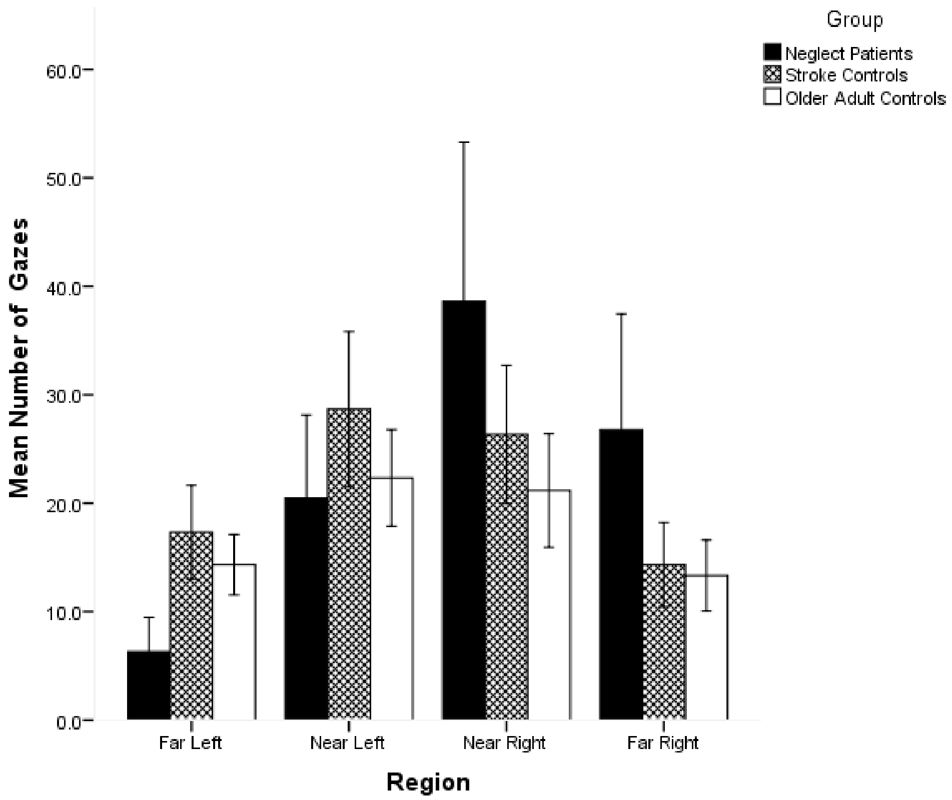

Figure 16. Mean number of gazes made on the four regions of the stimulus (Far Left, Near Left, Near Right, Far Right) of the SEAN task for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

There was no significant difference between NPs and controls in number of gazes made on the NL region, $t(32) = 1.26$, $p = .215$. This suggests that there was no spatial sampling bias contributing to poorer TIA in this region. It may be that NPs were fixating the information in that region but they were not spending enough time fixating that region to process targets sufficiently in order to respond to them, i.e. a temporal sampling deficit of information was occurring. This is considered in the next section, where analyses of the proportion of trial time spent fixating the different regions of the stimulus are reported.

The NPs made significantly more gazes on the NR and FR regions than controls, $t(32) = 2.18$, $p = .047$, $t(32) = 2.59$, $p = .022$, respectively. Therefore there was a right sided shift in the NPs' exploration of space within the stimulus; with eye movement measures capturing this bias. This suggests that the NPs were hyper-attending to the ipsilesional regions, in line with the findings for SS in Experiment 1.

3.5 Proportion of Total Trial Time spent fixating each Region

In order to investigate whether a counterpart temporal sampling deficit of information was contributing to poor contralesional TIA, proportion of time spent fixating regions on the SEAN cancellation task were analysed. There was no group effect, $F(2, 31) = 2.71$, $p = .082$, $\eta_p^2 = .15$, demonstrating the groups did not differ overall in the proportion of time spent fixating the stimulus during the trial. This means that NPs were not more likely to fixate regions outside of the stimulus than controls.

A significant main effect of region on proportion of fixation time was revealed, $F(1.43, 44.34) = 10.07$, $p = .001$, $\eta_p^2 = .25$, with the FR region receiving a higher proportion of fixation time than the other regions. There was also a significant region by group interaction, $F(2.86, 44.34) = 15.64$, $p < .001$, $\eta_p^2 = .50$. From *Figure 17* is is clear that control participants spent an equivalent amount of time on each region of the stimulus. On the contrary, NPs spent a disproprtionate amount of time fixating the right regions and fixation time decreased as the region became more contralesional.

As expected, NPs spent significantly less time fixating the FL and NL regions than controls, $t(32) = 6.43$, $p < .001$, $t(32) = 2.40$, $p = .032$ (see Table 12 for *M*s and *SD*s). However, for the NR region, NPs did not differ in proportion of time from SCs, $t(20) = 1.51$, $p = 1.47$, but had significantly longer fixation time on that region compared to the OACs, $t(23) = 2.79$, $p = .010$. For the FR region, NPs exhibited a significantly higher proportion of fixation time than both control groups, $t(32) = 4.60$, $p < .001$. This indicates that a temporal sampling deficit of the contralesional regions, therefore, was demonstrated to be contributing to neglect[5]. There was also a suggestion of hyper-attention to the most ipsilesional region (FR), demonstrating that the pattern of eye movements reflected the dysfunctional representation of space present in neglect.

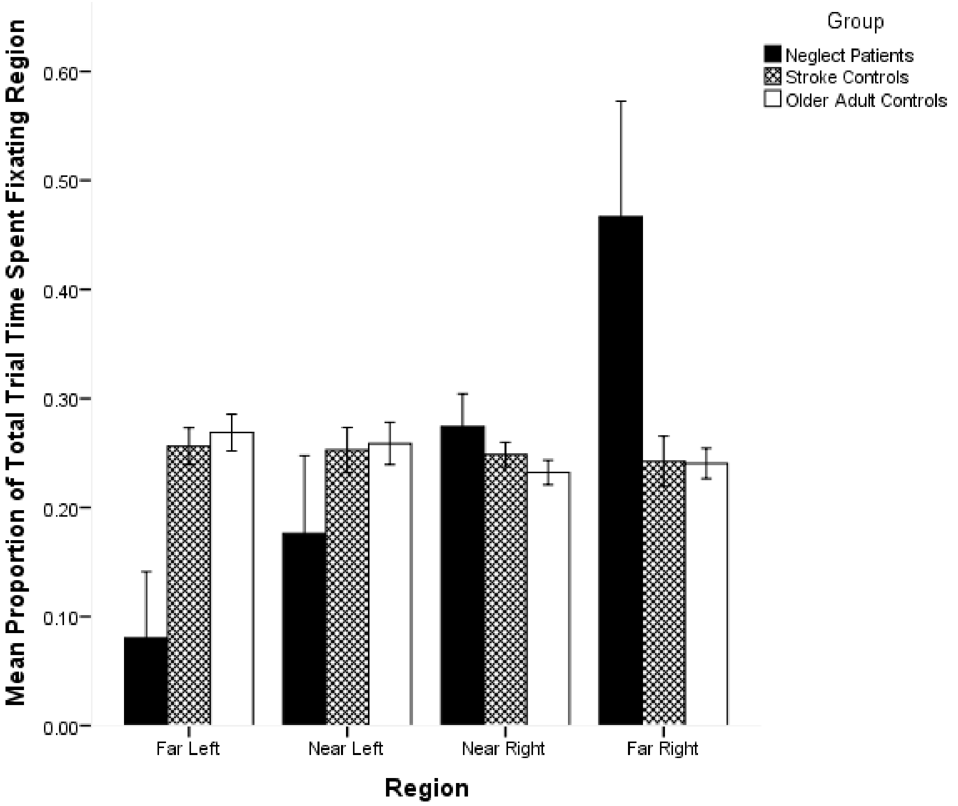

Figure 17. Proportion of total trial time spent fixating the four regions (Far Left; Near Left; Near Right; Far Right) on the SEAN task for the Neglect Patients, Stroke Controls, and Older Adult Controls. Error bars represent 95% confidence intervals around the mean.

3.6 Average Gaze Duration (AGD) on each Region

The above results suggest that there was a marked sampling deficit exhibited by NPs, with fewer gazes made to the FL and less time spent fixating the FL and NL regions. However, the data from the number of gazes demonstrated that NPs did saccade to the left regions on occasions. In order to investigate whether NPs required more time to process information during contralesional gazes compared to ipsilesional gazes than control participants, average gaze durations (AGD) were analysed. Recall that AGD are the amount of time a participant spent fixating a region before saccading to another region and inflated AGD reflect the amount of time that is required within that region to process information or a propensity to fixate that region for longer durations. There was a significant main effect of region on AGD, $F(3, 2820) = 57.42$, $p < .000$, $\eta_p^2 = .06$. The AGDs were longer on the external regions (FL and FR) than the internal regions (NL and NR). This is likely to be due to more gazes being made between the internal regions (as demonstrated by an increased number of gazes being made to these regions compared to the external regions) as these regions have more region boundaries. As these boundaries are likely to be transgressed more often than when fixating the external regions, AGD will be shorter on internal regions.

There was also a main effect of group on AGD, $F(2, 2820) = 9.62$, $p < .001$, $\eta_p^2 = .01$. This effect arose due to SCs, on average, having longer AGDs than NPs and OACs (see Table 13 in Appendix D). This may be due to a number of post-stroke factors, such as fatigue, limited sustained attention and more processing time being required as SCs are searching for two target items at once. As these factors would also apply for NPs it appears that neglect may result in shorter AGD overall. As can be seen from *Figure 18*, there was a significant region by group interaction for AGD, $F(6, 2820) = 4.78$, $p < .001$, $\eta_p^2 = .01$. One way ANOVAs with three levels (group) were conducted in order to determine which pair-wise comparisons needed to be conducted. These analyses revealed that the groups differed in AGD for the FL, NR and FR regions, $F(2, 407) = 3.59$, $p = .028$, $\eta_p^2 = .02$, $F(2, 990) = 8.35$, $p < .001$, $\eta_p^2 = .02$, $F(2, 634) = 5.94$, $p = .003$, $\eta_p^2 = .02$, respectively. For the FL region, NPs had significantly reduced AGDs than the SCs, $t(236) = 2.41$, $p = .017$ but not the OACs, $t(252) = 1.39$, $p = .207$. This demonstrated that the NPs, even though they obtained lower TIA for the FL region than OACs, spent as long in that region searching for target items during each gaze. It appears that SCs required more time within each gaze compared to the NPs, but recall, SCs obtained high TIA within all regions and therefore this extra time is likely to reflect extra time required to process and respond to all the targets within the region, along with the effect of post-stroke factors.

The NPs also spent less time on average in the NR region than the SCs, $t(737) = 3.43$, $p = .001$, but the same amount of time as OACs, $t(754) = .64$, $p = .525$. Therefore, NPs lower average gaze durations compared to SCs was not limited to the contralesional regions. In stark contrast, in the FR region, NPs had longer average gaze durations than the OACs, $t(506) = 4.18$, $p < .001$, but not the SCs, $t(475) = .58$, $p = .563$, suggesting that this region was harder for them to disengage from than the other regions and, therefore they fixated that region longer during a gaze.

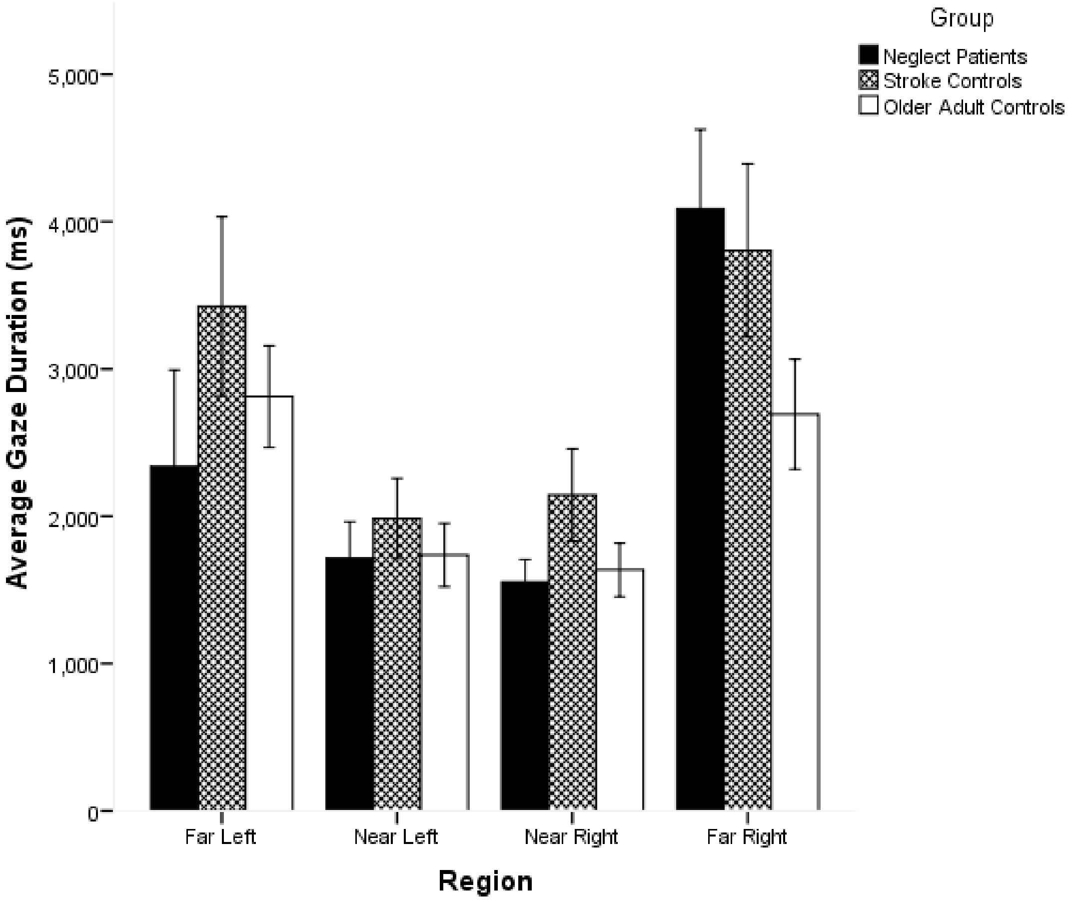

Figure 18. Average Gaze Durations (AGD; ms) made on the regions (Far Left; Near Left; Near Right; Far Right) of the SEAN task for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

Interestingly, there was no significant difference in AGD for the different groups on the NL region (see Table 13 for descriptive statistics in Appendix D), $F(2, 789) = 1.43$, $p = .240$, even though the NPs had poorer TIA in this region (refer back to Table 10). *Figure 18* shows that the NPs were spending as much time searching for targets during each gaze made to the NL region as control participants and made as many gazes there but, importantly, they were still failing to identify as many target items as the control participants within that region. This provides clear evidence that a processing deficit was also contributing to neglect. The amount of time that the control participants spent processing and identifying target items in each gaze made on the NL region did not appear to be sufficient in order for NPs to accurately identify all target items in the NL region. This suggests that NPs require more processing time than controls in order to accurately identify contralesional target items.

4. General Discussion

This experiment investigated the pattern of eye movements that patients with neglect exhibited during search for two target items, which appeared multiple times in a search array. A newly designed letter cancellation task, the SEAN task, was developed in order to investigate both allocentric and egocentric neglect simultaneously. This was the first time that the pattern of eye movements during completion of cancellation tasks produced by a group of patients with neglect has been reported, extending findings from the case study reported in Experiment 1. As expected, the NPs had severe neglect of information on the left, with poor accuracy for target identification in the left regions, demonstrating egocentric neglect on this task. An important behavioural finding was that none of the neglect patients examined in this study appeared to present with allocentric neglect.

The patterns of eye movements clearly demonstrated that deficient sampling of information within the contralesional area of space occurred and contributed to poor TIA in contralesional regions for NPs. Little overall time was spent fixating the left regions, (particularly the far left region) and few contralesional saccades were made, compared to right regions and control participants' eye movements. These results extend the case study findings reported in Experiment 1, demonstrating that deficient sampling was also contributing to neglect of information in a group of NPs.

The second important finding to note from the eye movement analyses was that more time was spent on, and more gazes were made to, the right of the stimulus by the NPs compared to the controls. Additionally, the NPs' attention was held there for longer before saccading to the left, as shown by inflated average gaze durations on the FR compared to OACs. This suggested that attention was captured and held by the right region in the neglect group and provided evidence that hyper-attention to the right side may have been contributing to the neglect of the left side of the stimulus in this task. Each of these main findings that have been summarised will be discussed in more detail in the following sections.

4.1 Why was there no Evidence of Allocentric Neglect Observed in this Experiment?

Three main reasons for the lack of evidence for allocentric neglect in NPs in this experiment were postulated. Firstly, a number of studies have demonstrated that allocentric neglect is far less common that egocentric neglect (e.g. Bickerton et al., 2011; Hillis et al., 2005). Hillis et al. (2005) found that only 25% of 16 neglect patients presented solely with allocentric neglect and 70% with exclusively egocentric neglect.

Therefore, it was possible that, by chance, none of the 13 neglect patients included in this study presented with allocentric neglect. Furthermore, their performance on the Ogden scene screening task indicated that none of the patients demonstrated allocentric neglect. It may be that a larger sample of NPs need to be investigated to determine whether any patients presented with allocentric neglect on this task. However, the existence of allocentric neglect is still highly contentious (e.g. Driver & Pouget, 2000).

Secondly, some researchers have postulated that allocentric neglect is a manifestation of egocentric neglect, for example, 'relative egocentric neglect' (Driver & Pouget, 2000). Relative egocentric neglect is the notion that the left part of an object is neglected because the neural response to that side of the object is relatively lower compared to that of the right side. So, when an object is presented upright, both the absolute egocentric position and the relative egocentric position of parts within the visual field are important in the spatial coding of information, and, therefore, which spatial information is neglected by NPs. Similarly, 'fixation-based neglect', which may result in what appears to be allocentric neglect, relies on the operation of egocentric frames of reference. This would result when the task requires the neglect participant to make sequential eye fixations to the centre of each object in order to obtain detailed information from it by bringing it under the high acuity area of the fovea.

Targeting of objects' centres during search tasks has been demonstrated. Henderson (1993) found that the initial landing position (LP) of the eyes on an object was found to be normally distributed around the centre of the object, with the modal LP at the centre. Thus, when a fixation is made on, or near, an object's centre in neglect, the left part of the object may be neglected due to that part now falling to the left of the point of fixation and, therefore, left in relation to an egocentric reference frame (the point of fixation, which has been shown to be an important egocentric reference frame; e.g. Behrmann et al., 2002). Evidence from a number of different paradigms has demonstrated that information that falls to the left of fixation (i.e. within the LVF) is neglected by NPs (e.g. Behrmann et al., 2002; Colby & Goldberg, 1999; Karnath & Hartje, 1987). Thus, disruption does not arise as a result of the left part of the object being neglected, but instead because the information to the left of any current fixation position is neglected. This, in turn, suggests that allocentric neglect may in fact be a form of egocentric neglect. Allocentric neglect that does not rely on egocentric frames of reference would result in a failure for the left side of an object to be perceived, even when allocentric and egocentric frames of reference were placed out of alignment. Such a situation could be easily achieved by rotating an object 180^{o} so that the canonical left side of the object would fall on the right side of an egocentric reference frame (e.g. to the right of the point of fixation).

The second explanation just outlined is based on the premise that allocentric neglect is in fact a result of ‘fixation-based neglect’. Fixation-based neglect is the idea that information falling to the left of a central fixation position was neglected. Thus, a pattern consistent with allocentric neglect would be apparent if the centre of each object was fixated during the task, which is in fact neglect operating at an egocentric level based on the position of gaze. Fixation-based neglect at the letter level may not have occurred during the SEAN task as each individual letter included may not have been directly fixated; therefore patterns of allocentric neglect were not evident. Even though information regarding precise fixation location information within the SEAN task could not be obtained due to the accuracy of the eye tracker, numerous letters were included in the task and, therefore, it was unlikely to be efficient to fixate each letter during search for targets in this task. Letters being presented in close proximity to one another in the task may have resulted in low-level featural information being extracted from letters that were not directly under the fovea (Treisman & Gelade, 1980; Rayner, 1998). Treisman & Gelade (1980) explained findings of display size increasing but processing time not, as being due to the larger displays having an increase in density of items within the array. This increase in density meant that more stimuli would, on average, have fallen within foveal vision during each fixation, allowing the number of items that could be processed in parallel to increase with display size. As the SEAN task was a dense array of small letters, each of the items may not have required a fixation. It has been shown that during normal reading, people can extract low-level featural information from letters 7-9 characters to the right of the current fixation position (Rayner, 1998).

A sequential search task including only letters, developed by Trukenbrod and Engbert (2007), demonstrated that the same oculomotor principles guided eye movements during the search task as those that operate during reading. Trukenbrod and Engbert provided evidence that low-level information can be extracted from letters that are not currently being fixated, indicating that parallel processing of letters can occur in this type of search task. Therefore, it would appear that each letter in the SEAN task may not have received individual central fixations, as has been demonstrated by a number of studies (e.g. Shiffrin & Gardner, 1979; Itti & Koch, 2000; Treisman & Gelade, 1980; Trukenbrod & Engbert, 2007; Rayner, 1998). Fixation-based neglect may be more likely to occur for larger objects presented in the visual field, where it is more likely that each object is directly fixated as in tasks employed by Henderson (1993). This would suggest that physical properties of the stimulus and the task demands, influence the nature and extent of neglect exhibited. In order to confirm that during this task, and similar tasks, that NPs did not fixate the centre of each letter, resulting in no fixation-based neglect occurring, and therefore no evidence being provided for allocentric neglect, a head-mounted eye tracker with higher spatial resolution would need to be developed and employed to record participants' landing positions within each letter.

Determining whether allocentric neglect is a result of fixation-based neglect will be directly addressed in the next experiment. Upright and inverted objects with canonical handedness were employed in Experiment 3 in order to investigate whether the left side of the object was neglected (i.e. its canonical left side) or, as predicted, information to the left of a central-fixation position was being neglected. This is a critical question, as evidence for fixation-based neglect may explain why allocentric neglect can be exhibited on occasions but has not been consistently demonstrated previously (due to the nature of the stimulus employed).

Thirdly, another reason for the lack of allocentric neglect presented in this task by the NPs is that the task may not have been sensitive to this type of neglect if it was present. As the target items were letters, it may be that each letter is not coded as an object, which would mean that the left side of the letter would not be neglected even if allocentric neglect was occurring. It may be more likely that a number of letters are grouped together to form an object (as discussed previously) and then the letters that fell on the left side of that group letters (i.e., that object) would be neglected, not the left side of each letter. Therefore, letters may not be an appropriate stimulus to employ to investigate allocentric (object-centred) neglect and so other targets and stimuli will be employed in the following experiments. Despite this, there is some suggestion that the intrinsic left side is neglected of letters that have been rotated and are presented in isolation (e.g., Behrmann & Moscovitch, 1994) so the premise that the left side of a letter may be neglected cannot be dismissed completely.

4.2 Did a Sampling or Processing Deficit of Contralesional Space Occur?

Importantly, the eye movement measures demonstrated that the oculomotor behaviour displayed by patients with neglect reflected their inattention, with little visual sampling of the contralesional regions resulting in poor contralesional target identification. This extended the findings from Experiment 1 on SS to a group of 13 NPs. As demonstrated in Experiment 1, task demands and complexity may affect the allocation of attention to areas of space. For example, whilst the NP is using a significant amount of cognitive resources to conduct dual-target search required during this task (determining whether a letter is 'h' or 'q'), the increased processing difficulty relative to single target search may have restricted attention to the left side of space.

The sampling deficit was interpreted as contributing to neglect of information on the left, as if saccades were not made to the contralesional regions, and time was not spent fixating those areas, targets within the contralesional regions were unlikely to be correctly identified. This sampling deficit may also be a direct result of neglect, whereby less time was spent fixating, and fewer saccades were made to, the left regions due to that area not being a part of the NPs' representation of space. If the sampling deficit was the sole factor linked with poor target identification accuracy within contralesional regions, this would provide strong evidence that this caused the neglect and was not a result of it. However, this was not the case.

Often NPs spent the same amount of time fixating the near left regions as controls during each gaze but still failed to identify the majority of targets during those gazes. This provides evidence that a deficit in processing contralesional targets also contributed to the neglect observed in this task. Knowledge of the underlying deficits contributing to visual neglect is critical in order to correctly characterise the disorder and develop appropriate and effective treatments to target underlying deficits. It is often assumed within the clinical setting that a sampling deficit of contralesional information is the exclusive cause of neglect and, therefore, if patients are encouraged to visually sample the left then targets will be detected and identified in that area. A common method for the treatment of neglect is visual scanning training, but this has shown only limited and temporary success in the treatment of neglect (see Manly, 2002). The current study provided insight into why these strategies alone may not be effective in ameliorating neglect. Combining this training with a technique that aids processing of information presented contralesionally may be shown to be a more effective and enduring treatment for neglect. For example, recently, Functional Electrical Stimulation (FES) has been demonstrated to increase brain activity in the affected hemisphere and this may improve processing of contralesional targets (e.g. Harding & Riddoch, 2009; and as demonstrated in Experiment 1 reported in this thesis).

Revealing that there was a deficit associated with processing contralesional information raised an additional issue. This processing deficit may be a result of NPs being unable to encode visual information presented in the contralesional regions (i.e.

sufficiently extract the visual information presented in order to detect and identify the information). On the other hand, the information may be encoded but not sufficiently represented in order for an accurate response to be made. How visual information is encoded and represented in neglect was directly addressed in Experiment 4 reported in Chapter 6.

4.3 Is Hyper-attention to the Ipsilesional Space Occurring in Neglect?

Many researchers believe that neglect is a result of hypo-attention to the contralesional side due to contralesional information evoking weaker competition than the right side (e.g. Bartolomeo & Chokron, 1999). Hypo-attention to the left would result in fewer visits being made to contralesional regions, less time spent fixating those regions, and it taking longer for those regions to capture attention in neglect. Other researchers have postulated that neglect is due to increased arousal of the ipsilesional hemispace causing exaggerated focus and preferential responding to the right (Kinsbourne, 1987). The findings of the present study showing that the NPs made significantly more saccades into the right regions (increased number of gazes) and exhibited a propensity to remain fixating the far right region during each gaze (as demonstrated through longer average gaze durations than the OACs). This supports the idea of 'visual capture' of the right side in neglect (Marshall & Halligan, 1989). These findings suggest that there is a problem with disengaging attention from the ipsilesional side of space in neglect, which may be contributing to inattention to the left side of space. Thus, it does appear that hyper-attention to the ipsilesional side of space did occur as neglect patients undertook the SEAN task. It still needs to be determined whether or not hyper-attention to ipsilesional regions can exclusively (i.e. without hypo-attention occurring) account for neglect.

4.4 Conclusions

Many researchers have stated the value of examining the eye movements made in patients with neglect (e.g. Behrmann et al., 1997; Olk, Harvey & Gilchrist, 2002). Despite measuring NPs' eye movements potentially being an 'arduous task' (Rorden et al., 2012), insights pertaining to debates regarding allocentric and egocentric neglect and the deficits underlying the disorder can be revealed by employing this methodology. It has been established in the current experiment that there is a fundamental sampling deficit expressed by those with acute neglect, verifying the case study results reported in Experiment 1. Furthermore, on occasions, NPs made as many fixations and spent as much time fixating the near left as controls but still obtained poor TIA within that region. This suggested that even when targets were fixated on the left, processing of that information was still inadequate for identification to take place. Additionally, the present study showed strong evidence that neglect patients hyper-attended to the ipsilesional side of space and this contributed to neglect of contralesional information. No suggestion for the existence of allocentric neglect was found, although this may be a result of employing letters as targets and each letter in the task not being coded as objects. The issue was raised as to whether allocentric neglect is true object-centred neglect or neglect resulting from the object's left side falling within the neglected LVF (fixation-based neglect). Investigation of this question was the main aim of Experiment 3 reported in the next chapter.

Chapter 4. Eye Movements in Neglect during Completion of Clock Cancellation Tasks: Distinguishing between Allocentric and Fixation-Based Neglect

Experiment 2 reported in Chapter 3 investigated the pattern of eye movements that patients with neglect exhibited during search for two target items (‘h’ and ‘q’) in a task that was designed to Simultaneously investigate Egocentric and Allocentric Neglect (the SEAN task). As expected, the neglect patients (NPs) neglected information that was contained within regions falling to the left of their trunk midline, clearly demonstrating the operation of egocentric frames of reference. Additionally, the patterns of eye movements produced by NPs provided further evidence to indicate that egocentric neglect was occurring, with fewer gazes being made to, and less time being spent fixating, the regions lying left of the patients’ midline. However, none of the NPs examined in the study exhibited, object-based, allocentric neglect in the SEAN task.

The lack of allocentric neglect in Experiment 2 may have arisen because the nature of neglect in these patients was not of this form, or because the task did not result in the left side of each letter being neglected as each letter was not centrally fixated during completion of the task. Fixation-based neglect may be responsible for many patterns of behaviour that could be interpreted as allocentric neglect (e.g. performance on the ‘Apples Test’; Bickerton, Samson, Williamson, & Humphreys, 2011; and the ‘Defect Detection Task’; Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001). A fixation made to the centre of each stimulus in the array would result in the left side of an upright object falling within the LVF. Subsequent neglect of that part of the object, therefore, could be based on the operation of egocentric reference frames in relation to the point of fixation. For example, for the ‘Defect Detection Task’ the participant is presented with a sheet of paper containing both normal circles and ‘pseudo-circles’. The pseudo-circles had a portion of the loop missing, so that the circle was incomplete. This gap was either on the left or right side of the circle. The patients were required to ring every complete circle and cross out every incomplete circle. Allocentric neglect was believed to be present if the patient placed a ring around pseudo-circles that had the gap on the left (perceiving them to be whole circles as the gap on the left side of the object was neglected). However, as an eye movement is likely to have been made to each circle to conduct the task, with fixations likely to be distributed around the centre of the object (Henderson, 1993), this could mean that the left side of the pseudo-circle may have been neglected due to falling to the left of a central fixation position (i.e. egocentric neglect). The same applies for the Apples Test, which involves participants detecting ‘bites’ taken out of apples presented (discussed below); highly similar to the Defect Detection Test.

The SEAN task may not have revealed the operation of allocentric neglect as each letter in the task was not directly fixated and, therefore, fixation-based neglect of the canonical left side of the letter did not occur. This may have been a result of the physical properties of the letters (e.g. small and densely packed) resulting in letter identity information being extracted without a direct, and central, fixation on each individual letter (e.g. Shiffrin & Gardner, 1979; Itti & Koch, 2000; Treisman & Gelade, 1980; Trukenbrod & Engbert, 2007; Rayner, 1998). If this was the case, then the left side of each letter would not necessarily be neglected. The present experiment employed larger objects that were unlikely to be able to be parafoveally processed in this manner, in order for an accurate decision to be made with regards to whether each object was a target or not. Furthermore, upright and inverted objects were included in order to investigate whether the left side of the *object* was neglected (i.e. its canonical left side was neglected even when rotated) or whether information to the left of a central fixation position was neglected, irrespective of the relationship of that information to the object as a whole.

Recently, the Apples Test was developed to distinguish between egocentric and allocentric neglect and validation of the test has been attempted (Bickerton et al., 2011). Bickerton et al. developed the ‘Apples Test’, where participants were required to search an A4 display, containing small and large apples. Apples were either whole or had a ‘bite’ taken out of them. The incomplete apples either had the bite taken out of them on the right or the left side of the object. The participants’ task was to circle whole apples. It was predicted that NPs with egocentric neglect would only circle whole apples on the ipsilesional side of space. In contrast, NPs with allocentric neglect, as in the Defect Detection Test (Ota et al., 2001), were predicted to circle apples that had the bite taken out of them on the left side of the apple, for apples that were presented across the full horizontal extent of the stimulus. Patients with egocentric and allocentric neglect would fail to ring targets on the contralesional side of the page and would incorrectly ring apples when a bite was taken out of the left side, for apples presented to the ipsilesional side.

Using the Apples Test, Bickerton et al. (2011) demonstrated that whereas some chronic and acute neglect patients displayed egocentric neglect solely, others displayed allocentric neglect in isolation. One third of the acute patients presented with both forms of neglect. The authors interpreted these findings as highlighting a clear dissociation between allocentric and egocentric neglect. However, it is important to note that the separation of allocentric neglect and egocentric neglect in the Apples Test is not as unequivocal as Bickerton et al. argue. For example the pattern of behaviour that is interpreted as allocentric neglect in the Apples Test may result from an eye movement being made to the centre of each apple, in order to make a decision about whether it is a target or not, and, therefore, reflects the operation of egocentric neglect in relation to the point of fixation. This type of neglect, with information falling in the LVF being neglected, has been demonstrated to occur in neglect (e.g. Behrmann et al., 2002; Colby & Goldberg, 1999; Gainotti, D'Erme, Monteleone, & Silveri, 1986; Karnath & Hartje, 1987). Therefore, the left side of the apple may be neglected due to that side falling to the left of a central fixation position.

Manipulating the orientation of an object allows meaningful conclusions to be drawn with regard to the operation of different frames of reference. This eliminates the confound between egocentric and allocentric frames of reference when an eye movement is made to the centre of an object. Allocentric neglect demonstrated in a task when the objects are rotated would be object-centred. Research has demonstrated that neglect can occur for the left side of an object in relation to its centre of each object, regardless of its orientation or position in relation to the viewer's position (e.g., Behrmann & Moscovitch, 1994; Caramazza & Hillis, 1990; Driver, Baylis, Goodrich, & Rafal, 1994). Driver, Baylis, Goodrich, and Rafal (1994) provided evidence for object-centred in three neglect patients included in their study. The authors employed triangle stimuli that remained physically identical across trials but could differ in the perceived direction in which they were pointing. This allowed manipulation of whether a gap, which was the participants' task to detect, was on the left or right of one of the triangles in the stimuli according to the perceived viewpoint. They demonstrated that the neglect patients missed more gaps when the gaps were on the left side of the triangle compared to the right, even though the only difference between the stimuli was the direction in which the triangles were perceived to be pointing. Even though this demonstrated the operation of allocentric frames of reference in neglect, the authors concluded that egocentric frames of reference were important as well, as assigning one side of the object as left and one side as right relies on the viewpoint, and an egocentric reference frame, and therefore the behaviour exhibited by the neglect patients could not be interpreted as *pure* allocentric neglect but involved an interplay between egocentric and allocentric reference frames.

Clocks have intrinsic left and right sides based on the egocentric viewpoint when the object is presented upright. The object-centred midline rotates with the object when its orientation is manipulated. Including these stimuli in a task enables investigation of whether object-centred neglect was occurring or fixation-based neglect resulted in a pattern of allocentric neglect. If an upright clock had time-telling information (i.e. the hands of the clock) presented only on the canonical left side of the object (the side including numbers 7-11) and this was neglected, fixation-based neglect may have resulted in this type of neglect. However, if the object was inverted and the canonical left side of the object was still neglected (even though it is now to the right of a central fixation position), then this would indicate the presence of pure allocentric neglect (object-centred neglect; see *Figure 19*). In order to investigate whether this is the case, the objects included in a task are required to possess canonical handedness, so that the intrinsic left and right side of the object remain the same part of the object when it is presented upright or rotated. Apples do not have canonical handedness as there is not a specific part of the object that can be represented as the left side and the right side intrinsic to the object (i.e. without taking into account what the egocentric left and right of the object are with regards to the viewer's midline). This is not the case for a clock, which has a canonical left side (including the numbers 7 to 11), which could still be represented as the left side of the clock even if the object was rotated. Thus, if the object was centrally fixated the part of the object that was considered to be left of an egocentric reference frame and to be left of an allocentric reference frame would not be the same. In order to accurately distinguish between the operation of allocentric and egocentric frames of reference, objects in the cancellation task need to possess canonical handedness (i.e. have canonical left and right sides that do not change when the object is rotated) and vary in orientation. Distinguishing between the operation of egocentric and allocentric frames of reference in neglect was the main aim of the present study. Specifically, the main aim of Experiment 3 was to determine whether the operation of allocentric neglect was due to the operation of fixation-based (egocentric) neglect in cancellation tasks.

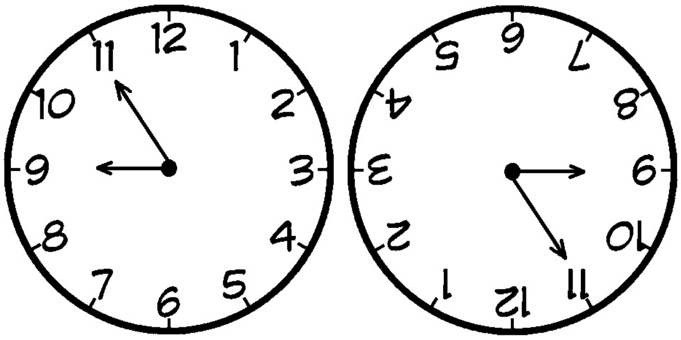

Figure 19. A clock presented upright or inverted. The operation of allocentric and egocentric reference frames would result in differential neglect of these clocks. Allocentric neglect would result in the numbers 7-11 being neglected, regardless of orientation. However, with egocentric neglect, the numbers 7-11 would be neglected when the clock was upright, but numbers 1-5 would be neglected when the clock was inverted.

1. The Present Study

Experiment 3 encompassed two tasks. Both tasks were clock cancellation tasks, where the participant was required to cross through clocks displaying specific times. One task required participants to cancel clocks that had the time-telling information (i.e. the hands of the clock) presented on the canonical left side of the clock (the hands indicated a time of five-to-nine), which were presented amongst high and low similarity distractors (Left Clock Task; LCT). The second stimulus contained ‘right sided targets’ (Right Clock Task; RCT); clocks that had the time telling information on the canonical right side of the clock (the hands indicated a time of five-past-three). In order to distinguish between allocentric neglect (neglect of the canonical left side of the clock regardless of orientation) and fixation-based account of neglect (neglect of the part of the target that was projected to the LVF when centrally fixating that target during search) the clocks also varied in orientation; presented upright and inverted throughout the task. the inclusion of inverted clocks enabled investigation of whether or not pure allocentric neglect was exhibited (i.e. the neglect of the intrinsic left side of an object regardless of the objects’ orientation, and independent of egocentric coordinates) as this ensured that the midlines of allocentric and egocentric reference frames were not aligned if a fixation was made to the centre of the object during search. All of the clocks (targets and distractors) presented in both of the tasks had identical angles between the clock hands. Furthermore, highly similar distractors were included in the task which had the same position of the hands as the targets when presented in the opposite orientation (see *Figure 20*). Therefore, the numbers on the clocks also needed to be encoded to complete the task (the patient could not accurately identify targets by only using the angle or position of the hands). This was to ensure that the clock could not be parafoveally processed and the whole clock representation was required in order to accurately identify the target items. These manipulations were designed to ensure that if allocentric frames of reference operate, these would be activated during the task, and therefore, allocentric neglect should be observed if it was present.

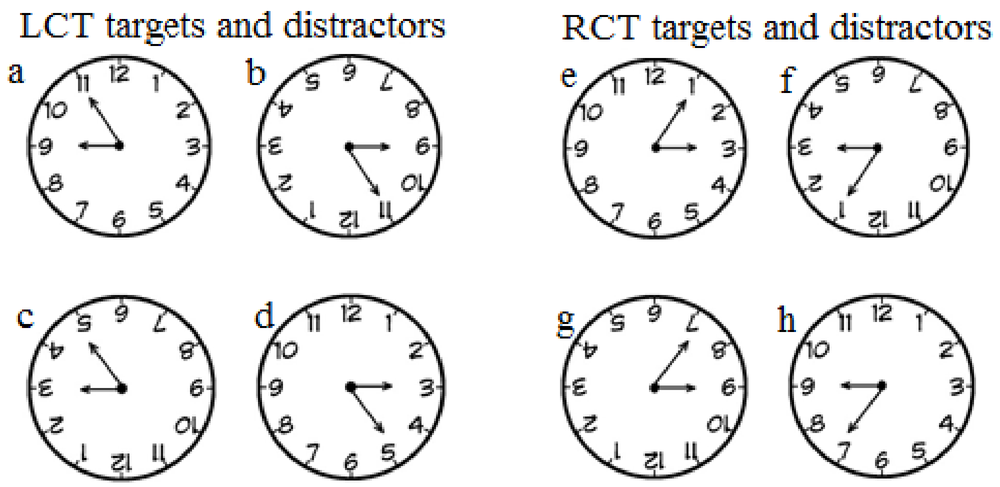

Figure 20. The highly similar distractors that were included (c, d, g, h) displayed the same position and angle of the hands to the targets in the Left Clock Task (LCT; a and b) and Right Clock Task (RCT; e and f) when they were presented in the opposite orientation. If fixation-based neglect was operating, with information that fell to the left of a central fixation position being neglected, then upright left sided targets (a) and inverted right sided targets (f) would be neglected. Left sided targets that were inverted (b) and upright right sided targets (e) would be able to be identified accurately, as information would have been projected to the RVF and therefore to the right of an egocentric midpoint. If Neglect Patients (NPs) presented with allocentric neglect, and this was not caused by fixation-based neglect, then the canonical left of the clock would always be neglected regardless of the clock's orientation. This would result in both targets in the LCT being identified less often than those in the RCT. Therefore, NPs would have lower Target Identification Accuracy (TIA) on the LCT than the RCT.

It was predicted that egocentric neglect would be exhibited in the clock cancellation tasks. This would result in lower TIA within the left regions of the LCT and RCT stimuli. The operation of egocentric neglect would also be associated with less sampling of contralesional information than ipsilesional regions compared to control participants. This would be evidenced in both the spatial (in number of gazes made on each region of the stimulus) and the temporal (the proportion of time spent fixating the regions on the stimulus) domains.

A subsidiary aim was to investigate which factors were affecting TIA performance. The clock tasks were less dense (including fewer items in each region) and contained larger target items compared to the SEAN cancellation task reported in Experiment 2. Furthermore, the clock tasks only required single-target search. Therefore, it was predicted that reduced density and single-target search would affect the cognitive difficulty of the task, as was found in Experiment 1 for the BIT tasks, and therefore TIA should be higher in the clock tasks than that reported for the SEAN task in Experiment 2. Furthermore, based on the results from Experiment 1, the properties of the clock cancellation tasks were expected to have an impact on the eye movement measures. It was predicted that there would be increased visual sampling of the left by NPs compared to that exhibited during completion of the SEAN task due to less cognitive load being imposed by the clock cancellation tasks and a reduction in task difficulty.

2. Method

2.1 Participants

In total there were 29 participants in this experiment: 11 patients with left hemispatial neglect who had right hemisphere damage (Neglect Patients; NPs), 6 patients who had experienced a right ischemic or haemorrhagic stroke but did not exhibit neglect (Stroke Controls; SCs) and 12 healthy Older Adult Controls (OACs). All NPs included in this experiment also participated in Experiment 2. However, there were two fewer NPs and two fewer SCs in this experiment (refer to Table 4 and Table 5 on pages 101-103 for information on which patients were included in both experiments) due to fatigue of the participants/time constraints resulting in the participants not being able to participate in both experiments. All OACs participated in both experiments.

There were 23 females and 6 males. All were right handed. NPs had an age range of 46-82 years (M = 70.36 years, SD = 11.04), SCs 67-83 years (M = 70.17 years, SD = 6.43) and OACs 52-82 years (M = 68.33 years, SD = 8.73). All NPs were in the acute phase (prior to 3-months post-stroke), with the number of days post-stroke at the time of participating in the experiment ranging from 2-59 (M = 29.82, SD = 17.01) for NPs and 2-62 for the SCs (M = 26.00, SD = 22.03), which did not differ significantly, $t(20) = .39$, p

= .700. This suggested that NPs poorer performance compared to SCs was unlikely to be due to the more acute nature of their condition.

Lesion location information was obtained from the available Computed Tomography (ST) head/brain scan reports (and additional Magnetic Resonance Imaging [MRI] scan report for Case 3) contained within the patients' medical notes at the admitting hospital. The majority of the NPs suffered an infarct within the right middle cerebral artery (RMCA) territory lesioning the right frontoparietal or temporal lobes and for some patients including the right internal capsule, basal ganglia and lentiform nucleus (see Table 5 in Chapter 3 [page 103] for lesion location information for each stroke patient). The SCs tended to have RMCA initiated infarcts resulting in damage to the right caudate nucleus, insula, external capsule, putamen, sylvian fissure, and lacunar.

As with Experiment 1, this study received School of Psychology, University of Southampton and NHS Southampton REC National Research Ethics Service ethical approval and was adopted by the UK Stroke Research Network (SRN) portfolio and the patients were recruited from the same sites as reported previously (see page 95).

2.2 Stimuli

Experiment 3 was designed to investigate whether allocentric and/or egocentric neglect were present in clock cancellation tasks. The participants were required to cross through all the clocks that displayed a specific time. The LCT stimulus contained 'left sided targets', which were target items that contained critical information for accurate target identification on the canonical left side of the clock (i.e. the side containing numbers 7-11). These target items displayed the time five-to-nine (see *Figure 21*). The RCT stimulus contained 'right sided targets', which contained critical information for accurate target identification on the canonical right side of the clock (i.e. the side including the numbers 1-5). These target items displayed the time five-past-three (see *Figure 22*).

The clock cancellation task stimuli were printed on A4 paper landscape in orientation and constituted approximately 21.6^{o} x 30.1^{o} of the visual angle. As in previous experiments reported, the stimuli were divided into four regions of interest for analysis of the behavioural and eye movement measures (Far Left [FL], Near Left [NL], Near Right [NR], Far Right [FR]; see *Figure 21* and *Figure 22* for regions of interest imposed on the stimuli). There were ten targets in each region, five upright targets and five inverted targets. There were also eight distractors in each region. For the LCT, there were four 'similar distractors': clocks displaying twenty-five-past-three (see *Figure 20*). Two were presented upright (distractor to inverted five-to-nine) and two were inverted (distractor to upright five-to-nine). There were also ‘less similar distractors’: clocks displaying twenty-to-ten (less similar distractor to five-to-nine), two presented upright and two inverted.

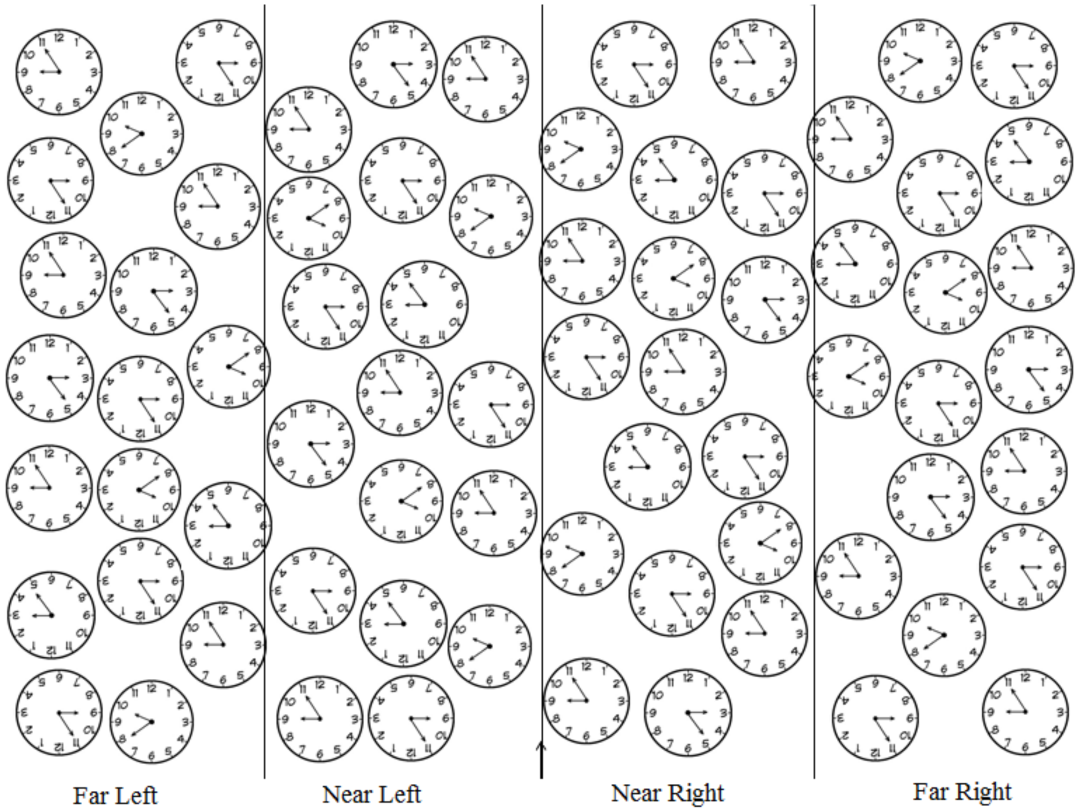

Figure 21. The Left Clock Task (LCT) stimulus. Participants were instructed to search for and cross through all the clocks displaying ‘five-to-nine’. Target items were presented both upright and inverted and distractor items had identical distances between the clock hands and similar positioning of the hands depicting the time in order to ensure participants could not use hand position to select and identify targets. The regions of interest employed for the analyses are denoted by the vertical lines presented in the figure (Far Left; Near Left; Near Right; Far Right). These lines were not present in the stimulus. The arrow at the bottom of the stimulus was aligned with the centre of the participants’ trunk to ensure that the regions on the left of the stimulus fell on the left of an egocentric reference frame.

The RCT contained the following distractors: two upright clocks displaying the time twenty-five-to-nine (distractor to inverted five-past-three) and two inverted twenty-five-to-nine clocks (distractor to upright five-past-three; see *Figure 20*). There were also four ‘less similar distractors’ of twenty-past-two (two upright, two inverted). The targets were placed in a pseudo-random order with the placement of the targets and distractors in the FL and NL regions being flipped horizontally and vertically for FR and NR regions, respectively. This was to ensure that the regions were equivalent for physical properties (e.g. relative position of distractors to targets).

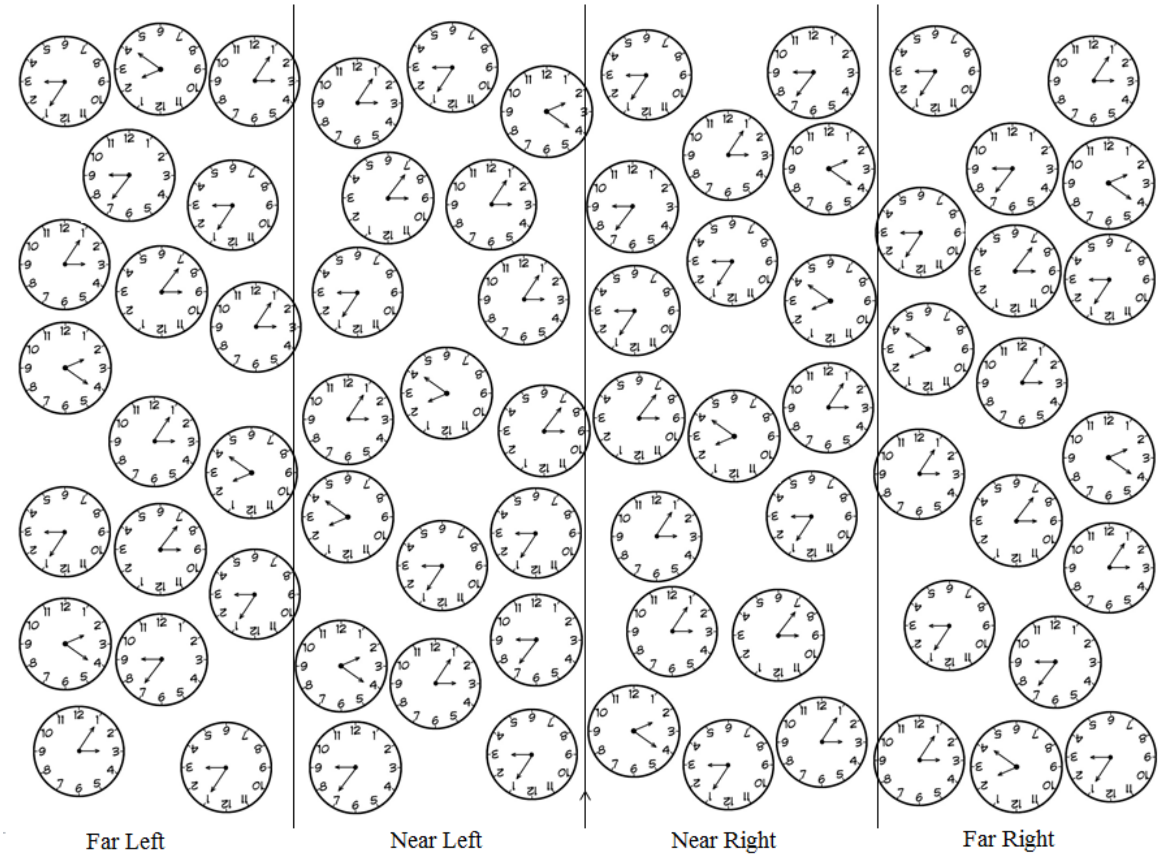

Figure 22. The Right Clock Task (RCT) stimulus. Participants were instructed to search for and cross through all the clocks displaying 'five-past-three'. The regions of interest employed for the analyses are denoted by the vertical lines presented in the figure (Far Left; Near Left; Near Right; Far Right). These lines were not present in the stimulus. Target items were presented both upright and inverted and distractor items had identical distances between the clock hands and similar positioning of the hands depicting the time in order to ensure participants could not use this information to select and identify targets.

2.3 Screening Tests

As for Experiment 2, reported in Chapter 3, before the experiment commenced a number of tests were conducted to estimate pre-stroke IQ (the NART test), memory ability (MMSE), visual acuity (Snellen), visual fields (Confrontation Visual Field Testing), and inattention (subset of the BIT). Additionally, demographic information was collected such as age, handedness, gender and lesion location for patients (see Table 4 and Table 5 in Chapter 3 on pages 101 and 103). The NPs did not significantly differ on scores obtained for the MMSE, NART and Snellen visual acuity test from SCs, $F(2, 30) = 1.22$, $p = .309$,

$t(20) = .43$, $p = .672$, $t(20) = .99$, $p = .333$. These screening results demonstrated that any poor performance on the clock cancellation tasks that was limited to NPs was unlikely to be a result of differences in IQ or visual acuity between NPs and OACs, otherwise SCs would have shown this effect too. Three of the eleven NPs presented with a degree of LVF loss (see Table 5). As described in Experiment 2, none of the patients demonstrated allocentric neglect in the Ogden scene.

2.4 Apparatus

The equipment used and the experimental set-up was the same as that of the experiment reported in Experiment 1, Chapter 2 (see section 2.3 *Apparatus* on page 57).

2.5 Design

There were three variables that were manipulated in this experiment. The first was target-type, which had two levels (left and right sided targets), which were presented in the LCT and RCT, respectively. Orientation of the targets was another variable with two levels (upright and inverted). These were within participant variables. The final variable was a between participants variable, group, with three levels (NPs, SCs, OACs).

2.6 Procedure

The procedure was the same as in Experiment 2, Chapter 3 (see 2.6 Procedure on page 105), except for the instructions presented to participants. The participants were instructed to search through the stimulus and place a single line through all target items, either clocks displaying the time five-to-nine (for the LCT) or five-past-three (for the RCT). All participants completed both tasks, counterbalanced for presentation order across participants. Participants were informed that target items could be upright and up-side-down. They were requested to check that the item they believed to be a target displayed the correct time due to similar clocks being presented in the task which had identical hand positions to the target clock when inverted. Participants were asked to indicate when they had finished the task by placing the pen on the table and looking at it. No time limit was imposed.

2.7 Data Analysis and Eye Movement Measures

The data analysis and eye movement measures used in this experiment were the same as described for Experiment 2 (see page 106). There were 58 trials in total lasting approximately 5 minutes each. A sub-set of the trials were also hand scored by an independent assessor to ensure there was inter-rater reliability for the eye movement data[3].

3. Results and Discussion

Both behavioural (TIA) and eye movement results are presented in this section. Omnibus 2 (target-type: left and right sided targets) x 2 (orientation: upright, inverted) x 3 (group: NPs, SCs, OACs) mixed model ANOVAs were conducted to determine initial effects and, where appropriate, post-hoc comparison tests and *t*-tests were conducted to investigate main effects and interactions. As in Experiment 2, Chapter 3, if SCs and OACs did not significantly differ on a measure, they were combined to form one control group to compare to the NPs. Lastly, when the Mauchly's test of severity was violated when conducting an ANOVA, Greenhouse-Geisser F values and degrees of freedom were reported. Due to similar information being presented in the figures included in this section, the tables of *M*s and *SD*s for post hoc comparison tests are presented in Appendix E.

3.1 Was Allocentric or Fixation-based Neglect Operating? The Effect of Identifying Left compared to Right Sided Targets on TIA.

In order to investigate whether NPs' TIA differed across the two target-types (left sided targets and right sided targets) and according to the orientation of those targets (upright or inverted) an ANOVA was conducted on TIA. If NPs presented with allocentric neglect, it would be expected that NPs would have poorer accuracy for left sided targets, regardless of orientation, as presentation of critical information for target identification being presented on the canonical left side of the *object* should cause disruption to identification. Therefore, there would be a significant target-type effect, with NPs obtaining poorer accuracy for left sided targets than for right sided targets and this should be absent in control participants. The ANOVA revealed a marginal effect of target-type, $F(1, 117) = 3.38$, $p = .069$, $\eta_p^2 = .03$, indicating that overall accuracy for the left sided targets was greater than for right sided targets, $t(239) = 1.98$, $p = .049$. There was no target-type by group interaction, suggesting that NPs did not differ from controls in the pattern of TIA across target-type, $F(2, 117) = .13$, $p = .875$. This suggests that NPs did not have poorer left sided TIA compared to right sided TIA than the controls. Given that left sided TIA was higher overall, it appears that pure allocentric neglect (neglect of the canonical left side of an object) was not present.

In order to check whether any individual NP presented with allocentric neglect, Crawford and Howell's (1998) single case study test was employed (as in Experiment 1, Chapter 2 for Patient SS). This was conducted by comparing each NP's difference score (TIA for left sided targets minus TIA for right sided targets) to the *M* and *SD* of control participants' difference scores, for participants that demonstrated poorer performance for left sided targets. This was in order to determine whether NPs' poorer TIA for left sided targets was outside of the normal range, and therefore could be demonstrating allocentric neglect. The NPs who had poorer TIA for left sided targets than right sided targets did not have a significantly larger difference scores than control participants who had lower left sided TIA, *t*s(4) < 1.04, *p* > .05. This demonstrates that none of the NPs exhibited significantly poorer performance for the left sided targets compared to controls, suggesting that none of the patients exhibited allocentric neglect on this task (see Table 6 for the mean TIA for left and right sided targets for each participant). This supports the findings from Experiment 2.

The orientation main effect was significant, $F(1, 117) = 32.05$, $p < .001$, $\eta_p^2 = .22$, demonstrating that, overall, there was poorer TIA for inverted targets compared to those that were upright. This is not a surprising result. It has been shown previously that typically developed controls' reaction time to decide whether a pair of items matched or not was linearly proportional to the angle of rotation of one the objects from the original position (Cooper, 1975). That is, if an object has been rotated from its usual presentation orientation, it is likely to take longer for an individual to determine if it is the same as when it is presented in its usual orientation. This slowed processing of that information may also may affect accuracy in making a decision regarding whether that item is a target or not during a gaze.

Table 6

Left and Right Sided Target Identification Accuracy (TIA; %) for and the Difference in Accuracy between Target-Types (Left Sided Target TIA minus Right Sided Target TIA).

Participant Number	Group	Left Sided TIA	Right Sided TIA	**Difference**
Case 1	NP	70.00	77.50	**-7.50**
Case 2	NP	72.50	47.50	**25.00**
Case 3	NP	55.00	65.00	**-10.00**
Case 4	NP	37.50	35.00	**2.50**
Case 5	NP	70.00	62.50	**7.50**
Case 6	NP	45.00	42.50	**2.50**
Case 7	NP	57.50	67.50	**-10.00**
Case 8	NP	57.50	60.00	**-2.50**
Case 9	NP	50.00	47.50	**2.50**
Case 10	NP	97.50	77.50	**20.00**
Case 11	NP	52.50	57.50	**-5.00**
SC1	SC	90.00	92.50	**-2.50**
SC2	SC	97.50	97.50	**0.00**
SC3	SC	100.00	85.00	**15.00**
SC4	SC	87.50	77.50	**10.00**
SC5	SC	100.00	97.50	**2.50**
SC6	SC	97.50	100.00	**-2.50**
OAC1	OAC	100.00	100.00	**0.00**
OAC2	OAC	100.00	97.50	**2.50**
OAC3	OAC	97.50	90.00	**7.50**
OAC4	OAC	100.00	100.00	**0.00**
OAC5	OAC	90.00	97.50	**-7.50**
OAC6	OAC	100.00	100.00	**0.00**
OAC7	OAC	100.00	87.50	**12.50**
OAC8	OAC	97.50	97.50	**0.00**
OAC9	OAC	100.00	100.00	**0.00**
OAC10	OAC	90.00	100.00	**-10.00**
OAC11	OAC	97.50	85.00	**12.50**
OAC12	OAC	100.00	95.00	**5.00**

Highlighted in grey are the NPs and control participants that demonstrated poorer performance for left-sided targets.

There was also a main effect of group, $F(2, 117) = 56.76$, $p < .001$, $\eta_p^2 = .49$, demonstrating that the NPs had poorer TIA overall than the control participants, as was also found in Experiments 1 and 2. If fixation-based neglect was operating, information falling to the left of a central fixation position would be neglected by NPs. Therefore, it would be expected that NPs would demonstrate poorer TIA for upright left sided targets and inverted right sided targets (where the critical information for accurate target identification was to the left of a central fixation position) than for inverted left sided targets and upright right sided targets (where the critical information was to the right of a central fixation position). Therefore, fixation-based neglect would lead to a significant target-type by orientation by group interaction. The main effect of group also significantly interacted with orientation of the target, $F(2, 117) = 12.93$, $p < .001$, $\eta_p^2 = .18$ and a target-type by orientation interaction, $F(1, 117) = 19.31$, $p < .001$, $\eta_p^2 = .14$. A three way target-type by orientation by group interaction was found, $F(2, 117) = 8.03$, $p < .001$, $\eta_p^2 = .12$. Based on these significant interactions, the following tests were conducted to investigate the accuracy for targets when time-telling information was on the canonical left side of the clock (allocentric neglect) or when the information fell to the left of a central fixation position (fixation-based neglect; see Table 7).

Table 7

Average Target Identification Accuracy (%; SD in parentheses) for Targets when the Critical Information for Accurate Identification Fell to the Left or to the Right of a Central Fixation Position for the Neglect Patients, Stroke Controls and Older Adult Controls.

Group	Information Falling within the LVF	Information Falling within the RVF
NPs	54.53 (33.70)	66.60 (35.56)
SCs	92.50 (14.07)	94.17 (10.88)
OACs	95.63 (10.14)	98.13 (5.86)

As can be seen from *Figure 23* the NPs had far poorer performance for inverted right sided targets than the inverted left sided targets (contributing to the significant target-type by orientation interaction). The inverted right sided targets contained information critical for accurate identification of the target to the left of a central fixation position, but the inverted left-sided targets did not. This suggests that poorer performance was due to fixation-based neglect. In fact, as predicted, the NPs had significantly poorer accuracy for targets when the information was on the left of a central fixation position than when the information was on the right, *t*(94) = 2.72, *p* = .008, with a difference of 12.07%. All but two NPs (Case 1 and Case 4) demonstrated poorer TIA for targets when the critical information for accurate identification was to the left of a central fixation position compared to when that information was to the right (see Appendix F for individual NP data). The SCs did not differ in TIA when the information was on the right or left of a central fixation position, *t*(47) = .59, *p* = .561 (see *Figure 24*). However, OACs obtained higher TIA for targets when the information was to the right of a central fixation position, which approached significance, *t*(95) = 1.98, *p* = .051 (see *Figure 25*). However, there was a very small difference (2.50%) between accuracy for targets when the information was falling to the left or right of a central fixation position.

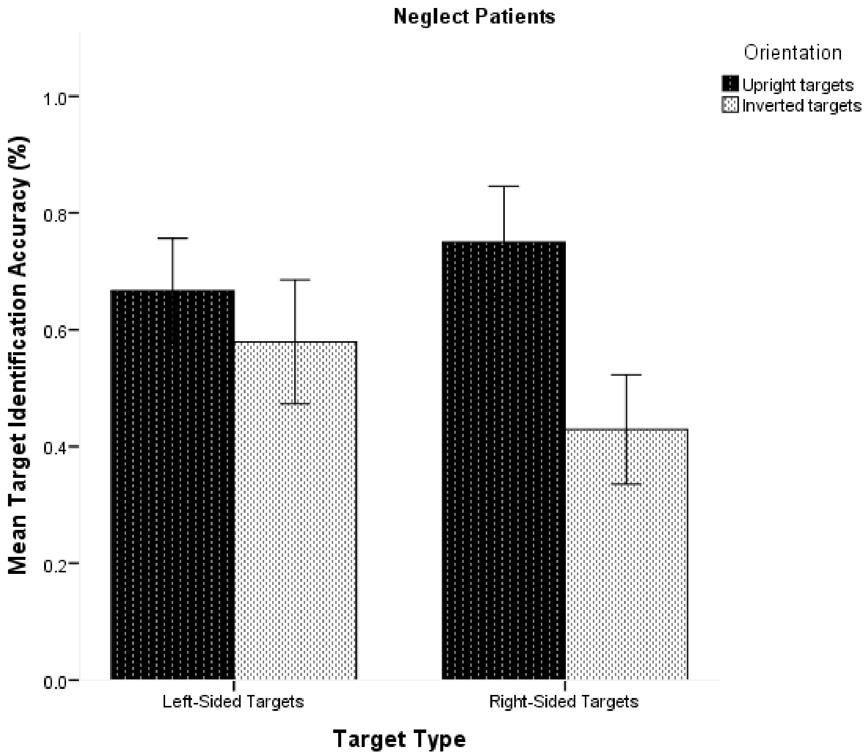

Figure 23. Target Identification Accuracy (TIA; %) for Left and Right Sided Targets presented Upright and Inverted in the Clock Cancellation Tasks for the Neglect Patients (NPs). Error bars represent 95% confidence intervals around the mean.

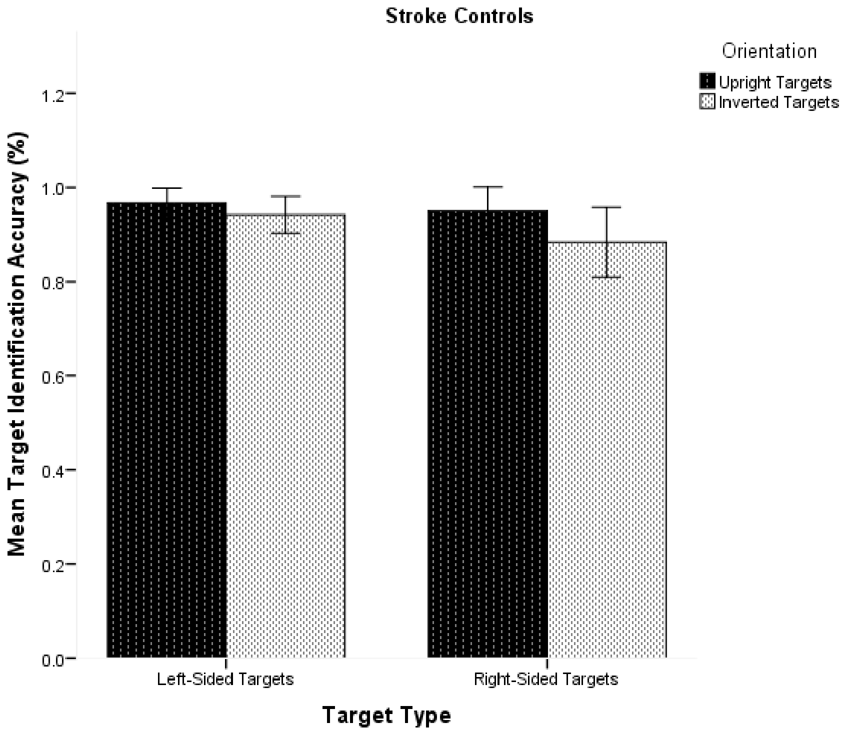

Figure 24. Target Identification Accuracy (TIA; %) for Left and Right Sided Targets presented Upright and Inverted in the Clock Cancellation Tasks for the Stroke Controls (SCs). Error bars represent 95% confidence intervals around the mean.

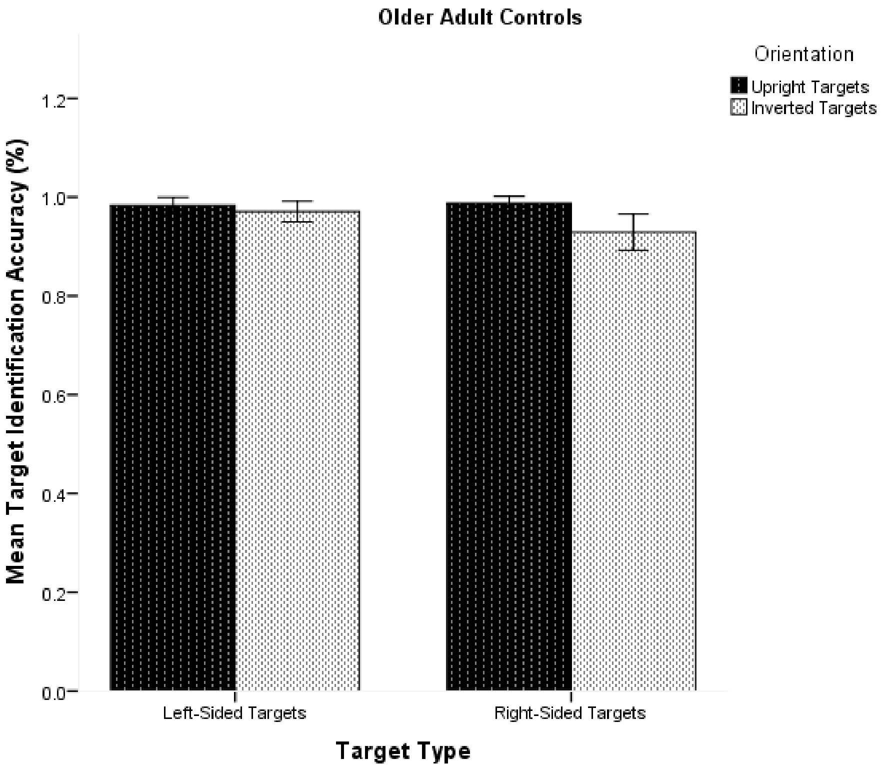

Figure 25. Target Identification Accuracy (TIA; %) for Left and Right Sided Targets presented Upright and Inverted in the Clock Cancellation Tasks for the Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

3.2 Did Neglect Patients Demonstrate Egocentric Neglect?

In order to investigate whether there were differences in accuracy across the stimulus, TIA within different regions of the LCT and RCT will be considered. If egocentric neglect was present in the NPs, information falling to the left of their trunk midline, and therefore within the left regions of the stimulus (as, recall, the centre of the stimulus was aligned with their trunk midline), one would expect that TIA would be poorer within the FL and NL regions of the stimulus for NPs compared to the NR and FR regions. The ANOVA revealed a main effect of region on TIA for the LCT, $F(2.32, 132) = 5.08$, $p = .005$, $\eta_p^2 = .08$, and RCT, $F(3, 171) = 6.31$, $p < .001$, $\eta_p^2 = .10$, with higher accuracy within the NR and FR region than the FL and NL regions. There was also a main effect of group on TIA for both the LCT, $F(2, 57) = 46.96$, $p < .001$, $\eta_p^2 = .62$, and RCT, $F(2, 57) = 35.43$, $p < .001$. As predicted, NPs had reduced overall performance on the task than SCs and OACs. This was likely a result of NPs' poorer performance within contralesional regions.

A region by group interaction for the LCT, $F(6, 171) = 6.88$, $p < .001$, $\eta_p^2 = .19$ (see *Figure 26*), and RCT, $F(6, 171) = 14.75$, $p < .001$, $\eta_p^2 = .34$ (see *Figure 27*), demonstrated that NPs had differential TIA across regions on the stimulus, whereas control participants did not. This is the same pattern of TIA that was found for NPs and controls in Experiments 1 and 2. For the FL, NL, NR and FR regions of the LCT, and as can be seen from *Figure 25*, TIA was equivalent across regions for control participants but decreased towards more contralesional regions for NPs. There was a significant difference in TIA between groups for each of the regions; FL, $F(2, 57) = 32.66$, $p < .001$, $\eta_p^2 = .53$; NL, $F(2, 57) = 27.57$, $p < .001$, $\eta_p^2 = .49$; NR, $F(2, 57) = 22.47$, $p < .001$, $\eta_p^2 = .44$; FR, $F(2, 57) = 4.34$, $p = .018$, $\eta_p^2 = .13$ (see Table 14 in Appendix E). This finding was driven by NPs having poorer performance overall in each region than the SCs and OACs (the FL region, $t(58) = 6.70$, $p < .001$, the NL region, $t(58) = 6.18$, $p < .001$, the NR region, $t(58) = 5.68$, $p < .001$, and the FR region, $t(58) = 2.49$, $p = .019$).

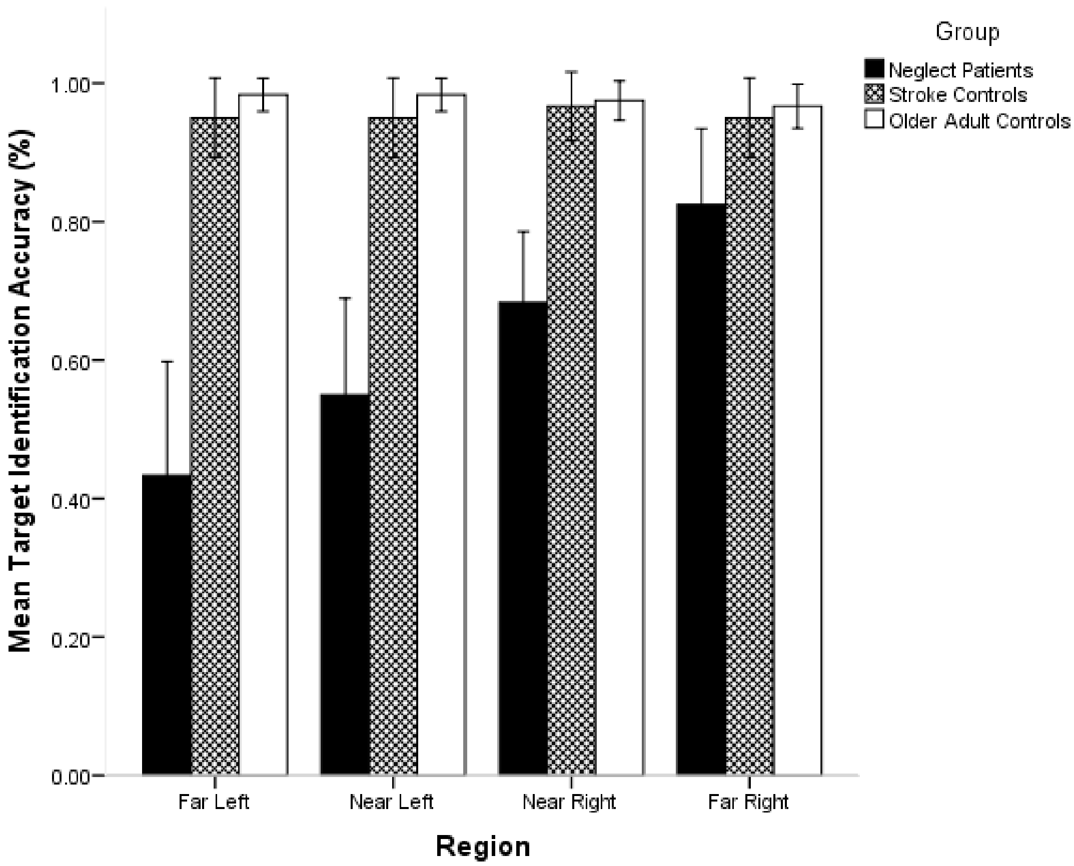

Figure 26. Target Identification Accuracy (TIA; %) on Different Regions of the Left Clock Task (Far Left; Near Left; Near Right; Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

This was also the case for the RCT, FL, $F(2, 57) = 3.40$, $p < .001$; NL, $F(2, 57) = 19.16$, $p < .001$; NR, $F(2, 57) = 42.40$, $p < .001$, although this trend was marginal for the FR region, $F(2, 57) = 2.93$, $p = .061$ (see Table 15 in Appendix E). NPs had significantly poorer TIA in the FL, NL and NR region than controls, $t(58) = 10.45$, $p < .001$, $t(58) = 5.30$, $p < .001$, $t(58) = 3.88$, $p = .001$, respectively. There was a trend in this direction for the FR region, but this was not significant, $t(58) = 1.76$, $p = .087$, suggesting that poorer TIA in NPs was limited to the left most regions. It is important to note that TIA in the FL region in the LCT was much higher (more than double) than that obtained by NPs in the FL region of the SEAN cancellation task (which was 22.32%). Reasons for this difference will be outlined in the General Discussion.

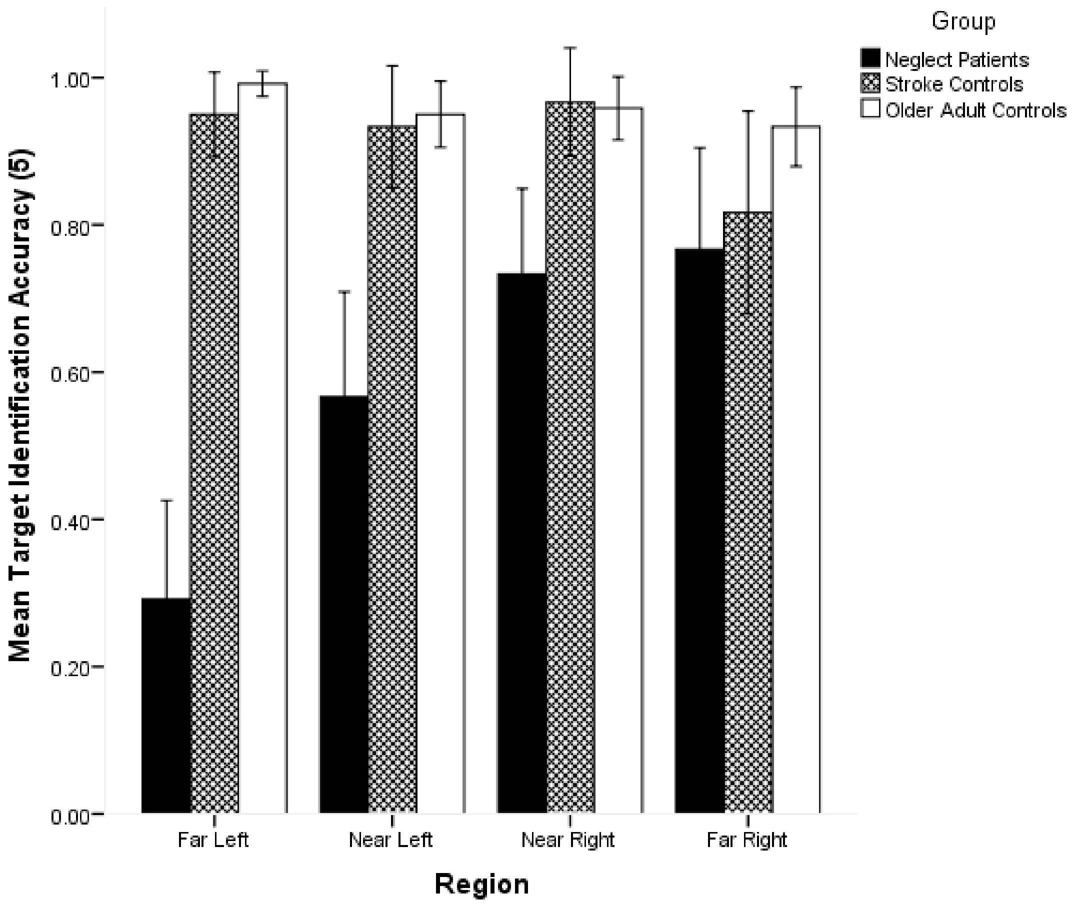

Figure 27. Target Identification Accuracy (TIA; %) for Different Regions on the Right Clock Task (Far Left; Near Left; Near Right; Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

3.3 Number of Gazes made on each Region

As different tasks employed in Experiment 1 reported in this thesis demonstrated that sampling and processing of visual information during cancellation tasks can be affected by complexity of the task, patterns of eye movements may be different during completion of the clock cancellation tasks compared to those exhibited during the SEAN task reported in Experiment 2. These will be considered next. As was predicted in Experiment 2, poor contralesional TIA demonstrated by NPs would be associated with reduced visual sampling of the left regions of space. An ANOVA was conducted on the number of gazes made on each region to investigate spatial sampling of information across the stimulus. This revealed a significant main effect of region on the number of gazes made for the LCT, $F(2, 53) = 39.99$, $p < .001$, $\eta_p^2 = .56$, and RCT, $F\ (1.9, 52.13) = 40.97$, $p < .001$, $\eta_p^2 = .60$. As demonstrated in Experiments 1 and 2, more gazes were made overall to the internal (NL and NR) regions than external (FL and FR) regions. There was no significant group effect on overall number of gazes made for the LCT, $F(2, 27) = .45$, $p = .648$, or RCT, $F(2, 27) = 1.51$, $p = .238$, demonstrating the NPs and control participants made similar number of gazes on the task as a whole.

As predicted there was a region by group interaction for the LCT, $F(3.93, 53) = 3.44$, $p = .005$, $\eta_p^2 = .20$, and RCT, $F(3.9, 52.13) = 9.38$, $p < .001$, $\eta_p^2 = .42$. This can be seen in *Figure 28* and *Figure 29*, which show that NPs tended to make fewer gazes on the left regions and more gazes on the right regions than the control participants. There was a marginal difference between NPs and controls for number of gazes made on the FL region for the LCT, with there being a trend towards less gazes made by the NPs on this region, $t(28) = 1.91$, $p = .066$ (see Table 16). For the RCT, NPs made significantly fewer gazes than the controls on the FL region, $t(28) < 2.61$, $p = .014$ (see

Table 17). This suggests that there was a sampling deficit contributing to poorer TIA obtained within this region.

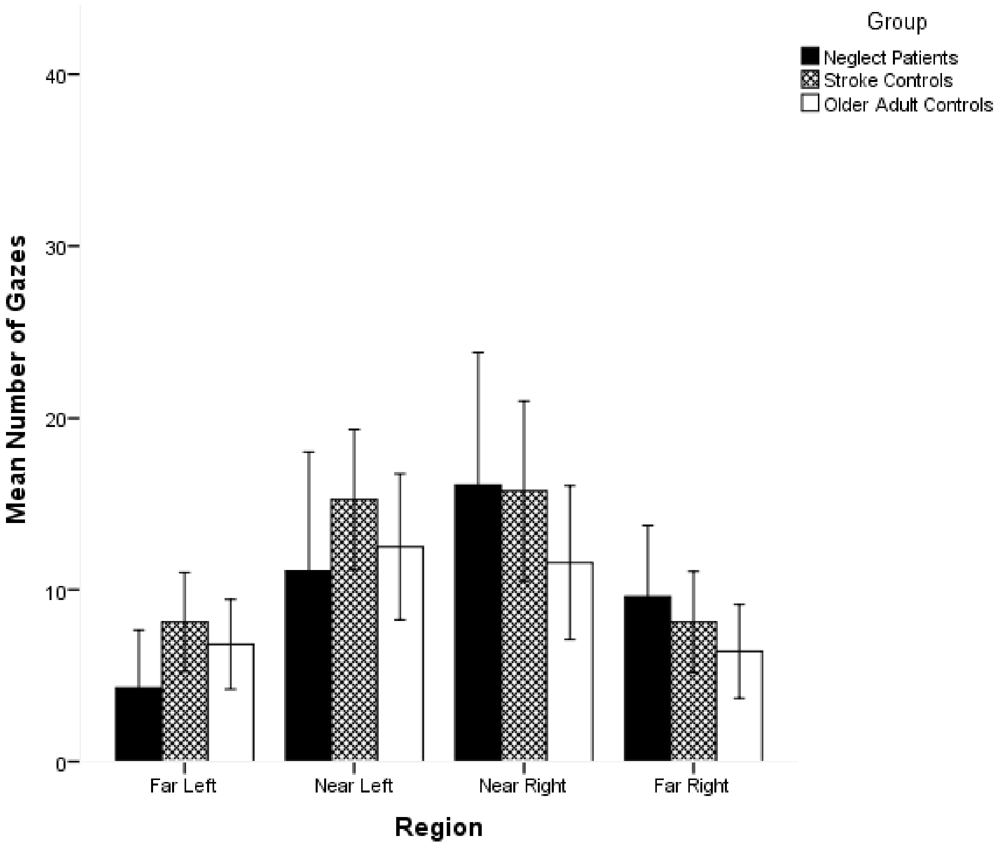

Figure 28. Number of gazes made on the different regions of the Left Clock Task (LCT; Far Left, Near Left, Near Right, Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals.

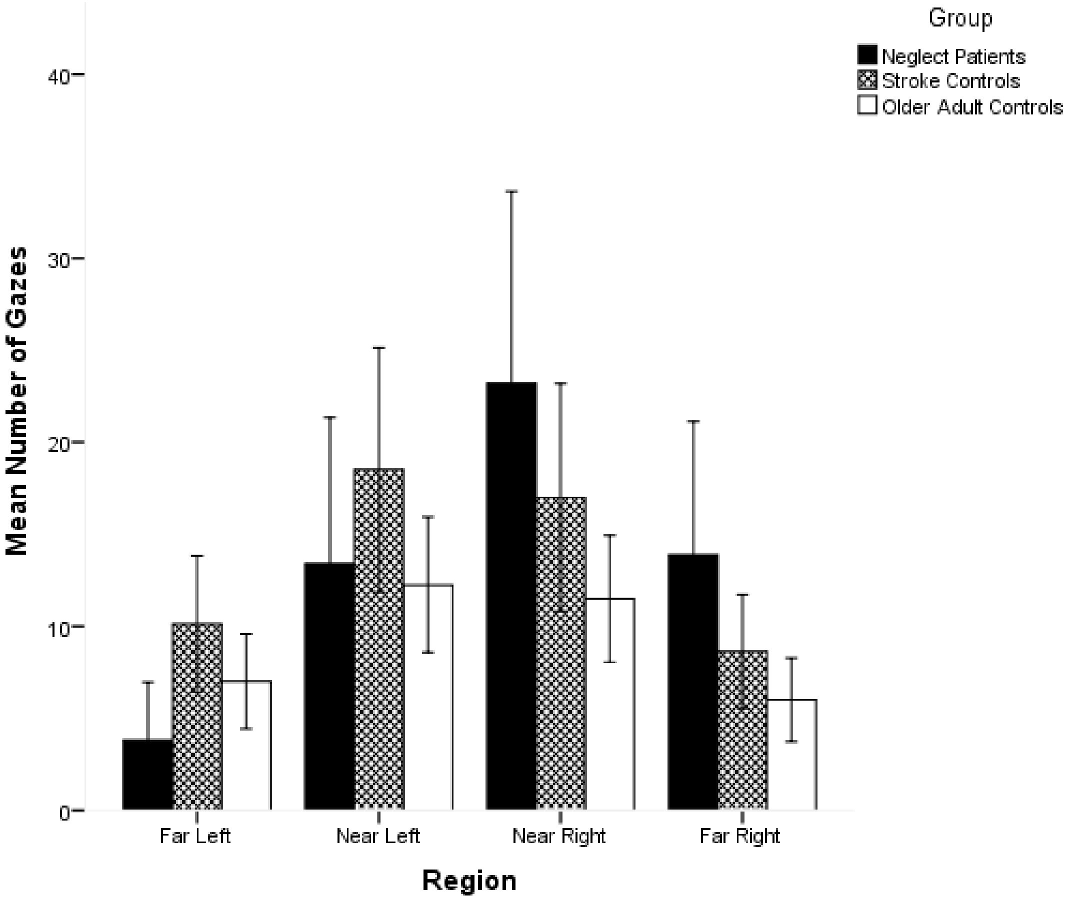

Figure 29. Number of gazes made on different regions of the Right Clock Task (RCT; Far Left, Near Left, Near Right, Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals.

Interestingly, there was no significant difference between NPs and controls for the number of gazes made on the NL region for the LCT, $t(28) = .870$, $p = .391$, and RCT, $t(28) = .40$, $p = .691$, a finding which was also observed in Experiments 1 and 2. This demonstrates that a sampling deficit was not contributing to the poor TIA within this region, as the NPs fixated this region as much as the controls did. Thus, poorer TIA in this region for NPs compared to controls (42% less targets identified by NPs in the LCT and 38% less in the RCT) was interpreted as to be associated with a processing deficit, whereby NPs were fixating the targets but failing to process them sufficiently during a gaze in order to identify them. It is important to consider how much time was spent overall fixating those regions, to investigate whether it was insufficient time that resulted in a failure to process the information (see the next section entitled *3.4 Proportion of Total Trial Time spent Fixating each Region*).

There was no significant difference in number of gazes made on the NR and FR regions for NPs and controls in the LCT, $t(28) = 1.11$, $p = .278$, $t(28) = .630$, $p = .537$, respectively. Interestingly, in the RCT, the NPs made marginally more gazes on the NR and FR regions than the controls, $t(28) = 1.96$, $p = .076$; $t(28) = 2.07$, $p = .065$. This provides evidence that hyper-attention to ipsilesional regions may have been occurring; contributing to poorer contralesional TIA in the RCT compared to the LCT for the NPs. This is an unexpected finding, as one could suggest that increased hyper-attention to the right may be associated with increased difficulty in conducting the task. Attentional resources being more limited due to cognitive load may result in attention to the left being restricted further. This was found in the letter cancellation task in Experiment 1. However, as it was expected that the LCT would be more difficult to conduct if patients presented with allocentric neglect, it is contrary to predictions that the RCT would be harder to conduct by NPs. This could provide evidence that the LCT was not as difficult to conduct as the RCT, suggesting NPs did not have more difficulty identifying left sided targets, which would be expected if they presented with allocentric neglect. Why the RCT may have resulted in fewer targets being identified by NPs will be considered in the General Discussion section of this chapter.

Interestingly, NPs did not significantly differ in the number of gazes they made to the NL and FR regions of the LCT, $t(9) = .18$, $p = .861$, or RCT, $t(9) = .18$, $p = .861$, but they were significantly poorer at identifying target items in the NL region compared to the FR region, $t(9) = 3.82$, $p = .001$ (refer back to Table 14 and Table 15). This is highly indicative of a contralesional processing deficit contributing to neglect, as NPs were making as many gazes to the NL region as the FR region but were identifying 27.5% and 30% less targets within that region in the LCT and RCT, respectively, than in the FR region of those tasks. However, once again, the fixation durations made on those regions also needs to be considered.

3.4 Proportion of Total Trial Time spent Fixating each Region

In order to determine whether a temporal sampling and processing deficit contributed to poor contralesional TIA for NPs, an ANOVA was conducted on the proportion of time spent fixating regions of interest on the LCT and RCT. This revealed a main effect of region on proportion of fixation time in the LCT, $F(3, 81) = 6.07$, $p = .001$, $\eta_p^2 = .18$, and RCT, $F(1.78, 48.10) = 5.67$, $p = .008$, $\eta_p^2 = .17$, with slightly more time spent fixating the right regions (FR and NR) than left regions (FL and NL). There was also a significant effect of group for the LCT, $F(2, 27) = 4.17$, $p = .026$, $\eta_p^2 = .24$. The group effect was driven by NPs having a marginally smaller proportion of time spent fixating the stimulus compared to SCs and OACs, $t(16) = 2.00$, $p = .077$; $t(20) = 2.28$, $p = .068$. However, this difference was very small, being on average .004%, meaning that the NPs spent this amount of time fixating outside of the stimulus, whereas the control participants did not. On the contrary, there was no effect of group on the total proportion of time spent fixating the regions of the stimulus for the RCT, $F(2, 27) = 1.00$, $p = .381$. However, there was a region by group interaction for both the LCT, $F(6, 81) = 7.32$, $p < .001$, $\eta_p^2 = .135$, and RCT, $F(3.56, 48.10) = 9.94$, $p < .001$, $\eta_p^2 = .42$ (see Appendix E for Tables of *M*s and *SD*s).

The region by group interaction, displayed in *Figure 30* and *Figure 31,* shows that whereas control participants spent an equivalent amount of time fixating each region, NPs spent more time fixating the FR and NR regions than the NL and FL regions. NPs spent significantly less time fixating the FL region than the control participants for the LCT, $t(28) = 3.70$, $p = .004$, and RCT, $t(28) = 5.32$, $p < .001$. This supports the findings from Experiments 1 and 2 that less time is spent sampling the left regions of space in neglect. Reduced fixation time by NPs on the FL region was likely to result in poor TIA, due to very little time spent searching and processing targets in that region leading to limited identification of target items. This temporal sampling deficit, however, was not a factor contributing to poor TIA in the NL region, as NPs did not significantly differ from controls in the amount of time spent fixating the NL region for the LCT, $t(28) = 1.60$, $p = .121$, or RCT, $t(28) = 1.08$, $p = .305$, but still identified fewer target items than the controls in that region. Therefore, even though a spatial sampling deficit (as indicated by the number of gazes measure) and a temporal sampling deficit (as indicated by the proportion of trial time measure) can account for low TIA in the FL region; it cannot explain the poor TIA for NPs in the NL region. The finding indicates that the time controls spent fixating the NL region to identify targets was not a sufficient amount of time for NPs to identify all target items. As the proportion of time was equivalent for the controls and the NPs in the NL region, but accuracy was reduced in the NP group for that region, this suggests that a processing deficit, rather than a sampling deficit, was the primary cause of poor TIA in this region.

There was no significant difference between the proportion of time NPs and controls spent fixating the NR region for the LCT, $t(28) = 1.06$, $p = .186$. Recall that NPs' TIA was closer to the controls' TIA in this region compared to in the NL region. However, NPs spent significantly more time than SCs and OACs fixating the FR region in the LCT, $t(16) = 2.75$, $p = .014$; $t(20) = 4.04$, $p = .003$, respectively. For the RCT, NPs spent significantly more time fixating both the NR and FR regions than the controls, $t(28) = 2.65$, $p = .025$; $t(28) = 2.87$, $p = .018$, respectively. This, again, provides evidence for hyper-attention to ipsilesional regions contributing to neglect of information on the left in the RCT. It appears that NPs did not require more time on the right than controls to accurately identify the target items as they spent as much time as the controls in the NR region of the LCT and had high TIA there. Thus, it is likely that the FR region was fixated for more time due to hyper-attention to that area of space, and not due to necessity in order to accurately complete the task, and this hyper-attention to the right also appears to be contributing to the neglect of information on the left side of the stimulus in the RCT.

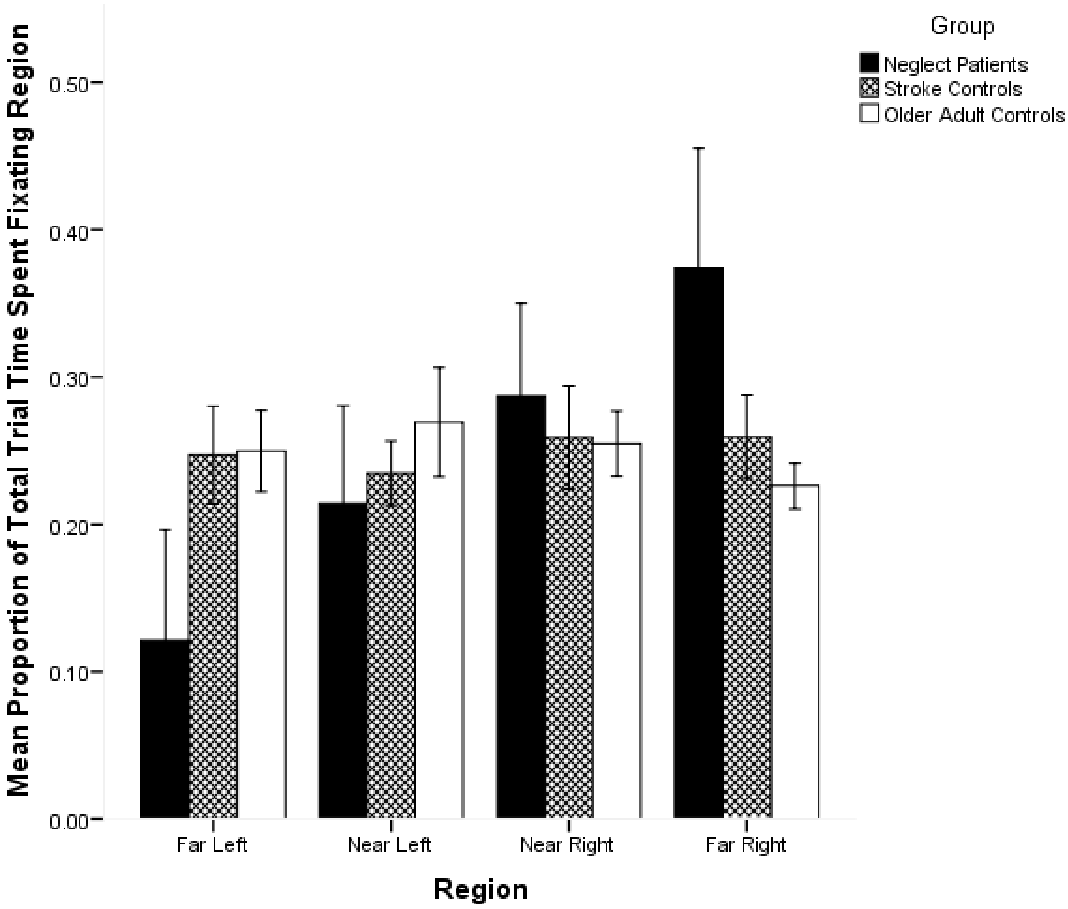

Figure 30. Proportion of the total trial time spent fixating the regions of the Left Clock Task (LCT; Far Left, Near Left, Near Right, Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

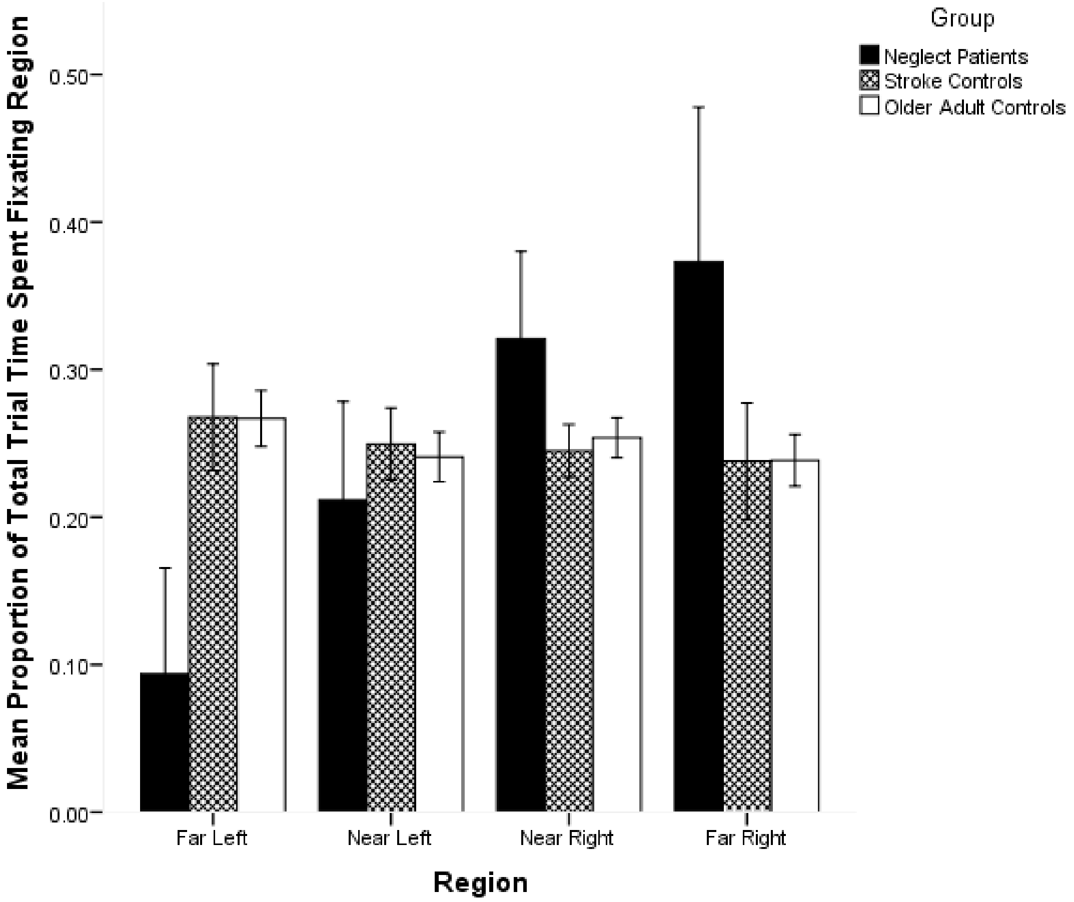

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Figure 31. Proportion of total trial time spent fixating the four regions of interest on the Right Clock Task (RCT; Far Left, Near Left, Near Right, Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

3.5 Average Gaze Duration on Regions of the Left and Right Clock Tasks

In order to investigate whether NPs spent longer searching for targets within a region before saccading to another region, an ANOVA was conducted on Average Gaze Durations (AGD; ms) made on the LCT and RCT. This revealed a main effect of region on AGD for the LCT, $F(3, 1225) = 19.39$, $p < .001$, $\eta_p^2 = .05$, and RCT, $F(3, 1406) = 18.92$, $p < .001$, $\eta_p^2 = .04$. *Figure 32* and *Figure 33* illustrate that overall AGDs were longer on the external (FL and FR) regions than the internal (NL and NR) regions for the LCT, $t(1235) = 7.65$, $p < .001$, and RCT, $t(1416) = 6.81$, $p < .001$. The explanation in Chapter 3 that this is likely to be a result of more gazes being made to the internal regions holds here too.

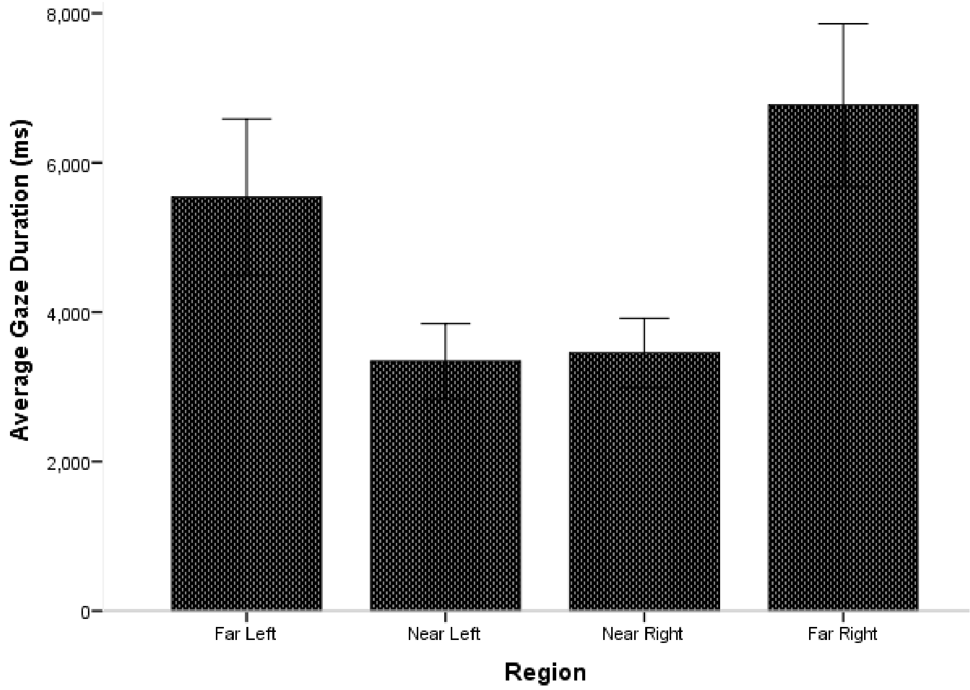

Figure 32. Average Gaze Durations (AGD; ms) made on the Left Clock Task (LCT) for each region on the stimulus (Far Left; Near Left; Near Right; Far Right). Error bars represent 95% confidence intervals around the mean.

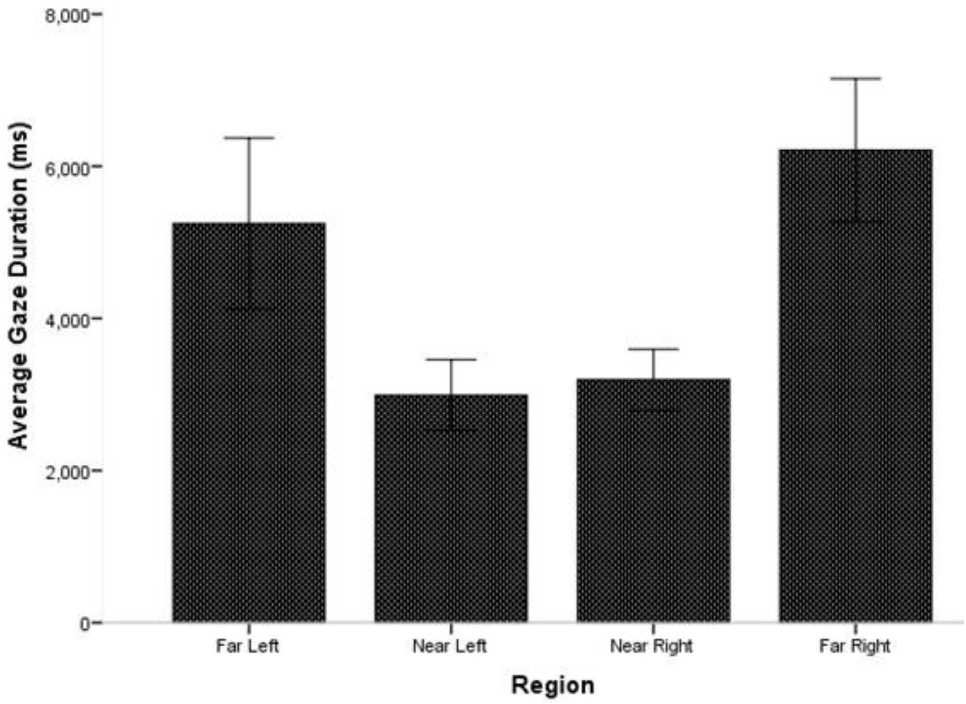

Figure 33. Average Gaze Durations (AGD; ms) made on the different regions of the Right Clock Task (RCT; Far Left, Near Left, Near Right, Far Right). Error bars represent 95% confidence intervals around the mean.

There was also a main effect of group on AGD made on the LCT, F (2, 1225) = 11.05, $p < .001$, and RCT, $F(2, 1406) = 9.17$, $p < .001$. As can be seen in *Figure 34* and *Figure 35*, the group effect resulted from NPs having longer AGD overall. For the LCT, NPs had longer AGD than SCs, $t(787) = 2.01$, $p = .044$, and OACs, $t(857) = 4.59$, $p < .001$. On this task, SCs also had significantly longer AGD compared to OACs, $t(824) = 2.51$, $p = .012$, which may be due to a number of post-stroke factors such as fatigue. For the RCT, NPs had longer AGDs overall than the control participants, $t(1416) = 3.93$, $p < .001$ (see *Figure 35*). However, there was no difference between SCs and OACs for this task, $t(873) = 1.60$, $p = .110$.

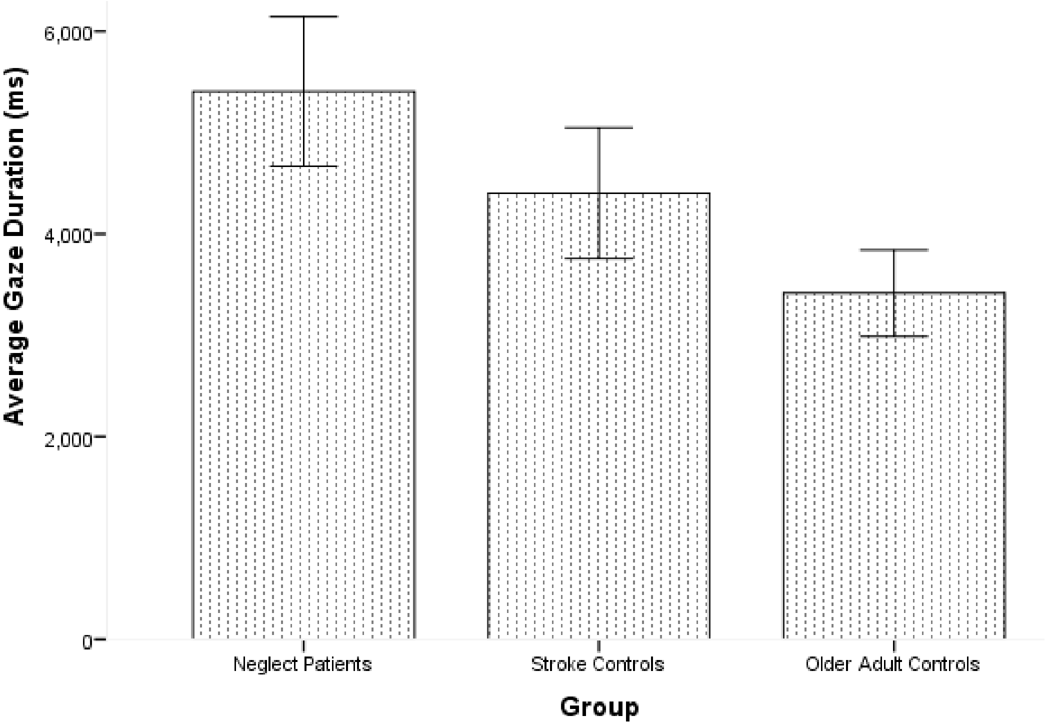

Figure 34. Average Gaze Durations (AGD; ms) made on the Left Clock Task for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

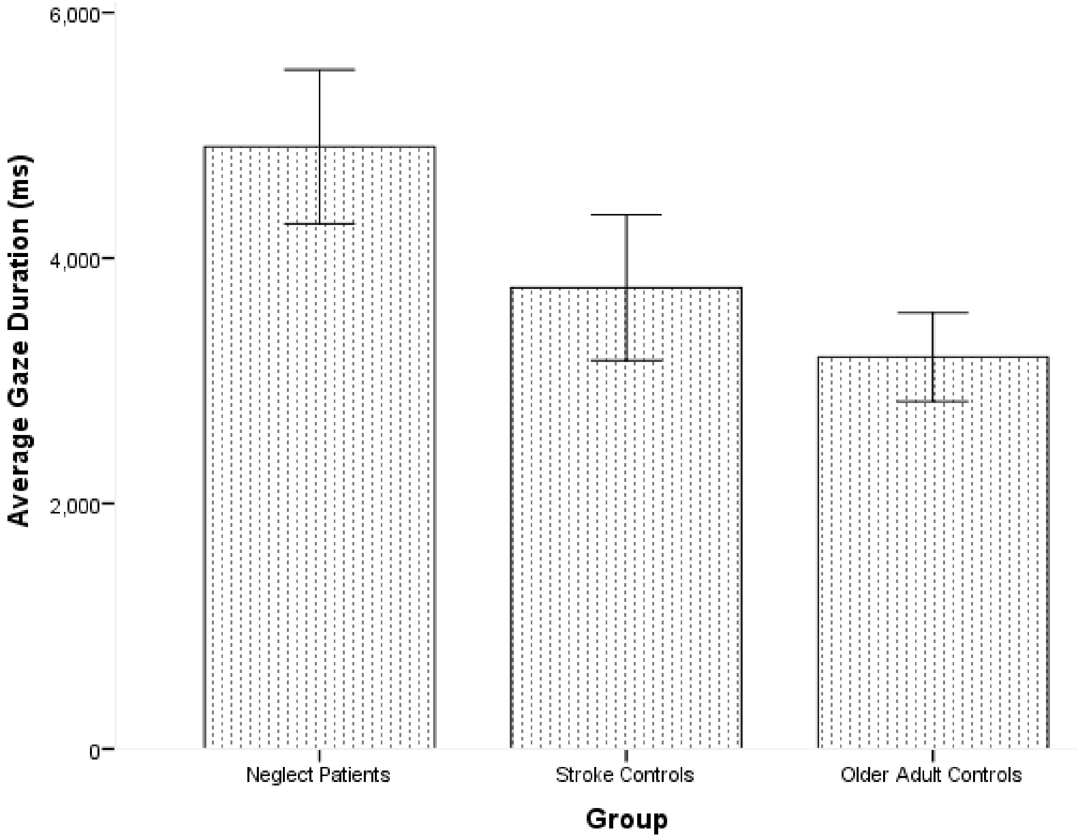

Figure 35. Average Gaze Duration (AGD; ms) made on the Right Clock Task for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs). Error bars represent 95% confidence intervals around the mean.

Surprisingly, there was no group by region interaction for AGD on the LCT, $F(6, 1225) = 1.54$, $p = .161$, or RCT, $F(6, 1406) = .38$, $p = .892$. As there was no interaction between these factors, this suggests that NPs did not spend less time fixating the FL region compared to the FR region during each gaze, as demonstrated in the SEAN task. As NPs had longer AGDs overall, this indicates that they often spent longer fixating the FL region during a gaze than controls but, importantly, they still identified far fewer targets within that region. This provides clear evidence that a processing deficit was contributing to the neglect of information and that neglect was not simply reflecting a failure to fixate information or reduced time spent fixating information in left regions for NPs.

4. General Discussion

4.1 Summary

This experiment aimed to investigate whether any observed allocentric neglect may instead reflect the operation of fixation-based neglect, a type of egocentric neglect. Two tasks with different target items, manipulated for orientation, were employed. One task contained target items with the critical information (the time telling information) for accurate target identification on the canonical left side of the clock. The other task contained target items that had the critical information for accurate target identification on the canonical right side of the clock. Clocks were presented upright and inverted in both tasks in order to investigate whether pure allocentric neglect for the intrinsic left side of an object occurs without this information falling to the left of a central fixation position. For both tasks, NPs displayed poorer target identification within the contralesional regions, demonstrating egocentric neglect (neglect of information to the left of the patients' trunk/head midpoint), whereas the control participants demonstrated equivalent accuracy across the stimulus. The NPs' poor contralesional accuracy was associated with little overall fixation time on, and fewer gazes being made to, the FL region compared to controls, supporting the findings reported in Experiment 1 for SS and Experiment 2 for thirteen NPs. This suggests that a sampling deficit was contributing to the manifest neglect in the most contralesional region.

The NPs did make gazes on the left regions, and in the NL region, they made the same number of gazes, and spent the same amount of time fixating, that region as the control participants, but still had reduced TIA in that region. Furthermore, NPs spent on average a longer amount of time fixating the NL region during each gaze than control participants and yet still failed to identify a significant number of target items within that region. This task enabled more sampling of the left in neglect and therefore provided the opportunity to further investigate whether any processing deficit for contralesional information occurs when it is sampled. This strongly supports the contribution of a processing deficit in neglect of contralesional information, further extending the findings of Experiment 1 and 2.

4.2 Was Allocentric Neglect or Fixation-Based Neglect Operating?

If pure allocentric neglect was occurring in this experiment then NPs would have displayed poorer accuracy for identifying target clocks when the critical information for accurate identification was on the canonical left side of the clock, regardless of its orientation. Thus, NPs' accuracy would have been poorer in the Left Clock Task than in the Right Clock Task. However, there was no significant group by target-type interaction for TIA in this experiment, suggesting NPs did not have poorer performance for one type of target compared to control participants. Furthermore, it was demonstrated that overall accuracy was significantly higher for left sided targets than right sided targets. This provides strong evidence that allocentric neglect of the canonical left side of a clock was not occurring for NPs and this was supported by individual analyses showing that none of the NPs had poorer left sided target performance compared to control participants. This is in line with the findings from Experiment 2 suggesting that allocentric neglect was not operating.

The lack of allocentric neglect in this experiment, as in Experiment 2, may be due to none of the patients included in this study presenting with allocentric neglect. However, there was evidence to suggest that fixation-based neglect was occurring in the clock cancelation tasks, which may explain many findings of allocentric neglect. The NPs were significantly poorer at identifying target items when the critical information for target identification was to the left of a central fixation position. Target identification accuracy for upright left sided targets and inverted right sided targets (when the critical information for target identification was now to the left of a central fixation position) was significantly lower than target identification when the critical information was to the right of a central fixation position (i.e. upright right sided targets and inverted left sided targets). This was consistent with the view that neglect operates from an egocentric frame of reference based on eye position, with information falling in the LVF being neglected (e.g. Behrmann et al., 2002; Gainotti et al., 1986). This is distinct from object-centred allocentric neglect, where the canonical left side of the object is neglected, even if that information falls within the RVF (i.e. when the left sided target is inverted; refer back to *Figure 4*).

Despite the interpretation that this finding provided evidence for fixation-based neglect, caution has to be taken with drawing this conclusion as no information from the eye tracking data was provided as to the position of the fixation within the clocks during completion of the task. Participants may approach task by fixating the hands and the numbers of the clock, rather than by centrally fixating the object. If this were the case, then the target items that had the information to the left of a central fixation position may not have been identified due to a reluctance to fixate the left side of the object (object-based allocentric neglect) and not because the information fell to the left of a central fixation position. This was the first study to demonstrate that allocentric neglect may be a result of fixation-based neglect. Thus, when the task demands necessitate that each item to be fixated in order to successfully complete the task, fixation-based neglect (not allocentric neglect) is observed. Further studies need to be conducted with highly spatially accurate head mounted eye trackers in order to verify the position of the eyes within the objects in the task.

The finding that task demands can affect the level at which neglect operates demonstrates further that neglect is a dynamic disorder that can be affected by a number of factors. Experiment 4 reported in Chapter 5 investigated in more detail the effect of task demands on the frame of reference that was operating in neglect. The finding of fixation-based neglect and that task demands affect the level at which neglect operates can explain the majority of effects that have been interpreted as support for allocentric neglect and may offer some explanation for inconsistencies in the literature with regard to the two different frames of reference. For example, patients failing to identify gaps on the left hand side of circles or apples when these are presented in the ipsilesional regions of the stimulus is likely to result from the task requiring each item in the stimulus to be directly fixated (Ota et al., 2001; Bickerton et al., 2011, respectively; refer back to section 2.1 *Frames of Reference for the Coding of Spatial Information* in Chapter 1) and may not be due to the operation of allocentric neglect.

Additionally, more global egocentric neglect was demonstrated by NPs in the clock cancellation task. Target identification accuracy was poorest in the FL region with TIA increasing towards the right. The existence of egocentric neglect is also far less controversial than allocentric neglect, and egocentric neglect has been evidenced in a number of studies investigating search behaviour in neglect (Behrmann et al., 2002; Behrmann & Moscovitch, 1994; Colby, & Goldberg, 1999; Hillis et al., 1998). One question that remains to be addressed relates to the factors that contribute to neglect of information to the left of a patient's midline. Target identification accuracy may be poor due to patients failing to fixate the information in that region. However, poor accuracy may also reflect restricted processing within contralesional regions of space for NPs, perhaps due to deficits in either or both encoding and/or representation of that information. The previous experiments reported have indicated that neglect may reflect a combination of these factors.

4.3 To what Extent were Sampling and Processing Deficits Contributing to the Egocentric Neglect Present in the Clock Cancellation Tasks?

There was slightly more time spent fixating the FL region in the left and right clock tasks by NPs compared to the time spent fixating that region in the SEAN task (see *Comparing the SEAN and Clock Cancellation Tasks: Which Factors Affected the Neglect*

Exhibited and Pattern of Eye Movements Produced? below). However, there was still evidence that a sampling deficit was contributing to poor contralesional TIA, as evidenced by the finding that the proportion of time across the four regions of interest increased from left to right, mirroring the pattern of target identification accuracy. Thus, TIA was likely to be reduced in the FL region due to NPs failing to fixate, or spend sufficient time fixating, contralesional information in order to process it for accurate target identification. This finding and explanation are in line with previous research showing that NPs fixate the neglected regions of space for less time than right regions when conducting search for target items (Behrmann et al., 1997) and viewing chimeric faces composed of different faces on the left and right side (e.g. Walker et al., 1996).

In the present study fewer gazes were made to the left regions, however, this was not to the extent expected considering the level of TIA within the left regions. A similar number of gazes were made on the NL region by NPs as were made in the FR region for the left and right clock tasks. Furthermore, an equivalent amount of time was spent fixating the NL region by NPs and control participants, during both clock cancellation tasks. Nevertheless, TIA was lower than the controls' in the NL region for NPs. Thus, the controls' fixation time in the NL region (who achieved almost 100% TIA) was insufficient for accurate target identification in the contralesional area of space for NPs. This is clear evidence that a processing deficit also contributed to poor target identification accuracy within neglected regions for NPs, as there was no sampling deficit (relative to controls and right regions of the stimulus) for the NL region, yet still NPs obtained poor TIA.

There was no interaction found between group and region on average gaze durations on either of the clock cancellation tasks. There was an overall group effect, whereby NPs spent longer on average during a gaze on a region than the other participant groups. These findings together demonstrated that often in the FL and NL regions, NPs were spending as much time fixating during a gaze as OACs when searching for target items. However, this time spent searching for target items during a gaze did not result in NPs being able to identify target items in this region, often neglecting the majority of targets presented there. This provides further evidence of a processing deficit in neglect, alongside limited sampling of information, as even when those regions were fixated for long periods of time during a gaze, targets were still not identified. This extends the findings from Experiment 1 on SS who had chronic left neglect and Experiment 2 reporting result on thirteen patients with left hemispatial neglect.

In the RCT, the NPs made more gazes on the NR and FR regions than the controls; this was not the case during completion of the LCT however. This suggests that hyper-attention to the ipsilesional regions in the RCT may have been contributing to the increased neglect of contralesional information compared to the LCT. As indicated by the findings from Experiment 1, SS tended to spend more time and make more gazes on the ipsilesional regions. However, it could not be determined whether this was a result of neglect of the left side of space (i.e. hypo-attention to contralesional regions) causing more time to be spent fixating ipsilesionally, or if hyper-attention to the right was contributing to neglect of contralesional information. Specifically, it was not determined whether hyper-attention to ipsilesional regions resulted in less targets being identified in contralesional regions. This experiment demonstrates that hyper-attention to ipsilesional regions (NR and FR) was associated with poorer performance in contralesional target identification in the RCT. This hyper-attention to the ipsilesional regions was not present in the LCT where contralesional TIA was higher. Therefore, it appears as though hyper-attention to the ipsilesional regions can contribute to neglect of contralesional information. This provided support for the inter-hemisphere rivalry hypothesis (Kinsbourne, 1977). This is the concept that left neglect results from the damaged, right, hemisphere no longer inhibiting the intact, left, hemisphere and therefore does not enable attention to be transferred to the left side of space. Therefore, the overactive left hemisphere causes preferential responding to the ipsilesional region of space (Kinsbourne, 1977), i.e. hyper-attention to the right.

4.4 Comparing the SEAN and Clock Cancellation Tasks: Which Factors Affected the Neglect Exhibited and Pattern of Eye Movements Produced?

The findings in Experiment 2, Chapter 3 for the SEAN cancellation task demonstrated NPs had poor TIA in the FL region, identifying under a quarter of the target items there. NPs had far higher TIA in the Left Clock Task, nearly double the TIA obtained in the SEAN cancellation task. Although the current experiment contained two less NPs than Experiment 2, all the other NPs contributed to both sets of experimental findings. Task complexity and other possible reasons for poorer TIA in the SEAN cancellation task compared to the clock cancellation tasks are discussed next. Unexpectedly, TIA in the FL region for the Right Clock Task was lower than in the Left Clock Task. This is the opposite effect to what was expected if NPs presented with allocentric, object-based, neglect and potential reasons for this are outlined in this section.

There may be a number of reasons for sampling being more restricted in the SEAN task than the clock tasks. Firstly, the SEAN task required dual-target search (searching for two target letters), whereas for both the clock cancellation tasks, the participants were only required to search for clocks displaying one specific time during each task. This increases cognitive load (i.e. the number of tasks one is currently required to complete). It has been demonstrated that healthy control participants are poorer at identifying target items when searching for two items simultaneously compared to a single item (Menneer et al., 2007). This has been suggested to be due to difficulties experienced with holding two target templates in working memory simultaneously (or one template which is more global) to guide search during dual-target search, compared to only one, highly specific, template aiding search in single-target search (Menneer et al., 2007). Dual-target search was demonstrated to exacerbate neglect in Experiment 1 which investigated chronic neglect patient SS. These findings support those from other studies that have shown that more omissions are made by neglect patients in conjunction tasks than in feature detection tasks (e.g. Aglioti et al., 1997).

Importantly, poorer TIA in dual-target search compared to single-target search appeared to be limited to the left regions in NPs, with equivalent TIA for NPs in the right regions in the SEAN and clock cancellation tasks (NPs achieving between 70 and 80% TIA in the NR and FR regions of all tasks). This suggests that dual-target search only hindered search performance when NPs were searching for targets within a contralesional region; an area of space where attentional resources were already limited. Dual-target search may require more attentional resources being readily available and, thus, in a region of space where processing was deficient or delayed, extra cognitive processing required results in poorer performance. However, this was not the case for areas in which the NPs had adequate processing of information, i.e. in the ipsilesional regions. This provides further evidence in support of the hypothesis that deficient processing in contralesional regions contributes to neglect of information, as well as limited sampling of that information.

Another explanation for the differential TIA within contralesional regions for the SEAN and clock cancellation tasks is that the stimuli differed in visual properties and perceptual load may be increased in the SEAN task compared to the clock cancellation tasks. Generally, there were more items contained within the SEAN task than in the clock cancellation tasks. There were 80 items in each region in the letter cancellation task, compared to 18 in each region in the clock cancellation tasks. This difference may make it more difficult to conduct search due to the density of the visual information displayed in the SEAN cancellation task. Increased density of stimuli has been shown previously to exacerbate neglect (Ferber & Karnath, 2001) and this was suggested to be a factor contributing to SS's poorer performance on the BIT letter cancellation task compared to the star and line cancellation tasks in Experiment 1. Together, the findings further support the premise that neglect is a dynamic disorder, with its presentation and manifestation being affected by a number of different factors. One of these factors, specifically, task demands, will be investigated and discussed in Chapter 5 in relation to its impact on neglect.

4.5 Conclusions

Neglect is a dynamic disorder, and with the level at which it operates (e.g. at an egocentric or a more allocentric level) within each individual, changes depending on a number of task-related factors. In the experiment reported in this chapter, the task demands necessitated that each individual item that was presented within the stimulus had to be fixated, which could have resulted in the left side of each object being neglected. In the SEAN task the task demands did not require each letter to be fixated in order to accurately identify targets, and so allocentric neglect was not exhibited. The findings from the current experiment indicated that the neglect shown was likely to be a result of information to the left of a central fixation position being neglected within individual target items, i.e. egocentric neglect relating to eye position. Previously, this type of neglect behaviour has been interpreted to provide evidence for allocentric neglect.

More global egocentric neglect (neglect of targets within the left regions) was associated with patients failing to sample the FL region to the same extent as controls and NPs spending less time fixating that region overall. This, however, was not the sole reason for poor target identification on the left. On occasions NPs were fixating contralesional information, and spent time processing that information, but still failed to accurately identify the information there. This demonstrated that a processing deficit was also contributing to neglect of information and that neglect was not simply due to patients failing to fixate neglected information. This processing deficit may be a result of the information either being inadequately encoded or represented properly. The experiments reported up to this point have not directly addressed this question, even though it has been repeatedly demonstrated that a processing deficit was contributing to neglect as well as limited sampling of contralesional information. Experiment 4 aims to address this question and to determine how NPs encode and represent contralesional information in order to investigate whether either or both of these processes were deficient in neglect.

Furthermore, there was poorer performance in contralesional regions and less sampling of those regions for NPs in the SEAN task (reported in Chapter 3) than in the clock cancellation tasks reported here, which was likely to be a result of the differing visual properties of the stimuli (e.g. density of the display, number of target and distractor items) and cognitive factors (e.g. dual or single target search). These factors were demonstrated to have more of an impact on search within contralesional regions, with accuracy in the right region being equivalent across the tasks, indicating that there was restricted processing of contralesional information. This, in conjunction with limited sampling of information, contributed to the neglect of target items within contralesional regions. These findings are important for developing effective rehabilitative methods for neglect, specifically, developing techniques that do not solely rely on attempting to increase sampling of the neglected region.

Chapter 5. Eye Movements in Hemispatial Neglect during Figure Tracing and Copying: Attempting to Complete the Picture.

Experiment 1 reported in this thesis demonstrated that task demands had an impact on the extent to which contralesional information was neglected during completion of the Behavioural Inattention Test (BIT) cancellation tasks by patient SS. Furthermore, all experiments have demonstrated that a processing deficit for contralesional regions of space contributes to neglect of visual information presented within those regions. The current experiment aimed to investigate (1) whether task demands affected how visual information was encoded and represented in neglect and control participants and (2) whether either, or both, of these stages of visual processing were deficient in neglect. Specifically, the first aim was to test whether the task demands affected the way in which the information was visually processed during the tasks, and how attention was allocated, (i.e. the frame of reference that was operating). The frame of reference that may operate in neglect has been suggested to relate to person-centred co-ordinates (egocentric frame of reference; e.g. Behrmann, Ghiselli-Crippa, Sweeney, Di Matteo, & Kass, 2002) or object-based co-ordinates (allocentric frame of reference; e.g. Caramazza and Hillis, 1990). It has been demonstrated in a select few experiments that task demands and the instructions provided to NPs can affect the frame of reference that operates and therefore which spatial information is neglected (Baylis, Baylis, & Gore, 2004; Driver & Halligan, 1991; Karnath & Niemeier, 2002). This issue will be considered in more detail in section 1.1 *Do Task Demands Effect Frames of Reference Operating in Neglect?*

All the previous experiments have shown that neglect of contralesional information was not solely due to a sampling deficit. In addition, when contralesional information was fixated, it was not processed adequately in order for Neglect Patients (NPs) to respond to it or there was a delay in processing targets that were accurately identified during completion of cancellation tasks. However, these experiments did not address the stages of cognitive processing that may be disrupted in neglect. The second aim of this experiment was to investigate whether there was a deficit experienced by NPs in visually encoding contralesional information (e.g. Denny-Brown, Meyer, & Horenstein, 1952) and/or in representing encoded information (e.g. Bisiach, Luzzatti, & Perani, 1979). This will be considered in section 1.2 *Does a Processing Deficit for Contralesional Information in Neglect result from Difficulty in Visually Encoding Information or Defective Representation of Encoded Information?*

1.1 Do Task Demands Effect Frames of Reference Operating in Neglect?

One of the main aims of the current experiment was to determine which frames of reference were operating when NPs were conducting two different tasks. The tasks were completed whilst eye movements were concurrently recorded to enable measures of cognitive processing and visual sampling to be obtained during task completion. Complex figures were developed to investigate the frames of reference that were operating when NPs were completing the task. The stimulus contained two figures (the head and shoulders of a male or female); one on the left of the stimulus and one on the right. This enabled investigation of whether of person-centred (egocentric) and/or object-based (allocentric) frames of reference were operating in neglect. If an egocentric frame of reference was operating, then the figure presented on the left of the patients' midline (and therefore the lefts side of the stimulus) would be neglected, as the stimulus was presented centrally to the patient. If an allocentric frame of reference was operating, then the left side of each object (i.e. each figure) would be neglected. Two tasks were employed to investigate the effect of task demands on the frame of reference operating. One condition involved the participant following the lines of a stimulus with a marker pen as if they were tracing the image onto a piece of paper placed over the stimulus (Tracing Condition). The other condition involved the participant copying the figures onto a piece of paper presented beneath the stimulus (Copying Condition).

Figure copying has been demonstrated to be highly sensitive test for visual neglect (Behrmann & Plaut, 2001; Black et al., 1994; Marshall & Halligan, 1993) and is, therefore, an appropriate experimental task that can be employed to reveal underlying deficits contributing to neglect of information on the left side of space (refer back to section 2.2 *The Value of Figure Copying Tasks in Revealing Frames of Reference Operating in Neglect* in Chapter 1). Figure copying requires visual encoding of the stimulus in order to produce an accurate copy. Additionally, during figure copying, participants are required to memorise either the whole, or parts of, the figure to be copied before producing it in the copy, and therefore a memory representation of encoded information needs to be formed. Participants have to commit a representation to memory and then reproduce it without the visual representation necessarily being there at hand as the copy is produced. This may mean that participants operate over smaller portions of the stimulus at any one time in order to accurately conduct the task.

To be specific, if there are two objects within the image to be copied, each image may be represented separately and the two objects copied serially and sequentially during the Copying Condition. This in turn may result in the left side of each object being neglected due to the patient reorienting their focus from one part of the stimulus to another during the task. In contrast, during the Tracing Condition (where the participants are required to follow all the lines of a stimulus with a pen), the visual information does not need to be stored within a representation in order to accurately complete the task. Therefore, the area which is deemed important for this task is the stimulus itself, and therefore this stimulus is likely to be acted on as a whole, rather than as separate parts, and this in turn may result in the left side of the whole stimulus being neglected.

Behrmann and Plaut (2001) demonstrated that figure copying was sensitive in revealing which frames of reference were operating in neglect. They employed complex figures that were to be copied and they manipulated what could be represented as an object within the stimulus (originally reported in Marshall and Halligan,1993). One figure was two conjoined daisies originating from one pot (perceived as a single object). The other figure was two separate daisies, one to the left of the other, which each originated from their own pot (perceived as two separate objects). If neglect was operating at the egocentric level, then the information to the left of the patients' midline would be neglected. In this case, the daisies to the left in both stimuli would be neglected. However, if neglect operated at the object level (allocentric), the left side of the object would be neglected. This would result in the whole left daisy being neglected in the conjoined figure but the left half of both daisies being neglected in the non-conjoined figure.

Behrmann and Plaut (2001) found that a combination of egocentric and allocentric neglect was contributing to neglect performance in these conditions. Specifically, they noted that as the focus of the participant changed e.g. from representing the object as a whole (when the daisies were conjoined) to representing it as two separate objects (when they originated from their own pots) in the other condition, so did the neglect behaviour. In the condition where the daisies were perceived as one object, the left daisy was neglected. However, in the condition where the daisies were two separate objects, the focus of the participant changed from one daisy to another and therefore the left side of each daisy was neglected. Therefore, the task demands affected the spatial information that was neglected by the NPs. Behrmann and Plaut suggested that the different task demands may have resulted in the participants reorienting their attention and head/body and eyes when copying the two different objects but not when they were copying the daisies that were perceived as a single object. However, this reorienting of attention during completion of the tasks could not be demonstrated in Behrmann and Plaut's (2001) study as no measure of how the stimulus was visually sampled and processed was obtained. Therefore, they could not precisely state whether orienting of attention in the two conditions was different.

Another study demonstrating the effects of task demands on the type of neglect exhibited (Baylis, Baylis, & Gore, 2004) was conducted on three patients with visual neglect. These patients were tested on their ability to detect target letters at ipsilesional and contralesional locations on a monitor. Another condition required the patients to detect target letters at different locations within large shapes presented on the monitor. For both conditions, the physical stimulus was exactly the same; the only difference was the information with regard to where the patient was likely to find a target item (either on the left or right of the screen or the left and right of an individual shape presented on the screen). When patients were asked to detect targets within the entire monitor, they showed neglect for information presented on the contralesional side of the monitor. In contrast, when they were asked to detect targets within a particular object, they showed object-based neglect, i.e. they failed to detect targets on the left side of the shape presented on the screen. In these two conditions the displays, the targets and the response were identical, with the only difference relating to the space that is deemed important for the task. These results showed that the reference frame of neglect may be altered by task instructions which can change how a structured visual scene is represented, with neglect of the contralesional side of this represented space occurring. Once again, in this study no measure of online visual processing was obtained and so it could not be determined whether these differences in the two experimental conditions related to how the information was sampled, encoded and represented in these two different conditions. The second aim of this experiment was to address this issue, which will be considered in the next section.

A study that has investigated patterns of eye movements in neglect during different tasks, and is therefore very relevant for the current study, was designed by Karnath and Niemeier (2002). They employed a visual search task to investigate whether the task imposed on three patients with left neglect affected the area to which they allocated attention during spontaneous search of their surroundings. The conditions varied in the experiment according to the instructions given to the participants in a visual search task. Importantly, the visual array was either segmented into vertical bands (where there were six segments of different coloured letters) or was a homogeneous stimulus. They found that when the participant was searching a homogeneous array (where all the letters were the same colour and the stimulus appeared as one whole section), the whole left half of the array was neglected. However, when the participants were informed that a target would only appear in a region denoted by a specific colour that was one sixth of the array and a boundary was placed around this region (the segmented condition), participants now failed to inspect the left side of that region (as demonstrated by their pattern of eye movements and neglect behaviour). This was previously attended to in the homogenous condition.

This study demonstrated that different frames of reference (i.e. egocentric or allocentric) can be imposed on the same stimulus by the same NP due to the task requirements affecting the regions of space that are imperative for conducting that task. Thus, frames of reference in neglect and patterns of eye movements exhibited can be influenced by the task at hand and the visual properties of the stimulus. This suggests that underlying spatial representations in neglect are dynamic and can be manipulated based on task demands. Karnath and Niemeier (2002) concluded that the representation of the same physical input is continuously reorganised according to the changing task requirements. This reorganisation of spatial representations is on-going in visual perception and, therefore, for NPs results in different information being neglected dependent upon the current representation that has been activated. This reasoning can explain why the disorder appears to be so heterogeneous; it is a dynamic disorder that is influenced by a number of factors. These factors (e.g. task demands) have an effect on the level at which neglect operates.

1.2 Does a Processing Deficit for Contralesional Information in Neglect result from Difficulty in Visually Encoding Information or Defective Representation of Encoded Information?

Another issue that can be investigated by using figure tracing and figure copying tasks are the stages at which cognitive processing is deficient in neglect. Specifically, are NPs able to encode information within the neglected region of space? If they are able to encode it, then they should be able to trace it. If they sufficiently extract the visual information presented, then they should be able to physically trace over that encoded information (assuming that there is no problem with their motor function). They do not need to know what the stimulus is or represent it in order to trace over the lines of the image. Even so, if poor representation of visual information in neglect affected behaviour, this may have an impact on tracing performance. If they accurately encode information as indicated by their tracing performance, are they then able to accurately represent this information? Accurate representation would result in participants being able to copy the figure onto another piece of paper presented beneath the stimulus. This would be demonstrated in their accuracy when copying the figures. These issues will be considered next.

In order to process information in the visual scene and create a representation of visual information, visual encoding is necessary (Salvucci, 2001). This occurs by directing attention through saccadic eye movements to the external environment allowing detailed visual information to be extracted from the scene (Liversedge & Findlay, 2000). This premise is included in various models of visual cognition (e.g. Just & Carpenter, 1980). The processing deficit found in the previous experiments may have resulted from a failure to encode information on the neglected side (e.g. Denny-Brown et al., 1952). Denny-Brown et al. (1952) proposed that NPs' discriminative ability for information presented in the contralesional space is diminished. They believed there was a loss in the ability to synthesize more than a few properties of a sensory stimulus which prevents information from being passed on to higher-level recognition processes (Riddoch & Humphreys, 1987a). Poor encoding of contralesional information does not necessarily result from sensory loss in a region of space (as in hemianopia) but could be due to an inability to integrate sensory information (e.g. different stimulus properties such as shape, orientation and contrast) that has been sampled in neglect. This may result in an inability to identify target items within contralesional regions of a cancellation task as important visual information required to accurately identify the target has not been accurately encoded. It has still not been determined whether difficulty in encoding information contributes to the information being neglected (Deouell, Bentin, & Soroker, 2000). Even though encoding appears to be necessary in order for the stimulus to be represented, some representation of the stimulus may be necessary in order to encode it, and this may be involved in the tracing condition, even though it is not necessary. If the stimulus is not represented properly (e.g. there is a deficient, or non-existent, representation of the left side of space), that region may not be traced over due to the representational issue and not due to the fact that that information could not be encoded.

It has been suggested that neglect is not solely due to a deficit in visually encoding information, as neglect can occur in other modalities (e.g. such as in the tactile modality; Gainotti, 1993). Therefore, neglect in the sensory modality cannot be due to patients failing to visually encode information presented within the contralesional region. Despite this, it has also been demonstrated that neglect is exacerbated when exhibited in the visual modality compared to the sensory modality (Gentilini, Barbieri, De Renzi, & Faglioni,

1989) and that visual neglect double dissociates from other types of neglect (Batholemeo, 2002). These facts strongly suggest that different types of neglect have different underlying mechanisms. Therefore, visual neglect may result from poor visual encoding of information presented in the contralesional side of space (Denny-Drown et al., 1952). Further investigation is required in order to determine the underlying mechanisms in neglect, particularly with regard to the deficits that contribute to deficient processing of contralesional information, which has been demonstrated in all the experiments reported so far in this thesis. Investigation of the underlying deficits present in visual neglect was the focus of the previous experiments, and will continue to be the focus in the current experiment. Particularly, whether or not sampled contralesional information is accurately visually encoded and represented in neglect will be investigated as part of this experiment.

If it is determined that contralesional visual information is encoded accurately in neglect, then any processing deficit may result from defective representation of the accurately encoded information. It may be that NPs are able to accurately encode contralesional information but there is an inability to form an accurate representation of that information once it has been encoded (e.g. Bisiach & Luzzatti, 1978; recall the section on *Eye Movements in Hemispatial Neglect* in Chapter 1). Representational deficits, as with encoding deficits, may result in a failure to respond to target items that have been fixated in cancellation tasks, in line with the previous experimental findings reported in this thesis. There have been many suggestions that neglect arises due to a representational deficit (e.g. Bisiach et al., 1979). Bisiach et al. investigated NPs' abilities to detect differences in pairs of cloud-like stimuli. The participant was presented with a cloud like stimulus moving from left to right, or right to left, and then another after a one second interval that was moving in the same direction. The patient had to report whether the stimuli were different or the same. Crucially, the patterns had only part of the image available to be viewed at any one moment. This was achieved by employing a black screen with the exception of a central vertical slit, which allowed a partial view of the stimulus as it moved beneath the slit. The authors argued that the part of the stimulus that could not be seen at any moment had to be reconstructed in imagery. Therefore, if there was neglect of the left side of the stimulus, it could not be due to poor visual encoding as there was not a physical stimulus to encode.

Bisiach et al. (1979) found that NPs with left neglect detected differences that were contained within the left side of the mentally reconstructed images less often than when the differences were on the right of the mentally reconstructed image. Therefore, they suggested that a representational disorder played a primary role in neglect. However, it cannot be determined from this experiment whether neglect observed during tasks involving a response to physical visual stimuli may be due to representational neglect (as the main focus was on images that had been mentally reconstructed and not visually encoded at that moment). Thus, it still remains to be determined for *visual* neglect whether or not processing may be inhibited or delayed due to defective representation of the encoded information, even when patients sample contralesional information. The second aim of Experiment 4 was, therefore, to determine whether there were any deficits in either or both of these stages of visual processing in neglect. These deficits would result in the finding of a processing deficit for contralesional information for NPs, which has been demonstrated in all the previous experiments. However, it has to be acknowledged that other factors that may differ in the conditions, such as vigilance or arousal, may have an impact on performance. For example, in the Tracing Condition, the participant may be less vigilant/have lower arousal during completion of this task due to it being easier to complete. However, in the Copying Condition, due to the higher cognitive load of the task (being required to represent the different aspects in the stimulus and maintain information with regards to the relationship between component parts), there may be higher levels of vigilance and arousal in this condition, which may result in the patients demonstrating better performance in this condition.

In summary, encoding and representational stages of visual processing may be deficient during fixation of contralesional information in NPs, resulting in the characteristic inability to accurately detect targets and copy figures presented within contralesional regions (e.g. Behrmann & Plaut; 2001; Black et al., 1994; Marshall & Halligan, 1993). The disruption in encoding visual information and storing of spatial representations should be revealed through examination of patterns of eye movements exhibited during figure tracing and figure copying in neglect, outlined next.

1.3 Present Study

To summarise, due to their sensitivity in the ability to reveal underlying deficits, and frames of reference operating, in neglect, figure tracing and figure copying were selected for the experimental tasks. In the present study, participants' eye movements were tracked as they took part in two different experimental conditions. One of the conditions required the participant to trace over the lines of a complex stimulus composed of two figures using a thick marker pen to mark on top of the lines of the stimulus (the

Tracing Condition). The other condition involved copying the figures on to a separate piece of paper (the Copying Condition).

1. 3. 1 Hypotheses: Task demands. If an egocentric frame of reference was operating during the task, which means that spatial information is coded with regards to the midline of the patient, then the figure on the left of the patients' midline would be neglected. If an object-based, allocentric, frame of reference was operating, which emphasises each object within the visual field, then the left side of each figure would be neglected. If task demands (i.e. tracing vs. copying the image) affected the frame of reference that was operating (egocentric vs. allocentric), then different patterns of eye movements and neglect behaviour would be exhibited in these two different conditions. Specifically, during the Tracing Condition the stimulus was expected to be processed as a whole. This task does not involve representing the stimulus and therefore *what* the stimulus is is not important for the task. Therefore, it is unlikely that the task would result in the stimulus to be segmented into its component parts in order to trace it. This processing of the stimulus as a whole, in turn, would lead to an egocentric frame of reference being apparent for NPs, i.e. the left figure would be neglected, as this is the left part of the space that is being operated on. However, when copying the stimulus, it was expected that the focus of the participant would change from one figure to another during the trial as a result of storing only one figure within the representation at any one moment. This would result in the left side of each figure being neglected and less sampling of the left side of each figure being apparent.

Additionally, neglect of the left side of each figure in the Copying Condition would be evident in the pattern of eye movements produced, with less fixation time and fewer gazes being made to the left side of each face (corresponding to the far left [FL] and near right [NR] regions of the stimulus). It was predicted that the stimulus in the Tracing Condition would be processed across the whole stimulus for NPs. For example, they may trace the whole outline of the image (i.e. the outline of both figures at once) as opposed to completing one figure before starting to trace the outline of the other figure. This would be demonstrated by each region of the stimulus being sampled at each stage of the trial (as opposed to a part of the stimulus being completed before another region was sampled), and this information will be provided by the time course of eye movements exhibited during the trial.

In order to memorise parts of the stimulus in order to copy them in the Copying Condition, the figures are expected to be represented separately and acted on in a serial and sequential fashion. Therefore, one figure would be expected to be copied completely, followed by the other figure. This would result in the left side of each figure being neglected (corresponding to the far left [FL] and near right [NR] regions). There is a tendency for NPs to start on the right of a stimulus (e.g. Azouvi et al., 2002), therefore the right figure would be completed first and the left figure completed last, demonstrated in the time course of the eye movements for NPs; the NPs would start fixating the far right (FR) region (the right side of the right figure) and visually sample regions towards the left the further into the trial the participant was. Little sampling of the left regions would be expected until copying of information within the right regions had been completed (i.e. demonstrating that the figures were represented in a serial and sequential fashion). This pattern would not be expected in controls, rather, a tendency to start from left and work towards the right would be predicted for control participants for this measure.

1. 3. 2 Hypotheses: Encoding or representational deficits. If an NP sampled contralesional information but demonstrated deficiencies in encoding that information (i.e. failed to trace contralesional information or exhibited inflated average gaze durations within contralesional regions) then this would suggest a deficit in visually encoding contralesional information as this is the main, or arguably only, visual process involved in this task. If an NP was able to sample and encode visual information in the contralesional regions of space (i.e. trace it) but still exhibited a deficit in copying that part of the image (i.e. failed to copy it accurately or exhibited inflated contralesional average gaze durations), this would suggest that there was a deficit in being able to accurately store and represent the encoded information. These findings could provide evidence for the likely cause of the observed processing deficits (i.e. visual encoding deficits, representational deficits, or both) in all previous experiments reported in this thesis. By measuring participants' eye movements during the two conditions employed in this experiment, one may be able to adequately evaluate the deficient mechanisms underlying neglect behaviour, the frames of reference that operate in neglect and factors that affect spatial processing of visual information.

2. Method

2.1 Participants

In total there were 20 participants involved in this experiment: 6 patients with left hemispatial neglect who had right hemisphere damage (NPs), 5 patients who had had a right ischemic or haemorrhagic stroke but did not exhibit neglect (Stroke Controls; SCs) and 9 healthy older adult controls (Older Adult Controls; OACs). All of these participants also took part in Experiment 2 and/or 3 reported in this thesis (see Appendix G for a cross reference list of all participant numbers included in the experiments reported in this thesis), apart from Case 4 and SC5, who did not take part in the other experiments due to fatigue and/or time constraints. There were 15 females and 5 males. All were right handed. As shown in Table 8, NPs had an age range of 50-78 years (M = 64.67 years, SD = 11.31 years), SCs 62-84 years (M = 73.20 years, SD = 9.83 years) and OACs 52-82 years (M = 67.56 years, SD = 9.95 years). All NPs were in the acute phase (prior to 3-months post-stroke), with the number of days post-stroke at the time of participating in the experiment ranging from 2-59 (M = 25.00, SD = 19.60) for NPs and 2-100 for the SCs (M = 47.00, SD = 42.83), which did not differ significantly, F (2, 17) = .95, p = .406 (see Table 9). NPs and SCs did not differ in number of years spent in education, t (9) = .31, p = .761. However, both NPs and SCs spent fewer years in education than the OACs, t (13) = 2.47, p = .028, although this was marginal for SCs, t (12) = 1.90, p = .081.

Lesion location information was obtained from the available Computed Tomography (CT) head/brain scan reports contained within the patients' medical notes at the admitting hospital (see Table 9). The majority of the NPs had a Partial Anterior Circulation (PACs) or Total Anterior Circulation (TACs) unilateral infarct within the Right Middle Cerebral Artery (RMCA) territory lesioning the right frontoparietal or occipital lobes and for some patients including the right insula, sulci, sylvian fissure, operculum, the internal capsule, and lentiform nucleus (see Table 9 for lesion location information for each stroke patient). One NP (Case 5) also had damage to the lateral aspect of the right occipital lobe but, note, that this participant did not demonstrate visual field loss. The SCs tended to have R MCA initiated infarcts resulting in damage to the right caudate nucleus, insula, putamen, lacunar, precentral gyrus and basal ganglia.

As was the case for Experiments 2 and 3, this study received School of Psychology, University of Southampton and NHS Southampton REC National Research Ethics Service ethical approval and was adopted by the UK Stroke Research Network (SRN) portfolio. The patients were recruited from the same sites as mentioned previously.

2.2 Stimuli

The Tracing Condition of Experiment 4 involved participants being presented with a line drawing of two faces displayed on an A4 landscape piece of paper, which were to be traced by the participant on top of the original image. To be clear, participants were required to mark all the lines within the image with a pen as if tracing the image onto another piece of paper on top of the original. The Copying Condition of Experiment 4 required the participant to copy the line drawing of two faces, similar to those included in the Tracing Condition, which were presented on a landscape A4 piece of paper, onto a separate piece of paper placed beneath the original. There were four versions of this stimulus to be used in these conditions (see *Figure 36*). Participants either received figures labelled 1 and 4 or 2 and 3 in *Figure 36*. These were counterbalanced across participants for the condition in which the stimulus appeared (i.e. Tracing or Copying Condition) and the conditions were counterbalanced for order presentation across participants.

Table 8

Age, Gender, Handedness, Years of Education, Mini-Mental State Examination (MMSE) score, National Adult Reading Test (NART) score, Behavioural Inattention Test (BIT) and Visual Acuity Information for Participants included in the Tracing and Copying Conditions of Experiment 4

Participant Number	Group	Age	Gender	Handedness	Years of Education	MMSE	NART	BIT (%)	Visual Acuity
Case 1	NP	63	F	R	11	27/30	32/50	81.05	32/16
Case 2	NP	78	F	R	10	18/30	17/50	67.28	56/16
Case 3	NP	62	F	R	12	29/30	29/50	83.36	54/80
Case 4	NP	50	F	R	10	20/30	19/50	67.90	48/16
Case 5	NP	78	F	R	10	18/30	30/50	66.67	40/16
Case 6	NP	57	F	R	12	27/30	34/50	87.04	48/16
SC1	SC	62	M	R	16	28/30	45/50	100.00	32/16
SC2	SC	67	M	R	10	27/30	35/50	98.15	56/16
SC3	SC	84	M	R	10	29/30	33/50	96.10	48/16
SC4	SC	83	F	R	10	25/30	26/50	96.30	40/16
SC5	SC	70	M	R	10	29/30	28/50	98.77	56/16
OAC1	OAC	82	F	R	16	24/30	44/50	100.00	24/16
OAC2	OAC	66	F	R	8	29/30	43/50	96.30	32/16
OAC3	OAC	73	F	R	10	29/30	44/50	100.00	56/16

OAC4	OAC	52	F	R	16	27/30	47/50	100.00	20/16
OAC5	OAC	54	M	R	16	30/30	43/50	98.69	16/16
OAC6	OAC	76	F	R	23	30/30	50/50	100.00	32/16
OAC7	OAC	64	F	R	16	28/30	33/50	99.35	16/16
OAC8	OAC	74	F	R	16	30/30	45/50	98.77	24/16
OAC9	OAC	67	F	R	16	29/30	38/50	99.35	16/16

NP = Neglect Patient; SC = Stroke Control; OAC = Older Adult Control; F = Female; M = Male

Table 9

Number of Days Post-Stroke, Aetiology, Lesion Area of Stroke and Hemianopic Status of the Neglect Patients (NPs) and Stroke Controls (SCs) included in Experiment 4.

Participant Number	Group	Days Post-Stroke	Aetiology	Lesion Area	Hemianopia
Case 1	NP	59	Infarct	R MCA territory	LH
Case 2	NP	28	Infarct	R MCA territory; R TACs	LLQ
Case 3	NP	25	Infarct	R MCA territory	None
Case 4	NP	26	Infarct	M1 segment of the R MCA extending to the M2 insula branches; effacement of the convexity sulci and R sylvian fissure	None
Case 5	NP	2	Infarct	R parietal and lateral occipital lobe	None
Case 6	NP	10	Infarct	R MCA territory; R frontoparietal, frontal operculum and insula	None
SC 1	SC	18	Infarct	R caudate nucleas; R lacunar	None
SC 2	SC	25	Infarct	Basal ganglia; R globus pallidus/putamen; R lacunar	None
SC 3	SC	100	Infarct	R precentral gyrus	None
SC 4	SC	6	Infarct	R lacunar	None
SC 5	SC	86	Infarct	MCA territory; insula cortex; R PACs	None

NP = Neglect Patient; SC = Stroke Control; R = Right; MCA = Middle Cerebral Artery; TACs = Total Anterior Circulation infarct; LH = Left Hemianopia, LLQ = Lower Left Quadrantanopia

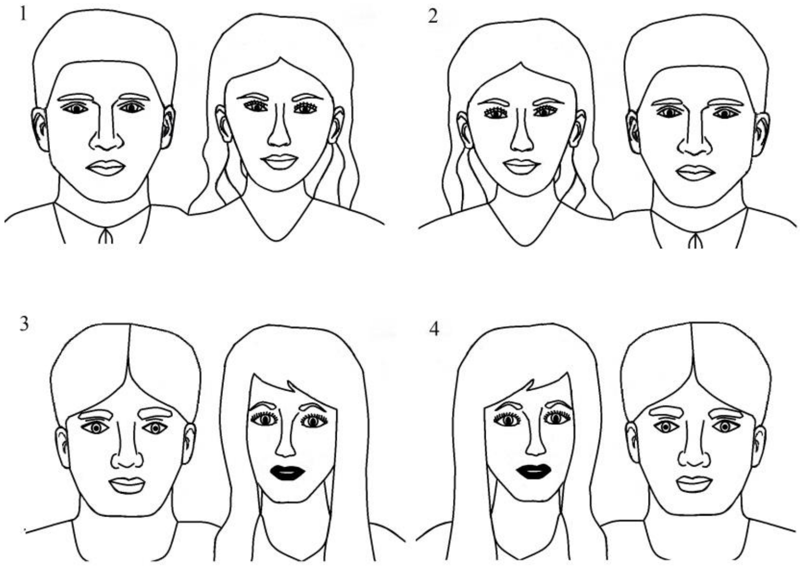

Figure 36. Figures used in the tracing and Copying Conditions of the Experiment 4. The participants either traced or copied (1) and (4) or (2) and (3).

2.3 Screening Tests

In line with the SEAN and Clock Cancellation experiments reported in Chapters 3 and 4, a number of tests were conducted prior to the tasks being completed for the current experiment and information was obtained to acquire measures of pre-stroke IQ (NART), memory ability (MMSE), visual acuity (Snellen), visual fields (Confrontation Visual Field Testing), inattention (BIT). Demographic information such as age, handedness, gender and lesion location for patients (see Table 8 and Table 9) was also gathered. The NPs did not significantly differ on the MMSE, NART and Visual Acuity Test from SCs, t (9) = 2.03, p = .087, t(9) = 1.50, p = .169, t(9) = .01, p = .989. These screening results demonstrate that any poor task performance limited to NPs would be unlikely to be a result of differences between NPs and controls on IQ, memory or visual acuity measures. As expected, groups significantly differed on the BIT, F (2, 17) = 42.47, p < .001, η_p^2 = .83. NPs had far poorer performance than SCs, t (9) = 5.79, p = .002, and OACs, t (13) = 6.21, p = .001, demonstrating clinical neglect. Thus, any differences in figure completion accuracy and patterns of eye movement measures between NPs and control participants were likely to be due to inattention.

2.4 Apparatus

The equipment used and the experimental set-up was the same as that of the Experiment 1 reported in Chapter 2 (see 2.3 *Apparatus* on page 57). In the Copying Condition an additional plain piece of paper was presented underneath the original stimulus for the participant to copy the image onto.

2.5 Design

There were three variables in Experiment 4. The first between participants variable was 'group', with three levels (NPs, SCs, OACs). The task completed was a within participants variable, with participants being assessed on both the Tracing and Copying Conditions whilst their eye movements were recorded. As in Experiments 1, 2 and 3, region of interest was another within participant variable, with the stimulus being divided into four regions (FL, NL, NR and FR, see *Figure 37*) for behavioural and eye movement measures.

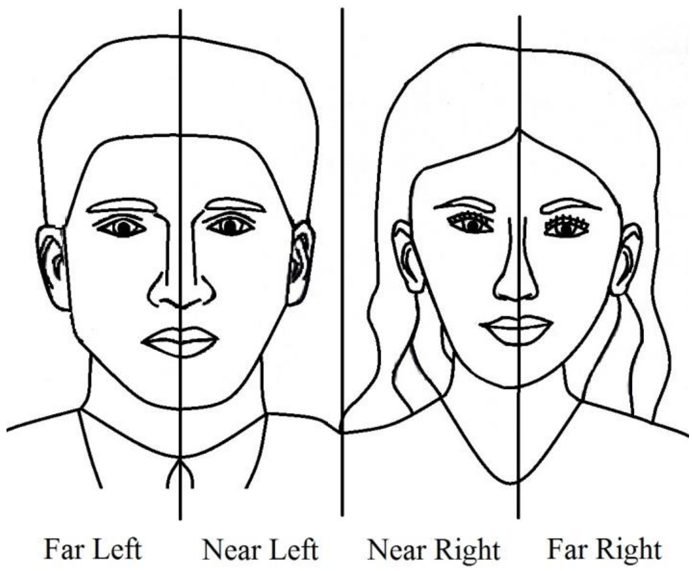

Figure 37. Regions of interest on one of the stimuli used in the Tracing and Copying Conditions of Experiment 4. The stimulus was divided into four equal quadrants that provided four regions of interest along the horizontal plane (Far Left, Near Left, Near Right and Far Right) for the behavioural (figure completion accuracy) and eye movement measures.

2.6 Procedure

The procedure was the same as reported in Chapter 3 (see section 2.6 *Procedure* on page 105), except for the instructions presented to participants. In the Tracing Condition, the participants were instructed to draw over the lines of the image in the stimulus with a marker pen, as if they were tracing the image onto a piece of paper presented over the top of the stimulus. For the Copying Condition, participants were required to copy the image onto an A4 piece of paper presented beneath the stimulus. Participants in both conditions were asked to indicate when they had finished the task by placing the pen on the table and looking at it. No time limit was imposed to ensure that limited time was not a factor contributing to incomplete figure tracing or copying.

3. Results and Discussion

3.1 Data Analysis and Eye Movement Measures

The data analysis and eye movement measures used in this experiment were the same as described for Chapter 3 (see sections 2.7 *Data* Analysis on page 106 and 3.1 *Eye Movement Measures* on page 107). Proportion of time fixating each region was reported instead of raw time spent fixating regions, as has been done in all the previous experiments, in order to meaningfully compare time spent fixating in different regions across groups as the participant groups spent different amounts of time conducting the task. An additional measure was included representing the time course of eye movements during each task. This measure was the proportion of time the participants spent fixating the four regions of the stimulus (FL, NL, NR and FR) at different stages of the trial (the first 25% of the trial, the second 25% of the trial [25-50%], the third 25% of the trial [50-75%] and the final 25% of the trial [75-100%]). Omnibus 3 (group: NP, SC, OAC) x 2 (task: Tracing Condition, Copying Condition) x 4 (region: FL, NL, NR, FR) mixed model ANOVAs were conducted to determine whether there were any differences in the behavioural and eye movement measures across the groups, tasks and regions of the stimulus. If significant main effects and interactions were revealed, then post hoc *t*-tests were conducted where appropriate. The *M*s and *SD*s for post-hoc tests are included in Table 22 to Table 24 in Appendix H.

The accuracy of the figure tracing and copying for each participant was scored using the following algorithm: for each region a score out of 10 was available, with one point being deducted for each part of the figure that was missing or incomplete. A point was deducted if the following features were incomplete or missing in each region: top hairline, bottom hairline, eye brow, eye (including pupil), nose, ear/side hairline, mouth, neck/chin, shoulder, collar/neckline (see *Figure 38* for these sections highlighted on the figures included in these conditions and Appendix I for an example of the scoring procedure). There was a maximum of ten marks per region for figure encoding or copying accuracy; 40 marks overall. This was transformed to proportion accuracy for each region.

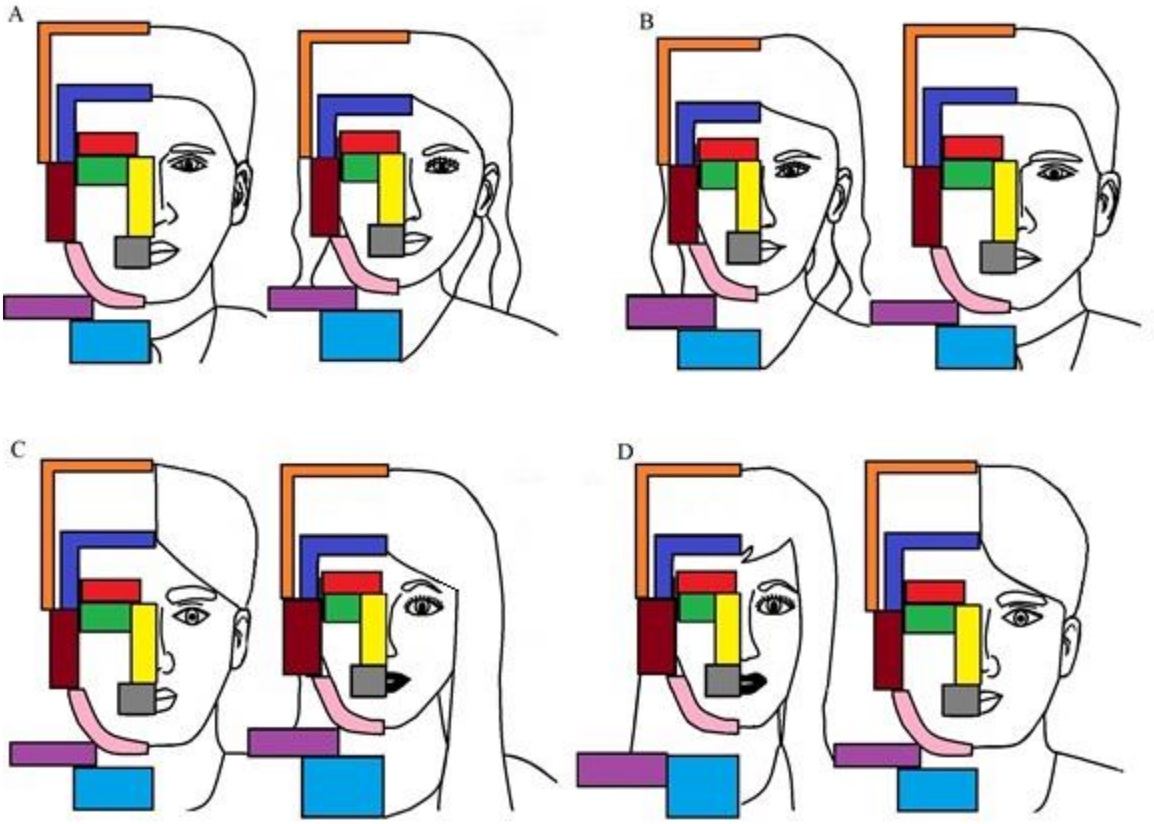

Figure 38. The regions that were used in the computation of figure completion accuracy for each of the four stimuli are denoted by the different coloured boxes.

3.2 Figure Completion Accuracy

In order to determine whether NPs were more accurate at encoding or representing visual information presented in the regions of the stimuli, an ANOVA was conducted on the figure completion accuracy data. It was predicted that NPs would have poorer performance for the Tracing Condition than control participants if they were experiencing problems with encoding the information. Additionally, it was expected that if a representational deficit (as opposed to a sole encoding deficit) was underlying neglect, then patients would have poorer performance in the Copying Condition compared to the Tracing Condition. A main effect of group was revealed, $F(2, 17) = 42.97$, $p < .001$, $\eta_p^2 = .84$, with NPs having lower overall figure completion accuracy in both tasks than SCs and OACs, and a main effect of region, $F(3, 51) = 12.47$, $p < .001$, $\eta_p^2 = .42$, with higher accuracy overall being apparent for right regions of the stimulus. The NPs' reduced performance compared to the control participants for both the Tracing and Copying Conditions suggests that both of these tasks could not be accurately conducted in neglect.

Interestingly, and contrary to predictions, there was no effect of the task (i.e. Tracing Condition vs Copying Condition), $F(1, 17) = .15$, $p = .701$, and no interactive effect of task and group, $F(3, 51) = .12$, $p = .882$, on figure completion accuracy. This means that NPs (and SCs and OACs) obtained the same completion accuracy when they were tracing the image (Tracing Condition) as when they were representing the image (Copying Condition). The non-significant group by task interaction suggests that NPs did not have more difficulty copying the image as opposed to tracing it. This indicates that NPs were not poorer at storing a representation of the encoded information. As there was no difference between accuracy when tracing the image compared to copying the image for NPs, this suggests that neither the encoding nor the representing stages were more disrupted than the other. However, even though it appeared that there was no difference in the overall accuracy for the Tracing Condition and Copying Condition for NPs, the way in which NPs conducted these two tasks was distinctly different. This was demonstrated clearly in the pattern of eye movements produced by NPs when completing these two tasks (see next sections).

It was expected that the task demands would affect the figure completion accuracy. In the Tracing Condition it was predicted that NPs would neglect information in the contralesional regions of space as a result of operating on the stimulus as a whole when tracing the lines. In contrast, in the Copying Condition it was expected that, as a representation of the information had to be formed and stored in order to accurately copy the information, each figure would be copied serially and sequentially resulting in the left side of each figure being neglected. There was no significant interaction of task and region, $F(3, 51) = .12$, $p = .950$, or task by region by group, $F(6, 51) = 1.01$, $p = .432$. This suggests that task demands did not have an impact on performance for NPs (or SCs and OACs). Despite the lack of interactions, it can clearly be seen from *Figure 39* that the NPs' performance reduced within more contralesional regions (as was demonstrated for NPs' performance on cancellation tasks employed in Experiments 1, 2 and 3). However, notably, in the Copying Condition (see *Figure 40*), the NPs had equivalent figure completion accuracy in the NR and NL regions which was not apparent in the Tracing Condition. This indicates that, NPs in the Copying Condition were more accurate in copying the right side of the left face (corresponding to the NL region) compared to performance for this region in the Tracing Condition. Individual NP statistics are reported in Appendix J. As the interaction was not significant, however, it is important to investigate whether this trend was robust in the eye movement measures, which were more precise measures of cognitive and visual processing. These results will be reported in the following sections.

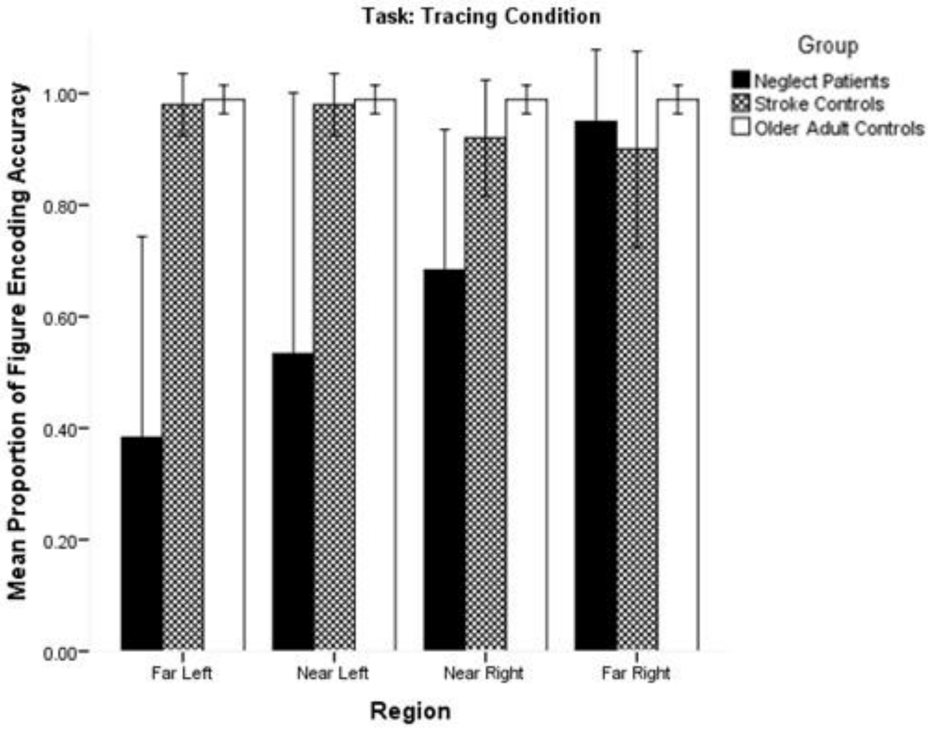

Figure 39. Figure completion accuracy for the Tracing Condition of Experiment 4. Displayed is the proportion of the figure in each region of the stimulus (Far Left; Near Left; Near Right; Far Right) that was completed accurately for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs).

There was a significant region by group effect, $F(6, 51) = 13.62$, $p < .001$, $\eta_p^2 = .62$, and this was in line with what was found in all three previous experiments. As depicted in *Figure 39* and *Figure 40*, control participants tended to have equivalent figure completion accuracy across all regions (with no significant difference in accuracy across regions for SCs and OACs, $F(3, 27) = .35$, $p = .792$; $F(3, 51) = .63$, $p = .597$, see Table 22 in Appendix H). In contrast, NPs had reducing figure completion accuracy for more leftward regions. A significant difference for accuracy across regions for NPs was apparent, $F(3, 33) = 8.53$, $p < .001$, $\eta_p^2 = .44$, with reduced performance in the FL and NL regions relative to the NR and FR regions for NPs, $t(11) = 3.60$, $p = .004$ (see tables containing *M*s and *SD*s for post-hoc tests in Appendix H). It is important to note that NPs had a similar accuracy to control participants in the FR region, demonstrating that they could complete the task accurately in the most ipsilesional region and that neglect resulted in inadequate encoding (demonstrated by the Tracing Condition) *and* inadequate representation (demonstrated by the Copying Condition) of contralesional information. Whether this poor encoding and representing of information in the contralesional regions was related to poor sampling of that information will be considered in later sections in which eye movement measures are presented to address these issues.

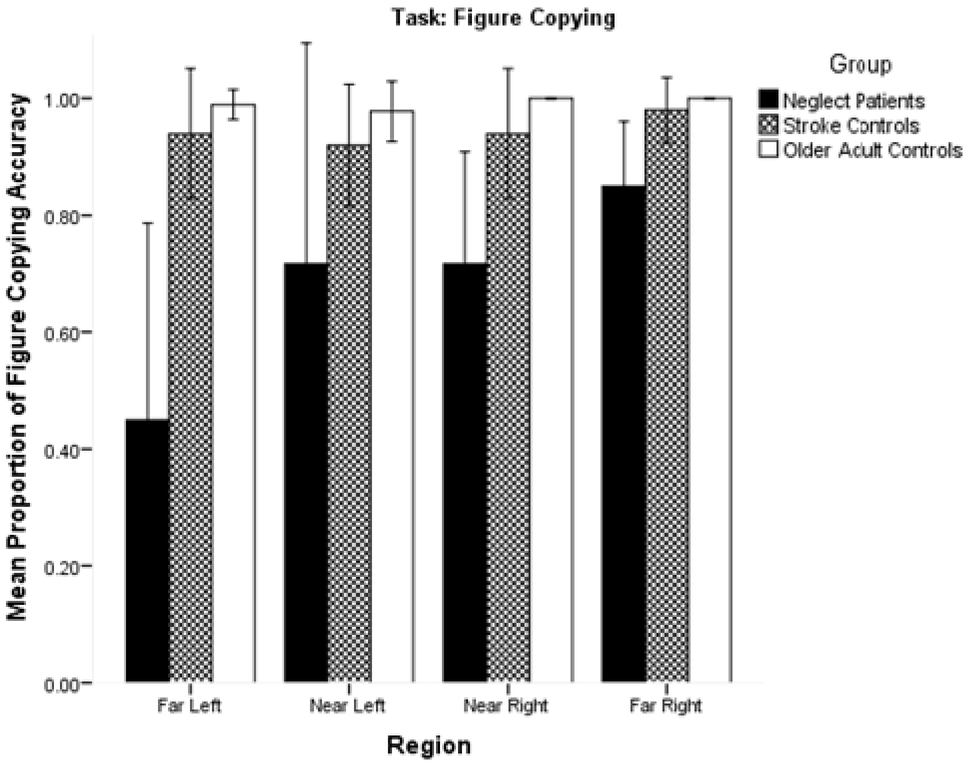

Figure 40. Figure completion accuracy during the Copying Condition of Experiment 4. Displayed is the proportion of the figure in each region of the stimulus (Far Left; Near Left; Near Right; Far Right) that was completed accurately for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs).

3.3 Proportion of Time Fixating the Four Regions of the Stimuli

In order to determine whether NPs differed in how they visually sampled information when tracing compared to copying information, the proportion of time spent fixating regions across the stimuli was investigated for the two different tasks and each participant group. An ANOVA revealed a main effect of region, $F(3, 51) = 7.20$, $p < .001$, $\eta_p^2 = .30$, with slightly more time being spent fixating the right regions of the stimulus, but no effect of group, $F(2, 17) = .69$, $p = .514$, or task, $F(1, 17) = .33$, $p = .574$, and no task by group interaction, $F(2, 17) = .91$, $p = .514$. The latter non-significant effect means that the groups did not differ in the total trial time spent fixating the stimulus (compared to fixating outside of the stimulus) during the trial and that the different tasks did not influence this measure either.

There were significant interactions between region and group, $F(6, 51) = 10.51$, $p < .001$, $\eta_p^2 = .55$, task and region, $F(3, 51) = 4.62$, $p = .006$, $\eta_p^2 = .21$, and region, group and task, $F(6, 51) = 6.08$, $p < .001$, $\eta_p^2 = .42$. These interactions arose from NPs differing in the proportion of time spent fixating regions in the stimuli across the two tasks, with a significant main effect of region, $F(3, 15) = 13.09$, $p < .001$, $\eta_p^2 = .72$, and region by task interaction for NPs, $F(3, 15) = 8.24$, $p = .002$, $\eta_p^2 = .62$, which was absent for SCs, $F(3, 12) = .69$, $p = .502$, and OACs, $F(3, 24) = 1.75$, $p = .184$. This pattern is apparent in the data presented *Figure 41* and *Figure 42*.

As expected, NPs, during the Tracing Condition, allocated attention in a way that indicated that they were processing the stimulus as a whole and an egocentric frame of reference was operating for that condition, (see *Figure 41*). Therefore, information to the left of their midline was fixated for less time compared to regions to the right of their midline, $t\ (11) = 4.08$, $p = .002$ (see tables containing *M*s and *SD*s for post-hoc tests in Appendix H). In stark contrast, when completing the Copying Condition, an allocentric frame of reference appeared to be operating (see *Figure 42*), with NPs spending less time fixating the left side of each figure (corresponding to the FL and NR regions) than the right side of each figure (corresponding to the NL and FR regions). NPs spent considerably more time fixating the NL region in the Copying Condition than in the Tracing Condition (see Table 23 in Appendix H) due to this region corresponding to the right side of the left figure and this information being attended in the Copying Condition. In the Copying Condition, NPs spent less time fixating the FL and NR regions (the left side of the figures) than the NL and FR regions (the right side of the figures), $t\ (11) = 6.07$, $p < .001$.

To be clear, the task demands had an impact on how the information presented in the stimulus was processed. The task affected which frame of reference was operating in neglect, and this was evident in the amount of time NPs spent fixating regions of the stimuli. In the Tracing Condition, where the NPs were required to trace over the whole image, the eye movements provided evidence to indicate that they were processing the stimulus as a whole, reflected in a failure to sample both of the contralesional regions of the stimulus (FL and NL). However, when NPs had to form and store a representation in order to accurately reproduce the figure in the Copying Condition, NPs appeared to be operating on one figure at a time, resulting in the left side of each figure not being fixated for as long as the right side. Therefore, processing of the two figures was serial and sequential in the Copying Condition. This processing strategy affected which part of the image was neglected, i.e. the left side of each figure, as opposed to the left side of the stimulus as a whole. This pattern of behaviour in neglect could be explained by the hypothesis of relative egocentric neglect (Driver & Pouget, 2000); the left side of the face is neglected due to receiving less activation than the right side of the face when that figure is being focused on during the copying procedure. These findings support previous research that has shown that what NPs deem as important to conduct the task, affects what they subsequently neglect (Baylis, Baylis, & Gore, 2004; Karnath & Niemeier, 2002). In the Tracing Condition, it does not appear to be important what the stimulus is (as otherwise it would have been processed in its component parts). This will be considered further in the General Discussion of this chapter.

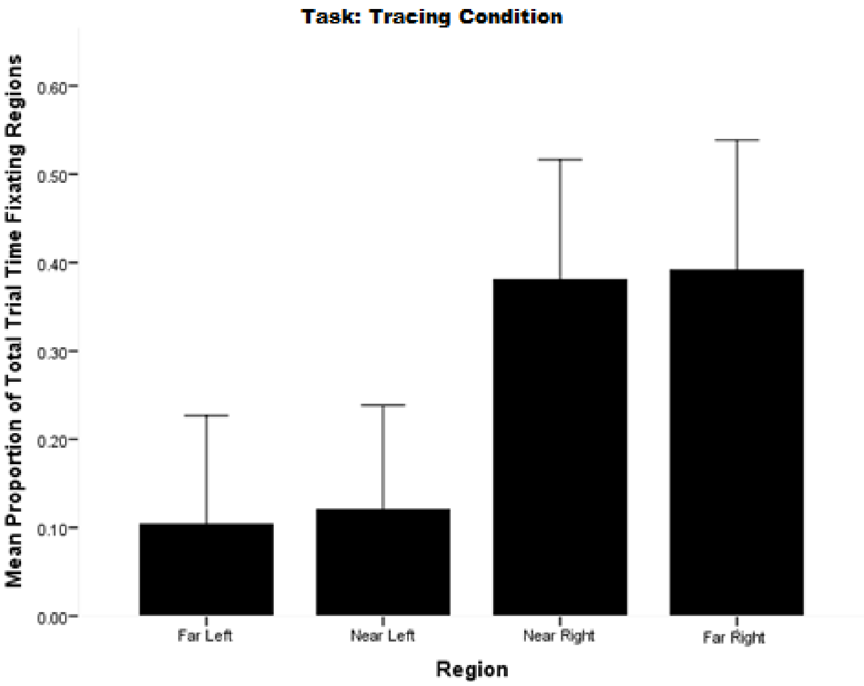

Figure 41. Proportion of total trial time spent fixating the four regions of the stimulus (Far Left, Near Left, Near Right and Far Right) during the Tracing Condition for the Neglect Patients (NPs).

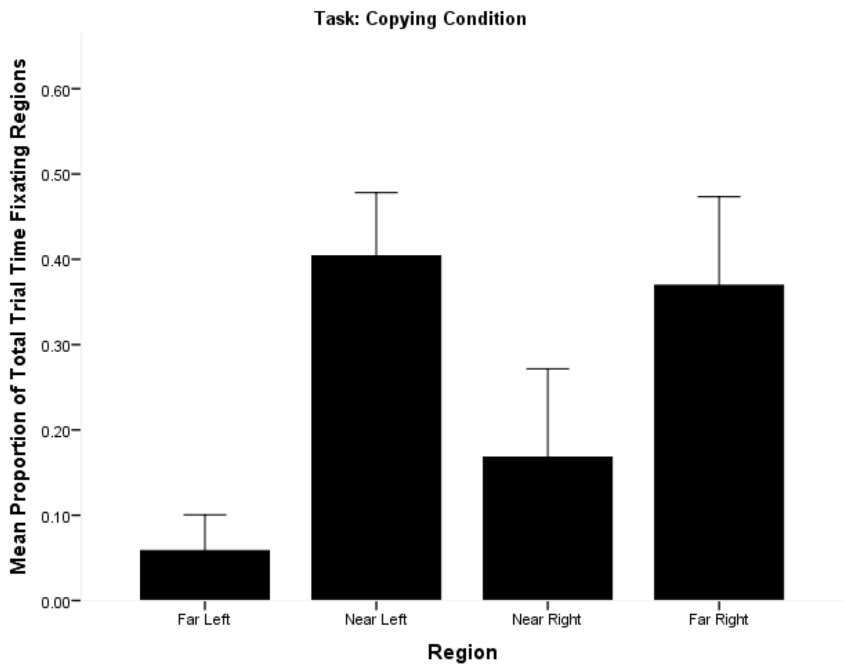

Figure 42. Proportion of total trial time spent fixating the four regions of the stimulus (Far Left, Near Left, Near Right and Far Right) during the Copying Condition for the Neglect Patients (NPs).

The trend for this measure was similar for each individual NP included in this experiment (see Appendix K for figures). For each participant more time was spent fixating the right regions overall than the left regions in the Tracing Condition demonstrating a pattern of egocentric neglect as the regions to the left of the patient's midline was neglected. For the Copying Condition, far more time was spent in the NL region than had been exhibited in the Tracing Condition demonstrating that an allocentric frame of reference was operating as the right sides of each face received more fixation time than the left sides.

The finding that the task can affect the area of space that is attended to in neglect is extremely insightful. If an area of space that is not attended to in one condition can be attended to in another condition, then one may assume that the neglected region may be able to be moderated through manipulating task demands that subsequently induce the operation of frames of reference. For example, in the Copying Condition more time was spent fixating a usually neglected region of space, the NL region (as this was the right side of the left face) compared to during the Tracing Condition. This suggests that neglect is a dynamic disorder and that task demands can have an impact on the extent of neglect *and* the type of neglect that is exhibited, specifically the reference frame that operates at any given time. The task demands that were manipulated in this study influenced the elements of the display over which neglect was operating (either the left side of the entire stimulus or the left side of each figure within the stimulus), as demonstrated in the pattern of visual sampling exhibited by NPs. This means that the current representation of the spatial environment affects the information that is subsequently neglected.

3.4 Number of Gazes Made on the Regions

In order to assess whether the pattern of gazes made on the stimuli differed according to participant group, the task being conducted and the region of the stimulus, an ANOVA was conducted. This revealed a main effect of task, $F(1, 17) = 100.19$, $p < .001$, $\eta_p^2 = .86$, with more gazes being made overall in the Copying Condition. Increased gazes in the Copying Condition compared to the Tracing Condition are not surprising, as the participant was required to alternate between looking at the original figure and their copy to ensure they were accurately copying the figure, and therefore this resulted in an increase in region boundaries being transgressed compared to in the Tracing Condition. A main effect of region, $F(3, 51) = 7.25$, $p < .001$, $\eta_p^2 = .30$, demonstrated that the FL region received fewer gazes overall and the FR region received the most. There was also a main effect of group which was marginal, $F(2, 17) = 3.44$, $p = .056$, $\eta_p^2 = .29$, with slightly fewer gazes being made overall by NPs than SCs and OACs. NPs were likely to have made less gazes overall as a part of the stimulus was being neglected and the region by group interaction was significant, $F(6, 51) = 6.23$, $p < .001$, $\eta_p^2 = .42$. There were also interactions between task and region, $F(3, 51) = 4.18$, $p = .010$, $\eta_p^2 = .20$, and task, region and group, $F(6, 51) = 4.28$, $p = .001$, $\eta_p^2 = .34$. However, there was no interaction between task and group, $F(2, 17) = 1.26$, $p = .31$, $\eta_p^2 = .13$, which demonstrated that the difference in the number of gazes made in the tasks was consistent across groups.

As can be seen from *Figure 43* and *Figure 44,* for NPs there was a significant task by region interaction, $F(3, 15) = 9.73$, $p < .001$, $\eta_p^2 = .66$, which was driven by NPs making more gazes in the Tracing Condition to the NR and FR regions than the FL and NL regions, $t(11) = 4.96$, $p < .001$ (see Table 24 in Appendix H for *M*s and *SD*s for post-hoc tests). However, the control participants made a similar number of gazes to each region across the stimulus. As predicted for the Copying Condition, NPs made less gazes to the left side of both the right and left faces (the FL and NR regions had fewer gazes made to them than the NR and FR regions, $t(11) = 5.06$, $p < .001$). This mirrors the pattern shown for the proportion of the trial time spent fixating each region measure and, once again, suggests that neglect was operating on an allocentric level (i.e. the left of each figure was neglected) in the Copying Condition. As for the proportion of total trial time measure, all NPs displayed a similar pattern of effect for the number of gazes made to regions, with egocentric neglect being apparent for the Tracing Condition, but allocentric neglect in operation for the Copying Condition. Each NPs' number of gazes across the stimulus are plotted in figures that are presented in Appendix L.

Unexpectedly, the pattern for the number of gazes measure for NPs was also apparent for OACs. There was a significant task by region interaction, $F(3, 24) = 3.35$, $p = .036$, $\eta_p^2 = .30$, for OACs, with less gazes being made to the FL and NR regions (i.e. the left sides of the faces) than the NL and FR regions in the Copying Condition, $t(17) = 2.47$, $p = .025$, although this was not to the same extent as NPs. The NPs made 14 more gazes on the NL region compared to the NR region, whereas the OACs only made 3 more gazes on the NL region compared to the NR region, demonstrating the reduced magnitude of the effect in OACs (see tables containing *M*s and *SD*s for post-hoc tests in Appendix H). However, this demonstrated that individuals code the spatial information differently in these two different tasks and this is not only related to neglect types or behaviour.

It appears that the task demands also affected how the OACs processed the visual information, with an emphasis being placed on each figure in the copying condition. Due to the nature of the stimuli, it seems highly plausible that the same number of eye movements do not need to be made to each half of the figure as faces are symmetrical and therefore participants do not necessarily need to sample the two halves of the face to the same extent in order to be able to accurately reproduce the image. Information can be easily extrapolated from one side of the figure to the other side when producing the copy. Recall that no evidence for OACs exhibiting this pattern of allocentric neglect occurred in the proportion of time measure, suggesting that the symmetrical nature of the figures influence how the visual information is spatially sampled and not the amount of time that is spent fixating regions of the stimulus. This finding demonstrates that during copying of two figures, control participants also represent each figure as an individual item, as the NPs do, and, when these figures are symmetrical, visual sampling of the each side of the figure to equivalent extents is not required for accurate completion.

For the SCs, there was not a significant region by task interaction, $F(3, 12) = .680$, $p = .581$. However, the trend for the SCs' number of gazes across the regions shows the opposite pattern of effect to the OACs and NPs (see Table 24 in Appendix H and *Figure 44*), with more gazes being made to the FL and NR regions (i.e. the left sides of each face) than the NL and FR regions. This supports the explanation that during the copying task, allocentric frames of reference are operating and individuals may not need to fixate each side of the figure to the same extent in order to accurately copy the symmetrical images.

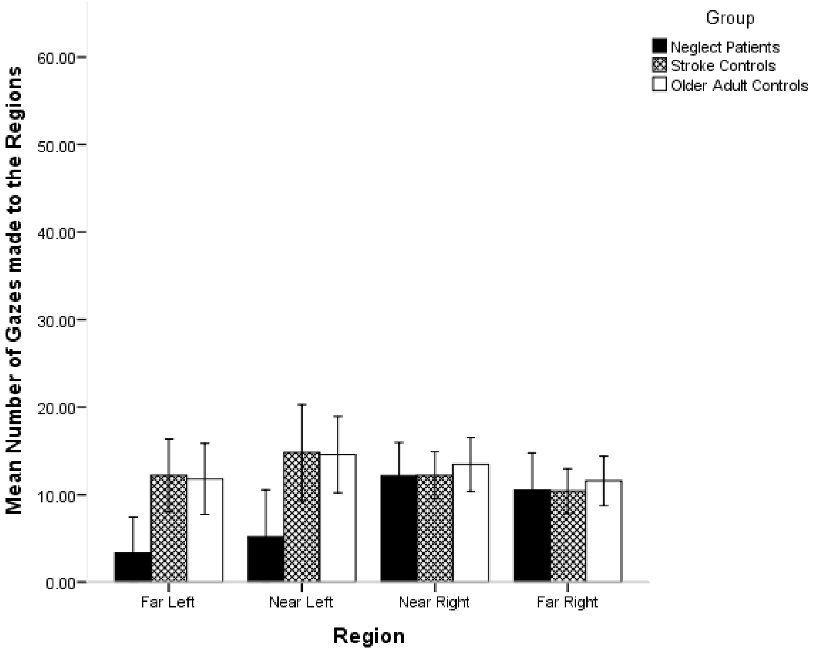

Figure 43. The average number of gazes made on the four regions of the stimulus (Far Left, Near Left, Near Right, Far Right) during the Tracing Condition for Neglect Patients, Stroke Controls and Older Adult Controls.

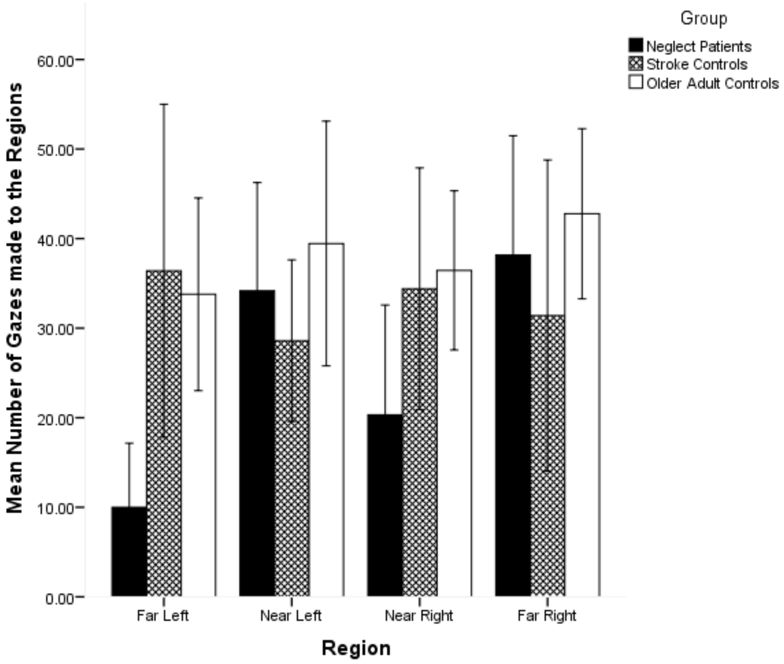

Figure 44. The average number of gazes made on the four regions of the stimulus (Far Left, Near Left, Near Right, Far Right) during the Copying Condition for Neglect Patients, Stroke Controls and Older Adult Controls.

3.5 Proportion of Time spent Fixating Regions on the Stimulus at Different Stages during the Trial

The differences in the pattern of eye movements exhibited by NPs when tracing and copying figures suggests that the way in which the task was completed varied greatly, with different frames of reference operating for the two tasks. In order to investigate the time course of processing during the Tracing and Copying Conditions, the proportion of fixation time on each region during different stages in the trial was plotted. *Figure 45* shows that the NPs spent a similar amount of time in the FR region in the first 25% of the trial as in the last 25% of the trial (the section of the bar filled in black). Additionally, the NPs spent a similar amount of fixation time on the left side of the stimulus (the NL and FL regions) during each stage of the task, even though this was less than time spent fixating the right side of the stimulus. Together, these trends suggest that NPs did not trace one of the figures completely before starting to trace the other figure. If this had been the case then a greater portion of time would have been spent fixating one of the figures for half of the trial (i.e. one figure was completed before the next figure).

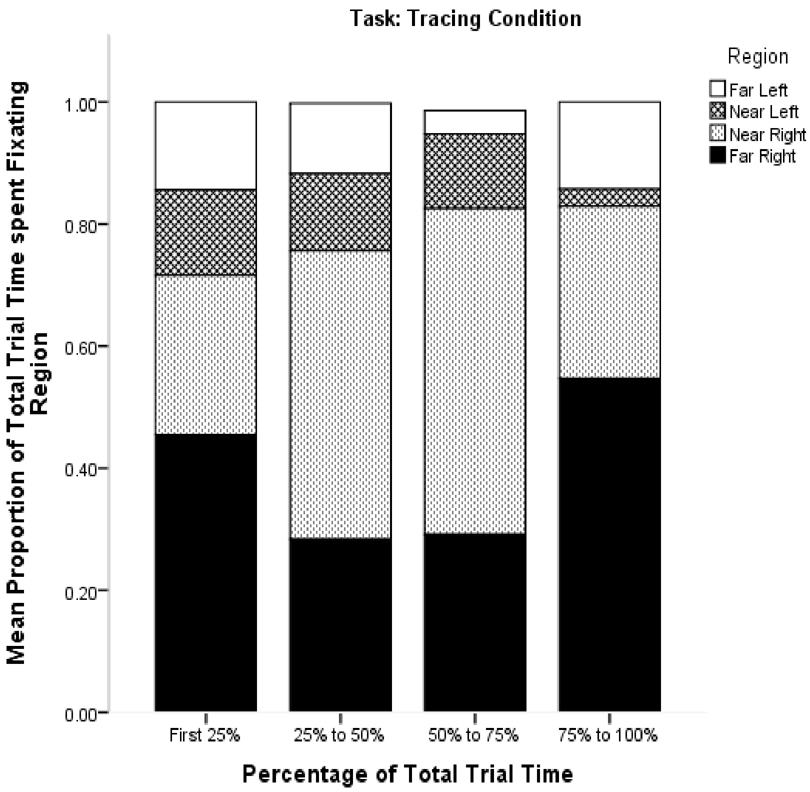

Figure 45. The proportion of time spent fixating each region of the stimulus (Far Left; Near Left; Near Right, Far Right) during different stages of the Copying Condition trial (the first 25% of the trial; 25% to 50% of the trial; 50% to 75% of the trial and 75% to 100% of the trial) for the Neglect Patients.

As can be seen from *Figure 46,* it appears that NPs in the Copying Condition spent the majority of the first half of the trial (the ‘first 25%’ and ‘25% to 50%’ of the trial elapsed) fixatig the left figure and the last half of the trial fixating the right figure. This indicates that the NPs were copying the figures serially and sequentially, completing the majority of the left figure before moving on to the right figure. The pattern the proportion of time spent on each region of the stimulus at different stages of the trial further supports the finding that task demands influenced the way in which information was processed across the two tasks.

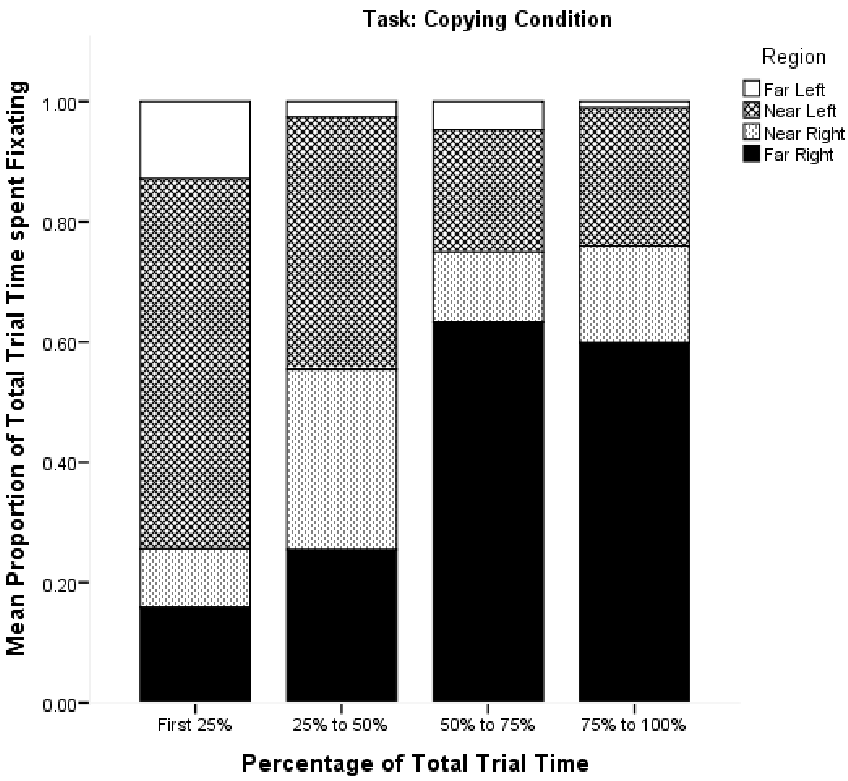

Figure 46. The proportion of time spent fixating each region of the stimulus (Far Left; Near Left; Near Right, Far Right) during different stages of the Copying Condition trial (the first 25% of the trial; 25% to 50% of the trial; 50% to 75% of the trial and 75% to 100% of the trial) for the Neglect Patients.

The OACs and SCs, in line with the NPs, tended to fixate each region for similar proportions of time during each stage of the Tracing Condition (see *Figure 48* for OACs; *Figure 50* for SCs) but spent a disproportinate amount of time fixating the left figure during the first half of the Copying Condition and the right figure during the second half of that trial (see *Figure 49* for OACs; *Figure 51* for SCs in Appendix H). This, again, demonstrates that during the Tracing Condition the information in the four regions of the stimulus are processed during each stage of the trial, suggesting that the stimulus is being operated over as a whole. However, in the Copying Condition, participants are more likely to copy each figure serially, the left figure first and then the right figure (see Appendix H).

3.6 Average Gaze Duration

In order to investigate whether NPs experienced more processing difficulty during the Tracing or Copying Conditions than the controls, an ANOVA was conducted on average gaze durations (AGD). This revealed there was no effect of group on the amount of time the participant spent processing information within a region before moving on to another region, $F(1, 17) = .480$, $p = .627$. This demonstrates that NPs, unexpectedly, did not have more difficulty overall in processing information in the stimuli. There was a main effect of task on AGD, $F(1, 17) = 71.29$, $p < .001$, $\eta_p^2 = .81$, with longer AGD being apparent in the Tracing Condition than the Copying Condition (see *M*s and *SD*s in Appendix H). This was likely to be due to participants looking from the stimulus to their copy in the Copying Condition, resulting in overall shorter AGD in this condition. This is in contrast to AGD in the Tracing Condition, where each region is likely to be fixated until the information has been traced and a saccade is made to the next region. There was a marginal task by region interaction, $F(3, 51) = 2.600$, $p = .062$, $\eta_p^2 = .13$, with AGD being equivalent across conditions in the Copying Condition but higher on external regions in the Tracing Condition (see *Figure 52* Appendix H). The Tracing Condition pattern of eye movements mirrors that found in previous experiments for the cancellation tasks. However, for the Copying Condition, there is a drastic change in visual sampling and processing for NPs and control participants. This, along with the time course measure (the proportion of total trial time spent fixating regions on the stimulus at different stages of the trial) reflects that differential processing was occurring in the two conditions for all participants.

If encoding visual information was more difficult, then it would be expected that AGD would be inflated in the Tracing Condition. If there were processing problems associated with representing information, then AGD would be predicted to be inflated in the Copying Condition. There was no interaction between task and group, $F(2, 17) = .341$, $p = .716$, demonstrating that NPs did not have greater processing difficulty during one of the tasks compared to the controls. This suggests that both encoding and representational deficits contributed to neglect. However, as these deficits are expected to be associated with processing of contralesional information, these findings should only be apparent for the contralesional (neglected) regions of the stimulus. There was no region by group $F(6, 51) = 1.706$, $p = .178$, or task by region by group interactions, $F(6, 51) = .856$, $p = .533$. However, as depicted in *Figure 47*, this means that NPs' AGDs were often the same duration as the control participants' AGD in the FL and NL regions. This corresponded to accurate figure completion accuracy in control participants but not the NPs. Therefore, NPs were spending the same amount of time fixating contralesional information as control participants, but still failed to accurately respond to information there in both the Tracing and Copying Conditions.

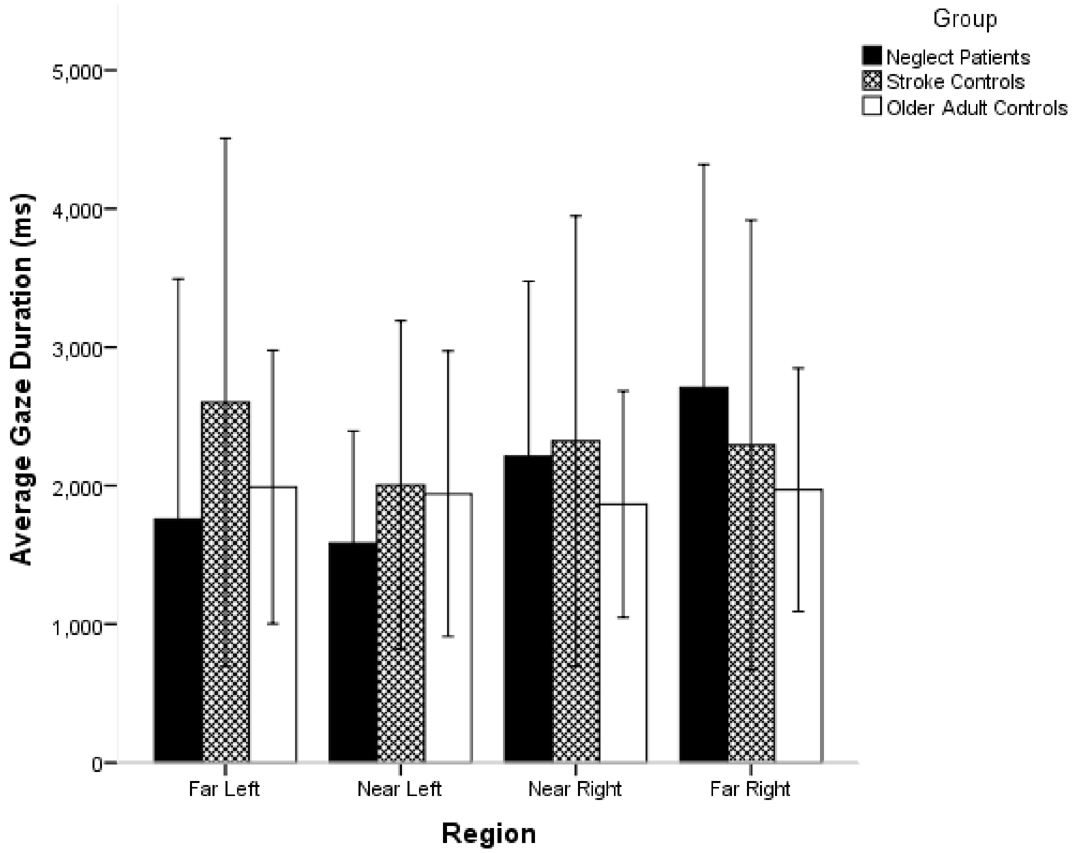

Figure 47. Average Gaze Durations (AGD; ms) made by the three participant groups (Neglect Patients, Stroke Controls and Older Adult Controls) on the four regions of the stimulus (Far Left, Near Left, Near Right, Far Right) during the Tracing and Copying Conditions.

In conclusion, the behavioural data (figure completion accuracy) demonstrated that NPs exhibited difficulty in both encoding and representing contralesional information, with poor contralesional figure completion accuracy in both the Tracing and Copying Conditions. The measures of proportion of fixation time and number of gazes demonstrated that the NPs were more likely to process the stimulus as a whole in the

Tracing Condition, neglecting the left regions of the stimulus, whereas in the Copying Condition they were operating on one figure at a time, therefore, neglecting the left side of each figure. The OACs and SCs exhibited this pattern as well, in the number of gazes measure, suggesting that task demands affect how spatial information is coded in all participants and is not related to disrupted systems particular to neglect, and its' proposed types (allocentric and egocentric). This was supported by the measure demonstrating the time course of processing during these two conditions (proportion of total trial time spent fixating regions of the stimulus at different stages during the trial). All groups demonstrated more serial processing of the figures presented in the stimulus during the Copying Condition than in the Tracing Condition. The AGD analyses indicated that NPs did not have any more difficulty processing information during encoding compared to representing information but still demonstrated that both these processes were deficient.

4. General Discussion

This experiment aimed to investigate the effect of task demands on how NPs encode and represent information, and to assess whether either (or both) of these processes were deficient in neglect. One task involved tracing visual information presented in the stimulus (Tracing Condition) and another required the participants to copy the information provided in the stimulus onto another piece of paper (Copying Condition). Stimuli in both conditions included two figures (the head and shoulders of a man and a woman); one of the figures positioned on the left of the stimulus and one on the right.

It was predicted that the demands of the tasks in the two conditions would affect how information was processed, and therefore influence which information in the stimuli was neglected by NPs. Specifically, in the Tracing Condition, it was predicted that NPs would operate on the stimulus as a whole. This task did not require the information to be stored within a representation, although it is still likely that a representation was formed in order to respond to the information, and therefore segmenting the stimulus into two objects was not required to the same extent as in the Copying Condition, where the information had to be stored in order to reproduce on a separate piece of paper. Thus, it was predicted that this would be apparent in the NPs' performance and eye movement measures. Specifically, it was predicted that NPs would neglect information that was within the contralesional regions of space in relation to their own midline during completion of the Tracing Condition. In contrast, due to representing the figures as individual objects during the Copying Condition, in order to accurately copy each figure, NPs would neglect the left side of each of the figures. These contrasting patterns of behaviour expected for the two tasks were demonstrated as a trend in the figure completion accuracy data for NPs. For the eye movement measures this pattern was more apparent. The NPs sampled of the left side of the stimulus less in comparison to sampling of the right side during the Tracing Condition. However, sampling of the left side of each of the two individual figures was less compared to the right sides during the Copying Condition.

The figure completion accuracy analyses demonstrated that both encoding and representational deficits were present in NPs, with poor tracing and copying of contralesional figures. In the Tracing Condition, poor encoding of the contralesional figure was related to poor sampling of contralesional regions. Therefore, when patients failed to make as many eye movements to, and spend as much time sampling, contralesional regions of space this resulted in poor visual encoding of that information. The figure completion accuracy was the same in the Copying Condition, with few parts of the contralesional figure being completed accurately. Therefore, the processing deficit that arose in the previous experiments reported in this thesis for NPs is likely to be a result of both encoding and representational deficits. The current tasks not only revealed that these stages of visual processing were deficient in neglect but also provided information about how visual stimuli were encoded and represented spatially and the effect of task demands on the neglect exhibited.

4.1 Do Task Demands affect the Operation of Different Frames of Reference in Neglect?

The two different tasks resulted in differential encoding and representing of the information during visual sampling in neglect. The findings clearly demonstrated that task demands influenced the manifestation of neglect. In the Tracing Condition, which involved the participant encoding the visual information in the image, an egocentric frame of reference appeared to be operating; with NPs neglecting the contralesional regions of space (i.e. parts of the contralesional figure). This was apparent in the pattern of figure completion accuracy and the eye movements produced during completion of the task. On the contrary, during completion of the Copying Condition, an allocentric frame of reference was underlying the neglect of information; with NPs failing to sample the left side of each figure to the same extent as the right side of the figure.

Task demands have also been demonstrated to affect the *extent* of neglect in the preceding experiments reported in this thesis. In Experiment 1 conducted on patient SS, the complexity of the task was demonstrated to have an impact on the extent of neglect exhibited, and on the impact that a treatment had on the amelioration of neglect. Furthermore, Experiments 2 and 3 confirmed that task complexity (dual-target search and visually dense arrays; the SEAN task) could exacerbate neglect in comparison to less visually complex stimuli and single-target search tasks (the clock cancellation tasks) in a large group of NPs. These previous findings indicate that the *extent* of neglect was affected by the complexity of the task. However, the current study extends these findings by demonstrating that *what is neglected* can be modified by influencing the task demands and what is deemed important for the task. In the present study it was found that attention allocation was moderated according to the task; different regions of space were neglected depending on the frame of reference that was operating according to the task demands. Interestingly, in the Tracing Condition, the NR region attracted more visual sampling than in the Copying Condition, where less time and fewer gazes were made to that region by NPs. In contrast, the NL region had a higher proportion of time spent fixating it and far more gazes made on it in the Copying Condition than in the Tracing Condition. The same region within a stimulus at the same location was attended to in one condition by all of the NPs, but neglected in another condition, simply as a result of the task demands. This suggests that attention can be allocated to a usually neglected region of space (the NL region) by changing the importance of different information by manipulating the task demands. This demonstrates the dynamic nature of neglect. In the Tracing Condition it was not important to know what the stimulus was as it could be traced without being represented. However, in the Copying Condition, it was important to represent the both figures in order to copy them.

These findings support those found in previous studies investigating the effect of task demands on neglect (e.g. Baylis, Baylis, & Gore, 2004; Driver & Halligan, 1991; Karnath & Niemeier, 2002). Karnath and Niemeier (2002) employed a visual search task to investigate whether the task imposed on three patients with left neglect affected the area to which they allocated attention during spontaneous search of their surroundings. The conditions varied in the experiment according to the instructions provided to the participants in a visual search task. Importantly, the visual array was either segmented into vertical bands (where there were six segments of different coloured letters) or was a homogeneous stimulus. They found that when the participant was searching a homogeneous array (where all the letters were the same colour and the stimulus appeared as one whole section), the left half of the array was neglected. However, when the participants were informed that a target would only appear in a region denoted by a specific colour that was one sixth of the array and a boundary was placed around this region (the segmented condition), participants now failed to inspect the left side of that region, which was previously attended to in the homogenous condition. This demonstrates that different frames of reference can be imposed on an array by influencing the area of space that is deemed imperative for that specific task. Thus, frames of reference in neglect and patterns of eye movements exhibited can be influenced by the task at hand and the visual properties of the stimulus. Karnath and Niemeier concluded that the brain continuously reorganises the representation of the same physical input according to the changing task requirements. This reorganisation of spatial representations is ongoing in visual perception and, therefore, for NPs results in different information being neglected dependent on the current representation that has been activated. This can explain why the disorder appears to be so heterogeneous; it is a dynamic disorder that is influenced by a number of factors. These factors (e.g. task demands) affect the level at which neglect operates.

The current findings suggest that allocentric neglect can be exhibited by NPs if the task encourages each object to be processed. This was also suggested by the findings of Experiments 2 and 3. In Experiment 3 it was indicated that neglect of information to the left of a central fixation position may present as allocentric neglect. This was not apparent in Experiment 2, where it was proposed that fixation-based neglect did not occur as the task did not necessitate each individual letter in the task to be fixated, therefore precluding fixation-based neglect and the apparent operation of allocentric neglect. Therefore, task demands affected the nature of the neglect exhibited by NPs and also the level at which it operated. Neglect was not at the level of the letter during the SEAN task but was at the level of the clock during the clock cancellation tasks. This suggests that allocentric neglect may not be based on the type of neglect the patient exhibits but by the task demands. Therefore, egocentric and allocentric neglect can be manifest within the same individual and this is determined by the current goal of the patient. To be clear, it appears that these findings suggest allocentric neglect may not be a specific sub-type of neglect in itself but may occur when object-based representations are activated and deemed imperative for task completion by NPs. For example, in the Copying Condition NPs appeared to be encouraged to serially process each figure (as demonstrated by the time course of processing). This reorienting of attention to the different figures that are present resulted in the left side of each figure being neglected because at one point in the trial it was the sole focus of the NP. This pattern of behaviour in neglect could be explained by the hypothesis of relative egocentric neglect (Driver & Pouget, 2000); the left side of the face is neglected due to receiving less activation than the right side of the face when that figure is being focused on during the copying procedure. This object-based neglect caused by the re-focusing of attention during the course of the copying task was demonstrated in Behrmann and Plaut's (2001) study. In the condition where the daisies were perceived as one object, the left daisy was neglected. However, in the condition where the daisies were two separate objects, the focus of the participant changed from one daisy to another during the trial and therefore the left side of each daisy was neglected.

The current findings agree with the conclusions of Karnath, Mandler and Clavagnier (2011) from an investigation of how allocentric neglect varies with regard to the relative egocentric position of the objects being presented to NPs. These authors stated that "visual input is coded in egocentric and object-based coordinates simultaneously and that egocentric and object-based neglect may constitute different manifestations of the same disturbed system" (Karnath et al., 2011, pp. 2991). The important aspect to note is that the manifestation of the type of neglect may often be a result of the task demands imposed on the participant and not particular deficits experienced by different NPs. Different task demands resulting in differential neglect of information may be able to explain a number of findings for the existence of allocentric neglect. For example, the neglect of the left side of a word has been postulated to be the result of the activation of object-based representations (e.g. Caramazza and Hillis, 1990). This is in contrast to words presented on the right side of the page being read correctly (and not only the right side of each word being perceived) when NPs' read lines of text. In these conditions whole words on the left are neglected as opposed to the left side of each word. However, in the latter case the stimulus being operated on is the page, and the NPs' task is to read the information presented across that page. This may result in the left side of that reference frame being neglected and apparent egocentric or stimulus centred neglect of words lying to the left of the patients' midline. In the former case, the word is the level at which the NP is operating as determined by the task demands (i.e. reading the word that is presented in isolation). This is, therefore, likely to result in the left side of the word being neglected, appearing to represent the operation of allocentric neglect.

Overall, findings from previous studies that have been discussed and those of the current study imply that if the area of space that is neglected can be manipulated, development of ways in which to moderate neglect, and potentially ameliorate it, may be possible. For example, when the whole stimulus is deemed important for the task and the left side of a page is, as a result, likely to be neglected, placing the relevant information for successful task completion on the right side of the stimulus may result in the majority of that information being perceived by NPs. The dynamic nature of neglect, with the level at which it operates being under the influence of a number of factors (e.g. stimulus properties, task demands, severity), makes amelioration a hard task to achieve for NPs in general.

4.2 Conclusions

This experiment demonstrated that the processing deficit that was exhibited by NPs in the previous experiments, reported in this thesis, was likely to reflect both encoding and representational deficits in visual neglect. All NPs encoded information in an egocentric way, with contralesional information that fell to the left of the NPs' midline being neglected during the Tracing Condition, as has been demonstrated in all previous experiments. Importantly, the frame of reference was determined by the task demands and when NPs were required to form a representation of the information, they all operated at a more allocentric level, neglecting information to the left side of each of the two figures presented in the stimulus. Even though these findings do not preclude the possibility of different NPs presenting with different types of neglect, namely egocentric and allocentric, they heavily imply that the nature of the neglect that is manifest depends upon the task that is being conducted by the NP at that current moment in time. Allocentric neglect has been found most often to be displayed by participants during completion of particular tasks that differ from those in which egocentric neglect has been demonstrated. This finding on its own offers a likely explanation for the majority of inconsistencies in neglect. Furthermore, information was revealed that attempts to 'complete the picture' of the contribution of different frames of reference in the coding of spatial information in neglect, and in normal populations.

Chapter 6. General Discussion

This thesis included a number of experiments that investigated visuocognitive processing in hemispatial neglect, through analysing patterns of eye movements during cancellation tasks and figure copying. All of the tasks included in the experiments were conducted during simultaneous tracking of neglect patients' and control participants' eye movements. This was novel research, with the measurement of patterns of eye movements in neglect during these tasks not having been collected previously. One of the aims of this research was to determine on-line sampling and processing of visual information in neglect. An important question that has not been fully addressed by previous studies investigating visuocognitive processing in neglect is whether an attentional deficit for contralesional space leads to a failure in sampling that information and therefore visual neglect (e.g. a sampling deficit of the contralesional side of space; Chédru, Leblanc, & Lhermitte, 1973; Karnath, Neimeire, & Dichgans, 1998). Alternatively, neglect patients may fixate contralesional information but fail to process it sufficiently in order to accurately respond to it (e.g. Forti et al., 2005; Walker et al., 1996). This processing deficit may result from the inability in neglect to accurately encode visual information or from a failure to represent adequately encoded information.

This research was one of the first empirical investigations providing direct evidence that deficits (and/or delays) in cognitive processing of information within contralesional regions, contribute to neglect for visual information in a group of NPs during several cancellation tasks and figure tracing and copying tasks. The relevance of this finding for current theories and characterisation of this disorder will be discussed in detail in this General Discussion Chapter. Further questions that were addressed by the current experiments concerned (1) factors that affect the allocation of spatial attention, (2) the nature of the spatial representations operating in neglect, and (3) whether demands of the task can modulate the *extent* of neglect exhibited, and, *which spatial aspects* of a visual stimulus are neglected (i.e. the frame of reference operating). All of these issues will be addressed in the following sections after experimental summarises presented next.

1. Summary of Experimental Chapters

1.2 Experiment 1, Chapter 2

Experiment 1 investigated the pattern of eye movements exhibited by a stroke patient with chronic neglect (SS), two stroke controls (SCs) and three older adult controls

(OACs), during completion of the three cancellation tasks included in the Behavioural Inattention Test (BIT; Wilson et al., 1987). Behavioural and eye movement data were obtained for standard letter, star and line cancellation tasks on three separate assessment sessions. The last session took place following limb activation treatment (functional electrical stimulation; FES) which had been administered for a period of six to eight weeks. This last session was included to assess the effect of this treatment on the underlying deficits contributing to neglect. The main aim of the study was to evaluate the viability of tracking stroke patients' eye movements with a head-mounted eye tracker during enactment of visual-motor actions that must be made during cancellation tasks. Eye tracking during these tasks had not been conducted before, even in adult control participants. To this extent, Experiment 1 represented a novel investigation of hemispatial neglect. This case study demonstrated that calibrating and measuring neglect and stroke patients' eye movements during cancellation (and potentially other) tasks was feasible and that insight into sampling and processing deficits in neglect can be gained by employing this paradigm.

The pattern of eye movements produced by SS demonstrated that during fixation of contralesional space there was a deficit in processing of target items. Furthermore, SS's line cancellation task performance indicated that there was also a delay in processing contralesional targets; when all the targets were identified within the contralesional region, SS, on average, spent nearly three times longer fixating the left region during each gaze compared to the control participants. This finding is indicative of a processing delay in identifying targets within the contralesional region.

A second important finding was that the task demands and physical properties of the stimuli appeared to have an effect on the sensitivity of the cancellation tasks in revealing neglect and therefore the extent of the neglect exhibited. The letter cancellation task, being the most cognitively demanding (requiring dual target search as opposed to single target search) and having the highest density of targets and distractors of the three tasks, was the most sensitive of the cancellation tasks. The effect of the cognitive demands of this task was evident in both SS's contralesional TIA and pattern of eye movements produced. This modulation of performance through the requirements of the task and the stimulus properties indicated that visual neglect can be exacerbated.

Finally, the effectiveness of limb stimulation as a treatment for neglect was evaluated (in relation to a single neglect patient; SS). The empirical findings suggested that both FES and robotic arm treatment were limited in ameliorating neglect. The number of targets identified within the contralesional regions did not improve in the most complex cancellation task (letter cancellation task). Performance for the less sensitive tasks (the star and line cancellation tasks) suggested that neglect and the processing deficit of contralesional information had mitigated after treatment. Specifically, in the line cancellation task, where the participants did not have to distinguish targets from distractors, contralesional processing time was equivalent to that of the control participants following treatment (recall that this was inflated before treatment). Furthermore, when it was easier to distinguish between targets and distractors (as in the star cancellation task compared to the letter cancellation task) neglect was not demonstrated on the task after treatment. The complexity of the task affected the cognitive demands required for task completion, and this impacted on the sensitivity of the task in revealing whether neglect was present after the treatment. It has been shown previously that the sensitivity of the task is important when considering the effectiveness of a treatment in improving neglect (Bonato, 2012). Understanding the influence of task demands on attention allocation and the efficacy of limb stimulation as a treatment was enhanced through eye movement analyses.

1.3 Experiment 2, Chapter 3

This experiment investigated the pattern of eye movements that patients with neglect exhibited during search for two target items, which both appeared multiple times in a search array. A newly designed letter cancellation task Simultaneously investigating Egocentric and Allocentric Neglect (SEAN task), was developed in order to investigate the operation of both allocentric and egocentric neglect simultaneously in this search task. This was the first time that patterns of eye movements had been recorded and reported for a group of patients with neglect whilst they completed cancellation tasks, and the findings extend those from the case study of SS reported in Experiment 1.

The patterns of eye movements clearly demonstrated that deficient sampling of information within the contralesional area of space occurred and was associated with poor TIA in contralesional regions by neglect patients (NPs). Little overall time was spent fixating the left regions (particularly the far left [FL] region) by NPs compared to time spent fixating the right regions. Additionally, few contralesional gazes were made on the left regions compared to the right regions and to those made by the control participants. These results further support and extend the case study findings reported in Experiment 1, and demonstrate that deficient sampling was a contributory factor of neglect of information in a group of NPs. A processing deficit was exhibited for the near left (NL) region, where

NPs made gazes on that region to the same extent as controls, and spent as long fixating that region during each gaze. Importantly, despite this sampling of the contralesional region occurring, NPs still exhibited a marked reduction in TIA compared to regions on the right that were sampled to the same extent.

As expected, the NPs showed severe neglect of information presented on the left, with poor target identification accuracy (TIA) within the left regions of the stimulus. This finding can be interpreted as evidence for egocentric neglect, as targets within left regions of the stimulus were to the left of the patients' trunk/head midline. There was no evidence for allocentric neglect being exhibited by any patients on the SEAN task. Allocentric neglect would have been indicated by NPs obtaining poorer TIA for left-sided targets (the letter 'h') compared to targets where critical information necessary for accurate letter identification was on the right side of the letter (target letter 'q'). None of the NPs exhibited this pattern. Every patient, on the other hand, neglected regions of the stimulus further to the left of their trunk/head midline, as demonstrated by TIA performance and the pattern of eye movements produced by NPs, which together suggested that egocentric neglect was in operation during this task.

It was proposed in the current thesis that allocentric neglect may be a result of information falling to the left of the current position of gaze being neglected (i.e. 'fixation-based neglect'). If this were the case then patterns of behaviour that could be interpreted as allocentric neglect would result if each object in the array was centrally fixated (which has been demonstrated to be a general tendency exhibited by participants when searching an array; Henderson, 1993). For example, the left side of an apple being neglected during completion of the Apples Test (Bickerton, Samson, Williamson, & Humphreys, 2011) or the left side of an object in the Defect Detection Task (Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001) could be explained by the objects in the task being centrally fixated and then fixation-based neglect occurring. Due to the stimulus properties of the SEAN task, with the stimulus comprising a dense array containing small target and distractor items that were presented close together, every letter would not need to be fixated, as more than one letter may have been able to be processed at once (e.g. Rayner, 1998). Therefore, if as it was suggested earlier that allocentric neglect is a result of fixation-based neglect, and, if in the SEAN task each letter was unlikely to be fixated, then the neglect of the left side of each letter would not be likely to occur.

If pure allocentric neglect (i.e. that not based on an egocentric frame of reference) had been present in NPs, then they would have exhibited poorer performance for left-sided targets, regardless of the point of fixation within the stimulus (i.e. the left side of the letter would have been neglected even if it did not fall within the LVF due to the letter being centrally fixated). Thus, it is suggested that this type of neglect was not shown on this task because pure allocentric neglect of this type does not exist and the neglect of the left side of objects can be explained by fixation-based neglect; the object is centrally fixated and, therefore, the left side of the object falls within the LVF.

1.4 Experiment 3, Chapter 4

Experiment 3 aimed to investigate whether allocentric neglect may be due to the operation of fixation-based neglect; i.e. egocentric neglect based on the position of gaze. In order to distinguish between allocentric neglect and neglect based on the position of gaze, two tasks, employing two target items that contained the critical information for accurate identification either on the intrinsic left or right side of the object (clocks) were used as stimuli in this experiment. For both tasks, NPs displayed poorer target identification within the contralesional regions, demonstrating egocentric neglect; i.e. the information to the left of the patients' trunk/head midpoint was neglected. The NPs' poor contralesional accuracy was linked with reduced fixation time on, and fewer gazes made to, the FL region compared to controls, supporting the findings reported in Experiments 1 and 2 and the idea that a sampling deficit contributed to neglect in the most contralesional region. However, in the near left (NL) region of the stimulus (second from the left), NPs made the same number of gazes, and spent the same amount of time fixating that region as the control participants, but the NPs still obtained poorer TIA than controls in that region. Furthermore, NPs spent, on average, a longer amount of time fixating the NL region during each gaze than control participants and yet still failed to identify a substantial number of target items within that region. This finding strongly supports the findings of Experiments 1 and 2, and further supports the idea that a processing deficit for contralesional information contributes to neglect.

In line with findings from Experiment 2, the behavioural results indicated that there was no evidence for any of the patients demonstrating allocentric neglect. If NPs had exhibited allocentric neglect during TIA for the target items, then performance would have been lower than for left sided targets compared to right sided targets. However, none of the NPs obtained lower TIA for the left sided target items. Overall, there was compelling evidence that neglect of the left side of objects was likely to be due to fixation-based neglect, i.e. the left side of the clock being neglected due to this information falling within the LVF. NPs obtained poorer TIA for upright left and inverted right-sided target items, where the critical information for accurate target identification fell to the left of a central fixation position, compared to targets where the critical information fell in the RVF. As mentioned previously, neglect of information based on fixation position can explain a number of reported findings of allocentric neglect (e.g. the Apples Test; Bickerton et al., 2011; the Defect Detection Task; Ota et al., 2001).

1.5 Experiment 4, Chapter 5

Experiment 4 aimed to investigate how NPs encoded and represented information, and whether either or both of these processes were deficient in neglect. Two tasks were employed, each using a similar visual stimulus. One task involved tracing the visual information presented in the stimulus (Tracing Condition) and the other required the participants to copy the information provided in the stimulus onto another piece of paper (Copying Condition). Stimuli in both conditions included two figures (the head and shoulders of a man and a woman); one of the figures appeared on the left of the stimulus and one on the right. This configuration allowed assessment of the way in which spatial information was processed during the two tasks.

A processing deficit of contralesional information has been demonstrated to be present in neglect in Experiments 1-3. It is possible that this processing deficit may result from NPs experiencing difficulties in (1) visually encoding information, or (2) representing encoded visual information. An encoding deficit would be defined as a failure for visual information to be sufficiently extracted in order to be responded to in the Tracing Condition, by NPs. The Tracing Condition was designed so that participants were only required to encode the information presented in the stimulus in order to do the task. It was thought that a representation of the stimulus would not need to be formed and stored in order for participants to trace over the lines in the stimulus. A failure to trace over contralesional stimulus lines in neglect would indicate that NPs experience difficulty encoding visual information presented within that region.

Alternatively, a representational deficit would be reflected in a failure to form or store a representation from adequately encoded information. During the Copying Condition, the participants were required to form and store a representation of the stimulus in order to copy the image onto a piece of paper presented beneath the stimulus. Poor performance in this condition would indicate problems associated with either forming or storing a representation of successfully encoded information. The behavioural data from the Tracing and Copying Conditions (the figure completion accuracy data) demonstrated that both encoding and representational deficits were present in NPs, with poor tracing and copying of contralesional figures despite NPs spending a similar amount of fixation time as the control participants when fixating contralesional regions.

These tasks not only revealed that these stages of visual processing were deficient in neglect but the effect of task demands on the neglect exhibited. It was predicted that the different task demands required in the two conditions would affect how information was processed and therefore the information that was neglected by NPs. Specifically, in the Tracing Condition, because participants could operate on the stimulus as a whole (as they did not need to represent the figures within the stimulus separately in order to conduct the task), it was expected that NPs would neglect information that was within the contralesional regions of space. In this condition, as predicted, the NPs neglected contralesional regions of space (i.e. the whole or parts of the contralesional figure). Therefore, a frame of reference based on egocentric co-ordinates appeared to be operating in this condition, with stimuli to the left of the patients' trunk being neglected, as demonstrated by the pattern of eye movements produced. In stark contrast, the pattern of eye movements during completion of the Copying Condition revealed that the two figures in the stimuli were represented separately. An allocentric frame of reference, which emphasises each object within the scene, appeared to be underlying the neglect of information in this condition. The NPs failed to sample the left side of each figure to the same extent as the right side of the figure. Together, the findings from the two different tasks demonstrate that similar visual information presented across the conditions was processed differently, depending exclusively on the task demands (tracing vs. copying the figures). Therefore, evidence of allocentric neglect was found, when the task required object-based representations of the stimuli to be activated, in patients primarily presenting with egocentric neglect.

In summary, the four empirical experiments conducted in this thesis have revealed three main findings: (1) both sampling and processing deficits underlie neglect of contralesional visual information; (2) allocentric frames of reference appear to be dependent upon egocentric frames of reference; and (3) task demands affect the extent of neglect and the way in which spatial information is processed, with allocentric neglect only being apparent if the task required object-based representations of information to be activated. These three main findings will now be explained and discussed in relation to visual processing and theories of neglect in the following sections.

2. Mechanisms Underlying Hemispatial Neglect: The Value of Eye Movement Analyses

Eye movements are recognised as a valuable methodology to investigate attentional and cognitive processing in a number of clinical populations (e.g. anxiety, Mogg, Millar, & Bradley, 2000; social phobia; Garner, Rutherford, Baldwin, Bradley, & Mogg, 2005; Autism Spectrum Disorder, Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; attention-deficit/hyperactivity disorder, Munoz, Armstrong, Hampton, & Moore, 2003; chronic pain, Liossi, Schoth, Godwin, & Liversedge, 2014). Eye movements are particularly relevant when investigating neglect, as neglect is considered a disorder of attention (e.g. Behrmann, Ghiselli-Crippa, Sweeney, Di Matteo, & Kass, 2002; Mesulam, 1981), and eye movements have been demonstrated to be strongly associated with attentional processing (Shepherd, Findlay, & Hockey, 1986).

2.1 Sampling and Processing of Contralesional Information in Neglect

It has been postulated that neglect reflects a 'breakdown in the mechanisms subserving the orienting response' (Heilman & Watson, 1977, pp. 285). The orienting hypothesis, and theories that postulate that there is a disruption to the attentional mechanisms for contralesional regions of space (e.g. Halligan & Marshall, 1994; Heilman & Valenstein, 1979; Mesulam, 1981), are supported by the finding of that a contralesional sampling deficit was associated with poor target identification within the left regions of space in neglect. This finding was replicated in all of the experiments reported in this thesis. Although these theories may differ in details, they share the notion that neglect is a consequence of a breakdown in a system that normally allocates attentional resources to locations in the neglected hemispace. A contralesional sampling deficit indicates that NPs exhibited a deficit in directing attention to the left side of space. If attention is not allocated to the left, it is likely that an eye movement will not be prepared and initiated into that region (Shepherd, Findlay, & Hockey, 1986) in order to sample information present in that region; a sampling deficit will, therefore, be apparent.

Another key finding was that, on occasions, when the left regions of space were fixated, neglect was still apparent. This suggests a processing deficit of fixated information was contributing to neglect, particularly in the far left region of space. The experiments in this thesis provided the first in depth study to demonstrate that a processing deficit contributed to neglect of visual information in a group of NPs. This was important in order to reveal whether such a deficit was an underlying mechanism in the disorder of neglect and that the deficit was not a result of specific lesions in a sub-set of neglect patients (i.e. in case studies reported; Benson et al., 2012; Forti et al., 2005; Walker et al., 1996). It has been suggested that there is impairment in information processing in neglect when information is presented in the contralesional region of space (Bartolomeo & Chokron, 2001; Denny-Brown, Meyer, & Horenstein, 1952; Riddoch & Humphreys, 1987a) but this has undergone very little empirical investigation in terms of its contribution to the neglect of visual information.

Denny-Brown et al. (1952) were the first to propose that the synthesis of multiple sensory data was deficient in neglect. They noted in a single case study of neglect that, during sensory stimulation (the patient touching an object with her left hand) without visual guidance (her eyes were closed), the patient was still not able to accurately identify the object's size, shape, texture or form. Therefore the object was accurately sampled through the sensory modality but was still not accurately reported. This is analogous to fixating information in the contralesional region of space but failing to process it adequately in order to identify it. As a result of the patient being able to recognise a single object presented in the contralesional region of space, yet neglecting to detect this in her natural behaviour, Denny-Brown and colleagues suggested that "the mechanism of recognition is essentially intact, therefore the explanation of failure must be sought in some complicating factor which interferes with the neural events leading to recognition" (Denny-Brown et al., 1952, pp. 452). The authors concluded that the discriminative ability for information presented in the contralesional space was diminished in neglect. They believed there to be a loss of fine discrimination; in the ability to synthesise more than a few properties of a sensory stimulus, which prevents information from being passed on to higher-level recognition processes (Riddoch & Humphreys, 1987a). Bisiach and Rusconi (1990) found that the left part of an image may still be neglected even though the neglect patient could accurately trace the information in that part of space with their finger. Bisiach and Rusconi concluded that this finding demonstrated "defective pick-up of information from the left-most part of the stimuli" (pp. 647). This provides support for an encoding deficit in neglect, which was suggested to contribute to poor tracing performance in Experiment 4.

Synthesising properties of a sensory stimulus relates to Treisman and Gelade's (1980) feature-integration theory. Treisman and Gelade proposed that the visual scene is analysed at an early stage of visual processing by specialised populations of receptors that respond selectively to aspects such as orientation, colour, spatial frequency, contrast, movement etc. These elements are, thus, processed separately. In order to recombine this separate encoded information and to ensure the correct synthesis of features for each object in a complex display, stimulus locations are processed serially with focal attention. Treisman and Gelade stated that any features which are present in any central ‘fixation’ of attention are combined to form a single object. This synthesis of properties when fixating the contralesional side of space appears to be deficient in neglect. If that is the case, then this would result in fewer target items being identified in the contralesional regions of space when they were fixated (or there being a delay in completing target identification) as the features of each potential target are not integrated (or are integrated inefficiently).

This reduction in discriminative ability on the contralesional side of space does not have to be due to a primary sensory deficit, but can be a deficit in the integration of multiple sources of sensory information that have been extracted for contralesional information. Denny-Brown and colleagues stated that there “was a depression of perceptive function for the left side without loss of the elementary sense of touch, pain or temperature” in neglect (Denny-Brown et al., 1952, pp. 452). Therefore, this theory of neglect could explain why there is evidence of a processing deficit of contralesional information. If there is a deficit or delay in integrating sensory information from the contralesional side of space this would explain a deficit in identifying target items within the contralesional region of space during cancellation tasks, and the inability to encode or represent information from the contralesional side of space during figure copying or tracing. However, the processing stage at which the breakdown occurs in patients suffering from neglect has still not been determined (Deouell, Hämäläinen, & Bentin, 2000). Experiment 4 reported in this thesis demonstrated that both encoding and representation of visual information presented within the contralesional region of space was deficient in neglect, with poor figure tracing and copying accuracy for contralesional regions shown by NPs.

As neglect occurs in other modalities other than in the visual domain (e.g. patients can neglect auditory stimuli on the left or sensory stimulation on their left limbs), it is not clear how sampling and processing deficits would be able to account for these deficits. As visual neglect dissociates from other types of neglect (e.g. auditory neglect, sensory neglect; Bartolomeo, 2002) it may be that there are different underlying deficits that are the cause of these different deficits and not one underlying mechanism can explain all types of neglect. Furthermore, as visual neglect is exacerbated compared to other types of neglect, often within the same individual, it may be that the reason for this is that visual processing is more complex and poor sampling and processing deficits that are apparent in neglect restrict responding to contralesional visual stimuli in neglect further than for other types of stimuli (e.g. auditory). Despite this, it appears that a processing deficit for contralesional information could also explain neglect of auditory or sensory information. For example, in auditory neglect, the sound may be registered by the auditory system but this information is not processed sufficiently in order to reach conscious awareness. This may result from a failure to encode the auditory information or to represent that information accordingly in order to respond to it, as has been suggested for visual neglect (e.g. Denny-Brown et al. 1952). New evidence comes from ERP studies demonstrating that there are deficits rather early in the stream of auditory processing for stimuli appearing on the contralesional side of neglect patients (e.g. Deouell et al., 2000).

Deouell et al. (2000) aimed to investigate whether encoding deficits contributed to auditory neglect in 10 neglect patients. Event-related potentials were measured whilst participants listened to auditory stimuli that differed either in pitch, duration or spatial location. They found that the magnitude of N1, which reflects the early response of the primary tonotopic cortex to auditory stimuli, did not differ when the auditory stimuli was placed on the left or right of the patient. This suggested that auditory stimuli were registered accordingly regardless of being presented on the contralesional or ipsilesional side in neglect. However, they did find that the mismatch negativity (MMN) signal, which shows whether a stimulus has been detected as differing on a parameter (e.g. pitch, duration, spatial location) from an existing auditory stimulus, was deficient (significantly reduced) for auditory stimuli that differed on a parameter when the stimuli were presented on the left side of space. The authors concluded that this finding suggests the existence of a rather early, albeit selective, deficit in processing auditory information in the left space for patients with neglect. The deficit may reflect problems with integrating the different properties of the sound in order to detect that it is different from another source and links to the proposed deficit in integrating multiple sensory information in visual neglect (e.g. Denny-Brown et al., 1952).

There are other possible factors that could explain the processing deficit that was apparent in the results of all the experiments reported in this thesis. Firstly, as outlined in Chapter 1, some researchers believe that working memory deficits can contribute to poor neglect performance. If NPs do present with this problem then it is likely that they would spend more time fixating the contralesional regions of space and make more fixations within those regions than the control participants due to re-fixating target items, despite them having been fixated before due to poor location memory for previously fixated targets. As this pattern of eye movements was demonstrated in the experiments, working memory deficits may be able to explain this effect. However, working memory deficits would be likely to cause problems within the non-affected regions of space as well (i.e., the ipsilesional near right and far right regions). As it was demonstrated that, as expected, performance was poorer within the contralesioal regions for NPs and that the average gaze durations were often inflated in these regions (or the same durations as the control participants' but NPs had poorer accuracy within those regions) compared to ipsilesional regions, this account may not be able to fully explain these results. Similarly, reduced vigilance and arousal may be able to explain the increase in average gaze duration in the left (as participants require more time to identify targets due to lower levels of arousal). However, a corresponding deficit on the right should have been apparent, which was not always indicated (on some occasions 'hyper-attention' on the far right was demonstrated which could provide evidence for an overall deificit in vigilance/arousal for NPs compared to controls). As the SCs exhibited longer average gaze durations overall compared to NPs during completion of the SEAN cancellation task (refer back to Table 13 in Appendix D), it appears that NPs did not demonstrate less arousal/vigilance overall than the stroke controls.

In summary, evidence has been provided to show that both poor sampling and processing of contralesional information can result in visual information being neglected. Sampling deficits of contralesional regions was apparent in neglect and were associated with poor target identification there. When information was sampled, particularly in the near left region, a processing deficit was apparent. Processing deficits, which may stem from an inability to integrate sensory information within contralesional regions of space, may be able to explain a number of different types of neglect irrespective of the modality. The stages at which processing deficits are apparent in visual neglect and whether these are present for other types of neglect requires further investigation.

3. The Allocation of Spatial Attention

The idea that a processing deficit represents an inability to integrate multiple sources of sensory information may explain why increasing cognitive demands would exacerbate neglect. The more information there is to integrate (e.g. in the letter cancellation task from the BIT), the greater the information processing deficit may be and, thus, the further the ability to discriminate between targets and distractors within that contralesional regions is diminished. This would result in fewer target items being identified there. The allocation of spatial attention, and the factors that affect this, will be considered next.

In Experiment 1, conducted on patient SS, the complexity of the task was demonstrated to have an impact on the extent of neglect that was exhibited. It has been demonstrated previously that task complexity can have an impact on the extent of neglect exhibited, but the reasons for these differences were poorly understood (Ferber & Karnath, 2001) and required elucidation. The letter cancellation task was a more complex task to complete, compared to the star and line cancellation tasks, because it comprised of a dense visual array and had high numbers of targets and distractors (Chatterjee et al., 1992; Mennemeier et al., 1998; Mennemeier, Morris, & Heilman, 2004; Rapcsak, Verfaellie, Fleet, & Heilman, 1989), with targets being similar to the distractors presented (Rapcsak et al., 1989; Riddoch & Humphreys, 1987b). This task also required dual-target search. Although it cannot be determined which specific factor of the letter cancellation task restricted attention to the contralesional regions by SS during completion of this task, it is likely that this resulted from a combination of factors. All of the manipulated factors in the letter cancellation task have the effect of increasing the cognitive load associated with conducting the task and result in attention being allocated more locally and serial search being induced, both of which have been demonstrated to affect the extent of neglect exhibited (Gainotti, D'erme, Monteleone, & Silveri, 1986; Mennemeier, Morris, & Heilman, 2004). It appears that expending processing resources at a local level (processing of each item within the array), restricted global attention to the stimulus and, therefore, to left regions of space. The influence of increased cognitive demands restricting contralesional attention in neglect supports findings from Aglioti et al. (1997) and Ferber and Karnath (2001). Aglioti et al. found that conjunction search tasks exacerbated neglect compared to feature detection tasks. Furthermore, Ferber and Karnath’s study demonstrated that complex and more visually demanding cancellation tasks were more sensitive in revealing the presence of neglect. These findings suggest that attention is dynamic and can be affected by a number of different aspects of the external environment (e.g. stimulus properties) and the internal state of the participant (e.g. number and the nature of the cognitive processes that are operating simultaneously).

The modulation of the extent of neglect as a result of differences in task demands supports the premise that cognitive resources are limited (Wickens, 2002) and therefore, if resources are expended in, for example dual-target search, fewer cognitive resources will be available to process contralesional information in neglect. Experiments 2 and 3 confirmed that task complexity (dual-target search and visually dense arrays; the SEAN task) could exacerbate neglect in comparison to less visually complex stimuli and single-target search tasks (the clock cancellation tasks) in a large group of NPs. The *extent* of neglect, thus, has been reliably shown to be affected by the complexity of the task.

Task demands were also demonstrated to affect *which spatial information* was neglected by NPs. In Experiment 2 it was found that neglect was not operating at the level of the letter during the SEAN task, otherwise the left side of the target would be neglected (therefore, the left sided targets would have been more difficult to identify by NPs), which was not the case in that study. However, in Experiment 3, the findings demonstrated that neglect was operating at the level of the clock during the clock cancellation tasks, with targets that contained critical information for accurate target identification on the left of a central fixation being identified on fewer occasions by NPs than for targets where this information was to the right of a central fixation position. Furthermore, in Experiment 4, the task demands affected the spatial aspects of the stimulus that were neglected. The left side of the stimulus was neglected in the Tracing Condition, as the whole stimulus was processed (*what* the image was did not matter in order to trace the stimulus). In stark contrast, during copying of a similar stimulus, the left side of each figure was neglected, as each figure had to be represented separately in order to accurately copy the image. Therefore, egocentric and allocentric neglect can be manifested within the same individual, and, this is determined by the current goal of the patient.

Findings that task demands can affect which spatial information is neglected suggest that allocentric neglect may not be based on the type of neglect the patient exhibited, but by the task demands. Allocentric neglect may not be a specific sub-type of neglect in itself but may occur when object-based representations are activated as they are deemed imperative for task completion by NPs. Crucially, all the NPs included in Experiment 4 presented primarily with egocentric neglect. However, all exhibited allocentric neglect when the task required the objects to be represented. These findings support those found in previous studies that task demands affect which information is neglected (e.g. Baylis, Baylis, & Gore, 2004; Behrmann & Plaut, 2001; Driver & Halligan, 1991; Karnath & Niemeier, 2002).

In summary, the cognitive processing that a task demands can affect the way in which spatial attention is allocated, and the type and location of information that is not attended to in neglect. Both allocentric and egocentric neglect being exhibited in *all* NPs, dependent upon the task demands, suggests that allocentric neglect may not be a specific sub-type of neglect but may operate due to relative egocentric neglect or fixation-based neglect if the task demands require activation of object-based representations. This will be considered in the next section.

4. Frames of Reference Operating in Neglect

Two main spatial reference frames have been proposed to operate in neglect, namely, egocentric and allocentric frames of reference. Egocentric reference frames refer to the coding of spatial information with respect to the viewer's position. 'Left' is defined in relation to the midpoint of the viewer (with this midpoint potentially relating to the eyes, head and/or trunk of the patient; Behrmann et al., 2002). If this reference frame was operating neglect then everything to the left of the patient's midline would be neglected. Egocentric reference frames based on eye positioning would result in information falling within the left visual field (LVF) being neglected.

Allocentric reference frames emphasise each individual object within the visual field. Left and right correspond to the left and right of each object, regardless of the object's orientation or its position in relation to the viewer (Behrmann & Moscovitch, 1994). However, this type of reference frame operating in neglect is still somewhat contentious. Furthermore, the dependence of the operation of allocentric neglect on egocentric frames of reference is unknown. Allocentric neglect may be explained by the left side of upright objects falling in the LVF (i.e. to the left of an egocentric midline) when the object is centrally fixated.

In Experiments 2-4 the frames of reference that operate in neglect, i.e. how spatial information is processed, was investigated. It was found in Experiments 2 and 3 that allocentric frames of reference were not operating in any of the NPs included in these studies. However, egocentric neglect was apparent in both patterns of TIA and eye movements exhibited by the NPs, with fewer targets being identified to the left of the patients' midline and less sampling of that region occurring. Experiment 3 demonstrated that what has been considered as allocentric neglect previously, may in fact have reflected the left side of an object being neglected due to falling within the neglected visual field when an object is centrally fixated. Although, further evidence needs to be provided with regards to the fixation position within the object for NPs during this type of task to determine whether information falling to the left of the fixation position is neglected or it is the left side of the object that is neglected regardless of the fixation position. Therefore, the left side of the object may be neglected due to the operation of an egocentric reference frame based on eye position.

As no evidence was provided for the existence of allocentric neglect in isolation in any NPs included in the experiments reported in this thesis, whether allocentric neglect can operate without the influence of egocentric neglect remains a highly contended issue. It seems highly implausible that an allocentric frame of reference is activated, a representation of the object is formed and then the left side of it is neglected. This concept is suggested by studies that have found that NPs neglect the the first part of the word (the canonical left side of the word) even when it is presented in another orientation (e.g., vertically) or in its mirror-reversal form (Caramazza & Hillis, 1990). To be clear, in order for the intrinsic left side of the word to be neglected when the word is presented in a mirror-reversed format, the word has to have been recognised, represented, rotated in order for the left side to be neglected when this part of the word is now presented in the intact hemispace. The word has to have been recognised before subsequent neglect of the intrinsic left side occurred when the word is presented in its mirror-reversed format, as otherwise this information would not be neglected due to falling within an ipsilesional region of space. However, it may be that these types of neglect (neglect of the intrinsic left side of an object when it has been rotated) are atypical of the syndrome. Often such demonstrations reflect rare cases, such as right neglect patients (as in Caramazza & Hillis, 1990) or sinistrals (left-handed individuals) with neglect, who are proposed to process object-centred representations (Walker, 1995).

Other evidence which has been provided as support for different frames of reference operating in neglect come from studies where the patient neglects information to their left in one task, and information on the left side of an object in another task. For example, neglect of the left side of a word has been suggested to reflect allocentric frames of reference operating (Walker, 1995). On the contrary, neglect of words lying to the left of a page could indicate egocentric neglect or the left side of the stimulus being neglected. Given the findings from Experiment 4 that task demands affect the frame of reference that is operating, it seems plausible that different frames of reference may result from the different task demands in these two conditions. When a word is presented in isolation, the focus of the individual is that word and neglect operates at that spatial scale. On the contrary, when words are presented on a piece of paper to be read, the page is important to conduct the task and therefore the left side of that page is likely to be neglected. Therefore, as task demands affect the frames of reference that are operating, it is important to measure the operation of both allocentric and egocentric neglect simultaneously, as in the SEAN and clock cancellation tasks in this thesis. Otherwise the different manifestations of neglect are likely to be a result of the different task demands (e.g. reading text vs. reading isolated words).

In the current experiments, no evidence was provided for allocentric neglect in tasks that simultaneously investigated the operation of the two reference frames. It is not suggested by the current experimental findings that patients do not neglect the left side of objects presented upright, but this has been suggested to be a result of the operation of egocentric neglect (based on eye position) irrespective of whether that information is on the intrinsic left side of the object. Furthermore, the operation of this type of neglect was found to be a direct result of the requirements of the task, in all neglect patients (i.e. in patients who primarily present with egocentric neglect which is the most common reported type of neglect). Relative egocentric neglect may be able to account for neglect behaviour consistent with the activation of allocentric frames of reference based on task demands. For example, in the Copying Condition, the left side of the figure presented on the right side of the stimulus, may have been neglected due to receiving less activation than the right side of the figure (Driver & Pouget, 2000).

The fact that task demands appear to have an impact on the way in which neglect operates over the stimulus would suggest that multiple frames of reference operate in the coding of spatial information. Karnath and Niemeier (2002) concluded from their investigation into the effects of task requirements on neglect that the representation of the same physical input is continuously reorganised according to the changing task requirements. This reorganisation of spatial representations is ongoing in visual perception and, therefore, for neglect patients results in different information being neglected dependent on the current representation that has been activated. This way of thinking can provide one explanation for why the disorder appears to be so heterogeneous; it is a dynamic disorder that is influenced by a number of factors, and these factors (e.g. task demands) affect the level at which neglect operates.

In summary, it appears that allocentric neglect is dependent on the operation of egocentric neglect, and allocentric frames of reference only operate in patients primarily exhibiting egocentric neglect when task demands require object-based representations to be processed. Therefore, allocentric neglect is likely to be a manifestation of egocentric neglect at different levels (e.g. relating to the position of the trunk, head, or eye midline). To be clear, the left side of an object is neglected irrespective of the relationship of that information to the object as a whole. It is neglected because this information falls relatively to the left of any one of these points (an egocentric reference frame). Furthermore, absolute egocentric position and the relative position of information in relation to other aspects of the stimulus (Driver & Pouget, 2000) is important in spatial processing in neglect.

5. Conclusions

The series of experiments reported in this thesis represented the first investigations to report patterns of eye movements in neglect during the completion of cancellation tasks and figure copying; the most common clinical screening tests for neglect. A number of novel contributions have arisen from this research. Insight was gained with regard to the extent that sampling and processing deficits contribute to the neglect of visual information during cancellation tasks. The findings suggested that, due to a processing deficit being demonstrated for a group of neglect patients, that it is an underlying deficit contributing to visual neglect and not just experienced by a sub-set of NPs previously reported in case studies (Forti et al., 2005; Walker et al., 1996). A processing deficit may result from a failure to integrate visually encoded properties of a visual stimulus in order to represent, and respond to, the information accurately. It is likely that a processing deficit of contralesional information could also explain other types of neglect (e.g., auditory, sensory).

There was no evidence for the existence for allocentric neglect presenting in isolation in any of the NPs for tasks simultaneously investigating the two reference frames. Simultaneous examination of egocentric and allocentric neglect is required in order to ensure that task demands do not have an impact on the type of neglect present. Task demands were demonstrated to have an impact on which spatial aspects of the scene that were neglected by NPs in Experiment 4. All patients presented with egocentric neglect. When allocentric neglect was exhibited this was due to the task demands resulting in egocentric neglect operating at a level that has previously been interpreted as allocentric neglect. It is likely that allocentric neglect has been demonstrated in some studies due to the demands of the task (e.g. Carmazza & Hillis, 1990; Hillist al., 1998) or because of the operation of fixation-based neglect (Bickerton et al., 2011; Ota et al., 2001).

The findings from these experiments have important implications for diagnosing and treating neglect. Firstly, in order to be able to diagnose different types of neglect, tasks must be developed to identify both egocentric and allocentric neglect simultaneously.

Even though the existence of the latter type of neglect is still contended, the evidence provided in the studies outlined in this thesis suggest that allocentric, object-based, neglect can occur if the task demands require focused, selective, attention on each individual item within the task. If object-based neglect occurred without more global egocentric neglect of target items on the left of the task, then these patients would not be identified as having neglect if the current diagnostic tasks (e.g., the BIT cancellation tasks) were employed in isolation. Secondly, the task demands and cognitive load that is imposed by a task must also be considered. If, for example, the line cancellation task were to be conducted in isolation, many patients with neglect may perform optimally and would fail to be diagnosed.

Finally, evidence was provided that not only a sampling deficit contributes to neglect. A processing deficit of fixated contralesional information was apparent from the results of all the experiments conducted. This heavily implies that scanning training alone would not be a sufficient treatment for neglect. Combining this type of treatment with another form of rehabilitation that increases the activation in the affected hemisphere (such as Functional Electrical Stimulation of the affected limb), and thus the processing of contralesional space, was suggested to be able to improve processing within contralesional regions of space. This type of combined treatment is likely to be the most effective and long-lasting rehabilitative method for neglect but requires further investigation to establish the longevity in ameliorating neglect.

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Footnotes

[1]Medical records detailing the exact lesion areas were not available for the stroke controls included in this study due to the out-patient nature of the recruitment. Information regarding hemispheric damage was sought from the participants and confirmed via clinical presentation (e.g., left hemiparesis).

[2] For Experiment 2, the hand scoring of the eye movement data was highly correlated for the two assessors (Louise-Ann Leyland and Joice Dickel Segabinazi), $r(20) = .848$, $p < .001$.

[3] For Experiment 3, the hand scoring of the eye movement data was highly correlated for the two assessors (Louise-Ann Leyland and Joice Dickel Segabinazi), $r(20) = .968$, $p < .001$.

[4]The restricted sampling of the FL region demonstrated in the number of gazes measure was significantly correlated with TIA within that region for the NPs, r (13) = .607, $p = .028$. The more gazes that were made to the FL region, the higher the TIA within that region.

[5]As for the number of gazes measure, the proportion of time spent fixating the FL region was significantly positively correlated with poor TIA, r (13) = .936, $p < .001$. The higher the proportion of time spent fixating the FL region, the higher the TIA within that region for NPs.

Appendices

Appendix A

Snellen Visual Acuity Test (Schneider, 2002).

Near Vision Test Card

Hold at a distance of 16 inches (40.6 centimeters).

160 in.	E O P Z T L C D F	4.0 m
80 in.	T D P C F Z O E L	2.0 m
56 in.	D Z E L C F O T P	1.4 m
48 in.	F E P C T L O Z D	1.2 m
40 in.	P T L F C Z D E O	1.0 m
32 in.	E L Z T C O F P D	80 cm
24 in.	D Z E C L P T O F	60 cm
20 in.	L O P F Z E D C T	50 cm
16 in.	[illegible]	40 cm

Appendix B

Mini-Mental State Examination

Name/Patient ID____ Date____________________

1. What is the date? Year________________________________ 1
   Season________________________________ 1
   Date________________________________ 1
   Day________________________________ 1
   Month________________________________ 1

2. What is the name of this hospital?____________________________ 1
   Country________________________________ 1
   County________________________________ 1
   Town________________________________ 1
   Floor________________________________ 1

3. Name three objects: (participant repeats) Plantpot________________________________ 1
   Television________________________________ 1
   Comb________________________________ 1

4. Count backwards from 100 in 7s (stop after 5 subtractions)
   93 ________________________________ 1
   86________________________________ 1
   79________________________________ 1
   72________________________________ 1
   65________________________________ 1

Or, if the participant cannot do this ask them to spell the word ‘WORLD’ backwards
DLROW________________________________ 5

5. Ask the participant to recall the 3 words remembered earlier
   Plantpot________________________________ 1
   Television________________________________ 1
   Comb________________________________ 1

6. Show the participant two objects and ask them what they are (pen and clock)
   Pen________________________________ 1
   Clock________________________________ 1

7. Ask the patient to repeat the following sentence:
   No ifs, ands or buts______________________ 1

8. Follow this instruction ‘Take a piece of paper, fold it in half and place it on the floor’
   ____________________3

9. Read and obey the following ‘close your eyes’__________________1

10. Write a sentence____ 1

11. Copy design (as a part of the BIT)____________________________ 1 TOTAL /30

Appendix C

Acquired Patient Information

Participant number/ Patient number	
Date of birth	
Gender	Male/Female
Handedness	Right/Left
Premorbid handedness	Right/Left
Aetiology	Infarct/hemorrhage/other/unknown Other:
Stroke damage	Area: Hemisphere: Right/Left
Date of stroke	Date: Type of scan/date:
Date diagnosed with neglect	Date: Extinction? Yes/No
Suffered a stroke before?	Yes/No

	If so, date(s) of stroke(s):
Comorbidity	Disease: Illness: Other disorders:
Currently on a course of medication?	Yes/No If yes What is the medication: Why is the patient taking the medication: How long is the patient taking it for:
Years of education	

Appendix D

Table 10

Average Target Identification Accuracy (%; sd in parentheses) across the Four Regions of the SEAN task (FL, NL, NR, FR) and Two Target-Types (Left sided Target, Right Sided Target and Total) for the Three Participant Groups (NP, SC, OAC)

	FL			NL			NR			FR		
	Left Target	Right Target	**Mean**	Left Target	Right Target	**Mean**	Left Target	Right Target	**Mean**	Left Target	Right Target	**Mean**
NP	26.78	17.86	**22.32**	53.57	44.64	**49.11**	73.21	61.60	**67.41**	76.79	73.41	**75.10**
	(30.95)	(27.61)	**(29.28)**	(37.79)	(32.79)	**(35.29)**	(27.67)	(27.94)	**(27.81)**	(25.40)	(27.70)	**(26.55)**
SC	87.50	84.38	**85.94**	95.31	95.31	**95.31**	92.19	92.19	**92.19**	90.63	92.19	**91.41**
	(13.36)	(8.83)	**(11.10)**	(6.47)	(9.30)	**(7.89)**	(13.25)	(13.25)	**(13.25)**	(12.94)	(9.30)	**(11.12)**
OAC	87.50	98.95	**93.23**	95.83	97.91	**96.87**	97.91	96.88	**97.40**	94.79	95.83	**95.31**
	(9.23)	(3.60)	**(6.42)**	(8.14)	(4.87)	**(6.51)**	(4.87)	(5.65)	**(5.26)**	(8.36)	(8.14)	**(8.25)**

Table 11

Average Number of Gazes (SD) made on the Four Regions (Far Left, Near Left, Near Right, Far Right) of the SEAN Task Stimulus for the NPs, SCs and OACs

Group	Region			
	Far Left	Near Left	Near Right	Far Right
NPs	6.31 (5.23)	20.46 (12.71)	38.62 (24.29)	26.77 (17.67)
SCs	17.33 (5.61)	28.67 (9.33)	26.33 (8.28)	14.33 (5.05)
OACs	14.33 (4.40)	22.33 (7.01)	21.17 (8.22)	13.33 (5.16)

Table 12

Average Proportion of Time (SD in parentheses) spent Fixating the Four Regions (Far Left, Near Left, Near Right, Far Right) of the Letter Cancellation Task Stimulus for the NPs, SCs and OACs

Group	Region			
	Far Left	Near Left	Near Right	Far Right
NPs	.09 (.10)	.18 (.12)	.28 (.05)	.46 (.18)
SCs	.26 (.02)	.25 (.03)	.25 (.01)	.24 (.03)
OACs	.27 (.03)	.26 (.03)	.23 (.02)	.24 (.02)

Table 13

Average Gaze Duration (ms; SD in parentheses) on the Four Regions (Far Left, Near Left, Near Right, Far Right) of the SEAN Task for the NPs, SCs and OACs

Group	Region				
	Far Left	Near Left	Near Right	Far Right	**Mean**
NPs	2339 (2983)	1716 (2040)	1555 (1723)	4086 (5129)	**2378 (3409)**
SCs	3425 (3843)	1984 (2219)	2145 (2442)	3805 (3377)	**2622 (2968)**
OACs	2811 (2296)	1736 (1787)	1636 (1475)	2693 (2391)	**2102 (2010)**

Appendix E

Table 14

Average Target Identification Accuracy (%; SD in parentheses) for the Four Regions (Far Left, Near Left, Near Right, Far Right) for each Participant Group in the Left Clock Task.

	Far Left	Near Left	Near Right	Far Right
NPs	43.33 (38.97)	55.00 (32.97)	68.33 (24.26)	82.50 (25.92)
SCs	95.00 (9.05)	95.00 (9.05)	96.67 (7.79)	95.00 (9.05)
OACs	98.33 (5.65)	98.33 (5.65)	97.50 (6.76)	96.67 (7.61)

Table 15

Average Target Identification Accuracy (%; SD in parentheses) for the Four Regions (Far Left, Near Left, Near Right, Far Right) for each Participant Group in the Right Clock Task.

	Far Left	Near Left	Near Right	Far Right
NPs	29.17 (31.75)	56.67 (33.71)	73.33 (27.45)	76.67 (32.66)
SCs	95.00 (9.05)	93.33 (13.03)	96.67 (11.55)	81.67 (21.67)
OACs	99.17 (4.08)	95.00 (10.63)	95.83 (10.18)	93.33 (12.74)

Table 16

Average Number of Gazes (SD in parentheses) made on the Four Regions (Far Left, Near Left, Near Right, Far Right) of the Left Clock Task by the Three Participant Groups.

	Far Left	Near Left	Near Right	Far Right
NPs	4.30 (4.69)	11.10 (9.69)	16.10 (10.80)	9.60 (5.80)
SCs	8.13 (3.44)	15.25 (4.89)	15.75 (6.27)	8.13 (3.52)
OACs	6.83 (4.11)	12.50 (6.68)	11.58 (7.04)	6.42 (4.29)

Table 17

Average Number of Gazes (SD in parentheses) made on the Four Regions (Far Left, Near Left, Near Right, Far Right) the Right Clock Task by the Three Participant Groups.

	Far Left	Near Left	Near Right	Far Right
NPs	3.80 (4.42)	13.40 (11.12)	23.20 (14.60)	13.90 (10.13)
SCs	10.13 (4.45)	18.50 (7.96)	17.00 (7.41)	8.63 (3.70)
OACs	7.00 (4.05)	12.25 (5.79)	11.50 (5.42)	6.00 (3.59)

Table 18

Average Proportion of Time (SD in parentheses) Spent Fixating the Four Regions (Far Left, Near Left, Near Right, Far Right) on the Left Clock Task and Total Proportion of Time Fixating the Stimulus (demonstrating the Group Effect) during the Trial by the Three Participant Groups.

	Far Left	Near Left	Near Right	Far Right	**Total**
NPs	.12 (.10)	.21 (.09)	.29 (.09)	.37 (.11)	**.996 (.005)**
SCs	.25 (.04)	.23 (.03)	.26 (.04)	.26 (.03)	**.999 (.000)**
OACs	.25 (.04)	.27 (.06)	.25 (.03)	.23 (.02)	**1.00 (.000)**

Table 19

Average Proportion of Time Spent Fixating (SD in parentheses) the Four Regions (Far Left, Near Left, Near Right, Far Right) on the Right Clock Task for the Three Participant Groups.

	Far Left	Near Left	Near Right	Far Right
NPs	.09 (.10)	.21 (.09)	.32 (.08)	.37 (.15)
SCs	.27 (.04)	.25 (.03)	.24 (.02)	.24 (.05)
OACs	.27 (.03)	.24 (.03)	.25 (.02)	.24 (.03)

Table 20

Average Gaze Duration (ms; SD in parentheses) spent Fixating the Four Regions (FL, NL, NR, FR) for the Three Participant Groups on the Left Clock Task

Group	Region				
	Far Left	Near Left	Near Right	Far Right	**Mean**
NPs	6052 (8665)	4294 (6147)	4006 (5410)	8749 (10378)	**5406 (7614)**
SCs	6381 (7942)	3166 (4740)	3466 (5392)	6557 (8000)	**4402 (6379)**
OACs	4602 (5874)	2783 (4154)	2803 (3450)	4487 (5255)	**3415 (4592)**
Mean	**5539 (7316)**	**3343 (5012)**	**3453 (4867)**	**6772 (8521)**	

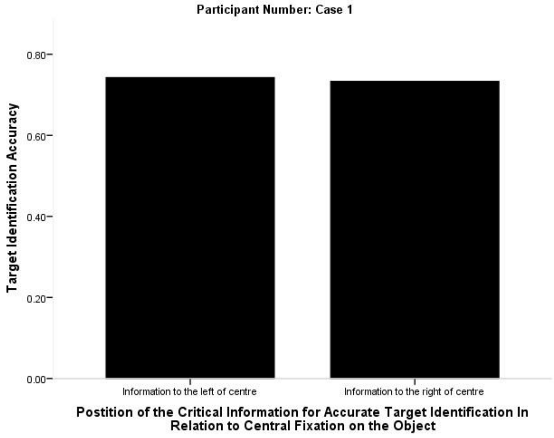
Table 21

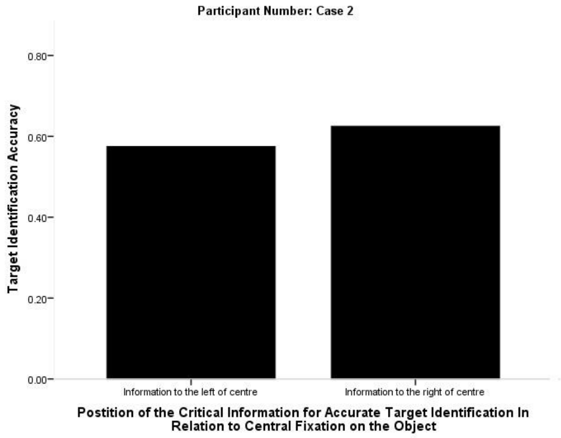
Average Gaze Duration (ms; SD in parentheses) spent Fixating the Four Regions (FL, NL, NR, FR) for the Three Participant Groups on the Right Clock Task

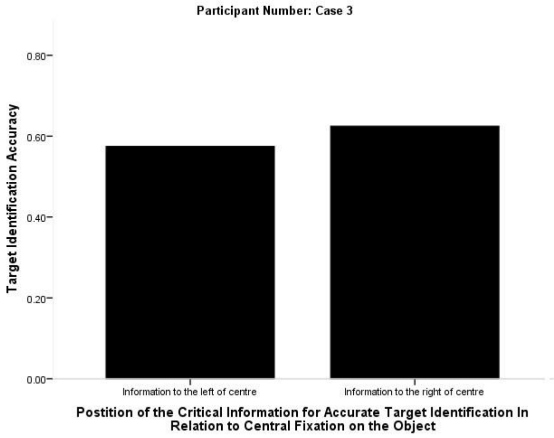
Group	Region				
	Far Left	Near Left	Near Right	Far Right	**Mean**
NPs	6471 (12510)	4005 (5319)	3723 (5434)	7324 (9456)	**4907 (7446)**
SCs	5436 (8700)	2769 (5766)	2899 (4000)	5606 (7011)	**3758 (6294)**
OACs	4512 (4080)	2292 (3099)	2589 (3397)	4648 (4955)	**3193 (3866)**
Mean	**5247 (8124)**	**2991 (4898)**	**3192 (4601)**	**6212 (7987)**	

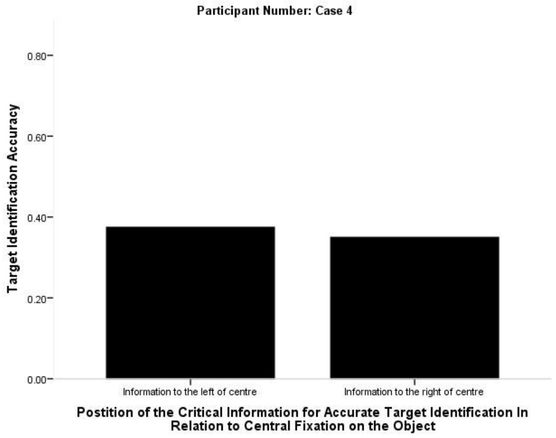
Appendix F

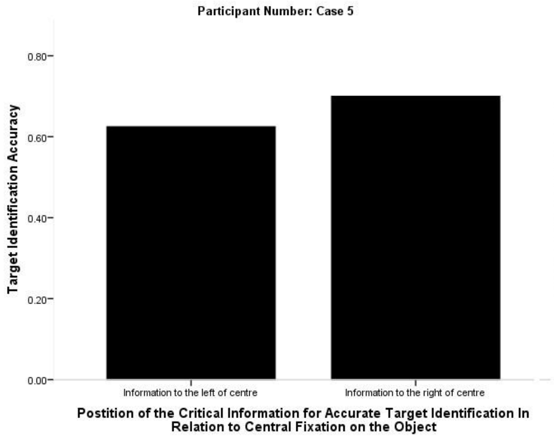
Target Identification Accuracy (%) for Information falling to the Left and Right of a Central Fixation Position for Individual NPs.

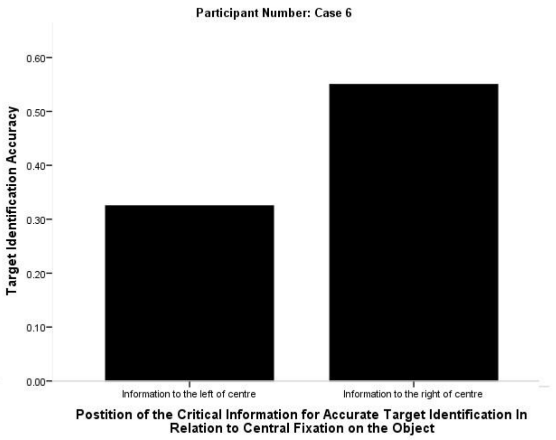


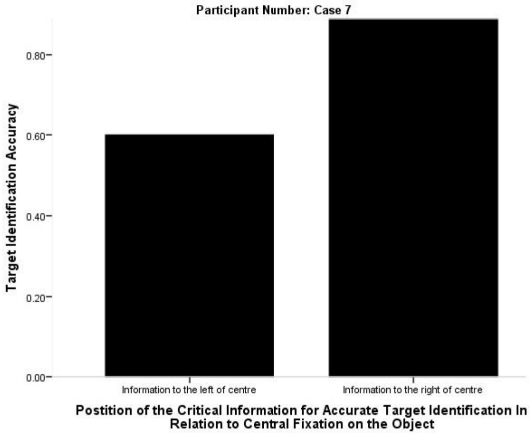


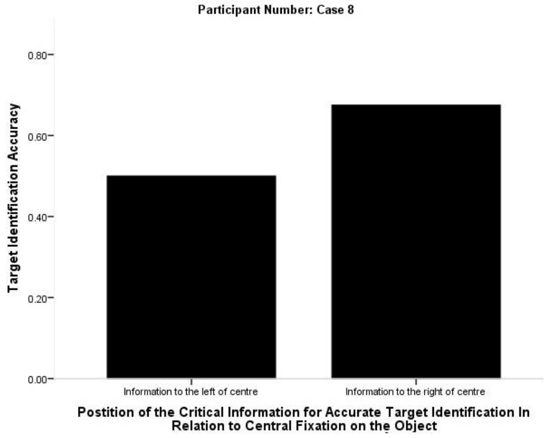


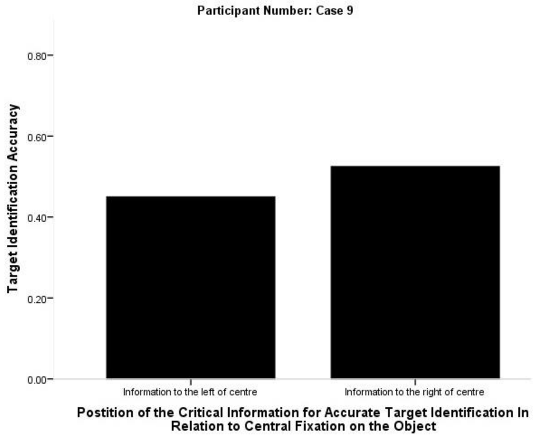


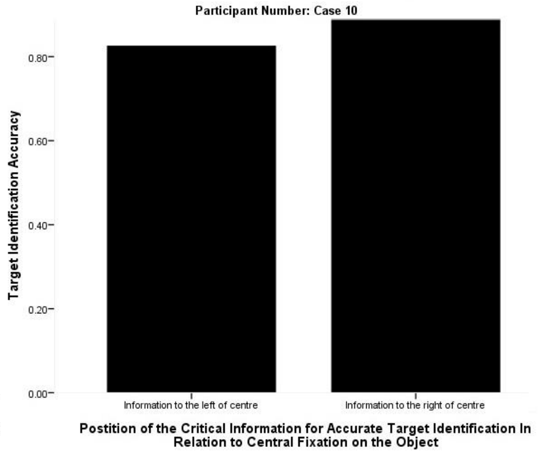


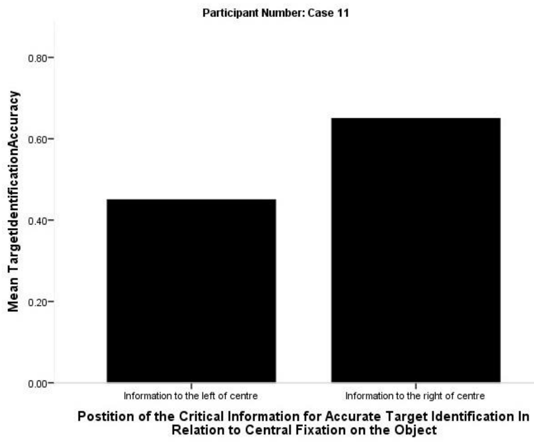



Participant Number: Case 7
Target Identification Accuracy
0.80
0.60
0.40
0.20
0.00
Information to the left of centre
Information to the right of centre
Postition of the Critical Information for Accurate Target Identification In Relation to Central Fixation on the Object


Participant Number: Case 8
Target Identification Accuracy
0.80
0.60
0.40
0.20
0.00
Information to the left of centre
Information to the right of centre
Postition of the Critical Information for Accurate Target Identification In Relation to Central Fixation on the Object


Participant Number: Case 9
Target Identification Accuracy
0.80
0.60
0.40
0.20
0.00
Information to the left of centre
Information to the right of centre
Postition of the Critical Information for Accurate Target Identification In Relation to Central Fixation on the Object


Participant Number: Case 10
Target Identification Accuracy
0.80
0.60
0.40
0.20
0.00
Information to the left of centre
Information to the right of centre
Postition of the Critical Information for Accurate Target Identification In Relation to Central Fixation on the Object


Participant Number: Case 11
Mean TargetIdentificationAccuracy
0.80
0.60
0.40
0.20
0.00
Information to the left of centre
Information to the right of centre
Postition of the Critical Information for Accurate Target Identification In Relation to Central Fixation on the Object

Appendix G

A cross reference list of all participant numbers included in the experiments reported in this thesis.

Pseudonym for Experiment 2	**Pseudonym for Experiment 3**	**Pseudonym for Experiment 4**
Case 1	Case 1	n/a
Case 2	Case 2	n/a
Case 3	Case 3	n/a
Case 4	Case 4	n/a
Case 5	Case 5	n/a
Case 6	n/a	n/a
Case 7	Case 6	n/a
Case 8	Case 7	n/a
Case 9	Case 8	Case 1
Case 10	Case 9	Case 2
Case 11	Case 10	Case 3
n/a	n/a	Case 4
Case 12	Case 11	Case 5
Case 13	n/a	Case 6
SC 1	SC 1	n/a
SC 2	SC 2	n/a
SC 3	SC 3	n/a
SC 4	SC 4	n/a
SC 5	n/a	SC 1
SC 6	SC 5	SC 2
SC 7	n/a	SC 3
SC 8	SC 6	SC 4
n/a	n/a	SC 5
OAC 1	OAC1	n/a
OAC 2	OAC2	n/a
OAC 3	OAC3	n/a
OAC 4	OAC4	OAC 1
OAC 5	OAC5	OAC 2
OAC 6	OAC6	OAC 3
OAC 7	OAC7	OAC 4
OAC 8	OAC8	OAC 5
OAC 9	OAC9	OAC 6
OAC 10	OAC10	OAC 7
OAC 11	OAC11	n/a
OAC 12	OAC12	n/a

Appendix H

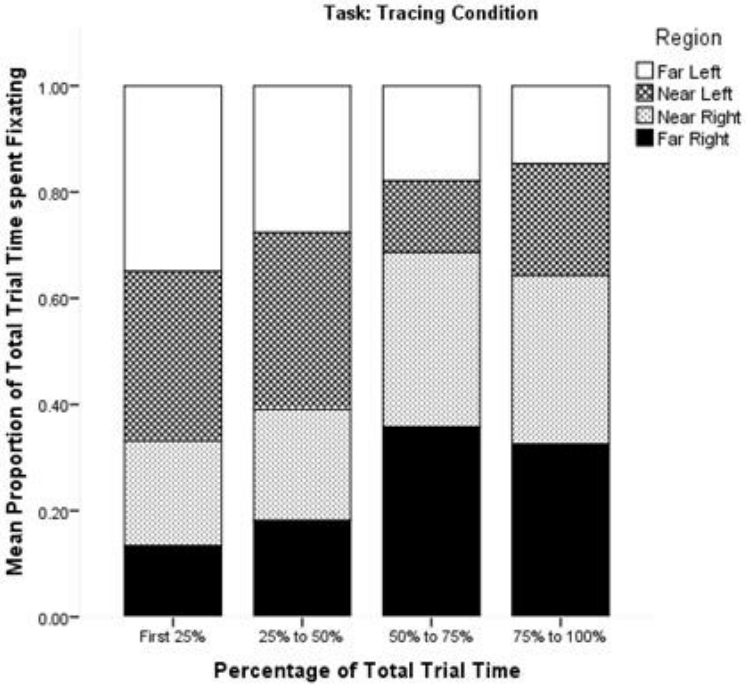


Figure 48. The proportion of time spent fixating each region of the stimulus (Far Left; Near Left; Near Right, Far Right) during different stages of the Tracing Condition trial (the first 25% of the trial; 25% to 50% of the trial; 50% to 75% of the trial and 75% to 100% of the trial) for the Older Adult Controls.

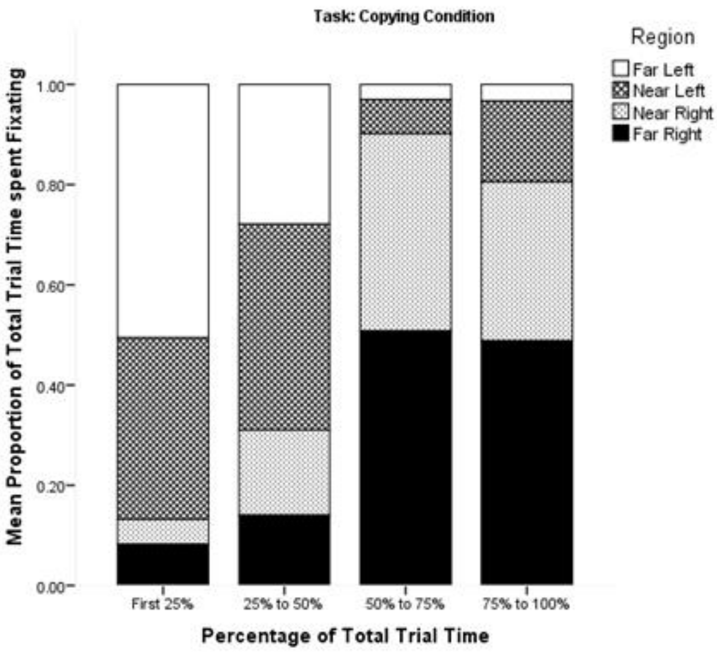


Figure 49. The proportion of time spent fixating each region of the stimulus (Far Left; Near Left; Near Right, Far Right) during different stages of the Copying Condition trial

(the first 25% of the trial; 25% to 50% of the trial; 50% to 75% of the trial and 75% to 100% of the trial) for the Older Adult Controls.

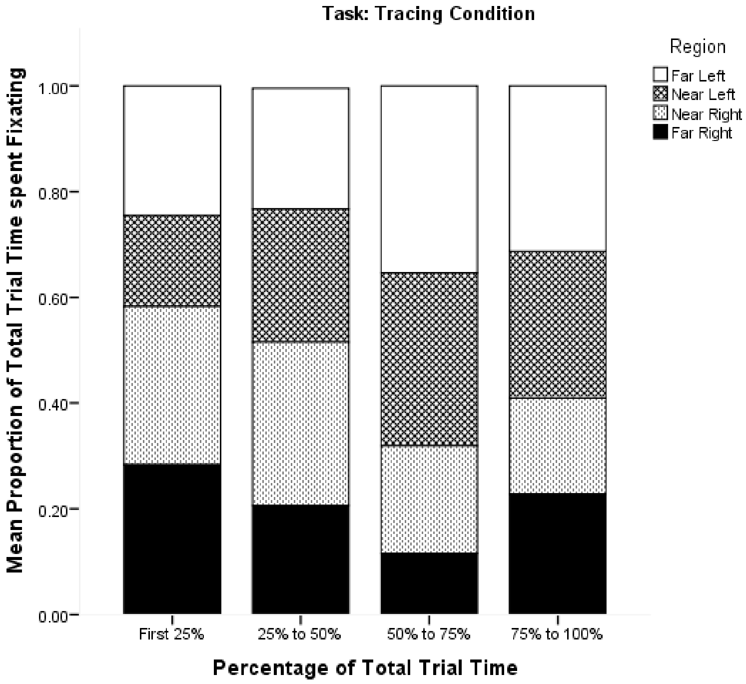


Figure 50. The proportion of time spent fixating each region of the stimulus (Far Left; Near Left; Near Right, Far Right) during different stages of the Tracing Condition trial (the first 25% of the trial; 25% to 50% of the trial; 50% to 75% of the trial and 75% to 100% of the trial) for the Stroke Controls.

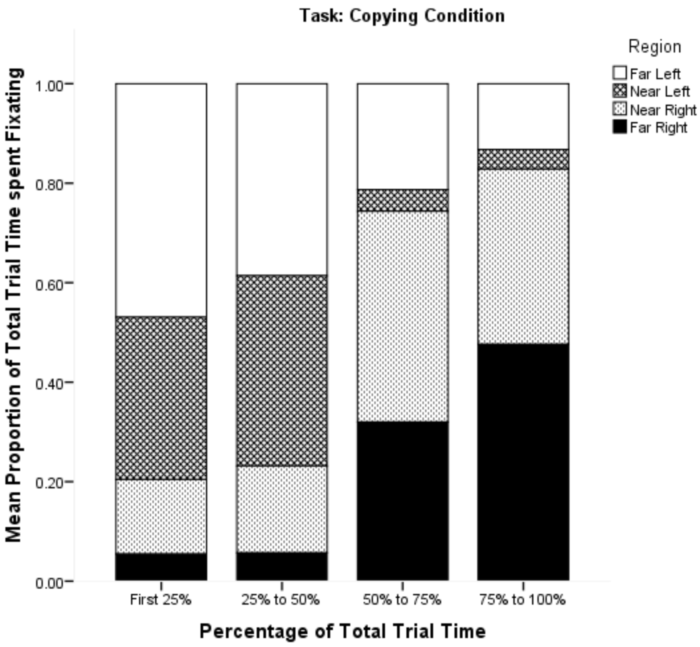


Figure 51. The proportion of time spent fixating each region of the stimulus (Far Left; Near Left; Near Right, Far Right) during different stages of the Copying Condition trial (the first 25% of the trial; 25% to 50% of the trial; 50% to 75% of the trial and 75% to 100% of the trial) for the Stroke Controls.

Table 22

Average Figure Completion Accuracy (%) for the Four Regions on the Stimulus (Far Left; Near Left; Near Right; Far Right) for Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs) for the Conditions included in Experiment 4.

Group	Far Left	Near Left	Near Right	Far Right
NPs	41.70 (31.86)	62.50 (39.80)	70.00 (20.45)	90.00 (12.06)
SCs	96.00 (6.99)	95.00 (7.07)	93.00 (8.23)	94.00 (10.75)
OACs	98.90 (3.23)	98.30 (5.14)	99.40 (2.36)	99.40 (2.36)

Table 23

Proportion of Time spent Fixating the Four Regions of the Stimulus (Far Left; Near Left; Near Right; Far Right) in the Tracing and Copying Conditions for the Neglect Patients.

Condition	Far Left	Near Left	Near Right	Far Right
Tracing	.10 (.12)	.12 (.11)	.38 (.13)	.39 (.14)
Copying	.06 (.04)	.39 (.08)	.17 (.10)	.37 (.10)

Table 24

Number of Gazes spent Fixating the Four Regions of the Stimulus (Far Left; Near Left; Near Right; Far Right) in the Tracing and Copying Conditions for the Neglect Patients (NPs), Stroke Controls (SCs) and Older Adult Controls (OACs).

Group	Condition	Far Left	Near Left	Near Right	Far Right
NP	Tracing	3.33 (3.88)	5.17 (5.12)	12.17 (3.60)	10.50 (4.04)
	Copying	10.00 (6.81)	34.17 (11.51)	20.33 (11.67)	38.17 (12.69)
SC	Tracing	12.20 (3.35)	14.80 (4.44)	12.20 (2.17)	10.40 (2.07)
	Copying	36.40 (14.77)	28.60 (7.26)	34.40 (10.88)	31.40 (13.99)
OAC	Tracing	11.78 (5.26)	14.56 (5.64)	13.44 (4.00)	11.56 (3.68)
	Copying	33.78 (13.99)	39.44 (17.77)	36.44 (11.57)	42.78 (12.36)

Table 25

Average Gaze Durations (AGD; ms) in the Tracing Condition and Copying Condition of Experiment 4.

	Tracing Condition	Copying Condition
AGD	3585.05	554.36
(SD)	1878.51	193.22

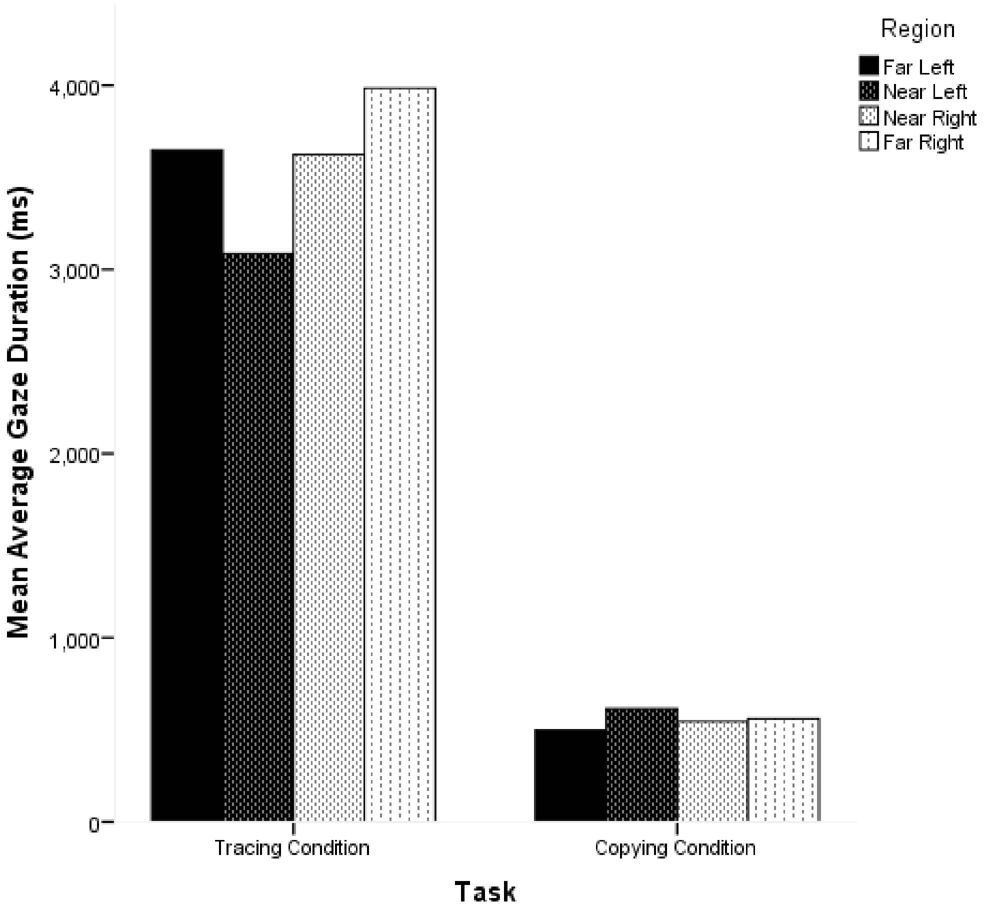
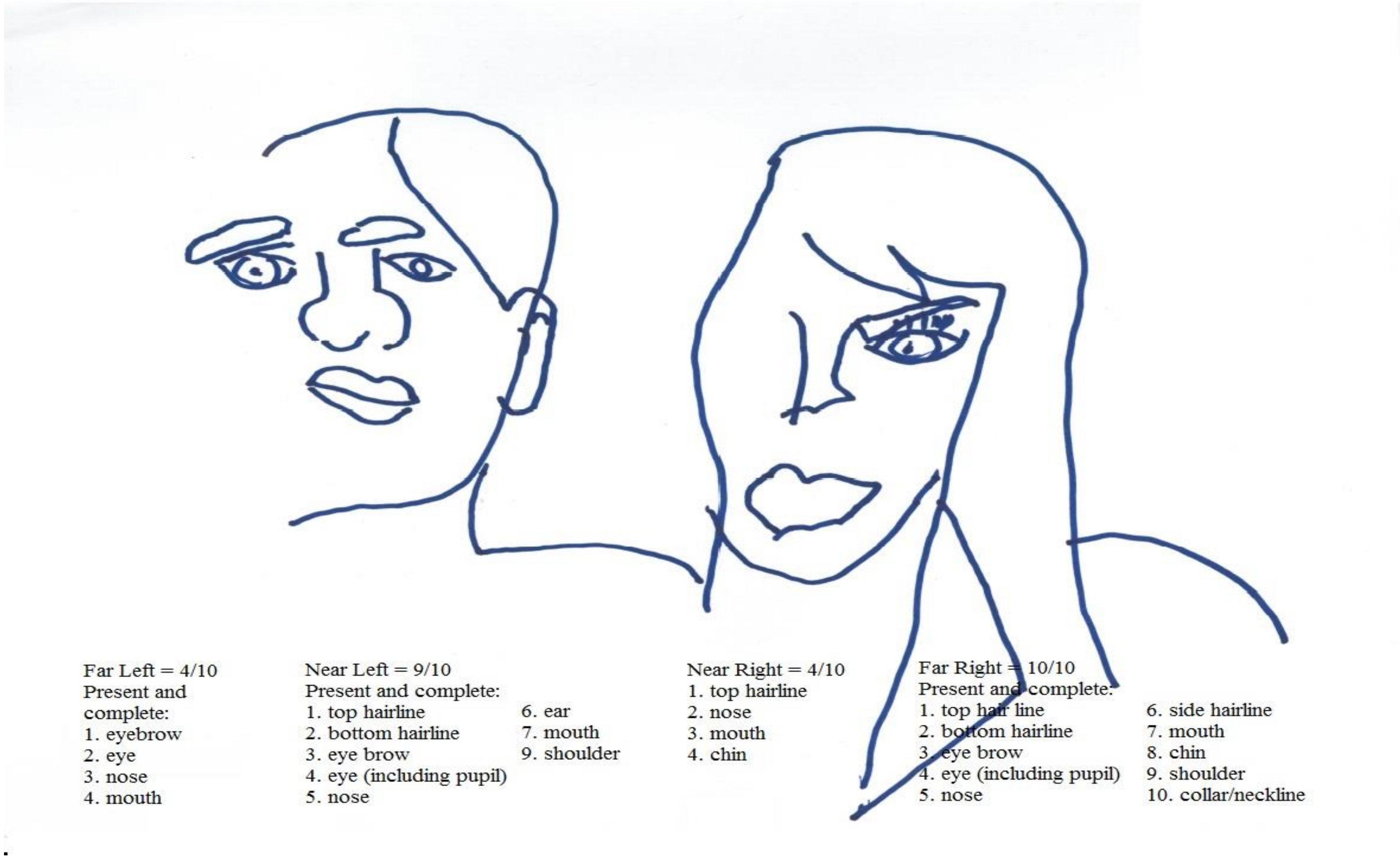


Figure 52. Average Gaze Duration (AGD; ms) made during the Tracing Condition and Copying Condition for the four regions of interest on the stimulus (Far Left, Near Left, Near Right, Far Right).

Appendix I

Example for scoring the figure completion accuracy data for Experiment 4.



Appendix J

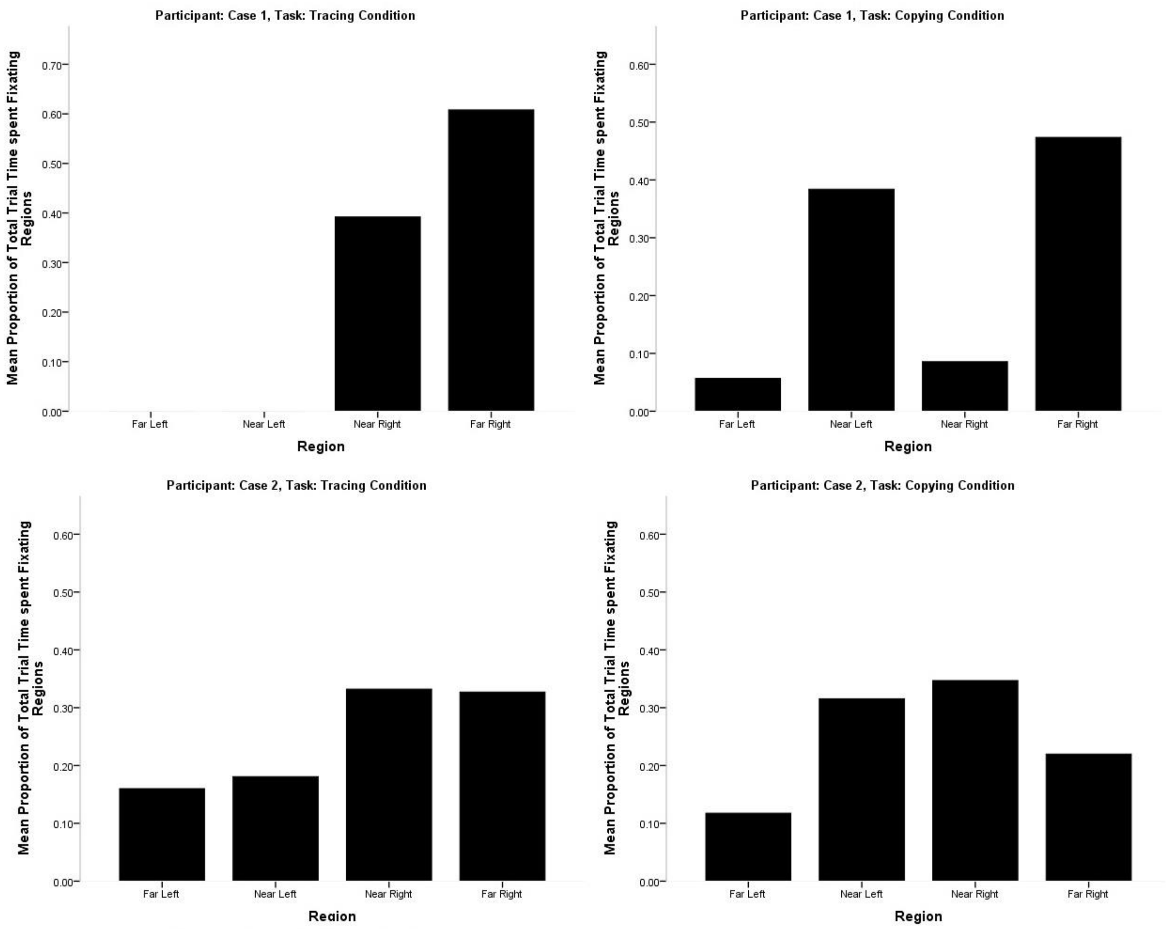
As neglect is a heterogeneous disorder, one NP may experience problems encoding visual information presented in the contralesional regions, but another may exhibit a deficit in representing contralesional information (i.e. there may be a double dissociation present for these two types of neglect; Bartolomeo, 2002; Vallar, Rusconi, & Bisiach, 1994). However, there is also dependence between these two factors, as if information is not encoded; it is highly unlikely to be represented as well. For individual patient comparisons, the Crawford, Garthwaite, and Wood (2010) method for comparing two scores was employed, which compares the difference between accuracy in the Tracing Condition and the Copying Condition using the *SD* of the control groups accuracy difference between conditions to determine whether the two patient's scores are outside the normal range of variability.

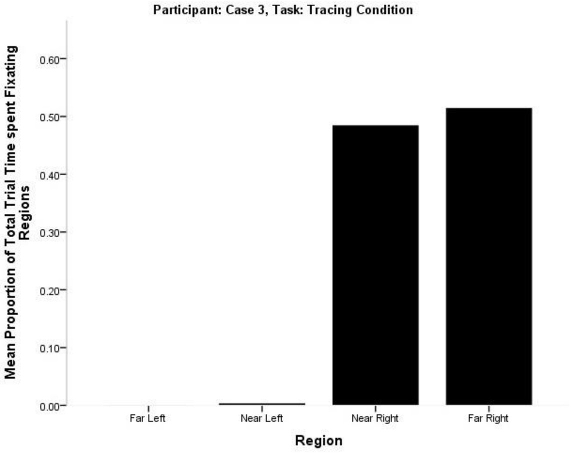
It appears from the individual accuracy scores for the two conditions that there were differences across NPs in accurately encoding and representing contralesional information. Case 1 was able to encode information presented in the left face (40% in the FL region; 100% in the NL region) but failed to represent any of the left face in the Copying Condition. This difference was significant, with overall accuracy being higher in the Tracing Condition (68% of the figure completed) compared to the Copying Condition, (38% of the figure completed), $t(13) = 3.54$, $p < .001$ (using Crawford et al.'s, 2010, method for comparing patient's scores to the control group). This suggests that information presented on the contralesional side could be encoded by Case 1 but there was a deficit in representing the encoded information sufficiently in order to accurately copy the figure during the Copying Condition. This may be due to this participant exhibiting imaginal neglect as well as visual neglect and this resulted in poorer performance in the Copying Condition. As this participant was the furthest post-stroke out of all the NPs, it may be that she managed to develop compensatory strategies for attending to contralesional information but this mechanism was not effective for attending to contralesional information that had been imagined (Bartolomeo, 2002). Similarly, Cases 5 and 6 were able to encode information presented in the left regions (with between 50% and 90% figure completion accuracy in the FL and NL regions for the Tracing Condition) but only copied 40%-50% of the items in the FL region during the Copying Condition. Case 5's difference between these conditions was not significant, $t(13) = .94$, $p = .363$, whereas Case 6's had significantly higher accuracy in the Tracing Condition (95% of the figure completed) than in the Copying Condition (60%), $t(13) = 4.13$, $p < .001$. This suggests they were unable to represent contralesional information to the same extent that they were able to encode the information.

Cases 2, 3 and 4 were more accurate in copying information from the contralesional figure than encoding information presented in that region. Case 2 had significantly lower accuracy for completing the figure in the Tracing Condition (70% of the figure completed) than in the Copying Condition (93%), $t(13) = 2.70$, $p < .001$. Case 3 had significantly higher accuracy for completing the figure in the Copying Condition (88% of the figure completed) as well, compared to the Tracing Condition (40%) $t(13) = 5.66$, $p < .001$. Case 4's difference was not significant, however, $t(13) = 1.77$, $p = .100$. This suggests that some neglect patients can visually encode neglected information but then fail to represent that information accurately in order to produce a complete copy of the encoded information. In addition to this, some patients appeared to be able to represent information in the Copying Condition when they failed to encode information in the Tracing Condition. This is likely to be due to the task demands affecting how information was processed in the different conditions. Interestingly, Case 2, 3 and 4 were all at a similar stage post-stroke (25-28 days, see Table 9), which may have had an impact on their performance if they are starting to develop compensatory mechanisms. Additionally, Case 2 and 4 demonstrated the severe neglect compared the other NPs (along with Case 5, as indicated by the overall BIT score, see Table 8), which may be impacting on the amount of information that is identified in the Tracing Condition. Furthermore, other idiosyncratic factors that may impact on performance are whether the patient displayed hyperattention to the right regions (as this may further restrict attention to the left; Kinsbourne, 1979), the patterns of eye movements produced (e.g., whether the patient was able to fixate the FL or NL region) and the impact of the task demands on these factors for each patient, which will all be considered in the eye movement sections of the results in Chapter 5.

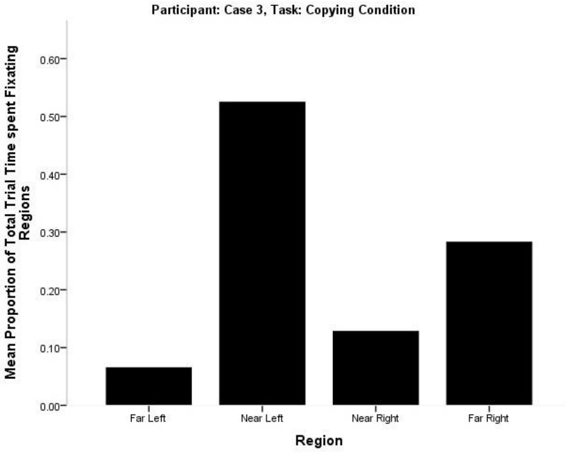
Appendix K

Figures depicting the proportion of the trial time spent fixating the four regions of the stimulus by each NP in both the Tracing and Copying conditions of Experiment 4.

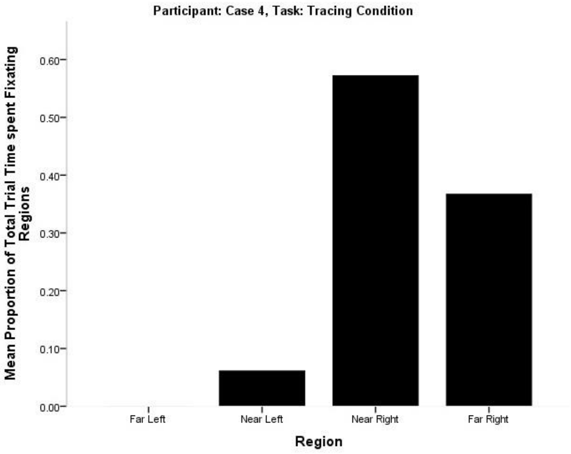




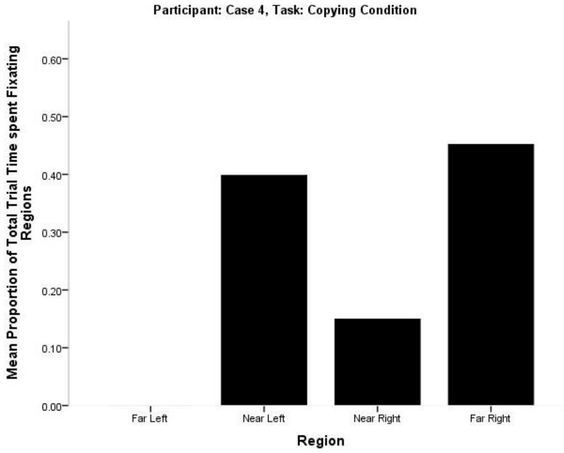
Participant: Case 3, Task: Tracing Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region



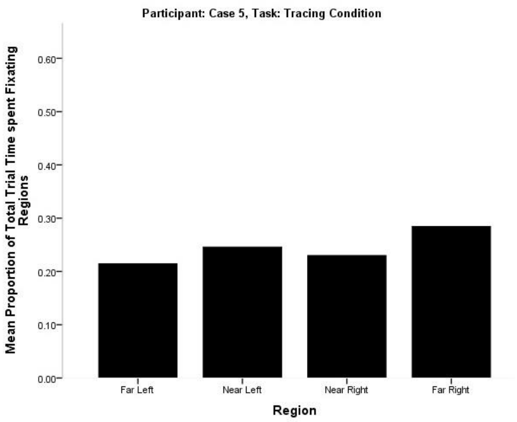
Participant: Case 3, Task: Copying Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region

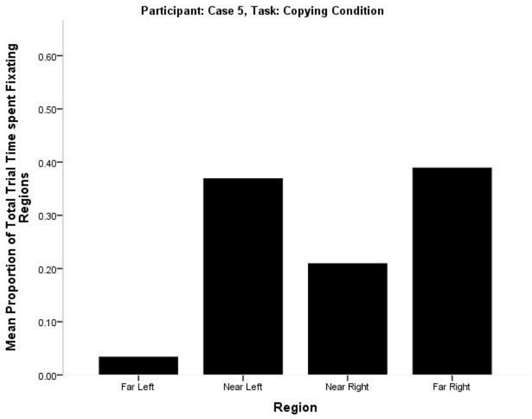


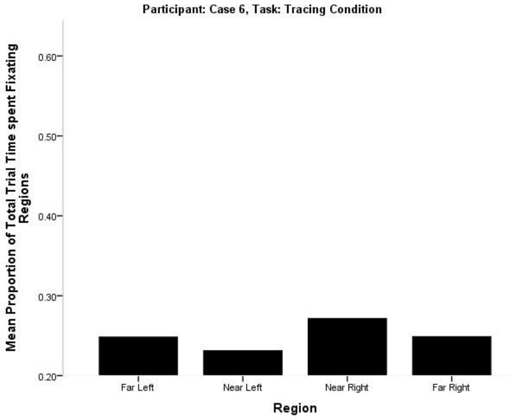
Participant: Case 4, Task: Tracing Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region

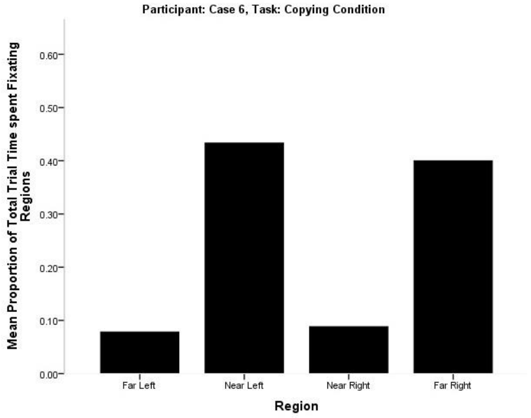


Participant: Case 4, Task: Copying Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region


Participant: Case 5, Task: Tracing Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region

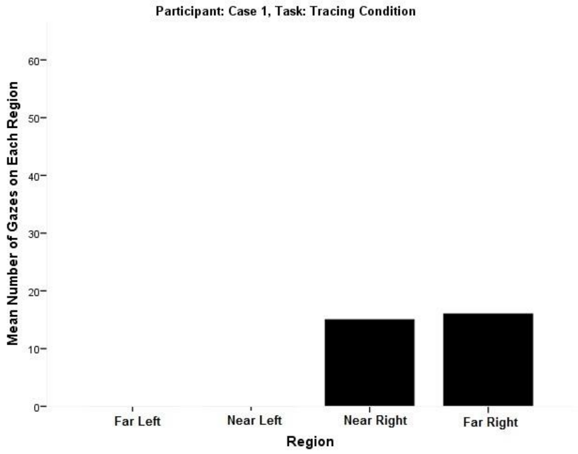

Participant: Case 5, Task: Copying Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region

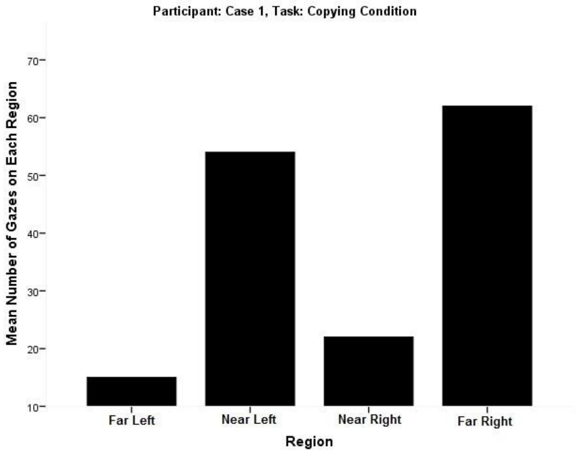

Participant: Case 6, Task: Tracing Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region

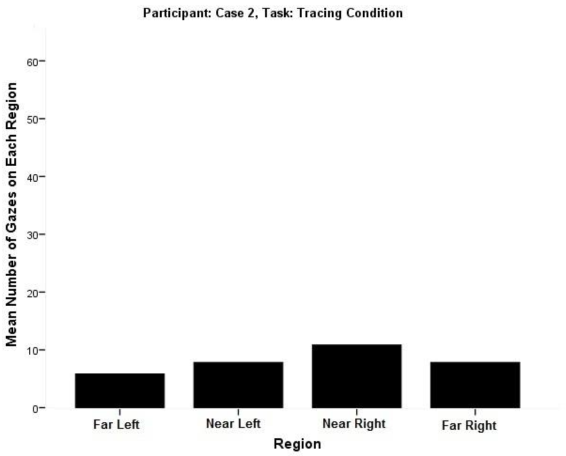

Participant: Case 6, Task: Copying Condition
Mean Proportion of Total Trial Time spent Fixating Regions
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Far Left
Near Left
Near Right
Far Right
Region

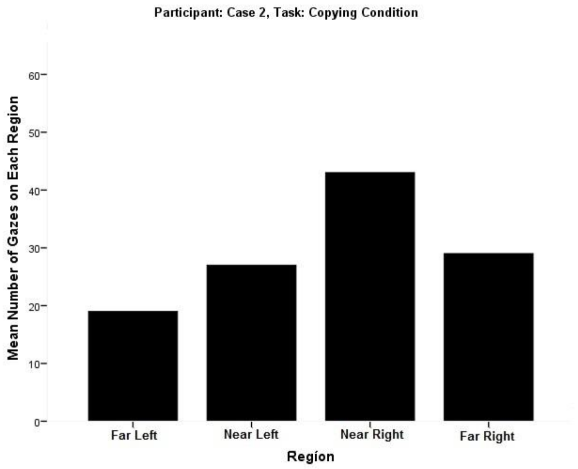
Appendix L

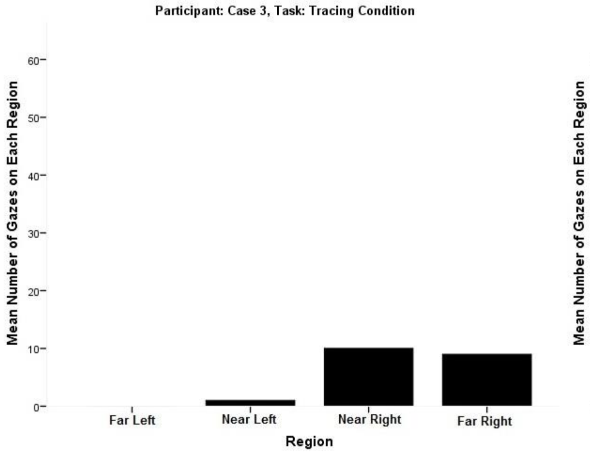
Figures depicting the number of gazes made to the four regions of the stimulus for each NP in the Tracing and Copying Conditions of Experiment 4.

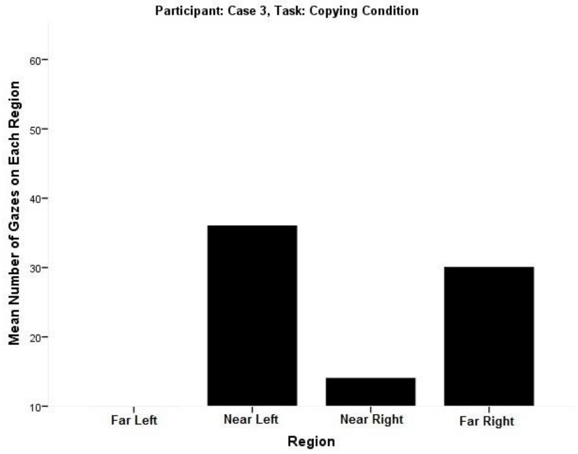


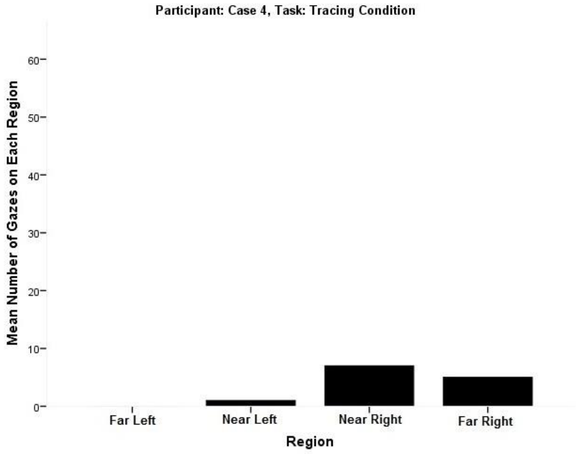


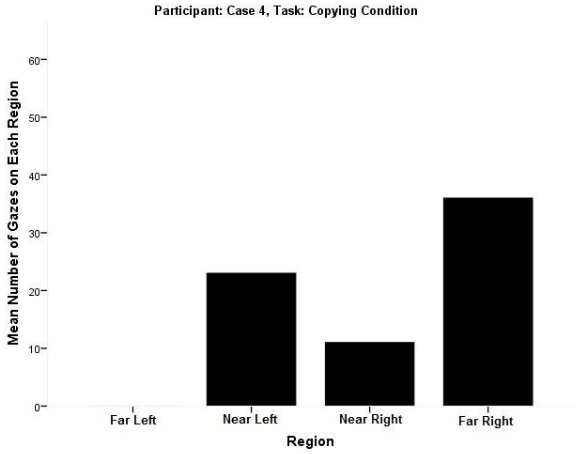


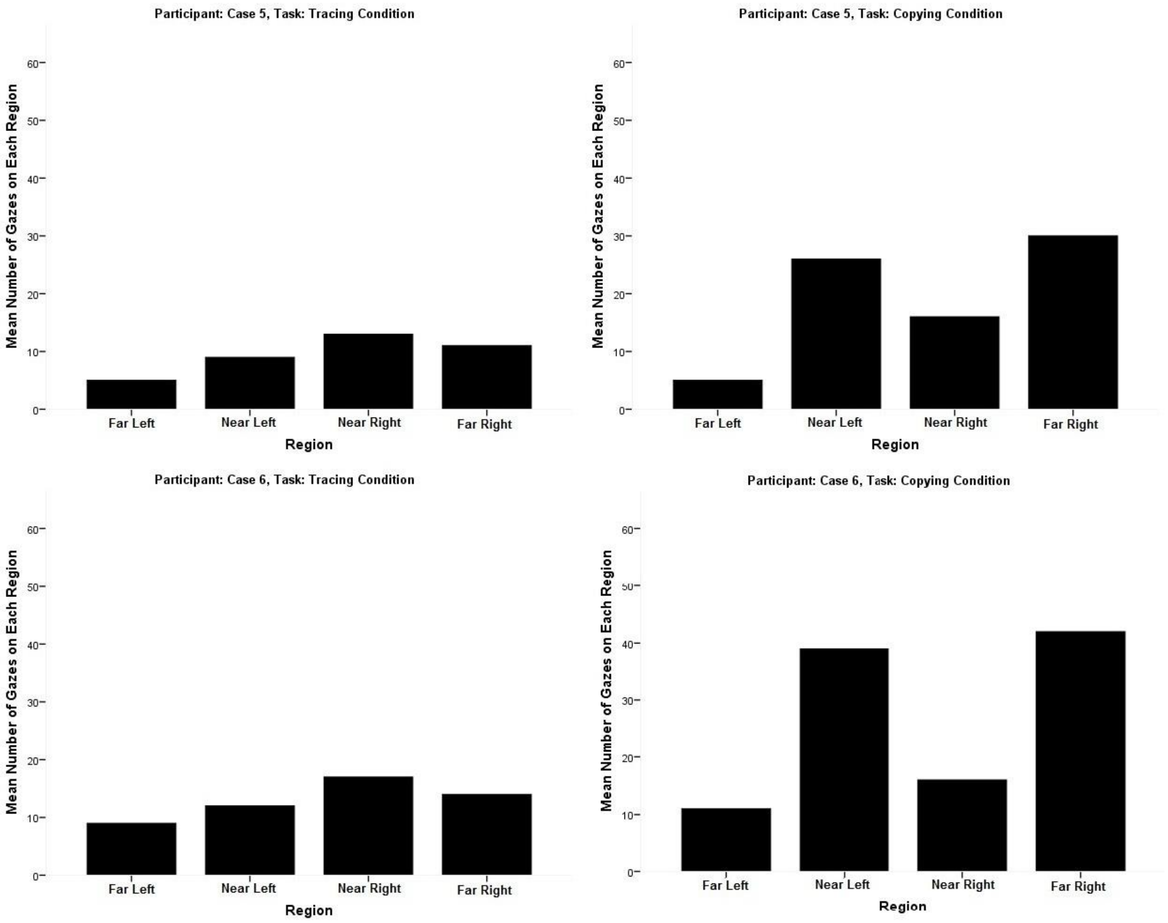



Participant: Case 3, Task: Tracing Condition
Mean Number of Gazes on Each Region
60
50
40
30
20
10
0
Far Left
Near Left
Near Right
Far Right
Region


Participant: Case 3, Task: Copying Condition
Mean Number of Gazes on Each Region
60
50
40
30
20
10
Far Left
Near Left
Near Right
Far Right
Region


Participant: Case 4, Task: Tracing Condition
Mean Number of Gazes on Each Region
60
50
40
30
20
10
0
Far Left
Near Left
Near Right
Far Right
Region


Participant: Case 4, Task: Copying Condition
Mean Number of Gazes on Each Region
60
50
40
30
20
10
0
Far Left
Near Left
Near Right
Far Right
Region


Participant: Case 5, Task: Tracing Condition
Mean Number of Gazes on Each Region
0
10
20
30
40
50
60
Far Left
Near Left
Near Right
Far Right
Region
Participant: Case 5, Task: Copying Condition
Mean Number of Gazes on Each Region
0
10
20
30
40
50
60
Far Left
Near Left
Near Right
Far Right
Region
Participant: Case 6, Task: Tracing Condition
Mean Number of Gazes on Each Region
0
10
20
30
40
50
60
Far Left
Near Left
Near Right
Far Right
Region
Participant: Case 6, Task: Copying Condition
Mean Number of Gazes on Each Region
0
10
20
30
40
50
60
Far Left
Near Left
Near Right
Far Right
Region