THE ROLE OF THE PARIETAL CORTEX IN SALIENCE-BASED SELECTION USING A COGNITIVE NEUROPSYCHOLOGICAL APPROACH

By

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ABSTRACT

It has been known that the parietal cortex is important for directing attention in order to fulfil search task goals, although how exactly this is done is unclear. Saliency has been identified as important in parietal selection of targets and suppression of distractors. This thesis attempted to explore the factors underlying salience-based selection in the parietal cortex using a cognitive neuropsychological approach. Chapter 1 explored the literature underlying saliency and the parietal cortex. Chapter 2 addressed the question of salience-based selection in a global-local task using a voxel-based morphometric approach in a wide range of patients, finding parietal and occipital regions as important regions for congruency interference and suppressing salient distractors. Chapter 3 inhibited the right precuneus using repetitive transcranial magnetic stimulation in neurotypical adults on the same task finding reduced congruency interference. Chapter 4 revealed the importance of saliency in mediating level selection in simultanagnosia. Chapters 5 and 6 examined in a bilateral parietal patient using spatial and non-spatial paradigms the importance of stimulus relevance as a means of guiding salience-based selection. The thesis concluded in Chapter 7 that the parietal cortex is important for salience-based selection and suppression mediated by the relevance of the stimulus being made salient.

DEDICATIONS

To my family who have supported me throughout this adventure

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CHAPTER 1 GENERAL INTRODUCTION

Background on the role of the parietal cortex attention and saliency

In everyday life, there is a need to search for objects whether they are house keys, appropriate clothes for a party or the office, or even food to make dinner. With an environment cluttered with many objects which need to be processed and assessed for their appropriate action, internal cognitive mechanisms are necessary to help search be as efficient as possible.

Attention can be a way of directing focus to achieve the search goal (Petersen & Posner, 2012). The neural correlates of attention are relatively diverse as there have been debates as to whether there are one or many different types of attention. Petersen and Posner (2012) argued that there were three networks of attention: alerting, orienting and executive. The alerting network is one of the most basic starting from subcortical brain stem mechanisms engaging higher-order systems to be vigilant to environmental changes and/or to maintain awareness of the surroundings.

This orienting network aims to direct attention towards salient items to enable them to be acted upon. Orienting of attention can be done towards a particular region of space or to a particular feature of a stimulus (Petersen & Posner, 2012).

There is a difference between the orientation to space and orientation to feature. Zhang and Luck (2009) argued that feature-based attentional orienting is an independent process to spatial based orienting. The authors based this claim on an

EEG experiment which involved the presentation of red and green dots split into peripheral hemifields in which the participants had to attend to just one of the colours in one visual hemifield and detect any change in luminance of the attended colour. In the opposite visual hemifield, probes of dots which were all of the same single target or distractor colours were flashed. Their results found earlier and larger onset of P1 (around 100ms from stimulus onset) when having to attend to feature (colour) even in the ignored spatial hemifield. The authors argued that P1 had been used in the past literature classically as a marker as a sensory evoked potential of the allocation of spatial attention. This shifting of P1 due to colour feature focus was argued to be a sign of the distinct attention processing of features in which is independent and starts earlier than spatial attentional processing.

Posner (1980) emphasised an importance of spatial information in the orienting of attention through his spatial cueing paradigms. One such example is his peripheral cueing task in which there are two boxes (left or right) of which will contain a target which needs to be detected by pressing a button and also to make an eye-movement to the target location. On certain trials, a cue appears in one of the two spatial locations before the appearance of the target, which is either largely predictive of the target (valid cue) with a minority of trials in which the cue is in the distracting opposite location (invalid), or a block of random cues which is not predictive of the target location (neutral). Participants are quicker to make responses and eye-movements when cues are valid predictors of targets compared to invalidly cued targets (in which they are slower than neutral conditions). Participants use the cue as a guide to orient their attention to the possible location of the target. In the case of the invalid trials, disengagement from the top-down task goal is required to ensure that the target is found in the correct (i.e. opposite) spatial location.

One such neural region involved in shifting attention in space is the superior parietal cortex (Corbetta & Shulman, 2011). Neuropsychological evidence suggests that the parietal cortex is particularly critical for this spatial orienting of attention. Posner et al. (1984) used the above spatial cueing paradigm in addition to a central cueing variant of the paradigm with parietal, frontal and temporal patients. The central cueing variant of the spatial cueing task is similar but, instead of a dot cue appearing in the peripheral target location boxes, there is a central arrow cue pointing to a spatial location. The cue validity effects work on the similar principle to the peripheral cueing paradigm explained beforehand. In both peripheral and central spatial cueing tasks, parietal patients failed to utilise cues and disengage from cued locations compared to frontal and temporal patients. These results highlight the crucial role of the parietal cortex in the allocation and disengagement of attention to cued locations.

The parietal cortex shows common attentional control for both spatial encoding and objects. In an fMRI study by Shomstein and Behrmann (2006), participants had to fixate centrally while covertly attending to one of four locations on a screen which were denoted by a colour target which was among three distractor colours while being scanned with fMRI. There were three target colours which require the participants to either hold attention at the same location (red), shift attention within the same object (blue), or the opposite object (green). In trials in which participants had to shift attention generally, there was significant BOLD activation in the bilateral precuneus and middle frontal gyrus. In trials in which the shift was within objects, there was a significant recruitment of the left parietal cortex. For shifts between objects, the posterior parietal cortex was activated. The authors concluded that the left parietal cortex was involved in object-specific shifts of attention.

The parietal cortex alone has not been the only region identified in attentional orienting in space. The frontoparietal network has been implicated in the attentional encoding of both spatial and featural aspects (Greenberg et al., 2010). Greenberg et al. (2010) asked participants to attend to the location, colour, and direction of a cloud of red and green moving dots which were presented laterally in the left and right hemisphere. Participants had to focus on the cued colour of dots. Participants were required to shift attention the opposite hemifield (where another cloud of moving dots appeared) while maintaining focus on the same cued colour if the motion of dots went upwards. Alternatively, or remain if the motion of the attended dots went downwards, the participants had to maintain attention to the same hemifield but change focus onto the opposite colour. Leftwards and rightwards moving dots denoted to keep attention at the same location and colour. Participants pressed a button to indicate when they saw these four motion cues. The posterior parietal cortex (in particular the precuneus), as well as the prefrontal cortex (in particular the medial frontal gyrus), were shown from the fMRI findings to be active in both shifting attention within and across featural domains (across spatial hemifields and to the alternative colour in this case). The coactivation of these two regions further supports the notion a common frontoparietal of attention orienting network. However, the authors further noted that whilst they were coactivation, there were subregions of the PPC that discretely activated for shifts of spatial location and colour.

An EEG study question by Shomstein, Kravitz and Behrmann (2012) has revealed that the frontal cortex, as well as the parietal cortex, are involved in orienting attention, however at different temporal stages. Participants were required to located in one of two RSVP streams, a target letter S while having EEG scalp recordings. Participants were cued as to which of the two laterally presented visual streams by the presence of one of two numbers (4 for shifting attention to the opposite stream and 2 for holding attending to the same stream). Participants were slower at detecting the target letter in the rapid presentation during trials in which they were cued to shift locations as opposed to holding attentional focus on a particular stream. The electrophysiological findings found that both the frontal and parietal regions were active while shifting attention. Critically, the frontal cortex showed early deployment of top-down attentional shifting (due to earlier firing) whereas, the parietal cortex shows later activity for orienting attention (Shomstein et al., 2012).

The executive network is the third attention network as proposed by Petersen and Posner (2012). This network is said to manage the task set and is goal driven. This network involves directing focussed attention to the task at hand and judging the appropriate actions to stimuli. Frontal regions were noted as important in this management of tasks and rules in this attention network. Additionally, the authors argued that anterior cingulate cortex has been implicated in the monitoring of information and conflict and assessing its relevance to the goal.

There have been arguments suggesting that attentional selection is mediated by the relative salience of the stimulus (Schubö, 2009; Theeuwes, 2004). Corbetta and Shulman (2011) defined saliency as a stimulus which sensory distinctiveness and behavioural relevance. This general definition does have some limit in cases of which a stimulus pops out from a display in search, but the stimulus itself is behaviourally irrelevant (that is not part of the task set). An example of saliency can be hearing the phone ring while you are cooking dinner in a quiet kitchen and having to divert attention towards the ringing phone to answer it (Shomstein, 2012). The sound of the ringing phone has a sensory distinctiveness compared to the cooking activity being done (compared to sounds from cooking), captures attention and shifts the behaviour to select an appropriate behavioural response (i.e. stopping the cooking task and answer the phone).

It has been argued by Schubö (2009) that saliency may have different components: bottom-up and top-down. Bottom-up saliency as described by Schubö (2009) being that it is physical distinctiveness of a stimulus in relation to its neighbours in space. An example of a distinct physical feature is a red letter T in an array of green Ts and Ls. The red stands out due to its difference in hue to the remaining objects in the display. This description of bottom-up saliency is closer to the definition by Corbetta and Shulman (2011). Top-down on the other and is driven by task goals, memory-based experience (Theeuwes, 2010).

Bottom-up saliency is stimulus-driven, independent of the control of the observer (Theeuwes, 2010) due to exogenous a physically distinctive feature of a stimulus (Awh, Belopolsky & Theeuwes, 2012). However, Awh, Belopolsky and Theeuwes (2012), noted that this mainly is reduced to features and avoids notions such as emotional valence as it is independent of the observer. According to Petersen and Posner (2012), bottom-up orientation to a stimulus or location is driven by the ventral stream.

One task that has been used to investigate bottom-up saliency is the singleton search tasks as exemplified by Theeuwes (1992; 2004). A singleton search task involves finding a particular target which is different from the distractors in a distinct way (in that one stimulus feature/attribute strongly pops out from the other stimuli: an example of perceptual distinctiveness). Theeuwes (1992) developed the irrelevant singleton task. This singleton search task there contained two singletons (one being the target and the other a task-irrelevant distractor singleton) amongst distractors. In this task and variants of this (such as Theeuwes & Van der Burg, 2007), participants are presented with a display of outline shapes with bars in their centre. The bars are tilted in different orientations (usually two different ones, horizontally and vertically) for which is the basis of the search task. The search task is to search for a particular shape (which is a singleton such as a circle) in amongst distractors (e.g. diamonds) and state the orientation of the bar within the target shape. The irrelevant distractor is not a feature which is needed for search, nor has any benefit in its utilisation (e.g. a green colour feature). The bottom-up saliency was argued by Theeuwes (1992) to be the irrelevant singleton feature. Whereas top-down control was argued to be the search for the target singleton, as it is the main goal which if it was superior to bottom-up saliency, it should override the bottom-up saliency of the irrelevant salient distractor feature. However, what was found was that the irrelevant distractor did capture attention above the top-down salient singleton target. Based on these experiments Theeuwes (1992) stated that in the most physically distinctive (bottom-up salient) feature automatically captures attention in search regardless of top-down control. In an extension to the study by Theeuwes (1992), Theeuwes (2004) compared the role of irrelevant singletons when having to perform both serial and parallel search. Participants had to search for a diamond (which acted as a top-down target) in an array of distractor shapes (triangles, squares, and circles which had bars of different orientations in their centre) and identify the orientation of a bar with was in the centre of the target shape. Regardless of set-size, having a singleton colour distractor increased search time compared to not having a singleton colour distractor. Theeuwes (2004) concluded that, including top-down strategies of only searching for a particular feature (shape in this case), could not stop the influence the effects of an extraneous salient bottom-up feature (colour in this case). Thus, bottom-up saliency overrides top-down strategies in visual search.

The neural basis of bottom-up saliency has been explored through diverse means and using different techniques and populations. Saliency has a strong seat in the parietal cortex (Gottlieb, Kusunoki & Goldberg, 1998). Gottlieb, Kusunoki and Goldberg (1998) conducted single-neuron electrophysiological recordings on two macaque monkeys in the lateral intraparietal area (LIP), the homologue of the human PPC while the monkeys had to make a saccade to a target shape (which was cued beforehand) among eight shapes of different forms and colours. Salience was defined by an abrupt onset of the stimulus with the receptive field of view. Neurons in the LIP is increased in firing when there was a salient onset of the stimulus. The authors concluded that the parietal cortex encoded salient changes during visual search.

Further to this, a single-neuron physiological recording study by Constantinidis and Steinmetz (2005) argued that saliency affects the encoding of spatial location in the parietal cortex. Macaque monkeys were required to pull a level on a matching to sample task of coloured square arrays (either one sole square or nine square arrays) in which either appeared in a salient stimulus (which was a different colour from the others) or not. The salient feature was independent of the task. Posterior parietal cortex neurons fired on the onset of the stimulus but also to its location in the visual field. The findings suggested that the bottom-up saliency promoted spatial orienting and encoding in the monkey posterior parietal cortex despite not being behavioural relevant for the task.

Additionally, Kusunoki, Gottlieb and Goldberg (2000) argued that the monkey LIP serves as a salience map identifying salient information to direct visual search. Macaque monkeys were required to make saccades to targets (cued outside of receptive field) in an array of different shapes and orientations. Salience was assessed as stimulus motion based on an abrupt onset. Neurons in the LIP responded not only to the salient motion of the cued target but also to the onset of the cued stimulus (compared to non-cued items). Pertinently this salience encoding was done for behaviourally relevant items (which cued saccades to the next location or the cue itself). The authors concluded that the LIP encoded behaviourally relevant stimuli which were salient and assessed the visual scene for locations which are goal relevant for search (hence acting as a map of behavioural relevance and salience of items in a scene).

Arcizet, Mipour and Bisley (2011) added further support that the PPC responds to salient stimuli. The authors argued that previously studies looking into bottom-up saliency had targets which made the target behaviourally relevant for search and did not isolate the general role of salience in the parietal cortex. Thus, Arcizet, Mipour and Bisley (2011) run a single-neuron neurophysiological study in which monkeys were presented with a green and red dots around an imaginary circle with one fixation dot at the circle. The monkeys had to maintain fixation on the central dot throughout the task. There was either a singleton dot which was salient (differently coloured from the central dot), or a peripheral dot was salient. Alternatively, the salient dot was in the circle with the other dots but was either a salient fixation point in the middle or a salient singleton distractor. Neurons from the LIP responded to the salient dot regardless of whether it was the fixation target or distractor. This evidence supports the notion that the posterior parietal cortex encodes saliency in general despite it not being behaviourally relevant.

There has been converging evidence from human fMRI studies that the parietal cortex is involved in salience-based selection. One such example is an fMRI study by Geng and Mangun (2009). In this study, participants were presented with two lateral hemifield streams in which there were squares which consisted or white vertical or horizontal lines. Participants were asked to identify when the stimulus with horizontal lines appeared in the stream. The participants were cued to which stream to attend to by a small rectangle which had a smaller blue rectangle on the left or right side indicating the cued stream. The target appeared with or without it being perceptually salient. Salience was defined as being of a different colour (grey) and contrast compared to the stimulus of the opposite stream. On certain trials, the distractor could also be perceptually salient. Reaction times to salient targets facilitated detection, however, slowed detection with distractors were salient. The salience was task-irrelevant and gave no predictive value with respect to the target. fMRI findings showed that the anterior inferior parietal sulcus was significantly active during the presence of salient stimuli, whereas the frontal eye fields (FEF) were active in maintaining goals to find the target and shifting to appropriately cued streams.

In a review of the monkey single-unit neurophysiology literature by Fecteau and Munoz (2006), the authors noted that in many neurophysiological studies use the term salience and relevance interchangeably. However, the authors argue that a salience map should reflect bottom-up processing (perceptually salient) as opposed to top-down goals (which would make it goal relevant). Their review found that salience and relevance are different notions with different neural signatures. Salience was noted as the starting registration of the target in early perceptual processing, whereas relevance was the increase in neural activity in response to the predictive and rewarding value of an attentional cue. This salience map notion was extended to be defined as a priority map for the selection of behaviourally relevant targets which is based in the distributed oculomotor system (FEF, IPS, the pulvinar brainstem reticular formation and the superior colliculus). The priority map, the authors argue, represents the bottom-up perceptual salience and the top-down relevance to the task's goals. Whilst it is done on the same map, the assessment and correlations of salience and relevance of an object which appears in space during visual search are done independently producing different output. However for feature-based attention, the relationship between salience and relevance is strong enough for it is not to see as distinct, so the map produces a summary of the inputs ready for later attentional processing.

In addition to the parietal cortex, this is also evidence which has been found from human fMRI has revealed that the temporoparietal junction (TPJ) has also been implicated in salience-based cueing. Geng and Mangun, (2011) asked participants to search for a grey vertical rectangle presented on a cued attentional lateral stream (cued by the a rectangle on the top vertical meridian with a smaller blue rectangle stating which stream (left or right) to attend to) which was narrower than the distractor rectangles while being scanned with fMRI. Participants had to state whether they detect the target or not throughout. A contextual cue was defined as a white bar rectangle which was of high luminance in the unattended visual hemifield stream. The contextual cue also appeared with the target simultaneously. Participants who saw a contextual cue with the target were faster at detecting the target despite the salient stimulus being in the unattended visual hemifield stream. In trials in which the salient contextual cue appeared but on its own without the target, there was an increase in right TPJ BOLD activity. This BOLD activity increased when the same contextual cue appeared with the target. The authors concluded that modulation of salient information helped in detecting the target which is task relevant was modulated by the TPJ.

The insula has also been targeted as part of a salience network of attentional control in addition to the anterior cingulate cortex (ACC) (Menon & Uddin, 2010). In particular, in a review by Menon and Uddin (2010) the insula has shown in neuroimaging studies to be activated during switching attention as a response to the detection of salient stimuli similar to the anterior cingulate cortex (ACC). The insula has connections to the conflict resolution areas such as dorsolateral prefrontal cortex and the ACC, both regions involved in attention control during visual search.

A single neuron electrophysiology study suggested that the prefrontal cortex in the monkey is also active in bottom-up pop-out search (Katsuki & Constantinidis, 2012a). Macaques were required to memorise a cued coloured square (red or green) in a specific location. The square with appeared on its own or as part of a 3*3 array with eight remaining squares being of the opposite colour to the cue (therefore making the cue pop-out salient. Afterwards, a delay match-to-sample was made as to whether the cue matched the same location or not and release a lever if the cue was matched (and also make a target fixation eye movement), or hold the lever if the target was absent. Single-neuron electrophysiological recordings were taken in the LIP and the (FEF) simultaneously. Both these two locations fired when the salient square was presented. The authors concluded that both the frontal cortex and the parietal cortex processed early bottom-up salience in visual search (Katsuki & Constantinidis, 2012a).

So far saliency has been described as attentional focus being driven by an external property of the stimulus. In contrast, top-down attention is deliberate choice driven capture by intentions and goals (Theeuwes, 2010). Top down control does not appropriately distinguish the aspects of which drive attentional selection more in a given task: the prior experience or the current goals. Top down saliency is selective (as it focusses on specific targets) and selective attention to stimuli has been argued by Corbetta and Shulman (2011) is driven by the dorsal attention network in the inferior parietal sulcus, superior parietal lobule, and the frontal eye fields.

An example of a top-down process could be shown from the effect of working memory on attentional selection in visual search by Soto et al., (2005; Soto et al., 2006; Soto & Humphreys, 2007). The paradigm used by Soto et al. (2005) uses a dual-task approach. Participants were required at the start of each trial by holding a cue item (a coloured shape) in working memory. While the participants remembered this object, they performed a singleton search task to find a tilted white bar in a search array of vertical bars and state its direction (left or right). The bars were in the centre of outlines of coloured objects which are irrelevant to the task. Once the target has been identified, a simple memory discrimination task is run asking the participants to compare the coloured shape to whatever they held in working memory at the start of the trial (either it is the same or not).

There is a manipulation of top-down saliency comes at the search stage. On (typically) two-thirds of the trials, the memory cue shape reappears in the search display. In one case it reappears with the singleton tilted bar (valid, memory target salient cue) leading typically to faster detection of the bar compared to no reappearance. Conversely, in the second case, the memory shape reappears with a distractor vertical bar leading to a slowing of search time compared to no cue reappearance (invalid salient distractor memory cue).

Soto et al. (2005) argued that these cue validity effects on search are automatic and reflect top-down guidance of search from working memory. Notably, the same effects do not occur when participants merely see or identify the first shape, suggesting that there is at best weak guidance of attention from bottom-up priming from the appearance of the cue. Later research implicated working memory-based guidance of attention depends on the frontal cortex (patients with frontal lesions show increased effects of working memory-based guidance; Soto et al., 2006; Soto et al., 2007). Additionally, Soto and Humphreys (2007) found that this memory guidance can be top-down as verbal cueing can also lead to validity effects.

These results can be classified in terms of saliency. Whilst the memory held item lacks feature distinctiveness from its neighbours in low-level properties (luminance, hue or form), it is salient due being held in working memory. If there should be a common theory for saliency, it should account for both physical and memory-based distinctiveness of an object among its neighbours.

Regarding neural substrates of top-down selection, the prefrontal cortex in has been implicated in controlling behaviour as suggested by a human fMRI study (Koechlin et al., 2003). Koechlin, Ody and Kouneiher (2003) ran fMRI on healthy participants and episodic memory task in which participants had to remember a series of blocks which were broken down. The memory items were either accompanied by a contextual cue (in which a signal was presented). Participants had to either perform a single-task memory recall or a dual response recall. Participants were slower at reporting the memory items during dual-task. The contextual control of memory during these two tasks was modulated activations in the lateral prefrontal cortex. This region was also important for the recall of episodic memory too. The authors concluded that the top-down control has a seat in the prefrontal cortex.

However, more recent evidence has shown that not only the frontal cortex but other regions have also been implicated in top-down control. An fMRI study by Weidner et al. (2008) demonstrated one example of how top-down control can modulate the effects of bottom-up perceptual saliency. This was demonstrated by participants having to perform a singleton (oddball) search task of lines which were in an array of coloured lines. At the start of the trial, participants were cued to the singleton was either the line’s orientation or its colour while being scanned by fMRI.

Seventy-percent of the times the cue was predicted to what the singleton was (valid top-down cue), and the remaining were distractors (invalid cue). The bottom-up perceptual saliency of the singleton was varied between trials (from high contrast easily distinctive to low contrast barely distinctive from its neighbours). Response times were modulated by cue validity (faster during valid cue trials and slower during invalid cue trials) and saliency (slower in low salience). The functional neuroimaging findings found that singleton stimulus saliency modulated bilaterally by the frontal, parietal and occipital cortices. The cue validity effects showed significant activation in the frontal cortex. However, the modulation of saliency in respect of cue validity was shown to be seated in the left TPJ. The authors concluded that the top-down control of bottom-up saliency during visual search could be controlled by the TPJ.

Noudoost et al. (2010) further explored the neural substrates of top-down attention in a review of the single-neuron neurophysiological literature. The reviewed identified that there are direct connections from the FEF to the monkey LIP and the superior colliculus (SC). Additionally, that goal-driven task shows downward control from the FEF to early visual areas directly (in particular area V4) and indirectly projections to via LIP (or attentional orienting). The FEF has direct projections to the SC for the control of eye-movements during the memory-guided search. The FEF also has been shown to have persistent activity during memory-guided eye-movements. However, there is also upward modulation of the FEF from LIP. The review concluded that the top-down control of attention has several structures in a network which overlap with regions involved in the programming of eye movements (e.g. the FEF, the SC and the LGN).

Theeuwes (2004) has argued that the perceptual distinctive of salient bottom-up items capture attention strongly enough that top-down intentions and task goals of the observer cannot overcome them. However, there has been disagreement about this from Leber and Egeth (2006). In an experiment by Leber and Egeth (2006) using a similar version of the irrelevant distractor task, two groups of participants were trained to focus on one of two possible targets: one group was asked to respond to target bar orientation to trials of which there was a singleton shape (unspecified what shape), and the other group had to search for a specific feature target (a circle). Reaction times were similar in both groups, suggesting that bottom-up capture could not explain search in the task as the saliency of an unspecified singleton shape, according to Theeuwes (2004) would have captured attention quicker than the top-down feature-based search group. Thus, the authors concluded that top-down control is involved in singleton search.

It should be noted that there had been an attempt at amalgamating the two variants of attentional control together (Awh, Belopolsky & Theeuwes, 2012). Awh, Belopolsky and Theeuwes (2012) proposed that there is an attentional priority map of which there are contributions of perceptual salience, experience, and task goals. This map takes into account the relative strength or weight of each of these factors, and the dominant one will orient attention to the appropriate item. However the seat of this mechanism and the process of assigning weights are still unclear and how these weights map directly on to a response is still unknown.

In a recent review, Shomstein (2012) has argued that there are discrete subregions in the parietal cortex that deal with top-down and bottom-up attention separately. In one neuropsychological study comparing patients with superior parietal lobe damage with patients with temporal-parietal junction lesions, top-down and bottom-up attention performance was compared (Shomstein et al., 2010). Shomstein et al. (2010) ran two attention tasks aimed to compare top-down and bottom-up attentional processing in patients with superior parietal and temporal-parietal junction lesions. Firstly, patients participated in a detection task using a rapid serial visual presentation (RSVP) with two letters presented laterally containing numbers and letters. Patients had to detect two numbers (2 and 4) that were presented in the RSVP among distractor letters which could appear in either the left visual stream or the right visual stream. Participants were initially cued as to which stream to attend to, and ignore the opposing stream. Addition to this, if patients detected a 2, they were asked to maintain attention on the same lateral stream where they found that target. However, if when they detected the 4 target, they were required to switch their attention to the opposite stream. Patients with superior parietal damage had impaired top-down shifting of attention (poorer detection of target letters when required to shift attention to opposite stream) compared to those with TPJ lesions. To best bottom-up attentional control, the same patients were presented with a single letter RSVP presented centrally but with four distractor hashes vertically and horizontally. Patients had to detect a coloured target letter (coloured red) in the stream of blue letters and state its identity. One of the hashes was coloured red or green to act as a salient bottom-up distractor. Patients who had lesions in the temporal-parietal junction had problems in ignoring the effects of the salient bottom-up distractor in detecting the letter target compared to those with just superior parietal lesions. The authors concluded that there are separate substrates of the parietal cortex which direct different aspects of attention: the TPJ mediating the effects of bottom-up attention and the superior parietal cortex controlling for top-down influences.

The prefrontal cortex has also been shown for both top-down and bottom-up attention in an fMRI study by Asplund et al. (2010). In their study, participants were presented with a stream of letters in a RSVP search for a target letter X. However occasionally a face stimulus appeared in the stream as a surprise. In trials in which the face stimulus appeared accuracy for detecting the target letter reduced. Additionally, there was increased fMRI activation in the inferior frontal junction, TPJ, and frontal gyrus when the salient stimulus appeared and also in when the target letter was detected. Equivalent regions (FEF, TPJ, and IPS) were similarly activated in if the salient stimulus was of a high luminance colour. The TPJ, unlike the FEF and IPS, showed deactivation anticorrelated to increased activation in the FEF and IPS. The authors concluded that frontal cortex was involved in stimulus-driven (bottom-up) and goal-directed (top-down) control of attention.

In a review by Vossel, Geng and Fink (2014) it was stated that PFC as part of the dorsal stream of attention interacts with the ventral stream, highlighting the common interaction between frontal cortex, parietal, and temporal areas both top-down and bottom-up attention. The ventral stream consists of the TPJ and ventral portion of the PFC. The dorsal stream consists of the IPS and the FEF. The review mentioned that in top-down cueing tasks; there is common overlap in activation frontal, parietal and temporal areas in the direction of cued attention, however with different profiles. In their overview, the authors noted that in top-down attention in tasks such as orienting, visual search and maintaining visual information tends to increase activity in dorsal areas (FEF and IPS) but decrease activation of the TPJ (which the authors term suppression of TPJ activity) with some inconsistent evidence suggesting both increase and decrease in activation in middle and inferior frontal gyri. However in bottom-up attention, for example, during the automatic orienting of exogenous cues, or unexpected onsets which are contextual or not, have shown increases in activations in dorsal and ventral areas which highlight overlap between streams. The authors concluded that the common brain region which manages top-down and bottom-up attention in these two streams was the PFC.

Further to this, a subsequent review by Katsuki and Constantindis (2014) suggested that there whilst there may be differences on a functional level between top-down and bottom-up attention, there two system share common neural structures. The authors stated that the primary distinction between bottom-up and top-down attention is based on the sources of which the information originates; with bottom-up being from initial low-level sensory percepts and top-down from higher cortical goals and experiences. However, the authors noted that there was common visual input which needs to be integrated and processed in both a bottom-up and top-down fashion. A common place however, after comparing the primate neurophysiological and human neuroimaging studies were the PPC and the PFC, which are involved in both bottom-up and top-down attention. This commonality, the authors argued, could be seen as acting as priority map of attentional control which merges the top-down control of salient bottom-up information in order to direct attention appropriate to task demands. Furthermore, the fact that these two regions serve in these two different attentional processes in a network may suggest that the distinction between top-down and bottom-up may be arbitrary although acknowledging they have different functions, but both involved in attentional prioritisation (similar to what was suggested by Fecteau & Munoz, 2006 in regards to saliency but in a broader perspective).

In a similar vein, one review suggested attempted to extend the bottom-up salience priority map notion by extending the notion of priority map by Fecteau and Munoz (2006) and integrate top-down modulation of salience as part of a wider frontoparietal network (Ptak, 2012). The frontoparietal network was seen as particularly important for integrating and modulating top-down signals of task selective and goal-relevant information from the frontal cortex (such as PFC and FEF) downstream with bottom-up information fo distinctive salient perceptual features upstream from the occipital and parietal cortices. Ptak (2012) argued in a review of both the monkey neurophysiological and human neuroimaging that this modulation from the two streams, which are integrated within the PPC, is a dynamic process. However, the review concluded that the PPC as a whole does not do all these modulations but instead there are specific subpopulations of neurons within the PPC which are dedicated to particular aspects of salience based modulation and prioritisation.

Summary and thesis aims

It is clear that parietal regions are involved in salience-based selection, however, it is unclear as to how this is done. It is shown that the parietal cortex as part of a wider network (of which integrates information from the frontal, temporal and occipital cortices) is involved in both top-down and bottom-up salience-based selection of attention. Likewise, it is still unclear as to the role of saliency in top-down and bottom-up orienting and whether there are distinct subregions of the parietal cortex that govern these processes. Additionally, it is unclear the role of saliency in these two distinct attentional processes. This thesis will attempt to show that salience-based selection works differently in different subregions of the parietal cortex depending on the behavioural relevance of the contents of stimulus being made salient.

Previous studies have varied saliency at a perceptual level and examined how it hinders the task in general, but not the process of response selection specifically. It is unclear about whether saliency, in either its top-down or bottom-up form, is influenced by the precise nature of the response at hand. Due to the uncertainty of the role of saliency in attentional selection, the rationale of this thesis is to explore saliency in how it has differential neural and behavioural effects on visual search. To explore this rationale, the thesis will use a neuropsychological approach, testing the performance of two different populations: neuropsychological brain damaged patients; and neurotypical individuals.

In order to examine search in a broad manner, three main types of cognitive paradigms will be used. The first main type is a non-spatial one. This involves the process of searching for specific aspects of an object. The way that this thesis will investigate this is by looking at the selection of global and local levels of hierarchical stimuli. Note that, in spatial terms; a local stimulus will be selected any time a global shape is selected, so spatial selection mechanisms alone fail to account for how stimuli in such hierarchical forms are selected.

Navon (1977) argued that object processing starts from the whole (the global level of detail) and then focuses on the small constituent parts of the object (the local level of detail). To investigate this notion, he devised a non-spatial search experiment using compound objects (objects comprised of other objects primarily on two levels). For example, a large letter H comprised of multiple smaller letter Ss. A real life analogy would be taking a house (a whole object) being made up of multiple bricks (local elements). The task involves the participant to search for a particular letter or shape which is either at a specific level (focussed attention) or in an unspecified level (divided attention) in the compound image.

From this paradigm, Navon (1977) found two principle effects. One is global precedence in which global targets are responded to faster than local ones. The other is that of global interference. This is the process by which the global level captures attention, and the participant needs to disengage from the captive global level and switch to local level details. This disengagement switch costs time and thus interferes with local processing. In summary, when viewing an object, the default is to start at the global level before processing the local.

Initial support for neural structures underlying global and local processing came from neuropsychological, behavioural studies with unilateral patients. For example, Delis, Robertson and Efron (1986) who found that patients with brain damage to the right hemisphere could only reproduce drawings from memory the local elements of a compound image. However, the reverse impairment was the case for those with left hemisphere damage only being able to reproduce drawings of the global level of a compound image. Further neuropsychological studies had supported this notion (e.g. Lamb Robertson & Knight, 1990; Robertson & Lamb, 1991). The neuropsychological evidence global and local processes are independently lateralised in opposing hemispheres of the brain.

Global-local tasks such as the one by Navon (1977) have been argued to resemble executive attention due to the need for perceptual grouping. Evidence in favour of this top-down distinction has come from an fMRI study by Weissmann Magnan and Woldorff (2002). Weissmann, Magnan and Woldorff (2002) ran an event-related fMRI study using a selective attention variant of the Navon task in which at the start of each trial, the target level was cued (instead of blocking a particular level target in multiple trials at a time). Distractor level incongruency was significantly higher in the local cued condition compared to the global target cued conditions. The fMRI results suggested that frontal and parietal mechanisms were active when the level was cued and for distractor level incongruency more generally. The authors argued that executive attention is required to suppress the response interference of the distractor level, and this occurred in the same brain areas as the orienting attention network (through target level cueing).

There have been further neuroimaging studies that have elucidated neural evidence for global and local processing. In particular, the temporal, occipital and parietal cortices appear to play a role in modulating level processing. Early neuroimaging studies have aimed at address the notion of level laterality between hemispheres which was introduced by discoveries in neuropsychological patients. One of the earliest examples was a PET study by Fink et al. (1996) which confirmed findings from neuropsychological patients suggesting the global processing was lateralised. There were significant activations of right lingual gyrus during the processing of the global level of letter compounds. However, there was a significant increase in brain activity in the left superior temporal and left occipital cortex when local letters were processed. These supported neuropsychological findings suggesting the global and local processing were distinctly lateralised in the human brain.

There evidence to suggest that occipital cortex maps global-local processing (Sasaki et al., 2001). Using fMRI retinotopic mapping, Sasaki et al. (2001) ran a global-local task with compound shapes. No difference behaviourally in level processing was found. However, in terms of the fMRI retinotopic mapping, both global and local processing were mapped onto the early visual cortex (V1, V2, V3,and V4) but were not hemispherically lateralised. The authors concluded that level processing was simply a case of visual attention.

Additionally, the oculomotor motor system appeared to play a role in global-local processing. Weber et al. (2000) fMRI and eye-movements were recorded (although not simultaneously) during a standard global-local task with letter compounds and shape compounds. It was found that more saccades are directed to local elements than to global figure. These eye-movements correlated with increased action in the bilateral superior parietal cortex, superior frontal gyrus and the inferior occipital gyrus. The authors reported that no saccades were made during the global processing tasks, although there was increased activation in the cuneus. The authors concluded that the oculomotor system mediated the processing of global and local processing in terms of modulating the window of attention during the scanning of features.

Bilateral inputs of compound stimuli also yield differences in global and local processing. Han et al. (2004) presented participants with two compound letters presented bilaterally in which they had to identify a specific global or local letter cue while they were being scanned with fMRI. Participants displayed a global advantage in their responses. The fMRI results found that the superior parietal cortex was involved in local processing, and the temporal cortex was involved in global level processing similar to previous studies. However, neither global nor local processing were hemispherically lateralised (Han et al., 2004).

However, in contrast, a similar study that did not use bilateral inputs did reveal hemispheric lateralisation of level. An fMRI study by Weissman and Woldorff (2005) using a divided attention variant of the Navon task in which participants were cued on each trial which level that had to be attended to, found that the parietal cortex and the temporal cortex have different hemispheric lateralisations in global-local processing. Global processing was lateralised in the left temporal and parietal cortices, whereas, local processing was lateralised to the right temporal and parietal cortices (Weissman, & Woldorff, 2005). Furthermore, the inferior parietal sulcus was significantly active during the cueing of a particular level, which too was also lateralised. The authors concluded that distinct hemispheres of the parietal cortex were important for preparing attention towards a particular level for later selection by the temporoparietal cortex (i.e. superior temporal gyrus, inferior parietal sulcus).

Further to this, the right TPJ has been found by fMRI to be significantly active in the processing of global forms (Huberle & Karnath, 2012). In a shape discrimination study, healthy participants were presented with whole circles and squares which were comprised of 900 smaller images of circles and squares on a grid. The contrast between the smaller shapes which created the global shape was greater than the shapes surrounding it. That is to say, the shape of a black circle was comprised of black circles in the grid. However, the surrounding remaining circles on the grid were white to denote background. The image was scrambled by different degrees of visual image degradation (20%, 40%, 60% and 80%) to allow for a global discrimination task be performed by the participants using fMRI. In trials which the global form was identified easily (at 20% degradation compared to hardly discriminable 80%), there was significant BOLD activation of the right TPJ, which the author concluded that had a role in processing the global form. Additionally in a later training study using similar compounds; the TPJ was also found to be involved to be active in the processing of novel global forms (Rennig et al., 2015).

Subcortical areas also have been implicated in modulating level processing (Müller-Oerhring et al., 2007). In an fMRI study by Müller-Oerhring et al. (2007) using both a selective and divided attention variant of the standard letter Navon task. Corpus callosum size was found to be correlated with global interference of local processing. Additionally, the participants’ age also accounted for explaining global interference along with the size of the anterior portion of the corpus. Likewise, the sex of the participant also modulates the size of the corpus callosum, with females having a significant correlation with corpus callosum size and local interference whereas this correlation was not shown in males. The above studies mean that in total, numerous regions of the brain contribute to global and local processing, largely parietal, temporal and occipital regions with some modulation from frontal and subcortical regions. Debate it still had as to whether these two level processes can be localised and lateralised in the brain (in which chapter 2 will also address).

In regards to saliency in hierarchical processing, one of the earliest neuroimaging studies which have investigated saliency with respect to global-local processing was conducted by Fink et al. (1999) using spatial frequencies and positron emission tomography (PET). Instead of using letter compounds, participants had to discriminate between horizontal and vertical orientations of striped rectangles of black and white bars which were of low spatial frequency of stripes or high spatial frequency. The local task was to determine the direction orientation of the component stripes whereas the global task was the compound rectangle. Participants were faster at determining the global orientation of the rectangle when it was in high frequency. The high spatial frequency significantly slowed local perception. There was increased glucose metabolism (from PET) in the early visual cortex in the right hemisphere for the global processing of high-frequency displays. Whereas, the local processing of low spatial frequency displays activated the left inferior occipital cortex. The authors concluded that level processing is lateralised with respect to spatial frequency. Furthermore, the authors argued that detecting local orientation was harder in high spatial frequency as it made the global level more salient (due to increased local elements of the high spatial frequency). Conversely, the authors stated that low spatial frequency allowed for the local level to be more salient due to the larger distance between each of the individual rectangle elements (thus making grouping harder to perform). Importantly, there was no main effect of spatial frequency was found. Thus, the authors concluded that relative perceptual salience of the frequency in respect to the target level modulated the level processing more than spatial frequency alone. More discussion about the lateralisation of global and local processing will be made in the following chapter (Chapter 2).

It has been argued that these global precedence effects are due to confounds in the stimuli. The stimuli were made so that the global level was salient. Saliency can be modified to alter global precedence and interference effects by changing the perceptual relationship between the two levels (e.g. using larger gaps to remove grouping cues, blurring of local elements) (Mevorach et al., 2006a, Mevorach et al., 2009, Huberle & Karnath, 2010). This thesis will use the latter saliency variant to assess the effects of both saliency and level of processing on different participant groups. More detail about the saliency aspect of this paradigm will be discussed in both Chapters 2, 3 and 4.

The second main type of paradigm involves assessing the effects of working memory on spatial search using the working memory-guided visual singleton search task was developed by Soto, Heinke, Humphreys, and Blanco (2005). This paradigm will be used as an example of top-down saliency due to the lack of perceptual distinctiveness from a bottom-up level in search but with top-down saliency from working memory. This paradigm will be used to see whether parietal cortex is involved in this working memory based automatic guidance of executive attention in what has previously been highlighted as a frontal function.

The third main paradigm that this thesis will use is an adapted variant of the irrelevant distractor task by Theeuwes and Van der Burg (2007). This paradigm will be used to compare on a spatial domain the claims that salience-based selection in the parietal cortex is response relevant by the manipulation of task demands and bottom-up saliency in targets and distractor items.

This thesis will investigate the role of saliency in relation to the parietal cortex using the above three paradigms and by using two principal approaches: the neuropsychological approach (brain damaged patients) and by using transcranial magnetic stimulation (TMS).

Neuropsychological studies

Neuropsychological studies have been important in distinguishing between effects of top-down and bottom-up attention (Shomstein et al., 2010; Shomstein, 2012). Having patients with discrete lesions can help elucidate the neural basis of atypical cognitions. That is to say; inferences are made of how attention is oriented and allocated based on atypical behaviour in standard tasks based on the fact that they have discrete and specific lesions.

The neuropsychological approach has been widely used to investigate the neural basis of global and local processing of hierarchical stimuli (e.g. Lamb et al., 1989; Robertson & Lamb, 1991; Shalev et al., 2005; Mevorach et al., 2006a; Shalev et al., 2007; Dalrymple et al., 2007; Huberle & Karnath, 2010). Much debate has been in the literature based on patient studies about the lateralisation of hierarchical processing, which examples of double dissociation of global and local process in distinct separate cerebral hemispheres (Lamb et al., 1986; Lamb et al., 1989), and others finding no such level form lateralisation also based on neuropsychological patients (Huberle & Karnath, 2010; Mevorach et al., 2006a, Riddoch et al., 2008).

Human neuropsychological evidence suggests that bottom-up salience influences the eye-movement control (Mannan et al., 2009). In a study by Mannan, Kennard and Hussain (2009), two patients with visual agnosia with posterior brain lesions to inspect and report the understanding of pictures of visual scenes and recorded their eye movements. The two patients made the first few fixations to salient items in the visual scene which were comparable to healthy controls. After the initial fixations, differences were found in fixations to other non-salient aspects of the scene (which the authors concluded required top-down control to direct eye-movements across the rest of the image to integrate items). The authors concluded that bottom-up salience did help drive initial eye movements to scenes but due to disrupted top-down control, could not report all aspects of understanding of the scene which relied on integrating salient and non-salient aspects. Although, in a replication study on a patient with visual agnosia having to report natural visual scenes and fractal images, modelling a saliency map onto visual agnosia suggests that saliency alone was not sufficient to predict eye-movement saccades during visual search but some top-down control did modulate direction to other non-salient items (Foulsham et al., 2011).

Further, neuropsychological evidence suggesting the influence of bottom-up salience, as well as top-down control, can be seen in visual search tasks with medicated patients with Parkinson’s disease (PD). Horowitz et al. (2006) asked PD patients and healthy elderly controls to perform a visual search of either feature or conjunction when the target was known beforehand (promoting top-down attention) or finding an oddball (target unknown) in an array were coloured bars which were of either horizontal or vertical. The patients with if performed better in search when there was a bottom-up salient target (regardless of whether it was known to the patient or not). Top-down control also attenuated visual search in PD during conjunction search conditions in which the target was known to the patients. The authors suggested that bottom-up salience does a direct search in PD, and they will rely on this if no top-down information is provided prior.

In the top-down working memory-guided search task, Soto, Heinke and Humphreys (2006) found that frontal lobe patients were particularly sensitive to memory shape cues in guiding their search for a target search bar. Further to this, de Bourbon Teles et al. (2014) reported that patients with thalamic lesions also showed problems in utilisation of memory cues in search. More exploration of this paradigm will be done in chapter 6.

In this thesis, the neuropsychological approach attempts to identify the mechanisms (neural and cognitive) behind salience-based selection by investigating the effects of saliency in neurologically atypical groups. This approach will be able to make interferences on cognitive mechanisms by looking at performance in those with and without brain lesions. It will also demonstrate the effects of damage or deficiency on behaviour with a neurotypical control group.

Transcranial Magnetic Stimulation

Transcranial magnetic stimulation (TMS) is a non-invasive technique in which a coil that emits an electromagnetic pulse is applied to the scalp to stimulate the cortical region in a focal point (Walsh & Cowey, 2000). The electromagnetic pulse is claimed to add noise to the neural activity which evokes action potentials (Walsh & Cowey, 2000). TMS has been claimed to have a good temporal resolution which is critical for the investigation of attention mechanisms (Chambers & Heinen, 2010).

This adding of noise by TMS has been argued to interfere with normal neural (thus cognitive) processing. This interference can be considered a creating temporary virtual lesion thus simulating neuropsychological patients in neurotypical (healthy) participants. For example, TMS in attention tasks has shown to display temporarily right hemispatial bias behaviours similar to that of hemispatial neglect (Hilgetag et al., 2001). Additionally, studies have generally found that stimulation of the parietal cortex prevents updating or adjustment of movements (limb or eye) based on reallocated attention (Rushworth & Taylor, 2006).

TMS has been used to investigate the three main experimental paradigms that this thesis will adopt. In reference to global-local processing, TMS has been used extensively to investigate the neural basis of these processes. Below are a few examples of how TMS has elucidated neural mechanisms behind hierarchical processing and salience-based selection. Two examples below have shown the role of the specific hemispheres of the parietal cortex in level form processing. One such example can be seen from a repetitive pulse TMS (rTMS) has also been used to investigate level lateralisation in global and local processing by Qin and Han (2007). Qin and Han (2007) inhibited the left and right parietal cortex in a global-local Navon task and found that local processing was poorer after inhibition of the left parietal cortex by TMS.

However, another example suggests that this level form lateralisation is dependent on handedness as found by rTMS. Mevorach, Shalev and Humphreys (2005) in which investigated the role of handedness and the parietal cortex in global-local processing using rTMS. The authors ran a global-local task with both letter compounds and shape compounds in which they stimulated the left and right posterior parietal cortex in a global-local using TMS, and compared global interference effect in left and right-handed participants. Regardless of the nature of the compound, those who were left-handed had significantly higher global interference after being stimulated in the right posterior parietal cortex (PPC), whereas the reverse lateralisation of global interference was found in left PPC in right-handed people. This finding signifies that lateralisation of global and local processes are not generalisable to all people since hemispheric laterality of handedness modules these visual processes.

Returning to the notion of bottom-up saliency, TMS has been used in a saliency-mediated global-local task (Mevorach et al. 2006b). Mevorach et al. (2006b) applied rTMS to the posterior parietal cortex (PPC) on neuro-typical participants performing the salience manipulated global-local task. As mentioned before, to make the global level salient, blurring of local elements in the hierarchical stimuli encourages global processing. Conversely, local saliency was made by increasing the inter-elemental distance between local letter elements and increasing contrast (by using alternating colours). The authors found that stimulation to the right hemisphere PPC was found to attract attention to high saliency targets (that is when the target level has clearly corresponding salient items). Whereas, when rTMS was applied to the left PPC, behavioural responses showed faster reaction times for low salience targets with high salience distractors.

Aside from the bottom-up saliency from the Navon task, a TMS study has also been run to investigate top-down saliency in the working memory-guided visual search task, as described earlier in this chapter. Soto et al. (2012) ran a similar variant to the working memory-guided visual search paradigm to Soto and

Humphreys (2007) using fMRI and offline-TMS. The fMRI results found, despite similar behavioural performance, distinct neural representations for verbal top-down working memory cue guidance in search (superior frontal gyrus and pulvinar) and visual cues (posterior cingulate cortex, right thalamus and inferior frontal gyrus). In a subsequent experiment, the authors compared the effects of rTMS on visual and verbal cue guidance. The same task was run to see whether inhibition of the superior frontal gyrus and the lateral occipital cortex could interfere with cue specific memory guidance of visual search. Inhibition of the superior frontal gyrus after rTMS stimulation impaired automatic guidance of the visual memory cue in search. Whereas, inhibition of the lateral occipital cortex reduced guidance of verbal memory cues in search.

In addition, a TMS study has been run on a variant of the irrelevant distractor singleton search task. Hodsoll, Mevorach and Humphreys (2009) showed a ring of white diamonds with horizontal and vertical white bars and the task was to search for a circle (singleton) and press a button as to the orientation of the bar. The irrelevant singleton distractor was a (colour feature) green diamond. The left and right posterior parietal cortices were stimulated using rTMS. It was found that stimulation of the right posterior parietal cortex reduced the interference of the irrelevant singleton distractor.

TMS has also revealed that the role of the frontal cortex, as well as the parietal cortex in salience-based selection. Zenon et al. (2009) conducted a three variants of a visual search task: a bar discrimination task, a goal-directed search task and a stimulus-driven search task. Participants were presented with a colour disk which acted as cue for the searching for targets in either of the three tasks that contain that colour feature. In the bar discrimination task, participants had to state the orientation of the target coloured bar among other bars of different colours and orientations. In the goal-directed search task, participants had to report all the letters that match the cued target colour from a ring of coloured letters which had colours close to the target colour. In the stimulus-driven letter search task, participants performed the same letter report as the goal-directed task however the target colour was more salient (pop-out) compared to the other letters. After the cue was presented but before the search task appeared, TMS was applied to the frontal eye fields (FEF), the angular gyrus and the vertex. Stimulation to both the FEF and the angular gyrus showed slower responses to goal-driven search and stimulus-driven serach if the number of items in the search array were close to the target colour were small. The authors concluded that bottom-up and top-down control of salience was controlled by a frontoparietal network.

This thesis will use rTMS to create virtual focal lesions in neurotypical participants in order to simulate findings from neuropsychological patients. Additionally, this approach will serve as a converging operation to the neuropsychological data.

Chapter by chapter outline

The following will describe in brief the outline for each of the following experimental chapters and how each addresses the main topic of parietal influences on salience-based selection in search.

The first experimental chapter is Chapter 2. Further investigations described in the subsequent chapters in this thesis will attempt to be more precise in the neuroanatomical localisation of this saliency utilisation. This will be shown by the neuropsychological brain damaged patients. The advantage of this method is that beyond mere implication, these patients have clear lesions which allow for more direct association of function to neuroanatomy to be made.

To find the seat of saliency selection more precisely, a voxel-based morphometric approach will be used in Chapter 2. This approach will compare behavioural performance in a saliency mediated global-local letter discrimination task (by Mevorach et al., 2009) in a wide range of neuropsychological brain damaged patients. This approach minimised the potential selection sample bias in patients used when investigating global and local processing.

In addition to saliency selection, this voxel-based morphometric analysis in the large patient study also aims to identify the neural basis of global and local object processing. The neural localisation and lateralisation of these processes have been debated for many years throughout the literature with conflict results due to differences in experimental methodology. Examples of such differences can be shown in types of stimuli used (Fink et al., 1997; Huberle & Karnath, 2010), the use of saliency as a mediator (Mevorach et al., 2006a), the sample used (Lamb, Robertson & Knight, 1990; Riddoch et al., 2008) and measures taken.

The chapter will conclude with findings that will argue for a lack of lateralisation for global and local processing and instead the left parietal cortex being responsible for the suppression of the distractor level when it is perceptually salient and has a different response to the target level. It will also show for the first time, white matter regions implicated in this process. Finally, the study will show the precuneus being a region for the resolution of response conflict in this task.

In Chapter 3, rTMS will be applied to normal healthy participants with the aim of inhibiting functioning of the right precuneus. By doing this, it will temporarily simulate the lesions that patients can have in a more focal area. These converging operations between the neuropsychological findings in Chapter 2 and the TMS finding in Chapter 3 will cement the link between the precuneus and response conflict (assessed by interference by incongruent hierarchical displays).

Chapter 4 will investigate the role of perceptual saliency in selection in a case study of a bilateral parieto-occipital patient with Balint’s syndrome (and simultanagnosia) JM. This chapter will demonstrate using the same saliency-based global-local task as in Chapter 2, that the parietal cortex is implicated in orienting attention towards salient top-down information. The perceptual distinctiveness of salient items (as defined by Corbetta & Shulman, 2011) overwhelms top-down task cues in this patient with simultanagnosia. This overwhelming capture of salient items in this patient, JM was strong enough to render her unable to disengage from salient distractor level in order to correctly identify the correct target level.

Returning to the notion of saliency in whole object processing, Chapter 5 will present another neuropsychological single subject case study of a bilateral superior parietal patient with intact frontal lobes using the saliency mediated global-local task (Mevorach et al., 2009). Chapter 5 will explore the notion of behavioural relevance in salience-based selection (as defined by Corbetta & Shulman, 2011). The chapter will argue that perceptual distinctiveness alone does not modulate salience-based selection in this particular patient with simultanagnosia and superior parietal lesions (Patient PF). The behavioural relevance of the distractor items mediates the selection of perceptually salient items.

It will reveal that this Patient (PF) does not show a typical selection of relevant, salient information (in which salient targets capture attention but are not effectively utilised in selection), in fact, the reverse to neurotypical participants. However, this reversed salience-based selection can be obtained again when the distractor objects are independent of a response category. That is to say, if the distractors are never a possible response, they will capture attention when salient. However if the response set is salient, then efficient attentional selection will be made, so long as semantically dissimilar distractors are present.

Whilst Chapter 5 demonstrates the response specificity of selection of salient items in search; it is done using a non-spatial selective attention task (the Navon global-local task). This case study with Patient PF will be extended in Chapter 6. The development in Chapter 6 will explore the generalisability of the claims made in Chapter 5 using the working memory-guided singleton search task (Soto & Humphreys, 2007) to investigate top-down saliency. In addition, I will report on an adapted variant of the irrelevant distractor task (Theeuwes, 1992; Theeuwes & Van der Burg, 2007) to show effects of bottom-up saliency.

Chapter 6 will conclude that utilisation of salient information depends on the top-down binding of a response to the salient feature. If a search target has a salient feature which is independent of the instructed response, patient PF is merely captured by the low-level properties of the target but does not automatically use this to help respond and conclude search. However, PF is able to utilise the salient target if the salient feature needed for the response.

The thesis will conclude in Chapter 7 that saliency can be affected by response types, and the selection of salient item depends on how they relate to the task set. This provides a clear extension of our current understanding of knowledge of the relationship between saliency and response selection in search. Additionally, the thesis will conclude that the parietal cortex plays a role in salience-based selection however in different ways. The thesis will argue that depending on nature of the distractor items and the relative saliency of the target with respect to its distractors on a semantic level and their top-down relevance to the task, different portions of the parietal cortex play a role in orienting attention for salience-based selection.

To start off the investigation, the following chapter (Chapter 2) will investigate the role of saliency in object form discrimination using a wide range of neuropsychological patients using a global-local task.

CHAPTER 2 A VOXEL-BASED MORPHOMETRIC APPROACH TO SALIENCY MEDIATED HIERARCHICAL PROCESSING: BEYOND TRADITIONAL COGNITIVE NEUROPSYCHOLOGY

Introduction

Chapter 1 presented the case that saliency could influence visual search and how attention is oriented. As mentioned previously, one non-spatial way that search can be investigated is by using a global-local task. There have been discrepancies between the neural basis of global-local processing and the extent to which saliency influences level selection. The following experiment in this chapter (Experiment 2.1) will address the debate in the literature of the hemispheric laterality of global and local processing using a wide range of neuropsychological patients. Moreover, the experiment will demonstrate that when using a saliency-mediated global-local task, there is little clear evidence in favour of laterality of these global and local level processes.

In relation to the processing of global and local Figures, early research claimed that global and local level processes were distinct and dissociated between the two cerebral hemispheres (Robertson & Lamb, 1991). Martin (1979) conducted behavioural experiments which presented compound images in split visual fields using a tachistoscope. Neurotypical participants were asked to attend and respond to either the global and local levels. Global level targets presented in the left visual hemifield (governed by the right hemisphere) were responded to faster than local targets. Likewise, local level targets presented in the right visual hemifield (governed by the left hemisphere) were responded to faster than global targets. It was therefore concluded that global processing was lateralised to the right hemisphere and local processing to the left hemisphere.

Further evidence of this cerebral lateralisation of global and local processing could be found not only in healthy adults but also in unilaterally damaged patients (Robertson & Lamb, 1991; Lamb Robertson and Knight, 1990). For instance, Delis, Robertson and Efron (1986) tested unilateral patients' (comparing groups of left and right hemispheric lesions) ability to memorise and reproduce (by drawing) hierarchical stimuli which were either linguistic (letter compounds such as an M made of smaller Zs) or non-linguistic (such as a triangle made up of smaller squares). The authors found that those with left hemisphere (posterior superior temporal lobe) damage could only reproduce the global aspect of the stimuli from memory. The reverse was shown in the right hemisphere patient group (only being able to reproduce local letters).

Brain imaging studies have also lent support for this lateralisation in neurotypical adults (Fink et al., 1996; Fink et al., 1997; Lux et al., 2004). Fink et al. (1996) used positron emission tomography (PET) to highlight higher cerebral blood flow to the right lingual gyrus during global processing and left inferior occipital cortex for local discrimination.

However, in recent years, there has been increasing evidence which challenges the notion of hemispheric lateralisation of global and local processing. Fink et al. (1997) for instance, demonstrated opposite lateralisation with shape compounds using PET (that is, left hemisphere sensitivity to global shapes and right hemisphere sensitivity to local ones). Furthermore, in peripheral presentations of compound stimuli, functional magnetic resonance imaging evidence has revealed that the right (rather than left) cingulate cortex appeared to play a role in local processing (Lux et al., 2004).

The type of the object to be perceived has also been shown to be critical in a study investigating a patient with simultanagnosia (Dalrymple, Kingstone and Barton, 2007). While such patients typically suffer from bilateral damage they tend to show specific impairment in global processing (Darlymple et al., 2007). Darlymple et al., (2007) compared level processing in hierarchical compound letters and face processing in a patient with simultanagnosia. Faces have been argued to be similar to compound Navon letters in that the whole face is comprised of multiple features (Dalrymple, Kingstone & Barton, 2007). The patient in this particular study showed global level processing deficit for compound letters but not for faces. This study has shown that the nature of the stimulus itself could influence level processing, even in disorders characterised by failure to integrate multiple components into a whole.

Continuing from the previous neuropsychological evidence, Riddoch et al. (2008) identified that certain patients with bilateral damage can have specific and dissociable level specific problems. In one particular experiment, the authors conducted a Navon type compound letter discrimination task with two patients: one with an object-form based visual agnosia with bilateral dorsal extrastriate damage as well as damage in right interparietal cortices; the other patient demonstrated an integrative visual agnosia (Riddoch & Humphreys, 1987a) following damage in the anterior occipital and inferior temporal cortices (Riddoch et al., 2008). Object-form based visual agnosia is a problem in identifying and discriminating between shapes and an inability in reproducing them (e.g. impaired copying). Integrative agnosia is a deficit in perceptually integrating (grouping) shape elements to form a whole coherent object (including encoding parts' relation), despite being able to identify individual shapes correctly. The patient with object-form based visual agnosia displayed a local level bias with hierarchical forms (and a global impairment). In contrast, the patient with integration-based visual agnosia showed a global level bias with hierarchical forms (and a local impairment). This study showed that symptom-based neuropsychological studies (that is, choosing patients based on neuropsychological deficits as opposed to discrete specific brain damage) could also show a double dissociation in level processing and as such challenges the concept of hemispheric specialisation in global/local processing.

Finally, even with unilateral patients, it has been found that left parietal patients could perform both global and local processing (Mevorach, Humphreys & Shalev, 2006a). Global and local processing in these patients could be done under specific manipulations of the relationship between global and local parts as these processes have been shown to be independent of each other (Mevorach, Humphreys & Shalev, 2006a). In the specific case of a study by Mevorach et al. (2006a), patients could perform global tasks when the hierarchical stimulus had local elements which were not salient (due to blurring and reducing contrast to promote grouping cues). In those global salient displays, patients found local elements hard to report due to the high salience of the distracting global level. Conversely, these patients could identify local elements easiest when the local elements were made salient (by using alternating colours to promote higher contrast segmentation thus slowing the perceptual grouping process). Likewise in these local salient displays, the patients found global processing difficult due to the high salience of the distracting local elements. This inconsistent evidence presented in the previous three cases shifts the focus to other influencing factors that may be lateralised in the brain beyond level processing.

Thus, previous neuropsychological investigations have failed to demonstrate consistent level deficits based on discrete damage. A potential intervening factor could be stimuli manipulations which may have an impact on the measured behaviour. Specifically, increasing the saliency of the global form can restore global perception in patients typically showing global deficits. One such example is given by Huberle and Karnath (2010). In this study, manipulating the size of the local elements in a compound letter improved global perception in a patient with simultanagnosia. Manipulating the relationship between local elements (e.g. inter-elemental distance, contrast) has been shown to promote global processing in Balint's syndrome and simultanagnosia (Shalev, Mevorach & Humphreys, 2005; Shalev, Mevorach & Humphreys, 2007; Montoro, Luna & Humphreys, 2011).These effects were strongest when local elements were not familiar with the patient (Shalev, Mevorach & Humphreys, 2007). Thus, there are contradictory findings even within a single neuropsychological disorder traditionally characterised by a deficit in global perception.

Indeed, the relative salience of the global and local levels of stimuli seems to have a critical impact on results. For example, left parietal patients were shown to be dramatically affected by the salience of the conflicting level of form in a compound letter task (Mevorach, Humphreys & Shalev, 2006a). That is, when the irrelevant level was more salient the patients were unable to resolve response competition by ignoring it. Importantly, this held for global and local identification alike. Transcranial magnetic stimulation (TMS) in healthy adults supported this showing that left posterior parietal cortex was responsible for driving attention away from the salient distracting level, and the right posterior parietal cortex for selecting the relevant, salient information (Mevorach, Humphreys & Shalev, 2006b). Similarly, using fMRI Mevorach, Shalev, Allen & Humphreys., (2009) have been unable to find brain lateralisation for level processing but rather of saliency suppression (in the left angular gyrus) in typical adults. Consequently, applying TMS to left angular gyrus increased salient distractor interference, consistent with the brain region mediating the suppression of salient distractors regardless of their level of form (Mevorach et al., 2010).

While using TMS has the benefit (compared to neuropsychological investigations) of simplifying the focus by selecting the critical brain sites using a specific ‘a priori’ criterion, it still neglects the possibility that other regions of the brain not judged ‘a priori’ could also be critical in either salience-based selection or level processing. One attempt to solve this problem is by a voxel-based morphometry (VBM) analysis which was proposed as a more inclusive alternative technique to the single case study approach (Ashburner & Friston, 2000). VBM is a data-driven technique which uses large numbers of structural brain images of patients to reveal consistent loss of neural tissue. Critically, rather than grouping patients with similar lesions, VBM uses patients with lesions in various locations and of various types, making this a non-discriminatory structure to function link (Bates et al., 2003).

Poirel et al. (2011) applied VBM to assess processing of local and global levels of form, using shape compounds on typically developing six-year-old children.

The analysis revealed that those children with a global bias had reduced grey matter (compared to individuals showing a local bias) in the right occipital regions and the bilateral lingual gyri. In contrast, children who presented with a local bias revealed low grey matter in the right precuneus and inferior parietal cortex. This finding showed overlapping regions with data on local and global processing in adults, thus indicating a potentially common mechanism across different age groups. However, since these children were still developing, these level-based effects might not remain localised to those precise brain regions once saliency suppression and inhibition mechanisms have developed in adulthood. To date, this VBM approach has not been applied to saliency mediated level processing in adults, who due to neurological injury, have lost or modified their visual selection abilities.

The present study will attempt to identify areas linked to the processing of distinct levels of form using a saliency-based compound letter discrimination task (Mevorach, Humphreys & Shalev, 2006b) and VBM. In particular, the study will focus on testing adults with lesions affecting various parts of the brain to identify common and distinct neural regions for processing different levels of form. The analysis will also consider other factors, particularly the relative saliency of the levels (which have been shown to have a critical impact) as well as the presence of response competition.

It would be expected that saliency would be lateralised. To address concerns from the past literature about lateralisation of level processing, the current experiment hypothesised that the level of form processing (global and local) will be discretely lateralised in the brain. It is expected that there will be differences in grey matter tissue integrity associated with of interference from incongruent displays.

Experiment 2.1 – Voxel-based morphometric analysis of global and local processing in patients with brain damage.

Methods

Participants

Thirty-one patients took part in the study (M_{Age} = 64.77 years, *SD* = 11.92 years). The patients were recruited from a database of volunteers who had neuropsychological problems following brain damage. All of the patients were regular volunteers in the School of Psychology, University of Birmingham. All of those who participated in the study had damage in location initially blind to the experimenter, to avoid any demand characteristics influencing the recording of data (see Figure 2.1.1 for the extent of lesions that patients had). The brain injury for all patients took place at least six months prior to the study. Twenty-four patients were right-handed and 26 had brain injury due to a stroke. The other five patients: one had hypoxia; one had lesions due to dementia, and three had lesions due to accident or medical anomalies. Exclusion of these latter patients had minimal effects upon the results.

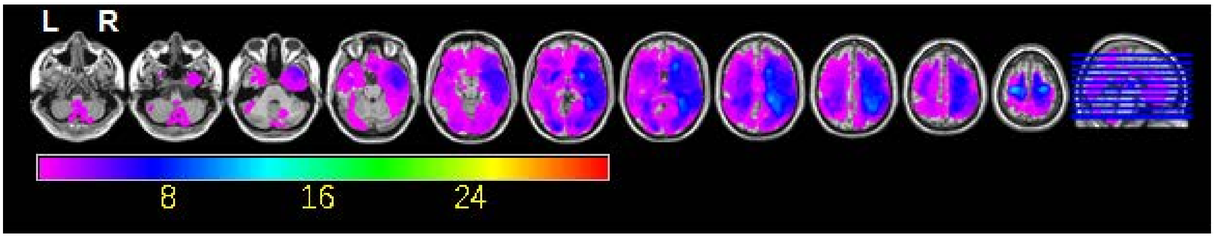

Figure 2.1.1: Axial slices of combined grey matter brain lesions of patients who participated in Experiment 2.1. Colour intensity represents the number of patients that have a common lesion in the particular brain region. The left-hand side of each brain scan slice (L) represents the left hemisphere, and the right-hand side (R) represents the right hemisphere.

Design, Stimulus and Materials

Design

The current experiment is a global local discrimination task based on Mevorach et al.'s (2010). There were three factors (level, saliency and congruency), each with two levels. The level was defined as either the Global or the Local aspect of a hierarchical letter (a large letter made up of smaller constituent letters) which should be identified in any one block (Identify global letter/identify local letter). The global task was defined as identifying the whole (big) outline letter. The local task was defined as identifying the smaller constituent parts of the compound letter. Saliency was operationally defined as the relative perceptual difference in target identification between the levels of form. Thus, two displays were used: (1) Global salient – using a blur procedure over the entire compound letter, or (2) Local salient - using alternating colours in local letters to break grouping. This then defined two experimental aspects of saliency: Target salient – when the *target* level is the more salient level (that is, global task with Global salient displays and local task with local salient displays); and Distractor salient – when the *distractor* level is the more salient level (that is, Global task with Local salient displays and Local task with Global salient displays). Finally, the congruency of the letters within the two levels was also manipulated as the third factor: congruent (the same letters appeared on both global and local levels) and incongruent (letters did not match between levels). Table 2.1.1 shows how the saliency of the global and local levels and the task (global and local identification) translated into the Target salient and Distractor salient conditions.

Table 2.1.1: Saliency conditions with respect to the level letter identification task, in which the salient display refers to:

Task	Target Salient	Distractor Salient
Global task	Global salient	Local salient
Local task	Local salient	Global salient

Stimuli and Materials

The experiment used the same compound letter stimuli as previously used in Mevorach et al. (2010). For the local salient displays, the local letter subtended 1.34 x 1.76° of visual angle in height and width, respectively and the global letter 6.7 x 10.81° of visual angle in height and width, respectively. The distance between each local letter was 0.46° of visual angle. The local letters appeared in either red or white; both colours were equal in number and alternated in their arrangement.

For the global salient displays, all the letters were red to facilitate perceptual grouping of the local elements into a coherent whole. Each local letter was subtended in the same dimensions of visual angle in the local salient stimuli. However, the global letter was subtended at a visual angle of 5.83 x 9.22° (height and width, respectively). The distance between each element was 0.15°. To enhance the saliency of the global level, the letters were blurred using PaintShop Pro 7.0 using a Gaussian blur factor of 7. The letters used were either ‘H’ or ‘S’ and the global letters where a depiction of these letters using a 5*4 array of the local letter (see Figure 2).

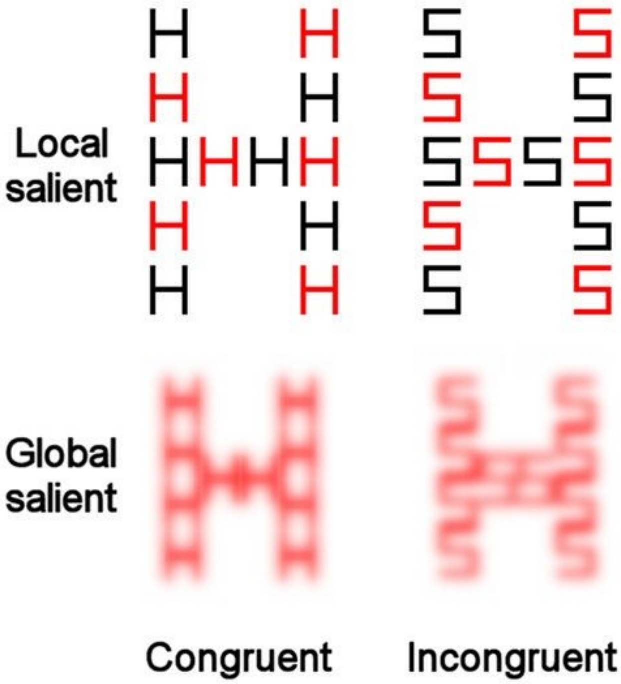

Figure 2.1.2: A selection of compound letter stimuli used in the experiment: one example of congruent letters that are salient at the global level and another salient at the local level. In addition, there are examples of incongruent hierarchical displays: again for both global salient and local salient displays.

Procedure

E-Prime 2.0 (Psychology Software Tools, 2002) was used to program the behavioural experiment and to record the accuracy of correct responses and response times. Participants were sat at a 36 x 30 cm (width x height) LCD monitor approximately 60cm away from the screen. The experimenter was sat at the patient's side. There were four types of blocks: Global salient- Global task, Global salient - Local task, Local salient- Global task, and Local salient - Local task). Each block was run twice in each run to give eight blocks in total. Each block had 32 trials, 16 of which were congruent displays (the same letter appeared in both the global and local level) and the other 16 were incongruent (different letters appeared in the global and local levels). The task was run twice to give 16 such blocks in total. At the beginning of each block, a message appeared instructing the patient to report the global shape (‘Global task’) or the local elements (‘Local Task’) in the coming trials.

At the start of each trial, a fixation asterisk was presented in the centre of the black screen for 505ms. Afterwards, the compound letter stimulus was presented centrally for 150ms, which was then followed by a blank black screen. The patients were then required to respond (with no time limitation) which letter (H or S) appeared at the target level. As some patients had productive aphasia or vocal articulation issues, a piece of paper with large printed letters H and S was used, so that the patients can point to their answer. Otherwise, patients could articulate the letter orally. Patients had the choice as to which medium of response they preferred. As soon as the patient had made their response, the experimenter pressed the corresponding keyboard button (m for “H” and k for “S”) with the right hand (index and middle fingers on respective keys) to record the response. Following the key press, a blank screen appeared for another 1000ms before the next trial started. Figure 2.1.3 shows a pictorial representation of a typical trial sequence. Reaction times and accuracy were recorded. However, only the accuracy data was used for further analyses in this study.

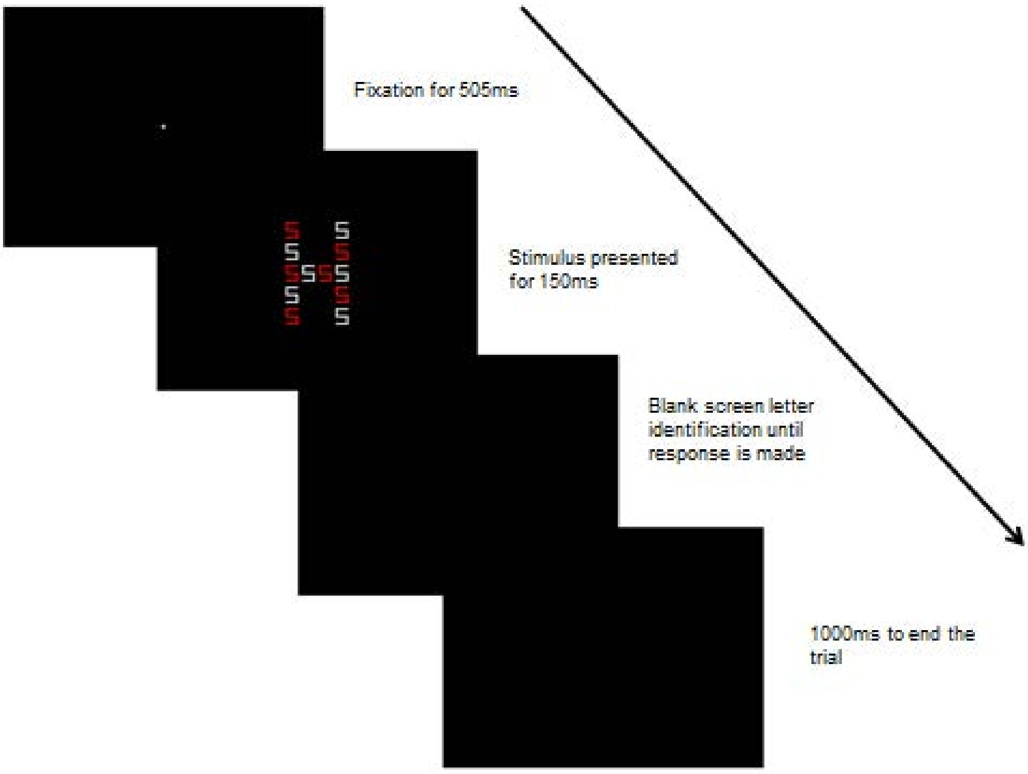

Figure 2.1.3: Schematic timeline sequence of events occurring in a single trial in the saliency-mediated global-local letter discrimination task (Experiment 2.1).

Voxel-Based Morphometry (VBM) Analysis Method

VBM analysis (Wright et al., 1995; Asburner & Friston, 2002) uses a General Linear Modelling approach to statistically assess whether a dependent variable (the brain scan) can be explained by weighted predictor variables (beta values). Once the model has been created, t-tests are conducted on every voxel in the anatomical T1 brain structure scan to compare each voxel lesion with beta value (a predictor of covariate). While each test is done at the voxel level, the analysis will focus on the cluster-level statistics, which are more representative of a grey/white matter lesion. To be consistent with other neuropsychological VBM studies, the analysis technique was similar to the technique used by Demeyere, Rotshtein and Humphreys (2010). The voxels reported consisted of at least 100 voxels at the p <.001 uncorrected at the voxel level. Afterwards, to correct for the issue of multiple comparisons, Family Wise Error correction (FWE) at p <.05 for the cluster level was imposed as the benchmark for a significant area of loss of grey/white matter integrity. This criterion for significant cluster level has been used in other VBM studies (Demeyere et al., 2010; Woodbridge et al., 2013). The analysis technique in this current study was used separately for grey matter and for white matter (VBM has been applied to both types of tissue matter; e.g. Wright et al., 1995; Ashburner & Friston, 2002).

Statistical Parametric Mapping (SPM 8, Wellcome Department of Cognitive Neurology, London UK) was used to analyse the anatomical T1 brain structure data. All the anatomical scans were pre-processed, normalised to a standard MNI template brain and then spatially smoothed with a Gaussian kernel to allow for effective inferential statistical analysis. The anatomical scans were segmented into grey matter, white matter and cerebrospinal fluid tissue classes, with an additional tissue class to take into account the abnormalities of brain structure due to lesions (see Seghier et al., 2008).

The dependent variable was the grey matter/white matter of the T1 patient scans. The independent variables were included as regressors of covariance. Apart from the case of analysing the difference between congruent and incongruent trials, each model had two experiment variables. The first experiment variable in the model was always the main testing variable. The second experimental variable was added as a covariate to partial out any variance which cannot be explained simply by the first experimental variable. The second experimental variable was simply the counter number to the main condition of interest (for example if global processing were the first variable then local processing would be the second). There were other covariates reflecting factors of no interest which were: age, sex, handedness, whether the damage caused was due to stroke or other problems and lesion volume. These factors were placed in this order to partial out any unexplained variable in the GLM model explaining the grey/white matter integrity loss.

The models (of first predictor variable) were the following: congruency difference (interference), global processing, local processing, target salient processing, distractor salient processing, congruency difference in global processing, congruency difference in local processing, congruency difference in target salient displays and congruency difference in distractor salient displays.

Once significant cluster regions were identified, they were localised using a combination of gross morphology mapping via Duvernoy Human Brain Atlas (Duvernoy, 1999) and the use of the SPM 8 Anatomy toolbox (Tzourio-Mazoyer et al., 2002) using the standardised MNI coordinates to give access to probabilistic cytoarchitectonic brain regions.

Results

Group behavioural results

Accuracy data was first analysed using a repeated measures Analysis of Variance (ANOVA) with level (global, local), saliency (target salient, distractor salient) and congruency: (congruent, incongruent) as within subject factors (see Figure 2.1.4 for means). No significant effect of level was found (global *M* = .96, *SEM* = .01, local *M* = .95, *SEM* = .01) (*F*(1, 30) = .10, n.s). The ANOVA produced a significant effect of saliency as patients identified target salient displays (*M* = .97, *SEM* = .01) more accurately than distractor salient ones (*M* = .94, *SEM* = .02) (*F*(1,30) = 4.49, p = .042, partial η^2 = .13). A significant main effect of congruency was also evident with higher accuracy for congruent (*M* = .98, *SEM* = .01) than incongruent displays (*M* = .93, *SEM* = .02) (*F*(1,30) = 8.32, p = .007, partial η^2 = .22). No significant interaction of level and saliency was found (*F*(1, 30) = 1.21, n.s). No significant interaction between congruency and level (*F*(1,30) = .92, n.s) was identified. Borderline significant interaction was revealed between saliency and congruency (*F*(1,30) = 3.95, p = .068). No significant interaction between level, saliency and congruency (*F*(1,30) = .04, n.s) was identified. For group means for each condition see Figure 2.1.4. The behavioural patterns shown by the group of patients roughly correspond to previous findings on healthy young participants on this task (e.g. as seen in Mevorach et al., 2009).

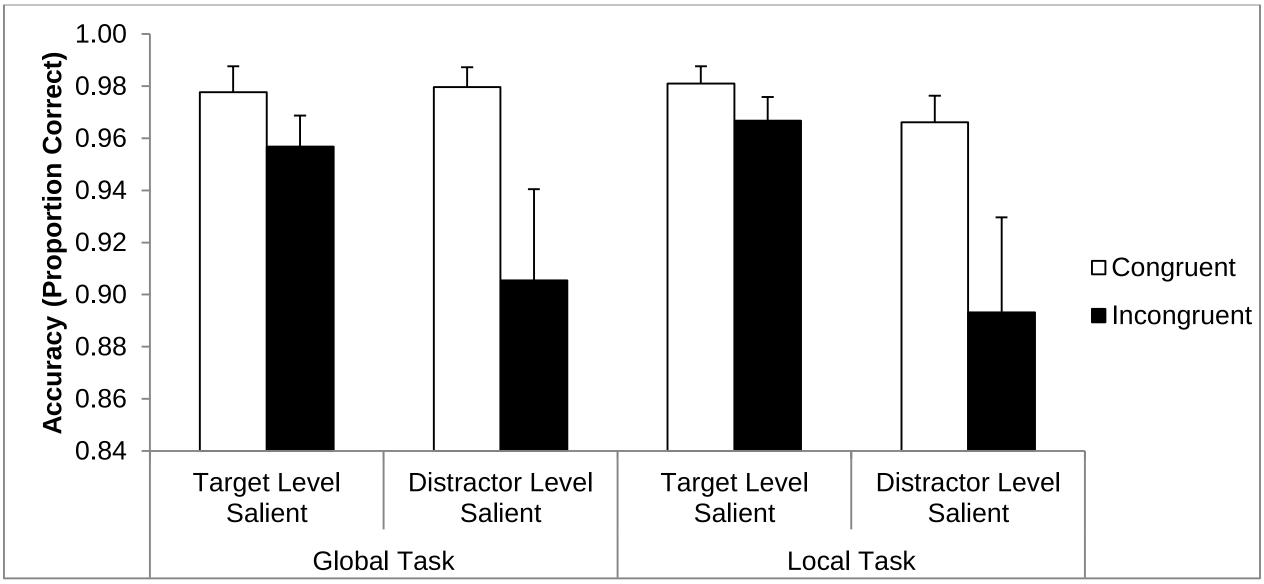

Figure 2.1.4: Mean accuracy scores of patients in the global-local letter discrimination task. Error bars represent standard error of the mean.

Histograms were constructed to show the distribution of the accuracy scores amongst patients. The distributions helped to identify a particularly impaired patient (JM).

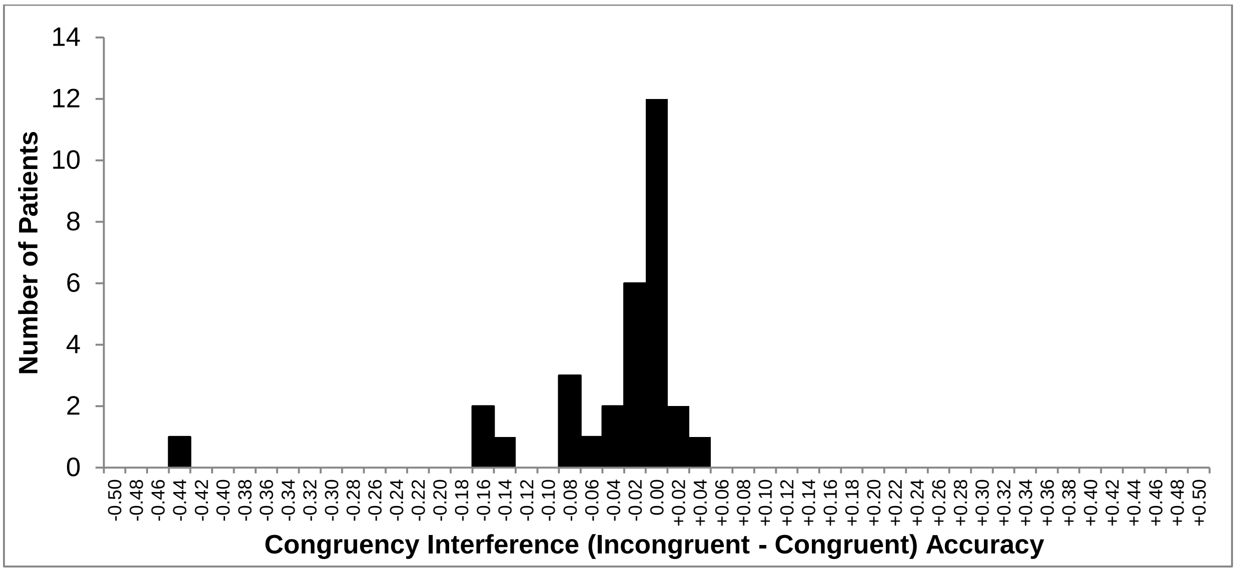

Figure 2.1.5: The distribution of the congruency effect (Congruent – Incongruent). Negative values indicate reduced accuracy for incongruent compared to congruent displays (congruency interference) while positive values indicate that responses to incongruent displays were more accurate than to congruent ones.

Congruency interference difference is displayed in Figure 2.1.5. While most patients exhibited effects with the -0.16 to +0.4 range, one patient (JM) had a substantially larger congruency effect of -0.44. Since the computed congruency interference (the difference between congruent and incongruent displays) was used as a predictor variable, a single samples t-test was run to verify that the difference maintained. A single samples t-test was done on the congruency difference as an extra sanity check to test whether the difference was beyond chance. This congruency difference was statistically significant (*M* = -.05, *SD* = .09) (*t*(30) = -2.891, p = .007). Even with the outlier patient JM who showed the largest congruency interference was removed the difference remained statistically significantly different from zero (*M* = -.03, *SD* = .05) (*t*(29) = -3.521, p = .001).

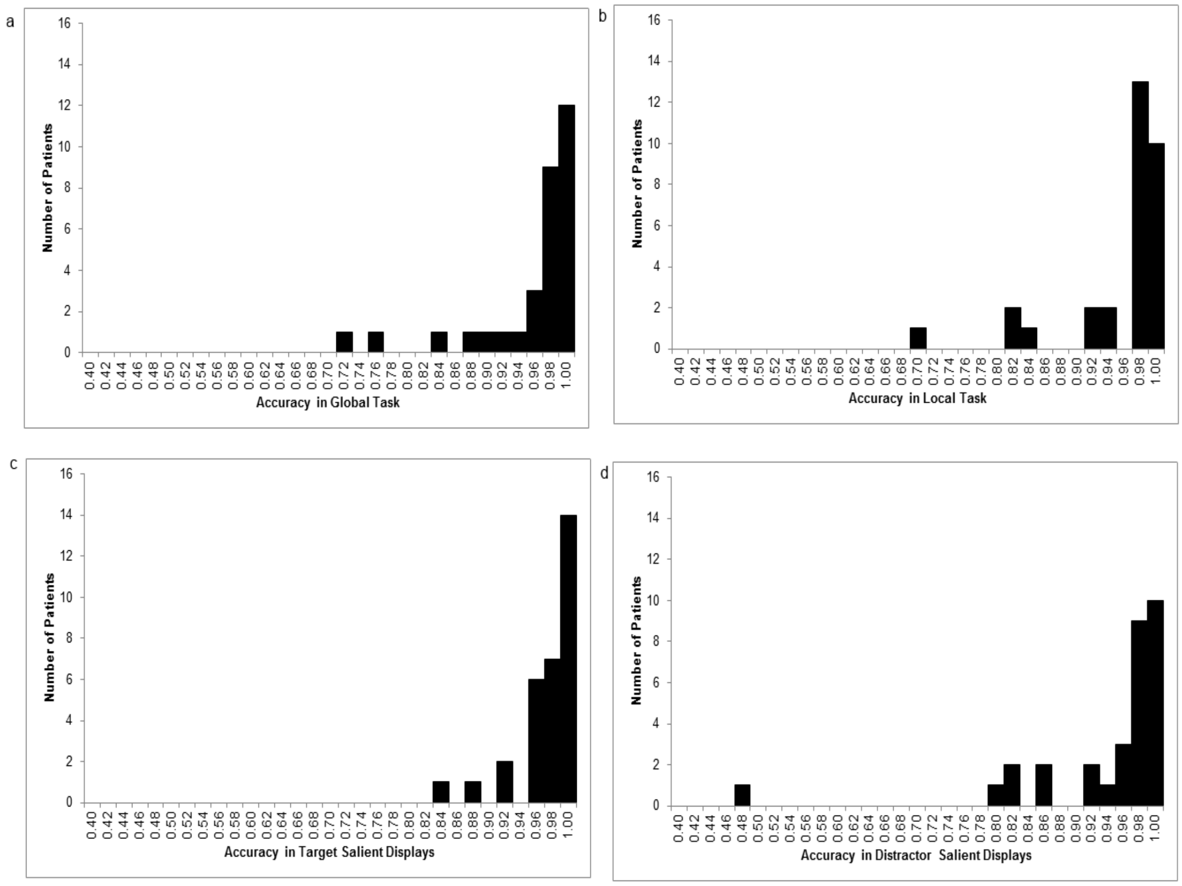

Figure 2.1.6: Histogram representing the distribution of correct responses to: a) global processing; b) local processing; c) target salient displays (across both global and local levels); d) distractor salient displays (across both global and local levels).

For both global and local identification (Figures 2.16a and 2.16b, respectively) the majority of patients performed at 0.98 or above accuracy (21 patients and 23 patients for global and local, respectively). Thus, across the group, there was no clear difference in distribution between global and local identification (which fits with the non-significant main effect of level in the ANOVA). Again, Patient JM was overall poor in accuracy in both levels.

Figures 2.1.6c and 2.1.6d depicts the distribution for target salient and distractor salient displays, respectively. Overall, accuracy in target salient displays was more closely distributed than accuracy in distractor salient displays. Patient JM had the lowest accuracy in the distractor salient condition but high accuracy in the target salient condition. Some patients had low accuracy in both saliency conditions but the difference between the two conditions was not as large as in the case of patient JM.

Although patient JM's performance could be considered an outlier in terms of behavioural performance, rerunning the analysis without JM did not alter the significance of the effects reported above. While removing the patients from the behavioural analysis had no remarkable effect I conducted the VBM analyses twice, firstly including this patient and secondly, after removal of this patient.

Grey Matter Analysis – 31 patients, significant findings

Only two factors which were significantly associated with loss of grey matter integrity were found in 31 patients: congruency interference and local processing. The data are summarised in Table 2.12 below. Figure 2.1.7 shows a pictorial representation of statistically significant lesions associated with accuracy in the two conditions.

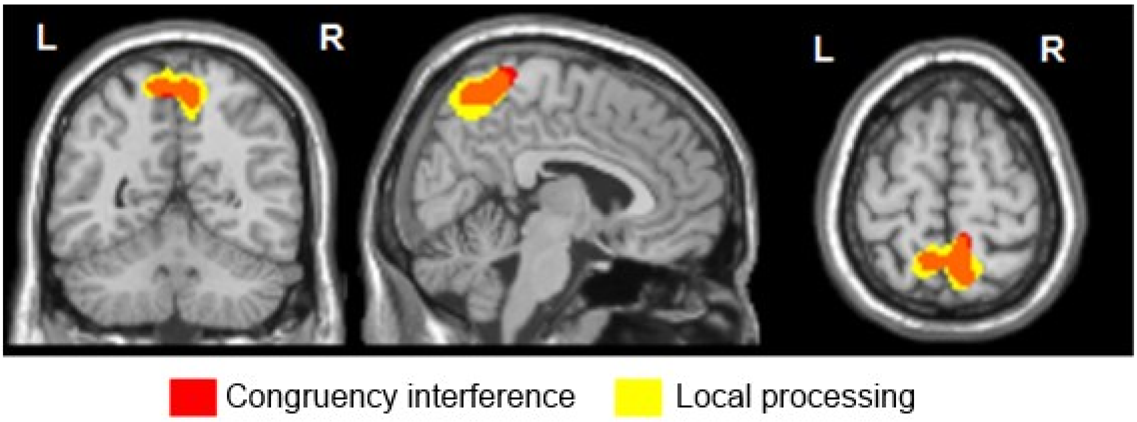

Figure 2.1.7: Sagittal, axial and coronal sections of significant areas of grey matter lesion (at SPM p <.001 FWE cluster level) in 31 patients overlay of congruency difference, and local processing, mapped onto a T1 weighted stereotaxic image. The orange blob represents the neural overlap of the congruency interference contrast (red) and local processing contrast (yellow). The L represents the left hemisphere and R represents the right hemisphere.

Table 2.1.2: Significant clusters of grey matter integrity in 31 patients correlated with accuracy in congruency interference and local processing. The table includes MNI coordinates and identification of gross morphology and probabilistic cytoarchitectonic regions. The starred (*) significant values are ones that were significant to the Family Wise Error (FWE) corrected p-value at the cluster level.

Contrast	**Brain Region (Gross Morphology)**	**Portion**	**Probabilistic Cytotectonic Architecture**	**Cluster p (FWE corrected)**	**Cluster p (Uncorrected .001)**	**Cluster Voxel Size (k)**	**MNI Coordinate**			**Z Peak**
							X	**Y**	**Z**	
Congruency Interference	Precuneus	Bilateral	Superior Parietal Lobule Area 7a (40%)	.016*	.003	699	10	-60	60	4.05
			Superior Parietal Lobule Area 5L (70%), Area 7a (40%)				-10	-54	64	3.86
	Paracentral Gyrus	Right	Area 3b (40%)				8	-44	68	3.86
	Middle Occipital Cortex	Left	Area 8 (20%), HOC 3v (10%)	.199	.046	276	-28	-98	14	3.72
			HOC 3v (30%), Area 18 (30%), Area 17 (20%)				-28	-100	-2	3.36
Local Processing	Precuneus	Right	Superior Parietal Lobule 7a (70%), Area 5L (30%)	.001*	.001	1199	10	-58	60	4.60
		Bilateral	Superior Parietal Lobule Area 7a (30%), Area 7p (30%)				-10	-66	52	4.39
			Superior Parietal Lobule 7a (60%)				-12	-54	64	3.90
	Superior Occipital Gyrus	Right		.306	.074	209	32	-96	16	426
							35	-80	30	3.93
	Superior Frontal Medial Gyrus	Left		.523	.15	130	-6	70	12	3.91
	Superior Occipital Gyrus	Left	Area 18 (10%), Superior Parietal Lobule (10%)	.153	.034	311	-24	-98	16	3.59
							-22	-82	36	3.59
	Middle Occipital Cortex	Left					-38	-90	16	3.52

The table also showed that the superior parietal cortex (precuneus) was also the most significant predictor of impairment when processing local information in hierarchical stimuli regardless of the saliency of the level. In fact, the peak voxels in both cases were almost identical.

Grey Matter Analysis – 30 patients significant findings

As mentioned above, I have repeated the VBM analysis with 30 patients (removing Patient JM). Here there were significant areas of impairment in both congruency difference (interference) and congruency interference in distractor salient displays (Table 2.1.3). As these two regions almost completely overlapped, only the congruency effect in the distractor salient condition is shown in Figure 2.1.8.

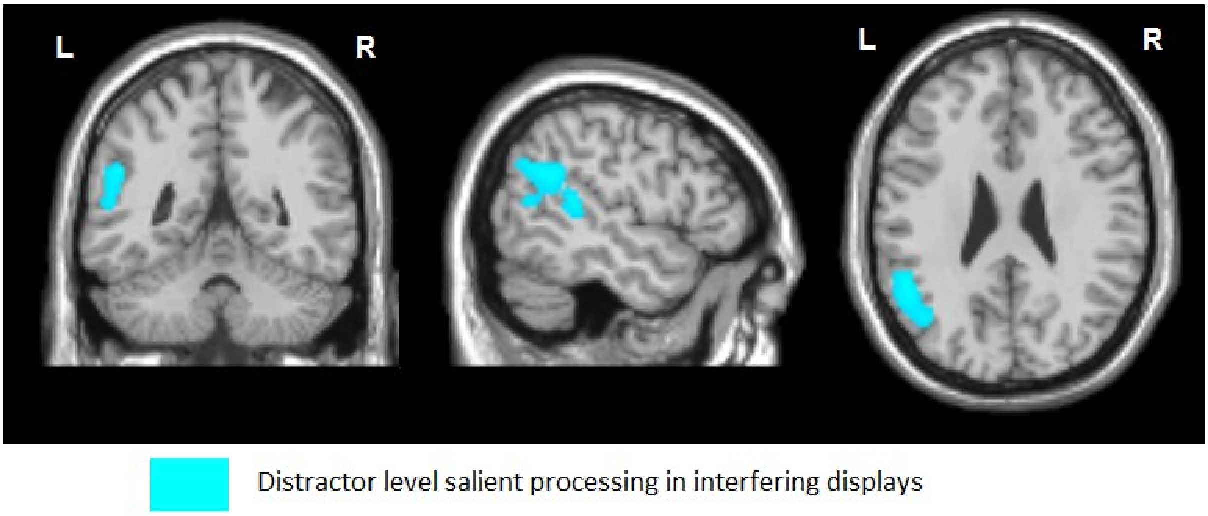

Figure 2.1.8: Sagittal, axial and coronal sections of significant regions of white matter integrity correlated to impairment (at SPM p <.001 FWE corrected cluster level) of accuracy in 31 patients for effects of interference with salient distractors, mapped onto a standard T1 weighted stereotaxic image. The L represents the left hemisphere and R represents the right hemisphere.

Table 2.1.3: Significant clusters of grey matter integrity in 30 patients correlated with accuracy in congruency interference and congruency interference in distractor level salient displays. The table includes MNI coordinates and identification of gross morphology and probabilistic cytoarchitectonic regions. The starred (*) significant values are ones that were significant to the Family Wise Error (FWE) corrected p-value at the cluster level.

Contrast	**Brain Region (Gross Morphology)**	**Portion**	**Probabilistic Cytotectonic Architecture**	**Cluster p (FWE corrected)**	**Cluster p (Uncorrected .001)**	**Cluster Voxel Size (k)**	**MNI Coordinate**			**Z Peak**
							X	**Y**	**Z**	
Congruency Interference	Angular Gyrus	Left	Inferior Parietal Cortex Area PGa (30%), Area PF (20%)	.034*	.007	557	-48	-52	26	4.03
	Superior Temporal Gyrus	Left					-50	-40	14	3.91
	Middle Occipital Gyrus	Left	Inferior Parietal Cortex Area PGp (40%)				-40	-66	24	3.50
Inference in Distractor Salient Displays	Angular Gyrus	Left	Inferior Parietal Cortex Area PGa (50%)	.047*	.009	489	-50	-52	26	3.69
	Superior Temporal Gyrus	Left					-52	-40	14	3.53
	Middle Occipital Gyrus	Left	Inferior Parietal Cortex Area PGp (40%)				-40	-66	24	3.43

The left inferior parietal and superior temporal cortices appeared to be a significant area of grey matter deficit in correctly identifying low salient targets on both the global and local levels. However, the same regions for congruency interference and distractor salient conditions alone were not found after removal of patient JM. This lack of finding suggested that the removal of one patient only drove the power of the result.

White Matter Analysis - 31 patients

White matter voxel-based morphometry analysis was also conducted to identify any fibre tracts which could be associated with any of the critical factors (level, saliency, congruency and their interaction). The method of the analysis was the same as for the grey matter. Only three conditions revealed significant white matter integrity loss associated with poor accuracy: congruency interference, distractor salient processing and the interaction between distractor salient processing and congruency interference (see Figure 2.1.9).

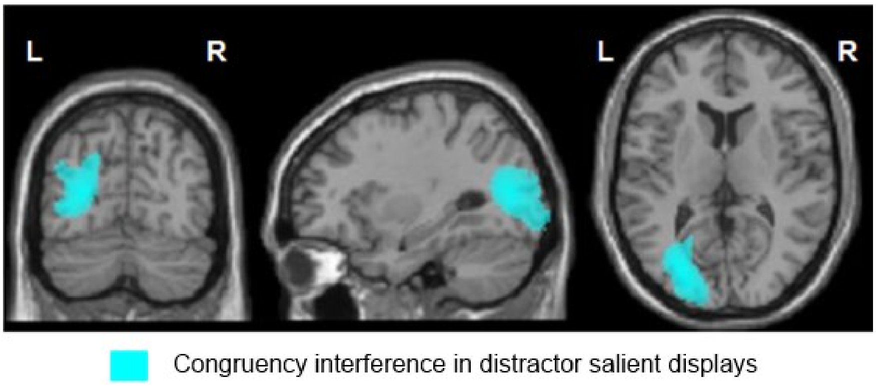

Figure 2.1.9: Sagittal, axial and coronal sections of significant regions of white matter integrity correlated to impairment (at SPM p <.001 FWE corrected cluster level) of accuracy in 31 patients for effects of interference with salient distractors, mapped onto a standard T1 weighted stereotaxic image. The L represents the left hemisphere and R represents the right hemisphere.

Table 2.1.4: Significant clusters of white matter fibre tract integrity in 31 patients correlated with accuracy in congruency difference, distractor level salient condition and congruency interference in distractor level salient displays. The table includes MNI coordinates and identification of white fibre tracts. The starred (*) significant values are significant to the Family Wise Error (FWE) corrected p-value at the cluster level.

Contrast	**White Matter Tract (Gross Morphology)**	**Portion**	**Cluster p (FWE corrected)**	**Cluster p (Uncorrected .001)**	**Cluster Voxel Size (k)**	**MNI Coordinate**			**Z Peak**
						X	**Y**	**Z**	
Congruency Interference	Callosal Body	Left	.001*	.001	1852	-18	-56	20	4.57
						-30	-74	12	4.47
	Inferior Temporal Gyrus	Right	.57	.139	110	58	-54	-14	3.70
						64	-60	-18	3.50
						66	-52	-20	3.10
Distractor Salient	Callosal Body	Left	.001*	.001	1456	-16	-56	20	4.27
						-22	-64	24	3.75
	Optic Radiation	Left				-26	-86	6	3.92
Interference in Distractor Salient Displays	Callosal Body	Left	.001*	.001	3435	-16	-54	20	4.83
						-26	-84	8	4.64
						-30	-76	10	4.51
	Inferior Temporal Gyrus	Right	.556	.129	112	60	-56	-12	3.72

The collosal body in the left hemisphere was significantly associated with deficits in congruency interference processing. The callosal body and optic radiation in the left hemisphere were significantly related to deficits in processing distractor level salient information both to the general accuracy in this condition and to the size of the congruency effect in this condition.

As mentioned above, the analysis was re-run with 30 patients (removing Patient JM). No significant white matter lesions were found to be linked to any of the behavioural measures tested.

Discussion

The principle aim of this study was to test on a wider scale whether global-local processing independent of saliency was lateralised in the brain. This study was done using a group of patients with brain lesions in different locations (with no a-priory selection criteria). VBM analysis for both grey and white matter revealed interesting findings. Impairments in local processing and as well as increased congruency interference were found to be associated with bilateral superior parietal cortex lesion (grey matter tissue integrity) though perhaps more biassed to the right hemisphere. There was also a link between left inferior parietal lobule (angular gyrus) and left superior temporal cortex and increased congruency interference, particularly in distractor salient displays (especially when Patient JM was removed from the analysis). Interestingly, these behavioural effects were also associated with reduced integrity in left white matter fibres that were in a similar broad area as the grey matter lesions.

Firstly, I will consider the findings regarding level processing. It is important to consider level laterality even if saliency suppression is the main focus because of the controversy surround hemispheric lateralisation of global and local level processing. Since a focussed global/local level identification task was used with neuropsychological patients, it is important to consider level effects before exploring saliency effects so as any effect of salience-based selection or suppression cannot be masked by the hemispheric difference in level processing. Critically, I found no evidence for level lateralisation. These findings support a growing body of literature suggesting that level processing is not an all-or-nothing process but may rather be critically dependent on stimulus features. Whilst the VBM analysis here produced significant results for local processing and not for global processing; there was no lateralisation in the effects. Importantly, finding effects for local but not global processing could not be attributed to a corresponding a bias in behaviour in our cohort as I found no behavioural differences between the levels in our patients.

As such the present findings challenge the claim that level processing is lateralised in the brain. It could be speculated that previous results of lateralised effects (e.g. Martin, 1979; Delis, Robertson & Efron, 1986; Fink et al., 1996) could have been due to the perceptual nature of the stimulus itself which made an unintentional bias towards responses at one level or another. Further suggestions supporting this account for perceptual influences in global-local effects have even been found in neurologically healthy participants, with shapes versus letter compounds producing different patterns of lateralisation of activation (Fink et al., 1997). Therefore, the results of this current study strengthen this growing body of literature to suggest that level does not necessarily rely on lateralised processes.

However, a recent study with a similar paradigm which applied transcranial direct current stimulation (tDCS) has observed that both local processing and the ability to select salient information improved under anodal stimulation to the right PPC (Bardi, Kanai, Mapelli & Walsh, 2013). Interestingly, level laterality was reversed if the tasks were not blocked by level (i.e. they were mixed). Additionally, the effects of saliency effects were diminished after tDCS stimulation to the parietal cortex (Bardi et al., 2013). It should, therefore, be acknowledged that the present findings were obtained with a blocked presentation of tasks as opposed to single trial levels. Thus, there would still be some possibility that results may differ if global and local processing were not blocked.

It should be appreciated that despite the seemingly random sample of patients, there may be a slight bias in the spread of damage within the group. In particular, there were more patients with right hemisphere lesions than left which may have led to problems in the statistical power of the findings. Nevertheless, our findings highlighted left lateralisation (which was supposedly underpowered in the cohort that was tested) and it is, therefore, hard to expect that this small bias in the cohort is the reason for not finding lateralised effects in the right hemisphere. There were also bilaterally damaged patients who may also obscure the nature of lateralisation.

Apart from the level of form I also considered the demand on conflict resolution, measured in the congruency effect. The VBM analysis highlighted grey matter loss in the precuneus and angular gyrus as important in predicting impaired conflict resolution. This finding is relatively novel. Previous studies have not strongly emphasised the importance of congruency independently of global-local processing.

Congruency interference has been typically used (e.g. Mevorach et al., 2010) as a gateway for revealing level processing or saliency selection and suppression mechanisms. Conflict resolution had been noted in parietal cortices (in and neighbouring the precuneus) in studies of numerical distance, Simon, flanker and semantic conflict tasks (Ansari et al., 2006; Wittfoth, Buck, Fahle & Herrmann, 2006; Coulthard, Nachev & Husain, 2008; Hoenig & Scheef, 2009).

Finally, general support for the parietal cortex role in the successful suppression of distracting information was found. Both parietal and occipital regions were shown to be affected by saliency which is similar results of a study by Huberle and Karnath (2010) which found these saliency effects to be independent of the level of processing. The main significant finding was that there were lesions correlated with reduced letter identification in the presence of conflicting information from salient distractors. The grey matter lesions that were associated with salience suppression were mainly lateralised to the left hemisphere inferior parietal cortex superior temporal gyrus. Also, there were correlations in white matter tracts in the collosal body and optic radiation with congruency interference and distractor saliency. Furthermore, I also found evidence for a link between white matter tracts in the left hemisphere and distractor salient displays. In particular, white matter loss in the left hemisphere was correlated with increased interference in the condition of high competition (when the distractor is more salient). In a recent VBM study by Chechlacz et al. (2010), patients had to complete an apple cancellation task (a task in which patients need to identify and cross out with a pen pictures of whole complete outline drawings of apples on a page which along contains distractor incomplete drawings of apples). It was found that patients who had difficulties in inhibiting distractor (incomplete drawings) apples (both allocentrically and egocentrically) had deficits in white matter pathways. Taken together these studies support the notion that white matter tracts play an important role in resolving attentional competition (Chechlacz et al., 2010). The link between white matter loss in the left hemisphere and increased interference in distractor salient displays I found may also add-up to the identification in Mevorach et al., (2010) of a parieto-occipital circuit involved in suppression of salient distractors. In their study, the authors had identified that interfering with the left parietal cortex (using TMS) resulted in an increase of activation in the occipital pole when salient distractor had to be ignored. Indeed, it may be the case that the left hemisphere white matter tracts I identify here are the medium through which the left parietal cortex is down-regulating early occipital cortex reaction to salient distractors. Thus, damage to these tracts may hinder the ability of the parietal cortex to exert its control over low-level visual areas when salient information needs to be ignored.

There could be possible network effects being uncovered by this current study. The first which was mentioned earlier was the white matter tracts shown in optic radiation which had projections from the occipital cortex to the parietal cortex to during the suppression of interfering salient distractors. There were superior temporal and inferior parietal regions identified in conflict resolutions in suppressing salient distractors. Inferior parietal lobe, angular gyrus and the temporal parietal junction has been known to be important in distractor suppression and rejection in general (Geng & Vossel, 2013). Since there were significant white matter findings in the occipital and parietal regions, this could show bottom-up attentional capture by perceptual saliency (as visual cortex has been known from electrophysiological, and psychophysical studies to create a salience map see Zhaoping, 2005) whilst the inferior parietal lobe, temporal-parietal regions may be involved in the later reactive rejection by suppressing conflicting salient responses (akin to rapid rejection notion by Geng, 2014).

The present study was one of the largest neuropsychological investigations of global-local processing. Most importantly, our approach was inclusive and used patients with a variety of neurological problems. Using such an approach, I was able to confirm previous neurotypical research on saliency suppression, as well as to enhance prior results by highlighting effects of white matter lesions and identifying suspect regions in the parietal cortex controlling suppression of interfering stimuli, regardless of level or saliency. While this study is the largest of its kind to date, it should still be acknowledged that the possibility that the patient cohort was limited. As mentioned above task specifics may also play a role here (e.g., blocked vs. mixed). Nevertheless, and given the growing body of evidence, I conclude that brain lateralisation in the context of global and local processing is more likely to be associated with stimulus-related parameters, especially the need to ignore conflicting information under conditions of increased distractor saliency.

Since one region was involved in multiple processes (the precuneus), it would be advisable to investigate more precisely what is the nature of the role played by this region. Thus, the following chapter will investigate if conflict resolution and local processing in neurotypical adults are affected by localised repetitive inhibitory stimulation by TMS over the precuneus region. Investigating the TMS effects in neurotypical individuals will help uncover whether the precuneus findings with 31 patients was a mere artefact of one extreme patient or a genuine effect. Since JM may be considered an outlier and generated different VBM results, she will be analysed separately in a case study in Chapter 4.

CHAPTER 3 RIGHT PRECUNEUS REDUCES RESPONSE CONFLICT

Introduction

The previous chapter revealed that those patients with a reduction in grey matter integrity in the precuneus were likely to have problems in resolving conflict, particularly when dealing with salient distractors. Additionally, a positive correlation with bilateral precuneus grey matter integrity and correct target discrimination were also found in relation to the processing of (to some extent) local targets. This chapter will argue that the findings from Chapter 2 could be translated to some degree to the neurotypical population. Here the congruency effect in the normal population was examined by testing the effects of TMS applied to the precuneus

The precuneus (Brodmann area 7) is situated in the posterior medial parietal lobe, extending into the superior parietal lobule (Cavanna & Trimble, 2006). It has been claimed that the precuneus is relatively poorly defined anatomically with cytoarchitectonic variations within the region (Cavanna & Trimble, 2006). Nevertheless, it has been noted that the precuneus has extensive white matter connections to the dorsal posterior cingulate cortex, an area involved in directing externally-driven attention (Yang et al., 2014).

As previously mentioned, the novelty of the finding from Chapter 2 was that there was neuropsychological evidence for the role of the precuneus in hierarchical processing. However, there has been conflicting evidence as to what precise this role is. One fMRI study into hierarchical processing has shown corroborating evidence which supports the finding made in Chapter 2 that the precuneus is associated with local processing. It had been found that local form processing was associated with higher activation in the bilateral superior parietal cortex which may have included the precuneus (Han, Jiang & Gu, 2004). Similar to the previous chapter, the finding was bilateral.

There is contradictory neuropsychological evidence provided by Himmelbach, Erb, Klockgether, Moskau and Karnath (2009). The authors tested hierarchical processing using fMRI in a patient with simultanagnosia who had been described as having poor integration of local elements. In the cases which the patient did successful integrate said local elements to identify the global percept in hierarchical figures, the authors reported strong activation in the bilateral ventral precuneus and the medio-inferior parietal cortices. The authors concluded that this region was more involved in the integration of local features as opposed to global-local processing more generally.

Beyond this notion, there is evidence that suggest that the precuneus is also associated with the processing of (or switching between) different levels of hierarchical stimuli. For example, one study found that the precuneus is involved in switching from global to local levels of a stimulus after repeat level trials in healthy adults (Wilkinson, Halligan, Marshall, Büschel & Dolan, 2001). The VBM results presented in Chapter 2 to an extent show that this region is more associated with local processing as the task was blocked by damage to the precuneus. Note that there was no opportunity in the experiment in Chapter 2 (Experiment 2.1) for patients to switch level on which the task was performed due to the blocked design. However, it could be speculated that level switching may have been required within a block due to the relative salience of the different levels. For example, with a globally salient distractor, attention may have switched to the local level following an initial capture by the salient (but task inappropriate) global level. Impaired switching in this condition may hence be associated with poor local identification.

From the evidence so far, it suggests that the precuneus does not necessarily or specifically processes any particular level. However, the evidence suggests that this brain area may be indirectly involved in level processing in the form or integration of multiple items and switching attention to a particular item in the display. Another way of seeing this process can be seen by the finding from the VBM study (Experiment 2.1) of the correlation between the precuneus and congruency interference. As mentioned in Chapter 2, this brain area is not typically discussed in relation to congruency interference (response conflict/competition resolution) despite occasionally being reported in fMRIs of its activation (Ansari et al., 2006; Wittfoth, Buck, Fahle & Herrmann, 2006).

To further the above point, the level switching component is important in congruency interference in that there are two competing responses within the same stimulus (the global response and the local response) for which ultimately one has to be chosen for behavioural execution. The attentional system must be able to decide how to orient itself to make this response final decision. Thus, this level switching would, therefore,, be a by-product of this decision making process. Since the parietal cortex is involved in orienting attention across space (Yantis et al., 2002; Corbetta & Shulman, 2011), and for disengaging and reorienting cued information (Posner et al., 1984), it could be argued that the precuneus is spreading attention throughout space to facilitate the integration and switching of levels by other brain regions in order for this congruency interference to be resolved.

In fMRI studies, the effects of congruency are more typically linked the anterior cingulate cortex (ACC) than the posterior parietal cortex. The ACC has been strongly associated with decision making, error processing and conflict resolution (Botvinick et al., 2001, 2004). It has been argued that this region detects conflict to transmit messages to other regions (e.g. the PFC) for the resolution of the conflict to take place (van Veen & Carter, 2005). For example, the pMFC cortex is linearly associated with increasing conflict monitoring and resolution regardless of response category (Carp, Kim, Taylor, Dimond Fitzgerald & Weissman, 2010). The ACC does have clear interactions with the task in the resolution of response conflict. Interestingly, the ACC, but also bilateral IPS has also been associated with numerical distance effect (similar to the congruency effect) using fMRI (Kaufmann et al., 2005). The numerical distance task is a Stroop-like task which requires the participant to select the larger of two numbers presented adjacently on a screen with differences on two dimensions: 1) difference in numerical value; 2) difference in perceptual size of the number itself (bigger or smaller). Response conflict occurs when the value of the larger number of the pair is the smaller in perceptual size (and vice versa), causing a delay in reaction times. In Kaufmann et al.'s (2005) they found in the numerical distance task that the ACC activation was more associated with general response mapped congruency. The Bilateral IPS, however,, was more activated for numerical distance. Despite not having the ACC appear in the VBM study, it is important to note that it does not mean that this region was not involved in response conflict interference (due to the widespread nature of patients' lesions this is hard to verify or contest), but what had not been discussed is what the precuneus does in relation to this conflict.

What it can be inferred from the above evidence is that the precuneus may not be directly involved in the resolution of congruency interference but it could be used for other cognitive processes which are related to it. For example, the conflicting nature of level switching and the precuneus suggest that this region may not deal with level processing per se but the integration of information of multiple items due to attentional allocation to such items. That is to say; the precuneus may be involved in directing attention to all items (in which in the global-local task involve two levels of form) for which other brain areas can process their contents (e.g. the precuneus identifies the two levels which are conflicting and the ACC resolves this conflict).

Experiment 3.1: Right precuneus offline stimulation reduced congruency interference in the global local task

The aim of this experiment was to evaluate the role played by the right precuneus in the previously tested global/local task. In particular, will inhibition of the right precuneus using TMS affect local processing and the resolution of response conflict in neurotypical adults? The advantage of using this technique is that stimulation of one location can be directly compared with the effects of stimulation applied to other control locations to see whether temporally interrupting the precuneus' typical functioning would affect processes in the identification of hierarchical forms particularly. Additionally unlike patient studies in which the lesions are widespread and permanent, TMS provides a more focal examination into the processing of this region.

I assume three possible outcomes precuneus stimulation may have on performance. First, if precuneus is indeed associated with local processing, I expect that stimulation of the region will result in a specific impairment in local processing (but not in global processing). If on the other hand, precuneus is specifically linked to response conflict resolution, I expect an increased congruency effects as a result of precuneus stimulation across levels and saliency. Finally, if the precuneus role is in switching between items in the display (or allocating attention across the display) then stimulating the region should have a detrimental effect when distractors are salient regardless of congruency (assuming switching is particularly relevant when salient distractor are likely to be inappropriately selected).

Methods

Participants

Eleven healthy neuro-typical adult participants (4 males) who were students of the University of Birmingham participated in this study. Participants had no medical history of a neurological problem, nor any surgery which would involve the implantation of metallic or electronic devices anywhere in the body. The mean age of the sample was 22.9 years (*SD* = 3.75 years). All participants were right-handed. All participants must have participated previously in an fMRI study to obtain a T1 structural anatomical scan (for precuneus localisation).

Design, materials and behavioural procedure

The experiment was a repeated measures design. The fundamental design and stimuli were the same as Experiment 2.1. The main difference in the procedure was that participants have to respond themselves (by pressing the associated buttons) to the target level instead of the experimenter doing so. The other main difference is that there were two testing sessions: one in which TMS was applied to the vertex (CZ) and the other applied to the right precuneus. The testing was carried out over two separate days (one stimulation site per session) at least 24 hours apart, with all the conditions fully counterbalanced.

Transcranial Magnetic Stimulation Procedure

A Magstim Rapid transcranial magnetic stimulator with a figure of eight 70mm coil was used. Six hundred pulses at 1Hz were repeatedly administered for ten minutes (1 pulse per second) at 60% of maximum stimulator output immediately before the experimental task commenced.

Two stimulation sites were defined. Cz (vertex) was used as a control site as it had no clear previous known relationship with modulating congruency interference. The Cz site was identified using the 10-20 EEG electrode map (effectively at the midpoint of the inion-nasian distance and the intramastoidal distance). Brainsight stereotaxic frameless neuronavigation was used to identify the precuneus stimulation site (experimental stimulation) based on the precuneus mask obtained from the congruency effect VBM analysis in Experiment 2.1 (Chapter 2).

Results

Inverse efficiency scores for each condition per participant were calculated by dividing the mean RT in milliseconds by proportion of correct responses (Townsend & Ashby, 1983) in the same way a similar task was analysed in Mevorach et al., (2006b). Two participants performed at accuracy levels below 80% in more than one condition and were therefore excluded from further analysis (leaving 9 participants). Of these two participants: one participant had shown 67% accuracy in one condition; the other showed atypical saliency effects in the control (CZ) condition not seen in previous studies therefore making comparing effects to the tested Precuneus condition unreliable. The 80% threshold was used due to recommendations by Bruyer and Brysbaert (2011) stating that using inverse efficiencies scores with accuracy scores 80% or below would add noise making the data unreliable and difficult to interpret. Means are represented by Figure 3.1.1.

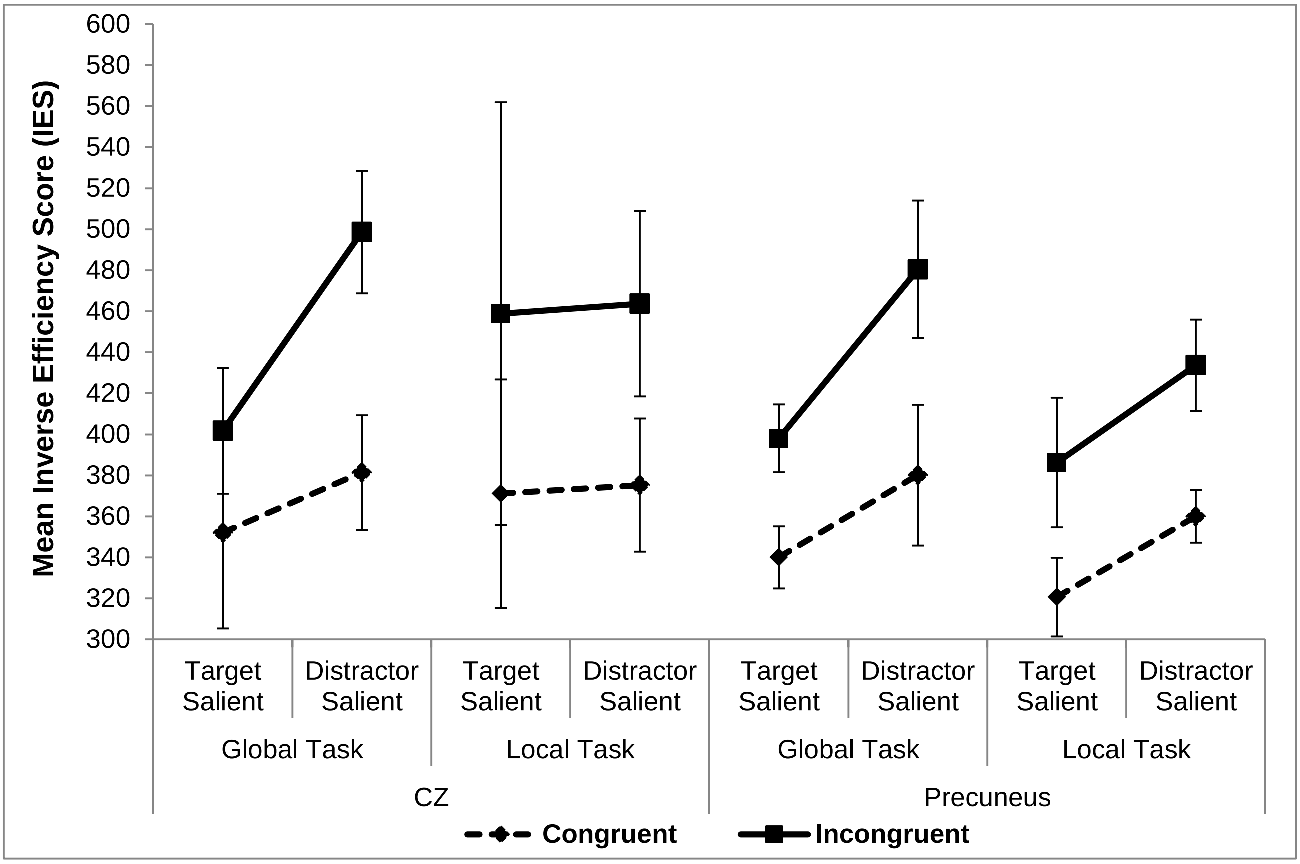

Figure 3.1.1: Mean Inverse Efficiency Scores (IES: Mean RT in milliseconds ÷ proportion correct responses) global-local task after being stimulated by offline rTMS at the vertex (Cz) and the right precuneus. Error bars represent standard error of the mean.

A repeated measures ANOVA with stimulation site (CZ vs Precuneus), level (global vs local), saliency (target salient vs distractor salient) and congruency (congruent vs incongruent) as within subject factors was used to analyse the inverse efficiency scores (IES). There was no main effect of stimulation (*F*(1,8) = .737, n.s.) (CZ *M* = 412.84ms, *SEM* = 41.63, Precuneus *M* = 387.41ms, *SEM* = 17.02), nor level (*F*(1,8) = .148, n.s.) (global *M* = 404.06ms, *SEM* = 21.82; local *M* = 396.19ms, *SEM* = 36.29) on inverse efficiency scores. Stimulation did not significantly alter the IES in either site. There was no significant advantage of one level over another. There was a main effect of saliency (*F*(1,8) = 7.11, *p* = .029). Target salient displays produced significantly lower IES (*M* = 378.60ms, *SEM* = 39.91), than distractor salient displays (*M* = 421.66ms, *SEM* = 23.77). There was a main effect of congruency (*F*(1,8) = 109.201, *p* < .001). Incongruent displays were significantly slower (*M* = 440.18ms, *SEM* = 30.61) than congruent ones (*M* = 360.07ms, *SEM* = 26.01).

Simulation site did not significantly interact with level (*F*(1,8) = 1.121, n.s.), or with saliency (*F*(1,8) = .195, n.s.). However, there was a statistically significant interaction between stimulation site and congruency (*F*(1,8) = 6.632, *p* = .033). To investigate this interaction congruency effects (incongruent - congruent) were calculated for each participant in each stimulation site (Cz and precuneus) separately. Planned comparisons revealed that the congruency effect was significantly reduced following stimulation of the precuneus (*M* = 74.43ms, *SEM* = 6.29) relative to CZ stimulation (*M* = 85.80ms, *SEM* = 9.36) (*t*(8) = 2.575, p = .033 d = -.858). None of the other two, three and four-way interactions were found to be statistically significant. Thus, the results highlight a differential effect on congruency following precuneus stimulation but not on level or saliency.

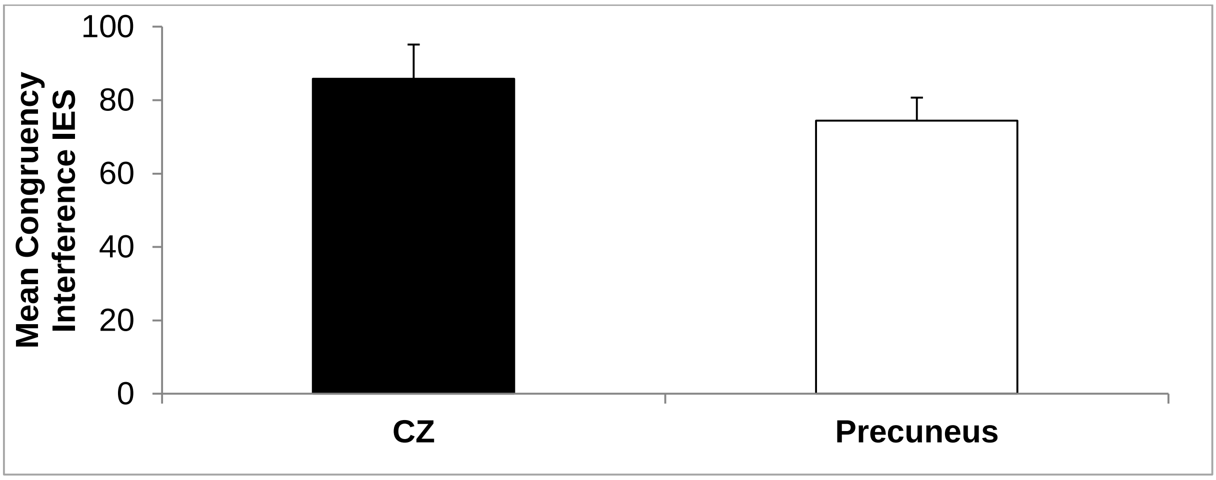

Figure 3.1.2: Mean congruency interference (incongruent minus congruent) inverse efficiency scores (Mean RT in milliseconds ÷ proportion correct responses) overall global-local task after offline repetitive TMS stimulation over Cz (the vertex) and the precuneus. Error bars represent standard error of the mean.

Discussion

The aim of this study was the further evaluate the contribution of the right precuneus to response conflict resolution and local processing. The results indicated no specific role for the precuneus in local processing after rTMS. However, TMS over the right precuneus resulted in a significant reduction in congruency interference compared with a control site. The findings have suggested that inhibition of the precuneus did not alter local processing; however the inhibition did reduce interference of distractors (by the reduction of the congruency effect).

These two main results may seem to contradict some of the findings reported in the previous chapter (2) where grey matter integrity in the right precuneus was linked with both reduced local processing and increased congruency interference. Whist there are some differences between the two studies (e.g., a bilaterally extending precuneus cluster in the VBM study vs. right precuneus stimulation in the

TMS one, as well as accuracy performance in the VBM study vs. inverse efficiency measures in the TMS one) I will explore the possibility that the explanation for the seemingly contradictory effects across the studies may be linked to the differences in the age groups across the studies and the actual role played by the precuneus. Whilst this may contradict the finding reported in Chapter 2 (VBM study), it is important to note that the two studies do no completely correspond. In the VBM study (Experiment 2.1) the precuneus cluster had a focus on the right hemisphere but was subtended bilaterally, while here (Experiment 3.1) only right hemisphere stimulation was applied.

Pertinently, a direct link between right precuneus and response conflict was found here too. However, and in contrast to the VBM study (Chapter 2), inhibiting the right precuneus with the TMS resulted in improved ability to ignore the irrelevant level (and therefore a reduced congruency effect across level and saliency conditions) while grey matter loss in the same region correlated with increased congruency effect in the patients. There are several possibilities to explain this seemingly contradictory finding. There is a mismatch in the age of the participants in both Experiment 2.1 and 3.1; with the former having a mean age of over 60 years of age, whilst the latter having a mean age of more than half of that. So, some may argue that ageing might play a role in explaining the contradictory results found between the two experiments.

Past literature has been conflicting regarding whether ageing effects global-local processing. One study suggesting that in one case, Straudinger et al. (2011) however found that older people have a reduced global precedence compared to younger people in a global-local task. However, Roux and Ceccaldi (2001) comparing older and younger participants on a global-local task found that older participants had a reduced increase global interference. However, this was not translated to general interference cost (from response competition) in older people. Thus, it could be argued that ageing whilst a critical difference between Experiments 2.1 and 3.1, does not necessarily explain the function of the precuneus.

In a saliency mediated global-local task (the same as used in the current experiments) however interference effects were shown which were modulated by saliency in older people compared to younger participants (Tsvetanov et al., 2013). More specifically, it was observed that older people in the global-local task had higher congruency interference when the distractor level was salient compared to younger participants. Whilst there were significant effects of saliency behaviourally in the current experiment, TMS inhibition did not modulate its effects on response competition. Barring this, this result could be seen as similar to the Tsvetanov et al. study.

It is important to note that this study (Experiment 3.1) has found a direct link in two different populations between the precuneus and congruency interference. Whilst this is unexpected and seemingly contradictory to the previous chapter, it is not unheard of that precuneus stimulation ameliorates performance. While TMS stimulation can induce benefits in performance in certain conditions (e.g. Hodsoll et al., 2009; Mevorach et al., 2010), one other study in numerical cognition has recently reported a similar effect. For example reductions of congruency interference after TMS has been seen in numerical distance tasks. This reduction was only seen after stimulation to right IPS, despite bilateral activations in the same parietal region from fMRI studies (Cohen-Kadosh et al., 2007). Whilst this is not directly the precuneus, this study shows similar findings to the experiment in another parietal region. This finding is analogous to the findings from the present experiment.

There has been an instance of which there has been an improvement in performance after TMS applied to the precuneus and neighbouring parietal regions in other cognitive domains. Improvements were found in a visuospatial working memory task (Oshio et al., 2010). However this is during online stimulation and not offline like the present study, and on-line stimulation is more likely to have excitatory effects compared with the protocol used here (Robertson, Théoret & Pascual-Leone, 2003). Additionally, amelioration of performance can be shown in the spatial domain too. Inhibition of the right PPC (P4; a parietal area near to the precuneus) reduced reaction time for salient singleton distractors in spatial search (Hodsoll, Mevorach & Humphreys, 2009). Similarly, in a study by Jin, Olk and Hilgetag (2010) on healthy controls using 1-Hz rTMS offline to the right PPC has found a reduction in flanker incongruent distractor interference but only on the left visual hemifield (linked to the right hemisphere (Jin Olk & Hilgetag, 2010). However in that same study, stimulation to the right dorsolateral PFC (another region also responsible for cognitive control) did not reduce congruency interference.

One possible explanation for the reduced congruency interference in this current study can be found from Coulthard, Nachev and Husain (2008). Patients with right PPC damaged patients were faster at moving to a direct of a central arrow in a pointing based incongruent trials (in which flankers adjacent on both sides of the central target arrow are stating the opposite pointing direction) during the Eriksen flanker task (Eriksen & Eriksen 1974). This effect was explained as a fronto-parietal command problem. The premotor area was argued to be responsible for generating the motor command to perform the action to the correct behaviour. The parietal cortex was argued to perform parallel discrimination of the target and other distractors and decide on a motor command. However, incongruent trials produce response conflict prolongs the decision-making process as they are being processed at the same time (along with a competing motor command), which leads to this delayed final motor command. With the parietal cortex lesioned, the frontal motor command will continue allowing for faster response times in incongruent conditions.

This issue with this theory is that the findings of this study did not suggest that participants are faster overall in incongruent trials versus congruent direct after precuneus inhibition. The congruency interference effect was present in the precuneus condition, meaning that incongruent trials still slowed performance, albeit not as much as after vertex stimulation. Therefore, the results cannot be explained completely by the theory suggested by Coulthard, Nachev and Husain (2008). Likewise, this may have been the case with the VBM study. However, only accuracy rates were analysed making it hard to ascertain whether this quickening of response times would show in those with damage to precuneus. Additionally, this current study had focal stimulation of the precuneus compared to the correlation finding of the VBM study. Patients in the VBM study also had damage in other areas which may interact with the precuneus. However, at least, this current study shows partial support for the notion of parallel detection of response conflict as proposed by Coulthard, Nachev and Husain (2008).

An alternative explanation could be taken from the attentional perspective about allocating attentional resources to all items in the display. The attentional white bear phenomenon (Tsal & Makovski, 2006) describes the notion that even when explicitly instructed to ignore, the attentional system allocates and process objects throughout the visual scene as a default process. As all items are attended to, the incongruent items are still processed creating the response competition. By inhibiting this diffuse attentional allocation, there is more efficient processing of the target and thus allows for quicker processing, a reduced response competition.

However, the attentional white bear theory on which this was based was spatial in nature and also had no support to date by neuroscientific testing. To clarify, this theory is cognitive in nature and has not yet been translated to the brain for explanations. The findings of this study cannot be confirmed nor refuted by this study due to its non-spatial nature, and an unclear way of stating whether all items are being attended.

In relation to the attentional white bear phenomenon (Tsal & Makovski, 2006), the superior parietal cortex has been associated with directing attention in space (Yantis et. al., 2002), synchronously with other features simultaneously with the medial prefrontal cortex (Nagahama et al., 1999). Although not discussed, the precuneus was significantly activated alongside the ACC in the Eriksen flanker task when the conflict was high and unexpected compared to the number of congruent trials in a block (Żurawska vel Grajewska et al., 2011). However in that study, the precuneus was not found to be active for congruency as the main effect. More recent evidence, however, has revealed (similarly to the Experiment 2.1 findings) that the bilateral precuneus showed incongruency BOLD activation with a picture based flanker task (Kelly, Rees & Lavie, 2013). However, it is important to reiterate that the attentional white bear phenomenon has not been tested on the neuroscientific level, which is a gap which must be filled to provide a biologically justified explanation of the effects that were found in the previous two experiments.

It appears from the literature and the findings from the current study (Experiment 3.1) that the precuneus may not be involved in congruency interference *per se* (hence the seemingly conflicting results between Experiments 2.1 and 3.1). However, it may be involved in a broader allocation of attention to all areas of space (suggested by the attentional white bear theory) in order to prepare a backup motor command ready for other regions (e.g. the ACC) to decide the most appropriate behavioural execution (as proposed by Coulthard et al., 2008). This broader allocation of attention does not resolve response conflict (congruency interference) in itself but could identify possible motor responses (or response options) from alternative items in the visual display which are linked to the relevant task goal. This elaborated explanation could also explain the apparent discrepancies in the literature in regards to the precuneus and level processing/switching.

To elaborate on this explanation, the precuneus does not appear to process level but the response properties that the items within the level have. For example, if there were a global H made of local Ss, then it would process the fact that there is an H as one possible response and an S as another possible response present in the display. Inhibiting the precuneus temporarily reduces its activity allowing for a more narrow window of attention for items to be processed in space, therefore allowing less influence of possible alternative responses being included in the back-up commands. The patients in Experiment 2.1 with damage to this area had issues with congruency interference which could be re-explained as an insufficient ability to spread attention to all areas of space allowing for any possible alternative motor commands to be processed. Since in the case of patients the brain region is absent altogether, there is not much chance of flexibly spreading attention across all items on the display for it to be processed in other brain regions (as opposed to minimally reduced in neural activity in the TMS study of neuro-typical participants).

In reference back to the contradictory findings presented in the introduction of this current chapter, the notion of the precuneus and level switching/integration may be partly explained by the expanded theory of attentional spreading to backup motor commands. The fact that switching/integration needs to occur would have to involve the process of widening the attentional window to all areas of space. This widening/spreading of attention allows to the entire display and all its contents to have equal processing. This processing would involve including all the possible alternative responses so that in the case of integration or level switching, these stimulus based motor responses could be executed at the request of other brain regions (e.g. the frontal cortex or ACC).

An alternative explanation for these findings would be the precuneus is involved in overlearned stimulus-response mappings. The argument goes that since it has been found that memory regions encode stimulus-response mappings (e.g. the hippocampus, Oehrn et al., 2015), inhibition of the said regions could impair the strength of the retention of these associations. To address this alternative explanation, first of all, the precuneus has been found to be linked to working memory systems. An example of this has been found in an fMRI study by Luber et al. (2007). In their TMS study, participants were asked to remember upper case letters in a 6*2 array for three seconds. After a retention period of seven seconds and then a lower case letter probe appeared for three seconds in which the participants had to respond as to whether the letter appeared in the array or not. Five Hertz TMS inhibition was applied to the midline precuneus during the retention and probe phases. Only stimulation during the retention phase showed quicker discrimination responses to probe memory items compared to during the stimulation during the probe onset. The authors concluded that the precuneus had some facilitator role in encoding and consolidating items for short-term memory.

Further evidence has which supports the role of the precuneus in memory reconsolidation has been provided by Dörfel et al. (2009) who ran an fMRI study on list learning of 150 nouns of which 108 nouns were shown at test in addition to 27 unlearned new words. Participants judged whether words in the test list were from the original 150 remembered list or new and also to state whether they were words were known to them (familiarity judgement). The left precuneus and the bilateral hippocampus were activated during trials when the remembered correctly recalled words appeared. This finding highlights the link between the precuneus and other memory structures (hippocampus in this case) as a potential role in memory.

Additionally, an fMRI study by Krebs Boehler, De Belder and Egner (2015) also found that the precuneus among other areas related to cognitive control of response conflict was active during memory of faces. The authors ran a Stroop-like face-word gender discrimination task with fMRI in which participants had to state the gender of a face or of a word (with the gender written on it) which is superimposed on a face in a familiarisation task. Their familiarity was tested after the fMRI scan with the inclusion of new faces. Precuneus activation was shown for incongruent stimuli (faces that did not match the gender word superimposed on it) in addition to the ACC and frontal areas demonstrating the relationship between memory and response conflict. Moreover, Leung and Zang (2004) investigated the role of conflict resolution in a spatial working memory task using fMRI. Participants had to remember the locations of four dots in a 4*4 grid matrix for two seconds but later ignore two of out of the four which were cued (they became remembered distractors). Afterwards, a probe stimulus appeared in a remembered non-cued location, or in the remembered distractor cued location or another non-cued location. Participants were slower at identifying whether the probe was part of the remembered target items or not when the probe appeared in the remembered cued (acting as an interfering distractor) location compared to the non-remembered or congruent (non-cued remembered target) location. FMRI results found that in conditions of the interfering cued memory distractor location there was increased activation in the superior parietal cortex and the precentral sulcus. Based on these results the authors suggested that the superior parietal cortex is involved in the spatial monitoring of distractors. This finding of the precuneus may imply that the precuneus may interact with the PFC since, in spatial working memory tasks, there are the superior parietal lobule co-activates with the PFC (Duncan & Owen, 2000) and both show similar deficits under TMS interference (Oliveri et al., 2001).

The precuneus has also been found to be associated with spatial memory. An fMRI study by Frings et al. (2006) demonstrated that the precuneus is active during the recognition of objects placed in different locations. Participants had to remember the position of the large black cube in relation to an environment (blocked surface) with respect to two smaller cubes on the same environment. When the cube was placed in different locations to the remembered set, the precuneus was activated signifying that the precuneus is involved in allocentric visual-spatial memory. This precuneus activation clearly links to the processing of items in space as argued earlier and by Coulthard et al. (2008) in that the precuneus did contain back up representation of spatial motor commands as well as the application to the attentional white bear phenomenon (Tsal & Makovski, 2006).

In relating the memory aspect back to response-mapping, the precuneus has been shown to be active has been demonstrated in an fMRI study by Barber and Carter (2005). In their study, participants had to press one of two buttons in which were mapped to a response to a simple letter target “L” or “R”. There two conditions: the prepotent intuitive stimulus-response mapping condition (in which the side of a button made an intuitive match to the letter) and the non-potent response which was the reverse (e.g. the response to “L” was the right-hand side button). Participants were cued with a coloured squared before the letter target appeared as to which type response mapping they should make. The precuneus was significantly active during non-pre-potent mapping conditions and during trials in which participants had to switch between mapping types (particularly in the stage post-cue in preparation to switch response). The authors concluded that the PFC and ACC were involved in conflict resolution whereas the precuneus was involved in preparing the system to switch between responses in an anticipatory manner.

Further to the precuneus, Oehrn et al. (2015) found using intracranial EEG that the hippocampus was present during high conflict in a pitch-word discrimination task. Participants had to discriminate the words “high” or “low” written on a screen were spoken either in a high pitch or low pitch voice either on a semantic level or a phonetic level. In cases in which the pitch did not match its written semantic representation (conflict in the phonetic task), the hippocampus increased in activity.

It was concluded by the authors that this subcortical structure has a role in strengthening the memory association between the stimulus and response mapping.

In summation of this alternative explanation, it could be considered that memory factors which are critical in forming appropriate stimulus-response mappings can be done in conjunction with top-down bias from the PFC and ACC as well as subcortical areas such as the hippocampus. The precuneus does have both spatial and non-spatial memory functions which help prepare the system to change perspectives and responses in anticipation to top-down changes in task instruction. So in integrating this explanation back to the TMS findings of Experiment 3.1, what the TMS inhibition may have weakened the strength of the memory strength of the stimulus-response mapping. It did not remove the associations completely due to possible subcortical mechanisms which were not inhibited in these unperturbed. base mappings. However, the strength of these mappings in the precuneus was not consolidated fully to allow to allowing for reduced congruency effects not due to improved conflict resolution but a weakened identification of conflict and not fully consolidated stimulus-response mapping.

It should be acknowledged that the sample size is small in this study. There may have been statistical interactions with level if the sample size increased, the power of the study would also have improved. However, this statistical speculation is hard to tell based on non-significant findings from the ANOVA at present. Additionally, since the finding in Experiment 2.1 (Chapter 2) showed bilateral precuneus links to congruency and local processing, perhaps the level effects may have come out from the TMS inhibition of the left precuneus. Although there was justification stating that stimulation of left parietal cortex in similar response conflict tasks did not change effects (e.g. the numerical distance task in Cohen-Kadosh et al., 2007), perhaps it would have been optimal to compare inhibition of the left precuneus as well as the right precuneus to ensure that the level aspect of the question could have been fully addressed. Additionally, a non-TMS equivalent would have helped establish a better baseline compared to Cz, although Cz has not been known to influence global-local processing. Perhaps to ensure a better analysis of the direction of the congruency effect, a genuine neutral response distractors option should have been included to establish whether the difference in congruency found in the precuneus was affected by congruent or incongruent displays specifically.

This chapter aimed to find corroborating evidence for the role of the precuneus in congruency interference and local form processing, based on neuropsychological lesion data (from Experiment 2.1), in the neurotypical population using TMS in a global-local task. The findings from the current study (Experiment 3.1) revealed that after repetitive stimulation of the right precuneus, there was a reduction in congruency interference (response conflict). This experiment revealed a link between the precuneus and response competition revealed in the previous chapter. It has been concluded that there is a necessity of the precuneus in the detection of response conflict. This detection mechanism could be due to the spreading of attention across all ofspace: keeping and consolidating the mappings of multiple response commands for other brain regions (ACC, PFC) to decide a final appropriate behavioural response.

This current chapter focussed on specific findings regarding the precuneus based on the VBM study. However, it is important to note that these were not the only findings from that study. One particular aspect of note was the variability within particular patients with specific neuropsychological syndromes which could be explored based on their performance in the global-local task. The following chapter will return to the neuropsychological findings of Chapter 2 and focus on a single patient who was identified as having inflexible attentional capture by salient information in a global-local task.

CHAPTER 4 HIERARCHICAL PROCESSING IN BALINT'S SYNDROME: A FAILURE OF FLEXIBLE TOP-DOWN ATTENTION.

A note to the reader

This chapter in a modified form constituted part of a peer-reviewed published article: Mevorach, C., Shalev, L., Green, R.J., Chechlacz, M., Riddoch, J., & Humphreys, G.W. (2014). Hierarchical processing in Balint's syndrome: A failure of flexible top-down attention. *Frontiers in Human Neuroscience*. Adaptations have been since made by the author of this thesis to ensure good continuity and theoretical linkage to the rest of thesis.

Introduction

In Chapter 2, the VBM analysis of behavioural performance in a broad variety of patients with brain damage doing a global-local task revealed that the precuneus (part of the superior parietal cortex) was responsible for the suppression of objects of high salience when there is direct response conflict and local level processing. That chapter addressed the debate as to the lateralisation of global-local processing and found no evidence for hemisphere specific lateralisation for neither global nor local levels (local level processing was bilateral). Following on from these findings, the previous chapter (Chapter 3) revealed that temporarily inhibiting the neural activity in a part of the parietal cortex (precuneus) in younger healthy neuro-typical adults using TMS reduced congruency interference (response conflict). Whilst Experiment 2.1

investigated a general debate about level lateralisation, and Experiment 3.1 a more specific role of the precuneus; this current chapter will focus on investigating the role of saliency in a specific neuropsychological syndrome: simultanagnosia/Balint's syndrome. This current chapter (Chapter 4) will also return to the discussion as to the role of the parietal cortex and saliency aspect being discussed in chapter two using the neuropsychological approach.

This current study will use the information gained from Chapter 2 to ask more specific questions about the role of the parietal cortex in the capture and disengagement of attention in a neuropsychological case partially characterised by having a problem in perceiving global forms. As mentioned before in Chapter 2, there was a Patient (JM) who was identified as an outlier regarding behavioural performance in Experiment 2.1 (see Chapter 2 for details). This particular patient was later revealed to have Balint's syndrome. This chapter will investigate this particular case of Patient JM to discover what her deficit is and the role of her neuroanatomical damage (parietal and occipital cortices) in global-local perception.

This chapter will argue that in a case of Balint's syndrome/simultanagnosia (used interchangeably in this chapter due to the nature of the patient), the loss of the parietal cortices could explain deficits in allocating attention via top-down cues and also difficulties in disengaging attention away from bottom-up salient capturing items. That is to say; there is a deficit in being able to manipulate input from the top-down goal set to direct attention appropriately to perform the task at the first stage, but then also a problem in directing attention away from salient items once captured. This deficit, therefore, is not dependent on specific levels of processing, but one of attentional allocation and its redeployment instead.

Balint’s syndrome is a rare neurological disorder associated with bilateral parieto-occipital damage (Balint, 1909). The syndrome typically consists of disturbed organization of eye movements (ocular apraxia), inaccurate reach responses to objects under visual guidance (optic ataxia), impairments of spatial orienting and localization, and impaired ability to detect and identify more than one object or one of its local features at a time (simultanagnosia; Balint, 1909; Karnath & Zihl, 2003; Rafal, 1996; Rizzo & Vecera, 2002). As mentioned in the previous chapter, simultanagnosia refers to severe difficulty in interpreting complex, multi-object scenes (such as the Boston Cookie Thief picture), and poor ability to perceive two simultaneously presented objects relative to the presentation of single objects (Humphrey et al., 1994; Kinsbourne & Warrington, 1962; Shalev, et al., 2002). Thus, such deficits are observed not only in complex scenes, but also when separate components are required to be integrated into a single object.

The process of integrating parts into wholes has been examined most extensively in tasks where the patients are asked to respond to the local or global levels of compound shapes, where the global form is derived from the configuration of the multiple local elements (Navon, 1977). It has been shown previously that patients with simultanagnosia demonstrate a bias towards the local forms in such tasks, a bias that in some cases causes a complete failure to perceive the global aspect of the compound item (Huberle & Karnath, 2006; Humphrey, Goodale, Jakobson, & Servos, 1994; Jackson, Swainson, Mort, Husain, & Jackson, 2004; Karnath, Ferber, & Bulthoff, 2000; Shalev, Humphreys, & Mevorach, 2005).

One explanation that has been proposed for the deficient global perception in Balint’s syndrome is a narrow and restricted window of attention (Darlymple et al., 2007, 2011, 2013; Michel & Henaff, 2004; Shalev & Humphreys, 2002; Thaiss & De Bleser, 1992). While the perception of local parts may still operate with a narrow attentional window, global object identification typically requires a distributed spread of attention, which the patients cannot achieve. However, it should be noted that such an explanation cannot provide a full account for several of the findings that have been reported with patients with simultanagnosia. One example is illusory conjunctions of colour and form which reflect the processing of features of more than one object (Friedman-Hill et al., 1995); others include the ability of patients with simultanagnosia to statistically average across stimuli (Demeyere et al., 2008), to estimate magnitudes (Demeyere & Humphreys, 2007), to perceive one spatial area when elements group but a reduced area when elements segment apart (Gilchrist et al., 1996; Humphreys & Riddoch, 1993; Luria, 1959) and to show implicit processing of global shape (e.g., interference in responding to the local shape when the global shape is incongruent; Karnath et al., 2000; Jackson et al., 2004; Shalev et al., 2005). Moreover, Balint's patients can also identify large forms, matched in size to the global compounds they fail to perceive (Shalev et al., 2005). In such cases, the impaired global perception of Balint's patients cannot be the result of a mere inability to spread attention across a wide area. Shalev et al. (2005) additionally showed that attention could be pre-cued by the prior identification of a large solid figure, so that global compound stimuli presented shortly afterwards could also be identified successfully. Thus, there is not necessarily a limit on whether attention can be distributed across a wide spatial area, though distributed attention may be difficult to sustain. Consistent with the latter argument, Shalev et al. (2005) found that the perception of global compound stimuli decreased as the time interval between the initial large letter and the compound shape increased.

Additionally, as mentioned in Chapter 2, those with simultanagnosia can also perceive global form dependent on the nature of the stimulus presented. The example was given from a study by Dalrymple, Kingstone and Barton (2007) who presented a patient with simultanagnosia the traditional hierarchical Navon letters and also faces. The patient was able to make better discrimination on faces (which could be argued to be a composite image of multiple parts akin to the classic compound letters) than on the global-local task with Navon letters. This meant that those with simultanagnosia could perceive the global form but dependent on certain perceptual arrangement characteristics. These characteristics would in turn influence how attention is spread across the visual scene.

In additional to the nature of the stimulus, the manipulation of the perceptual arrangement and organisation within a stimulus also been shown to be important in finding out the extent of global level processing in those with simultanagnosia. Attempt to elucidate key factors determining the spread of attention in these patients has been done in a study by Huberle and Karnath (2006). In this study, the authors manipulated the distances between the local letters in compound forms. They found that performance systematically improved as the inter-element distances decreased, keeping constant the global size of the letters (see also Dalrymple et al., 2007; Huberle & Karnath, 2010; Montoro, Luna & Humphreys, 2011). Reduced inter-element distances presumably promote grouping and the spread of attention across the grouped elements. Familiarity is also a contributory factor. Coslett and Safran (1991) reported a patient with simultanagnosia who named words but not non-words although the spatial characteristics of both words and non-words were the same (see also Baylis, Driver, Baylis & Rafal, 1994; Kumada & Humphreys, 2001). These data suggested that letters in words are grouped so that the word is processed as a single perceptual object whereas letters in non-words are coded as distinct objects. The converse effect, of familiarity disrupting performance, can also occur when local rather than global forms are familiar. Shalev, Mevorach, and Humphreys (2007) demonstrated that their patient with simultanagnosia perceived the global shape of a compound letter as long as its local elements were unfamiliar; however, after the patient was trained to identify the local (previously unfamiliar) elements, it became difficult to perceive global forms containing the now-familiar local elements.

These various manipulations cannot be boiled down to a single perceptual factor being responsible for simultanagnosia (e.g., differential sensitivity to set spatial frequencies; Huberle & Karnath, 2006); nevertheless, it can be argued that the effects represent a variety of manipulations all of which may have an impact on the relative saliency of the local and global levels of stimuli (Shalev et al., 2007). When the local elements have high saliency (and are more salient than the global form), then patients with simultanagnosia will demonstrate ‘local capture’ and only identify the local items. In contrast, when the global configuration is more salient the patients can exhibit global capture (Dalrymple et al., 2007; Montoro et al., 2011). That is, as, with normal participants (e.g., Mevorach et al., 2006b, 2010), stimulus characteristics can bias both a narrow or a wide attention window, but once attention is captured at one level, patients with Balint’s syndrome find it difficult to flexibly re-allocate attention to other levels. This reduced flexibility in selective attention is additional to any default bias towards a restricted (local) attentional field.

The following experiment in this chapter (Experiment 4.1) is different to that of Shalev et al. (2005) and Shalev et al. (2007) because the focus is based not on level specifically but on saliency as the modulating factor in level selection regardless of time-dependency by priming. That is, when patient GK was primed with a large letter, he could process the global level, overcoming the local bias. Furthermore, the Shalev et al. (2007) study emphasised that it was familiarity which was modulating the focus of top-down attention in simultanagnosia. However, subsequent studies by Mevorach et al. (2006a; 2006b; 2010) have indicated that lower level perceptual factor of saliency in familiar displays can also modulate level processing. Whilst parietal patients (Mevorach et al., 2006a) and the occipital cortex (Mevorach et al., 2010) have been tested directly; these brain regions have not been directly applied to a neuropsychological syndrome which has behavioural deficits as well as structural deficits. Critically, if a better association between parieto-occipital regions have to salience based selection and suppression of level form is to be made, a direct test with a neuropsychological syndrome (simultanagnosia) which has characteristic level deficit which can be overcome by top-down modulation (e.g. familiarity of distractors as in Shalev et al., 2007) and timing between exposure of visual primes (Shalev et al., 2005) should be made. This chapter aims to test with a patient with simultanagnosia could perform global and local processing when saliency is modulated and that the issue with the disorder is a problem in managing top-down goals (without visual priming beforehand) when salient distractors conflict with the form level selection task.

Experiment 4.1: Saliency capture in a patient with Balint’s syndrome compared to neuro-atypical controls in a global-local letter discrimination task.

This chapter aims to test the above explanation by comparing performance in the same global-local task as was presented in the previous chapter, on a patient with Balint's syndrome, JM and non-Balint syndrome controls (Experiment 4.1). If saliency is the driving force with could explain the narrow spread of attention in a patient with Balint’s syndrome, then it would be expected that the patient should be able to process global forms when the global level is salient and would find local elements harder to detect when the global level is salient due its capturing of attention making it a distraction to local processing (in line with studies reflecting this effect by Mevorach et al., 2006a, 2006b, 2010). That is to say; it is expected that JM should show saliency-mediated effects of level selection as opposed to a specific level deficit in local processing would be classically defined by Balint’s syndrome/simultanagnosia.

Methods

Case report

JM

JM was 45 years old and a housewife at the time of testing. Four years prior to testing she suffered a bilateral stroke while giving birth. This resulted in bilateral lesions in occipital and parietal cortices extending in the right hemisphere into frontal cortex (lesion volume 141.2 cubic centimetres). MRI scans (T1 and FLAIR) are shown in Figure 4.1.1. Following the stroke, JM had no major motor weakness but presented with symptoms characteristic of Balint’s syndrome, she has optic ataxia, with inaccurate visually guided reaching to objects, especially in peripheral vision. She showed signs of ocular apraxia, with a poor ability to make saccades to peripheral signals. She had simultanagnosia. She found it very difficult to identify the events in visual scenes, reporting only on the presence of a woman washing dishes in the Boston cookie theft picture. In a test of visual extinction, she required over 2 seconds to be able to identify two letters though she was able to identify single letters presented in either her left or right field for only 200ms. These two deficits, in interpreting complex scenes and in identifying more than one object at a time, are key defining symptoms of simultanagnosia (Kinsbourne & Warrington, 1962). There was no evidence for spatial bias in JM’s performance – and she identified about half of the letters in the right field and half in the left field under the extinction conditions (above). Also, she only cancelled lines down the centre of the page in a cancellation task. JM’s single word reading was good (12/12 for both regular and irregular words matched for length and frequency) but text was extremely difficult (even reading single sentences was not possible). Her identification of single objects was relatively spared (13/15 on naming items from the BCoS battery; Humphreys et al., 2012). Verbal long- and short-term memory was good (forward digit span =6; backwards digit span = 4; story recall from the BCoS was within normal limits, 11/15).

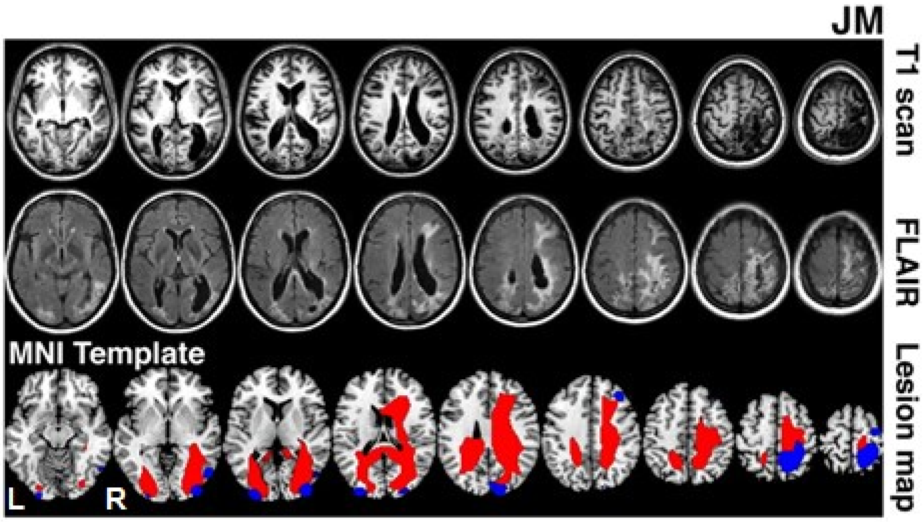

Figure 4.1.1: Structural anatomical T1 scan and binary lesion definition for Patient JM. Lesions are shown on a normalised T1 image. Blue areas are grey matter damage and red being white matter damage. L represents the left hemisphere and R represents the right hemisphere.

Control Participants

Six other neurologically impaired patients, all male, were tested (see Table 4.1.1 for their clinical details). The patients were selected to represent an age-matched patient control group for JM and to include a range of neuropsychological problems including neglect (patient RP), dysexecutive function (GA, JQ), extinction (PH) and visual field loss (ST). Using a patient control group here can ascertain that any difficulty observed in JM is not attributed to a general non-specific reduced capacity that often accompanies brain lesions or a specific spatial deficit such as unilateral neglect, extinction and field loss. The neuropsychological symptoms of the patients are listed in Table 5. Prior to participating in the study the patients were clinically assessed using the BCoS battery (Humphreys et al., 2012) and T1 structural MRI scans were acquired (see Figure 4.1.2). The neuropsychological symptoms described in Table 4.1.1 reflect instances where performance fell 3 SD's > mean for that participant on tests from the BCoS for memory, executive function, picture naming, extinction and visual field loss.

Table 4.1.1: Control patients with their associative ages, gender and lesion information.

Patient initials	**Age at test (years)**	**Time since injury (years)**	**Gender**	**Damaged acquired by**	**Lesion Volume (Voxels)**	**Lesion location**	**Side**	**Neuropsychological deficit**
GA	56	16	Male	Herpes simplex encephalitis	81290	Temporal, frontal	Bilateral	Amnesia, dysexecutive syndrome
JmQ	57	2	Male	Stroke	45570	Frontal Temporal	Right	Dysexecutive syndrome
PH	38	12	Male	Stroke	41568	Frontal	Left	Aphasia, dyslexia, right hemispatial extinction
PJ	42	2	Male	Vasculitis	4184	No clear lesion		Aphasia
RP	56	6	Male	Stroke	46884	Temporo-parietal	Right	Left hemispatial neglect
ST	54	3	Male	Stroke	7786	Occipital	Bilateral	Visual field defect

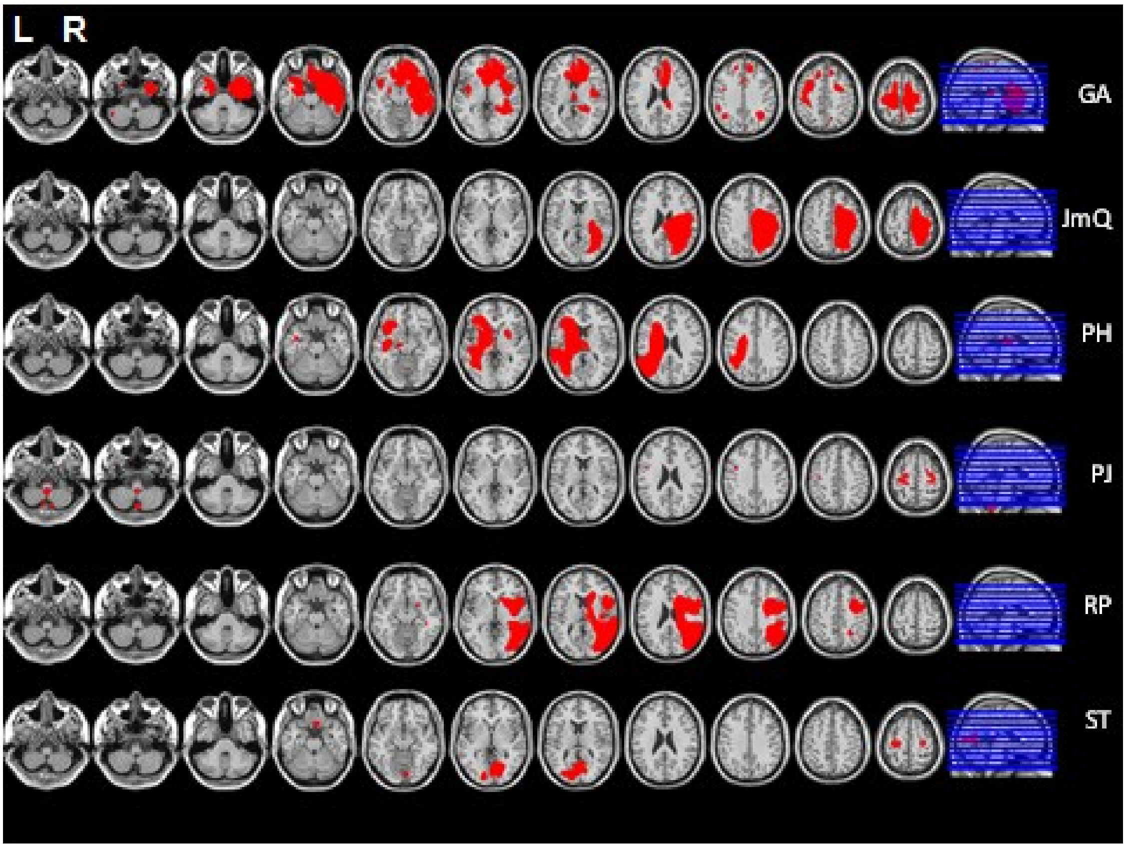

Figure 4.1.2: Grey matter lesion definitions of control patients mapped onto a standardised normalised T1 weighted anatomical image.

Experimental design, stimuli and procedure

JM and the control patients were part of the VBM study (Experiment 2.1) in Chapter 2 using the saliency mediated global-local letter discrimination task. Refer to the methods section of Chapter 2 for a reminder of the experimental procedure.

Results

Accuracy data for JM and the control patients were analysed using Chi square and Fisher Exact Probability Tests. The proportions of correct responses in the different experimental conditions are presented in Figure 4.1.3 for the control participants and

JM, respectively (please note that percentages in this section are proportion correct multiplied by 100). The question was then posed as to whether JM was impaired compared to the other patients when she was required to ignore the salient irrelevant level of the compound letter stimuli. For this reason, the congruency effect (the accuracy for congruent trials minus that for incongruent trials) was calculated when the target level had high relative saliency and when the distractor level had high relative saliency (across level of processing). JM's congruency effect in the target-salient condition was small (62/64; 96.9% correct responses in congruent trials vs. 60/64; 93.8% correct responses in incongruent trials) and similar in magnitude to the control patients; thus no statistically significant difference was found between JM and the control patients (383/384; 99.7% correct responses in congruent trials vs. 380/384; 99.0% in incongruent trials; $\chi^2(1)= .002$, $p = .89$). However, in the distractor-salient condition JM had difficulties in ignoring the identity of the salient distractor (she made 58/64; 90.6% correct responses to congruent trials vs. only 4/64; 6.3% correct responses to incongruent trials) in contrast to the control patients, who showed a modest congruency effect, which makes this difference statistically significant (they made 382/384; 99.5% correct responses to congruent trials vs. 373/384; 97.1% correct responses to incongruent trials; $\chi^2(1)= 42.5$, $p <.001$). This inability to report a target on a non-salient level when the distractor level was salient and incongruent was not associated with a particular level of the stimulus. JM showed increased congruency effects, compared with the control patients, for both local and global non-salient targets. For the local task JM responded correctly to 27/32 (84.4%) congruent trials vs. 3/32 (9.4%) incongruent ones; in contrast, the controls answered correctly to 191/192 (99.5%) congruent trials vs. 184/192 (95.8%)

incongruent ones. This difference was statistically significant ($\chi^2(1)= 17.1$, $p <.001$). In the global task JM responded correctly to 31/32 (96.97%) congruent trials vs. 1/32 (3.1%) incongruent one whereas the control participants answered correctly to 191/192 (99.5%) congruent trials vs. 189/192 (98.4%) incongruent ones; a difference which was statistically significant (Fisher Exact Probability Test, $p <.001$). For JM, the magnitude of the congruency effects in the global and local conditions was similar (for local targets – 27/32 vs. 3/32 and for global targets – 31/32 vs. 1/32 for congruent and incongruent trials, respectively; Fisher Exact Probability Test, $p = .28$). Thus no statistically significant difference was found. It should also be noted that JM (and the control patients) were required to provide a response in each and every trial (there were no 'miss' or 'pass' trials) and her low accuracy in incongruent trials are therefore attributed to responding to the letter on the distractor level.

It is also evident that local identification for JM was lower distractor level salient conditions, where her performance in congruent trials was significantly lower that of the control patients (27 correct responses out of 32 trials [84.4%] compared with 191/192 [99.5%] of the controls; Fisher Exact Probability Test, $p <.001$). JM's difficulty in identifying the local elements was also evident in her performance under target-salient conditions where her accuracy was significantly lower than in the global task (58/64 [90.1%] vs. 64/64 [100%] for local and global identification, respectively; Fisher Exact Probability Test, $p = .014$) or that of the controls (58/64 [90.1%] vs. 381/384 [99.2%]; Fisher Exact Probability Test, $p <.001$).

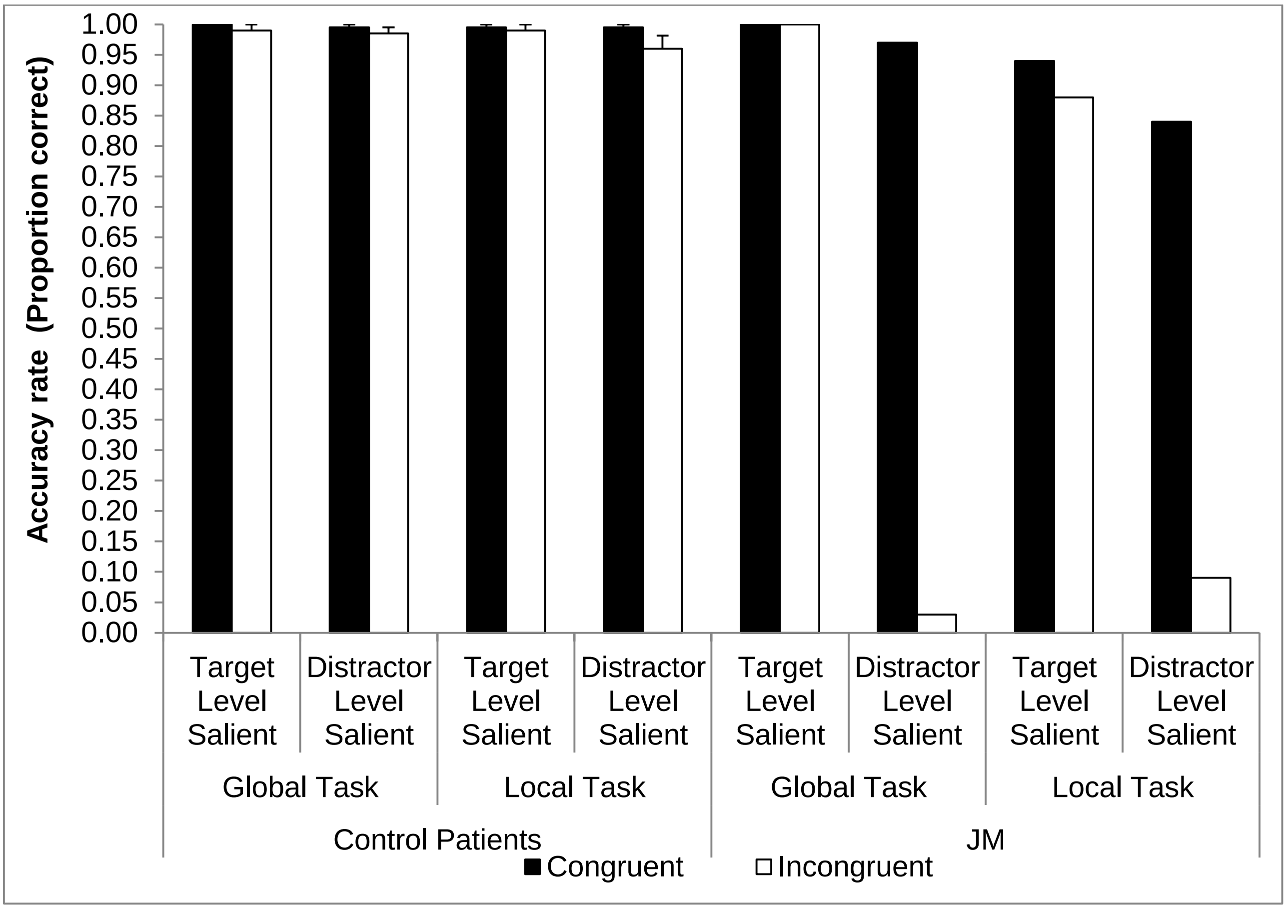

Figure 4.1.3: Accuracy rates expressed as proportion correct for patient JM and mean accuracy rates for the control patients in the compound letter task. Error bars for control patients represent standard error of the mean.

Discussion

In this current chapter, Experiment 4.1 aimed to examine whether saliency played a role in global processing in a case patient with simultanagnosia (Balint’s syndrome). The study aimed to address the question posed whether those with Balint’s syndrome had a generic global level deficit, or could it be modulated by a deficit in attentional allocation mediated by perceptually salient bottom-up cues. This study (Experiment 4.1) has found that patient JM was able to process the global form of a compound object, however, only when the necessary perceptual information was salient enough to facilitate global processing.

Simultanagnosia within the context of Balint's syndrome has been previously associated with a bias towards processing local items at the expense of global processing (Darlymple, et al., 2007, 2011, 2013; Michel & Henaff, 2004; Shalev & Humphreys, 2002; Thaiss & De Bleser, 1992). However, evidence for at least some aspects of global shape processing in the syndrome (e.g., interference from incongruent global stimuli; statistical averaging; magnitude estimate; Demeyere & Humphreys, 2007; Demeyere et al., 2008; Shalev et al., 2005) indicates that global processing can still operate to some degree and that a constricted attention window cannot be the sole underlying reason for the problem.

As mentioned in both Chapters 1 and 2, attempts have been made to elucidate the flexibility of level processing by altering the perceptual relationships between global and local forms of objects by making one level more salient compared to another (Huberle & Karnath, 2010; Mevorach et al., 2006a, 2006b). For example, it was shown in the study by Mevorach, Shalev and Humphreys (2006b) that there was capture of attention by either the local or the global shape, dependent on their relative salience. When applying that study to the results of this current chapter's study, patient JM was typically unaware of the non-selected level and reported only the salient stimulus. The results that were reported in the study of this current chapter are similar to some prior data where the representation of the global form has been enhanced by using closely aligned local elements (Huberle and Karnath, 2006; Montoro et al., 2011) or shapes constructed to make the global forms salient (Dalrymple et al., 2007). The data show evidence that patients with simultanagnosia can process the global form and that their attention can be locked to that level of representation when the global form is high in saliency and the local relatively low in saliency.

In his original report, Balint (1909) discussed the inability of his patient to make saccades to stimuli as ‘psychic paralysis of gaze’ (that was termed previously as this ocular apraxia). The results from Experiment 4.1 suggest that this ‘paralysis’ is not confined to gaze (overt attention) but affects even covert attention. In the context of Experiment 4.1, when JM attended to a salient global form she did not need to shift her gaze in order to subsequently attend to a centrally positioned local form (in a local identification task). Her failure to identify the local form then is not a paralysis of gaze but rather a paralysis of attention; she was unable to shift attention from the global to the local level (or vice versa).

One possible alternative explanation for JM’s performance in this study is that the manipulation of perceptual saliency created conditions that are perceptually rather than attentionally difficult for her. For instance, blurring the local elements in the global-salient displays might have created local elements that JM was simply unable to identify, regardless of the presence of the global information. However, it should be noted that JM was able to identify a single blurred local letter when the remaining local letters were covered. In addition, if JM was simply unable to identify local elements under these conditions it would have expected that her performance to be at chance level (indicating her inability to identify the stimuli). However, JM’s performance was considerably below chance and thus reflected the identification of the irrelevant (but salient) level. This in itself suggests that JM’s attention was allocated to the irrelevant (but salient) aspect of the compound letter and that she was simply unable to ignore that information (even if no other information was available for her) and to disengage from it. Poor perception of the local letters, but good disengagement from the global form, should generate chance levels of identification for the local stimuli. In contrast, JM performed worse than chance.

Posner et al. (1984) first documented problems in the disengagement of attention associated with unilateral lesions to the PPC – patients were poor at shifting attention to the contralesional side if attention was earlier cued to the ipsilesional side. Posner et al. argued that a critical function of the PPC was to disengage attention from a given spatial region. This result has been confirmed in subsequent brain imaging studies (see Corbetta & Shulman, 2002), where it has been argued that the PPC (and in particular the right temporo-parietal junction, rTPJ) acts to detect new events and through this, to trigger the attentional disengagement process (the attentional disengagement account of PPC function). The data from the study in this particular chapter concur with the proposal that the PPC is critical for the disengagement of visual attention – though here the problem is not manifest in poor spatial disengagement (local forms would fall within a spatial window of attention when the global form is selected) but in poor disengagement from one level of form to another. This suggests that the PPC may subserve a number of different forms of attentional disengagement. In addition, the data from the study in this particular chapter do not fit with the account of one region of the PPC, the rTPJ, proposed by Corbetta and Shulman (2002). These authors argue that the right TPJ acts as a ‘circuit breaker’ for attention, disengaging attention from its current focus on the occurrence of an unexpected, salient stimulus. Note that, in this study in this current chapter, disengagement of attention from a high to a low saliency stimulus is not triggered by the occurrence of an unexpected event, since the low salient aspects of the stimulus were presented at the same time as the high saliency distractor – so a problem in stimulus-driven circuit breaking cannot be critical.

Moreover, it is suggested that the problem JM exhibited here not only involves disengagement, but also initial attention allocation. While in Posner's spatial disengagement a spatial cue acts to direct attention, here JM was unable to allocate attention according to a top-down cue (attend to the local or global shape) in the presence of salient distraction. Attention selection is dominated by the relative saliency of the local or global levels.

The failure to overcome bottom-up salience signals in JM also fits with recent work pointing to the PPC (and LIP in monkeys) as the locus of top-down and bottom-up interactions that yield a dynamic priority map for attention selection (Bisley & Goldberg, 2010; Ptak, 2012). More specifically, however, a study by Mevorach, Humphreys and Shalev (2006a) have previously provided evidence both from unilateral brain lesions and TMS (Mevorach et al., 2006b) that the left PPC is particularly involved in ignoring salient distractors and orienting attention in a task-based manner to a low saliency target. In particular, the left PPC is involved in a preparatory selection process whereby the processing of early visual cortex signals representing salient distracters is attenuated. This attenuation process, in turn, facilitates selection of the less salient target. Thus, the failure in top-down selection in JM is likely to reflect an impairment in top-down attentional control modulated through the left PPC.

In sum, it is suggested that the deficit it is observed here in the current study of this chapter that JM reflects a particularly severe instance of a problem in both salience-based selections (so that selection is determined by the relative saliency of stimuli), which is typically associated with the left PPC, and in disengaging attention once the wrong (but salient) level has been selected (typically associated with the right PPC in the spatial modality). It follows that the left and right PPC damage suffered by JM may both be critical here, which results in a general problem in attentional control.

It should be noted that, though, that JM had some problems identifying local letters even in the target salient, congruent condition. To account for this, it is suggested that JM had, on some trials, awareness that she had selected the wrong level of the stimulus (e.g., the global form), but the problem with attentional disengagement led to her guessing the identity of the local form.

Therefore, it is concluded that global processing (especially with high saliency global shapes) still operates in simultanagnosia and that an impairment in controlling attention can be a core factor that impedes the patient's ability to actively and flexibly select the stimuli relevant to a task. This deficit impairs not only the initial selection of the stimuli but also the ability to flexibly shift attention from one level of processing to another. As a consequence selection is dominated by the relative saliency of the visual input and there is a reduced possibility that a patient can ‘correct’ and shift selection once a salient element has been attended.

It cannot be entirely clear whether the seeming response bias is due to a failure of task comprehension as the author of the thesis did not meet the patient directly due to constraints of accessibility to the patient leading to another experimenter testing the individual. An alternative explanation is that JM had a bias towards salient stimulus due to perseveration (due to highly acute lesions in the frontal cortex). It has been known in classic neuropsychological tests such as the Wisconsin Card Sorting test, that those with frontal lesions display preservative behaviours in which they repeat a previous action or rule despite a rule change (see Demakis, 2003 for a meta-analytic review). A voxel-symptom lesion mapping study by Gandola et al. (2013) suggested that right hemisphere patients with left hemispatial neglect displayed different types of preservative behaviours in a line cancellation task which corresponded to different neural structures. Patients who made additional cancellation marks to a cancelled target object also had lesions in the inferior frontal gyrus, temporal gyri, postcentral gyri and the insula. Other patients who made cancellation marks outside the target line object (termed flying marks) in the premotor and temporal pole lesions. Finally, patients who made multiple continuous marks on the same already cancelled line (termed as scribble perseveration) also had lesions also had lesions in the orbitofrontal cortex, the caudate nucleus.

Despite having an acute frontal lesion, it is evident that JM did not display the typical response bias that could be considered perseveration in the classic sense. Critically with perseveration, there is a repetition of a stereotypical response. Since the two possible responses were randomised throughout the block and JM still scored highly in certain conditions (e.g. congruent trials but to some extent incongruent trials too), she could not have shown classic perseveration. She may have shown salience based preservation of only responding to the salient item. However, this would not be classified under the classic definition. What the salient item did was to bias attentional focus to respond in a particular manner which may produce preservative-like behaviour, but it is able to select information and change responses (i.e. the change between H and S targets) which would not be symptomatic of preservation. Additionally, two of the control patients had frontal lesions and did not display the same behavioural effect. However, it should be noted that the frontal cortex is important for response selection (as mentioned in Chapter 3) and that JM does have white matter lesions in the frontal cortex therefore that the top-down goals may not have been effectively communicated to the parietal cortex to allow for task-based selection and suppression to occur. This communication between frontoparietal regions for top-down selection network has been noted (see Ptak 2012).

Considering that JM has white matter lesions from the parietal cortex to the occipital cortex, the effects may be explained by a disruption to the salience suppression network (similar to that proposed by Mevorach et al., 2010). As a reminder, Mevorach et al (2010) found that after TMS inhibition of the left IPS there was increased fMRI BOLD activation of the occipital pole during global/local trials in when there was interference of salient distractors (reflect behaviourally by increase in reaction times in distractor salient condition of the saliency-mediated global/task like Experiment 4.1). Furthermore, in their second experiment after TMS online excitation of the left occipital cortex showed increased interference from salient distractors similar to what was seen after left IPS stimulation. So what is seen in the case of JM is that her parietal lesions have prevented for effective down-regulation of the occipital cortex when salient distractors are present. Likewise, the occipital lesions would not allow for any feed-forward projection of the salient information to control to the parietal cortex via white matter tracks which lead to poorer performance (poorer suppression of salient distractors). This neuropsychological case-study evidence complements the white matter findings from the VBM study (Experiment 2.1) in which patients (excluding JM) had reduced white matter integrity displayed poorer performance in interfering salient distractors.

The current chapter has shown that the parietal cortex as exhibited by a patient with Balint's syndrome has some implications in shifting top-down attention towards bottom-up perceptually salient information. Furthermore, it has shown that once captured, a patient with Balint's syndrome fails to disengage from salient information, leading to behavioural responses which align to the salient aspect of an object as opposed to the required part of object needed for selection. It has also shown that those with Balint's syndrome can also perceive global forms if the global level was salient, contrary to traditional classifications of the disorder, which state a general problem of global processing. This case study approach has benefited knowledge in revealing this subtly flexible nature of saliency mediated top-down selection in the parietal cortex.

On a similar vein to the current chapter, the following chapter will look more specifically at another patient single case study. The next chapter will focus on a bilateral parietal patient (with no occipital damage unlike patient JM) who shows reversed saliency effects in the global-local task as run in Chapter 2. In this particular case it will show a different contribution to the parietal cortex in salience based selection; showing that perceptual saliency is mediated by response categorisation and the relevance of the options needed to respond to the task guides how the bottom-up salient information is to be used by the top-down task set.

CHAPTER 5 HIERARCHICAL PROCESSING IN BILATERAL PARIETAL PATIENT: SALIENCE-BASED SELECTION DEPENDS ON RESPONSE RELEVANCE TO THE TASK.

Introduction

The previous chapter investigated the role of the parietal cortex as a mechanism for allocating and disengaging attention towards and away from salient items in a global-local task (Experiment 3 in Chapter 4) in a patient with Balint's syndrome. The patient (JM) was automatically captured by salient items and not being able to utilise top-down information to disengage from the salient item once captured. This effect occurred regardless of the specific level of form; a phenomenon which added to the growing literature against a specific level bias in Balint's syndrome. It was argued that this effect was driven largely due to the posterior parietal cortex which was lesioned in this patient. The focus of the previous chapter was the effect of salient distractors and how it influenced level form processing via the manipulation of top-down control.

The current chapter will demonstrate a substantially different performance following parietal damage that can further our understanding of the salient-based selection processes in this region. In the case study presented here of a patient with damaged parietal cortices (and intact frontal lobes), I will highlight a link between salience-based selection in the parietal cortex and response relevance. Thus, the focus in this chapter will shift to the exact nature of the response items themselves.

The experimental paradigms I have utilised in the thesis thus far involved behaviourally relevant distractors. That is, the identity of the distractor belonged to the response set and could, therefore,, match (or mismatch) with the identity of the target. The findings presented, supported the role played by the parietal cortices in selection and suppression of high salient information. However, it is still an open question whether the involvement of the parietal cortices is dependent on target and distractors belonging to the same response set. The notion that the parietal cortex contribution to salience-based selection and suppression is particularly relevant when both target and distractors belong to the same response set is supported by a previously reported case study of a Balint's patient. Shalev et al., (2005) had investigated global perception in a Balint's patient (GM) who was unable to report the identity of the global letter when local elements that competed for response where used. However, the patient was much better at identifying the global letter once the local elements became unfamiliar symbols (Hebrew letters). This pattern of performance suggests that flexible selection and suppression of hierarchical stimuli is impaired in patients with parietal damage only when the two levels compete for a response. While for GM, the benefit disappeared once he became familiar with the Hebrew letters it may still be the case that the parietal cortex is particularly needed when the distractors represent a valid alternative to the targets. In the context of salience-based selection, this may imply that bilateral parietal damage will impede selection as long as the salient distractor represents items that are taken from the same response set as the targets (or that represent a valid alternative to the targets). Initial evidence in support for this conjecture comes from unpublished data (Mevorach et al., 2012) where left parietal patients performed a salience-based selection task using superimposed faces and houses. When the houses and faces were mapped to the same response set, left parietal patients were greatly impaired in conditions of high distractor salience. However, when no such cross mapping occurred patients performance resembled that of healthy controls.

Therefore, in this chapter, I will explore whether the contribution of the parietal cortex to salience based selection depends on whether the distractors represent a viable alternative to the targets in another patient with bilateral parietal damage who shows abnormal performance in the hierarchical letter task I have used so far. In the first experiment (Experiment 5.1) the same global local task used so far will be tested to establish the link between salience-based selection and superior parietal lobule damage in the patient. In the following experiments, different versions of the global-local task are utilised to manipulate whether or not the distractors represent a viable response alternative to targets.

Experiment 5.1 Case study evidence for reversed salience-based selection in a global-local task in a patient with simultanagnosia

The current experiment (Experiment 5.1) will examine Patient PF's performance in the saliency-mediated global-local task compared to age-equivalent neurotypical controls. It is predicted that PF will have significantly different effects of saliency compared to the controls.

General methodology

PF Case history and neuropsychological analysis

At the time of testing, PF was a 64-year-old white British woman, who suffered two strokes throughout a period of fifteen years. Her first stroke which resulted in a left parietal lesion occurred when she was 47 years old (as reported by Braet & Humphreys, 2009). Her second stroke happened approximately eight years later and resulted with a right parietal cortex lesion. She is right handed.

Structural MRI scans in 2006 (see figures 5.1.1 and 5.1.2) revealed that she has bilateral posterior parietal cortex stroke lesions extending to the superior parietal cortex.

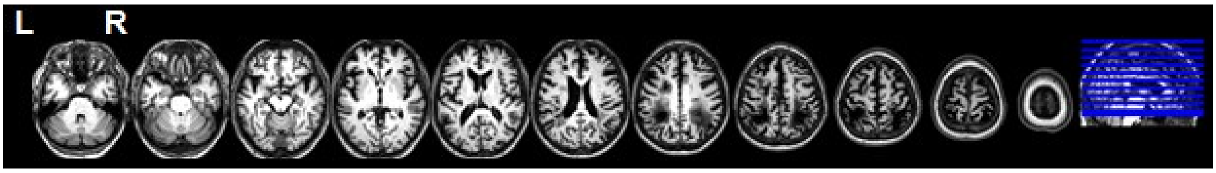

Figure 5.1.1: Grey matter lesions (un-normalised) MRI T1 structural scan image of PF's lesions.

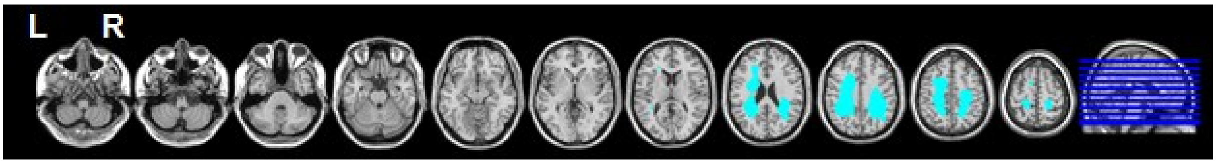

Figure 5.1.2: White matter lesions of PF normalised to a standard T1 image.

Cognitive functions were assessed in PF using BCoS (Birmingham Cognitive Screen, 2012 (Humphreys et al., 2012) which is a paper and pencil tool assessing five different cognitive domains. According to the results, PF has retained normal functioning picture naming abilities and is able to construct sentences normally according to the screen. She showed borderline normal functioning in sentence reading (41 cut-off = 42), however, did take more time to read information (30.6s, cut-off = 23s). In non-word reading, she is quicker than the cut-off limit (9s, cut-off = 14s). Her ability to read numbers is also within the normal range (8, cut-off =8). In tasks of visual neglect (apple cancellation), she performed within the normal range (49 apple completions selected, cut-off = 42). Additionally, in tasks of visual extinction, she also performed within the normal range (100% correct).

In terms of impairments according to the BCos, she has dysgraphia. She showed poor reproduction of a complex figure (total score = 11, cut-off 42). Also, she was impaired in tests of auditory attention (44 correct responses, cut-off = 51). She also showed impaired performance in executive tasks of rule finding and rule switching in the Birmingham Rule Finding and Switching Test (0 correct response, cut-off = 6). She had problems in long-term recall of story information (Total Score = 6, cut-off = 8).

Controls

Six healthy age-matched controls (all females) with no reported or known history of neurological illness or conditions gave informed consent and participated in the study. The mean age was 64.43 years with a standard deviation of 2.07 years. One control was left handed (based on self-report).

Experimental methodology

The same global/local task with manipulation of relative saliency that was used in Experiment 2.1 was used here. However, both accuracy and reaction time (in milliseconds) were recorded in the present experiment. Other than that the experimental method was identical to what is described in Experiment 2.1.

Results

Accuracy for PF and controls are displayed in Figure 5.1.3. Overall accuracy for PF (*M* = .89) was significantly lower than that of controls (*M* = .992, *SD* = .0005) (*adjF*(1,4) = 433.5, p < 001) however, the lowest accuracy for PF was no lower than 75% in any given condition thus reaction times were analysed.

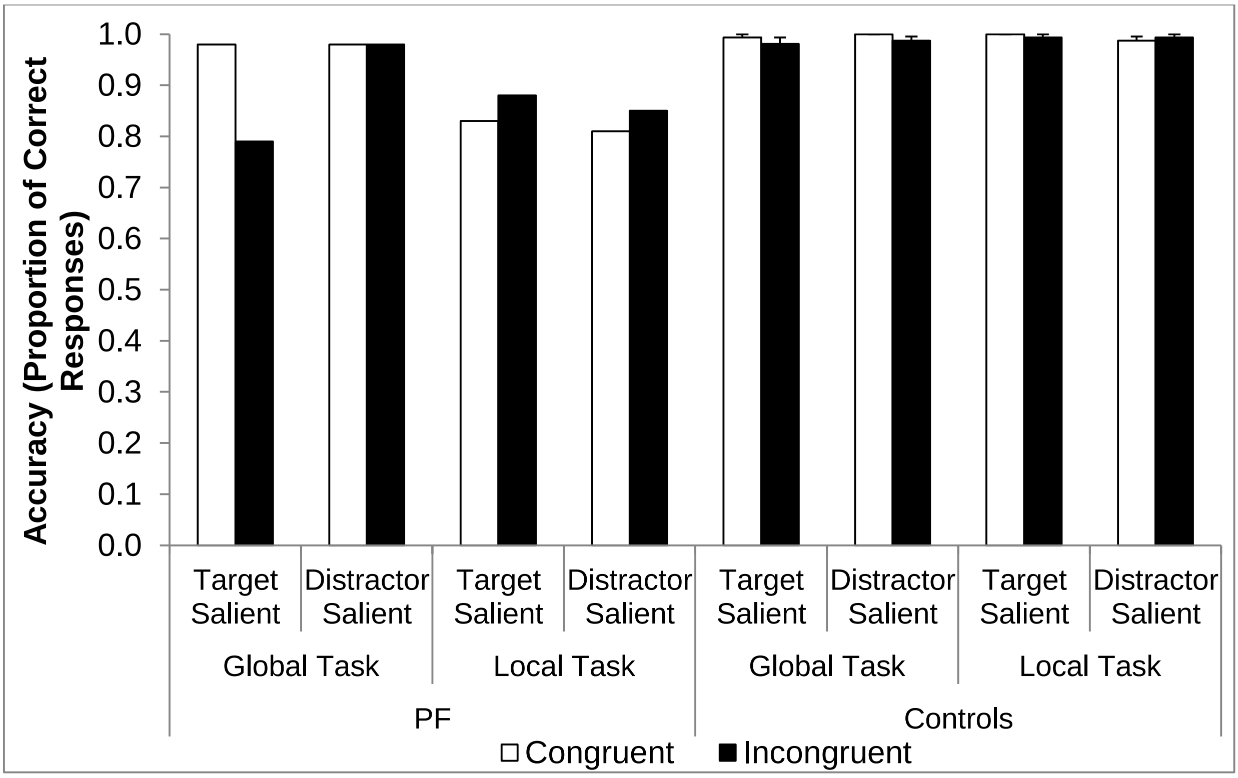

Figure 5.1.3: Accuracy rates to correctly identified targets in the global-local task (Experiment 5.1) for Patient PF and a healthy age-matched control group. Error bars for control group represent standard error of the mean.

Mean reaction times (RT) for correct responses (shown in Figure 5.1.4) were statistically compared between PF and the controls using the adjusted F methodology (see below). Firstly, overall RTs (pooled across all conditions) were significantly longer for PF (*M* = 1923.88ms, *SD* = 232.65ms) than neurotypical controls (*M* = 534.70ms, *SD* = 52.32ms) (*adjF*(1, 4) = 587.53, p < .001). Based on this, all reaction times were transformed in Z-scores using the method used by Tsvetanov et al. (2013).

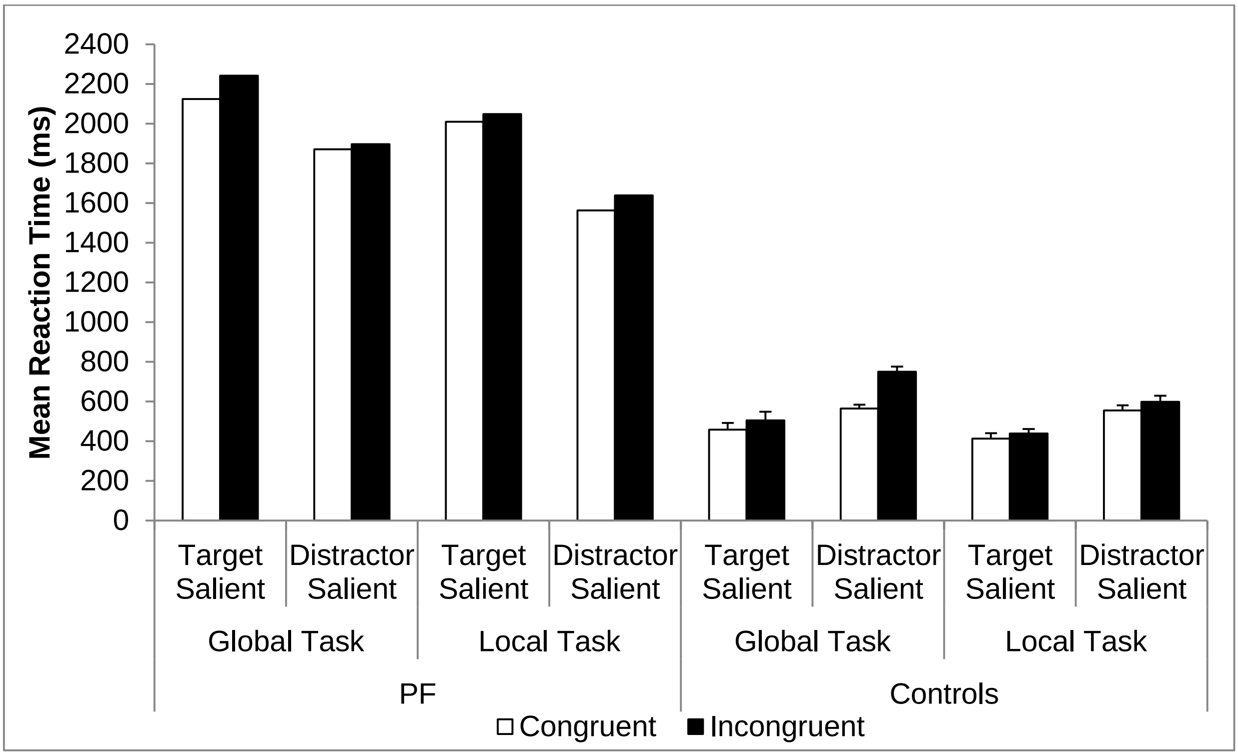

Figure 5.1.4: Mean reaction times (ms) to correctly identified targets in the global-local task (Experiment 5.1) for Patient PF and a healthy age-matched control group. Error bars for control group represent standard error of the mean. Error bars for control group represent standard error of the mean.

Tsvetanov et al. (2013) ran a similar variant of the saliency mediated global-local task comparing younger and older adults. In order for effective and fair comparisons to made between younger and older groups (due to differences in a general slowing of reaction times in older people: Faust, Balota, Speiler & Ferraro, 1999; Salthouse, 2000), reaction time efficiency (inverse efficiency scores) were standardised into Z-scores. Due to the finding in the current study of this chapter that Patient PF was significantly slower than controls, it is reasonable to apply the same principle of reaction time standardisation since the standardisation has been used in a cognate study previously. The Z-score transformation of reaction times was calculated to ensure that the effects of the task were not masked by the general slowness of the patient compared to controls. Z-transformation has been used for clinical purposes to ensure fairness in comparability of behavioural effects between a patient group and controls (Faust et al., 1999). For this experiment (and subsequent experiments in this chapter), within each participant, the mean reaction times for all experimental conditions was normalised by the standard deviation across all conditions. This method was applied to each condition and each participant separately. It is important to note that whilst, in Tsvetanov et al. (2013) the Z-transformation was done for inverse efficiency scores (combining both RT and accuracy), here the Z-transformation is applied only for reaction times. The Z-transformed RTs for all conditions in Patient PF and controls are displayed in Figure 5.1.5.

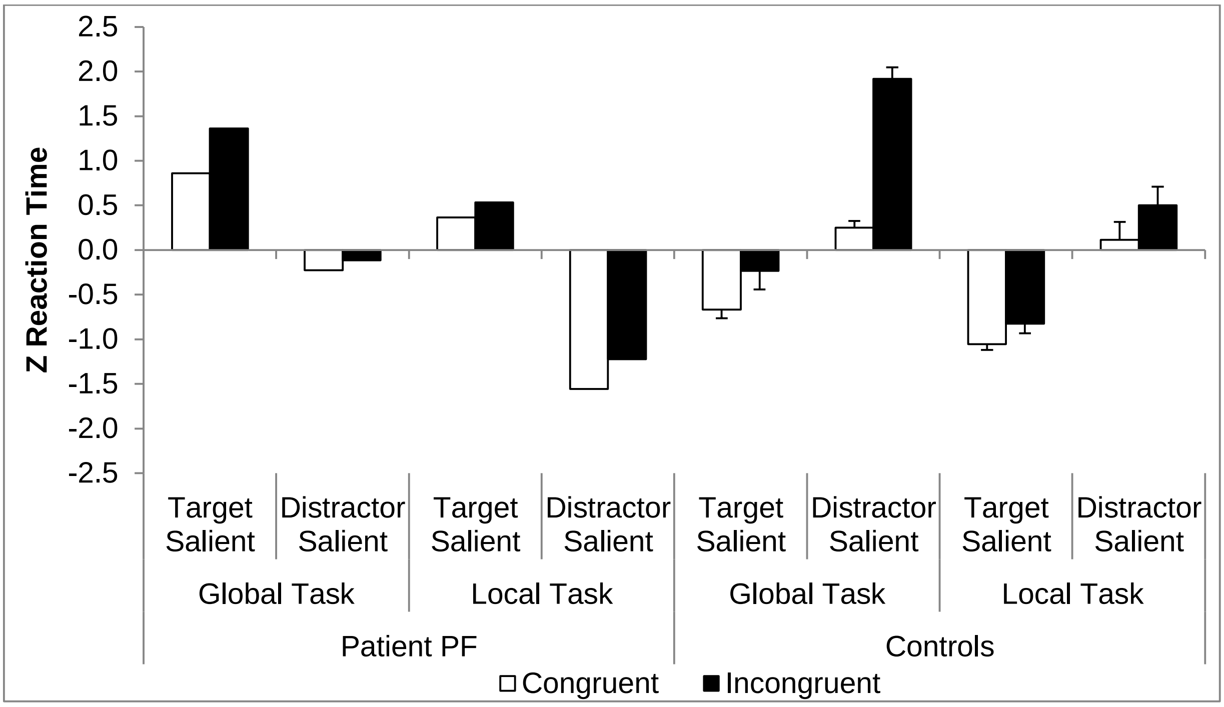

Figure 5.1.5: Mean Z reaction time (measured in milliseconds) of correctly identified letter targets in the global-local task (Experiment 5.1) between Patient PF and healthy control participants. Error bars for control group represent standard error of the mean.

Using the adjusted F calculator (Hulleman & Humphreys, 2007) which was designed to analyse statistically single patient with controls, the following contrasts were run: level difference (local – global), saliency main effect (distractor salient displays – target salient displays) and congruency interference (incongruent displays – congruent displays). There were no statistically different level effects in PF (*M* = -.94) compared with the controls (*M* = -.63, *SD* = .37) (*adjF*(1, 4) = .57, p = ns). However, statistically significant congruency interference difference was found in PF compared with the controls *(adjF*(1, 4) = 3.33, p = .011) as PF showed a reduced congruency interference (*M* = .28) compared to controls (*M* = .68, *SD* =.2). In addition, PF exhibited a reversed pattern of saliency which was statistically significant compared to controls (*adjF*(1, 4) = 55.79, p < .001). In particular, PFs performance with distractor salient displays was better than with target salient displays (salience difference = -1.56) while the controls showed the typical pattern of worse performance with distractor salient displays compared with target salient ones (*M* = 1.39, *SD* = .36) In summary, PF did not differ from controls as a function of level of processing, but rather showed atypical performance as a function of congruency (reduced congruency interference) and saliency (reversed saliency cost) compared to healthy controls.

Discussion

The aim of this experiment was to ascertain the expected association between damage to the superior parietal cortex and salience-based selection in a global-local task. The main finding was that Patient PF showed reversed saliency effects compared to neurotypical participants. That is, PF was able to identify the target when the distractor level was salient more quickly than when the target level was salient. While this is somewhat unexpected (as previous reports, including Chapter 1 and 2 here, anticipate increased saliency cost for patients with parietal damage), critically it still highlights a link between SPL damage and atypical performance in salience-based selection. Importantly the patient did not show atypical level identification behaviour. Thus, performance differences cannot be associated with atypical level processing in the patient. Despite having significantly lower accuracy, it is important to note PF's trend of accuracy did generally correspond with the pattern of reaction times, thus not displaying a compromising speed-accuracy trade-off.

It was also found that congruency interference was reduced in Patient PF compared to controls. This result resembles the finding of Experiment 3.1 where TMS inhibition of the precuneus (part of the superior parietal cortex) reduced congruency interference in a similar global local task. Thus, this finding may provide further evidence for the role the parietal cortex is playing in allocating attention to all aspects of the display (both targets and distractors)..

While both case studies reported in this thesis (JM, Chapter 4; and PH here) point to a link between bilateral parietal cortex damage and salience-based selection they also show substantially different patterns of performance (an exaggerated saliency cost for JM and a reversed saliency cost for PF). It is important to note, however, that the two patients represent two very different cases. In the former case of JM, only accuracy was assessed, whereas, in this current case of PF, only reaction times were assessed. However, both of these case studies show two important similarities: both did not have level specific problems, and both were abnormally affected by the salient information.

Although not within the focus of this investigation one could still speculate about the cause of the reversed saliency effect exhibited by PF. It could be argued that the task involves two simultaneously occurring selection cues: task instruction (top-down selection cue) and perceptual saliency (bottom-up selection cue). Indeed, salience-based selection incorporates an interaction between these two selection cues with (especially left) IPS thought to be important in inhibiting the bottom-up salience cue (Mevorach et al., 2010) while the right PPC seem to important for selecting the salient information (Mevorach et al., 2006b). The reversed saliency cost exhibited by PF can, therefore, stem from a difficulty associating the letters identity with the selection cue. For instance, when both task instruction (e.g., attend local) and bottom-up saliency (e.g., local salient displays) point to the same information (in this case the local letter), PF may have difficulty ascertaining that the information identified is indeed also related to the task instruction and not only to the bottom-up selection cue. Thisproblem is more easily solved when the two selection cue point to different levels, which then allow for a later stage of processing (most likely outside the parietal cortex) to differentiate the top-down from the bottom-up cues. This may also explain the overly long time it took PF to make a decision about target identity (as this process may involve a later decision process which attempts to distinguish between the sources of the information). While this remains a speculation what is evident is that PF cannot rely on normal salience-based selection mechanisms to perform the task.

As the link between superior parietal lobule damage and atypical salience-based selection is established I can now move to explore the main question of this chapter which is to manipulate whether or not the distractors represent a viable response alternative to targets and whether this will dictate the contribution of the parietal cortex to salience-based selection.

Experiment 5.2: Divided attention version of the Global/Local task.

In Experiment 5, I utilised a divided attention version of the global/local task to create a condition where the distractor level does not include a variable alternative to the target. In this task, the participant is required to identify which of two target letters appear in the display. Critically, only one such letter appears (either on the global or the local levels) and the participant simply needs to identify this letter. The relative salience of the global and local letters is still manipulated as before. If the patient problem occurs regardless of the whether or not distractors represent a viable alternative to targets then a similar pattern of performance should be shown (i.e., distractor salient displays will be reported quicker than target salient ones). If on the other hand, the contribution of the parietal cortex is only necessary when distractors represent and alternative then the patient's performance here should be more similar to controls.

Method

Participants

Four of the six controls mentioned previously participated in this study (no exclusions). The mean age was 65.25 years (*SD* = 2.22 years) (2 left handed).

Design

Only neutral stimuli (i.e., a target letter on one level together with a non-target letter on the other level) were used in this experiment. Thus, if a distractor (non-target letter) is selected and identified it cannot be confused with the target as it always has a different identity. The target letter could appear at either the global or local levels with equal probability.

Stimuli

All compound letters were constructed using the same basic principles. Compound shapes were made using Paint.NET. For local salient, the entire shape was 7.60° by 4.75°. All compound shapes had no more than four local letters in width and no more than 5 local letters in height. Each local element was subtended 1.14° by 0.67° in height and width respectively. Local elements were separated by a 0.29° inter-elemental distance. Each alternating local letter was coloured red or white. The target letters were H and S and the non-target letters were E and I. A target letter on one level was always coupled with a non-target letter on the other level (see Figure 30).

For global salient, the same local elements were used but were only coloured red. A Gaussian blur of 17 was applied to each compound letter to make the global aspect more salient. This removed the inter-elemental distance and thus made the overall global shape slightly smaller (6.65° by 4.75°). Due to the Gaussian blur, the individual local elements were made smaller from their original size (0.95° by 0.95°).

This stimuli generation procedure is the same for the remaining experiments in this chapter (Experiments 6 and 7).

Figure 5.2.1: Compound letters used in Experiment 5.2. The targets were H and S with distractor level being E and I.

Procedure

Participants were sat at an LCD monitor of which was 36 x 30 cm (width x height) in size, 60cm away from the screen. There was a fixation cross for 505ms. Participants were instructed to search for either an H or an S, which could appear in either the global or local level. At the start of each trial, there was a fixation cross which appeared for 500ms. Afterwards, the compound letter stimulus appeared for 150ms on a black background, followed by a blank black screen. Participants had to respond as quickly as possible as to which letter was the target in the stimulus. No other letter or passes were allowed. The responses were mapped to two keys on a keyboard (m for “H” and k for “S”).

Results

PF had a significantly longer reaction time to respond to targets (pooled across all conditions) (*M* = 1562.50ms, *SD* = 263.16ms) than neurotypical controls (*M* = 510.68ms, *SD* = 128.23ms) (*adjF*(1,3) = 53.83, p < .001) (see Figure 5.2.2 for condition mean reaction times). Thus all mean reaction times were transformed into Z-scores by the method proposed by Tsvetanov et al (2013) (as mentioned in the Results section of Experiment 4) and displayed in Figure 5.2.3.

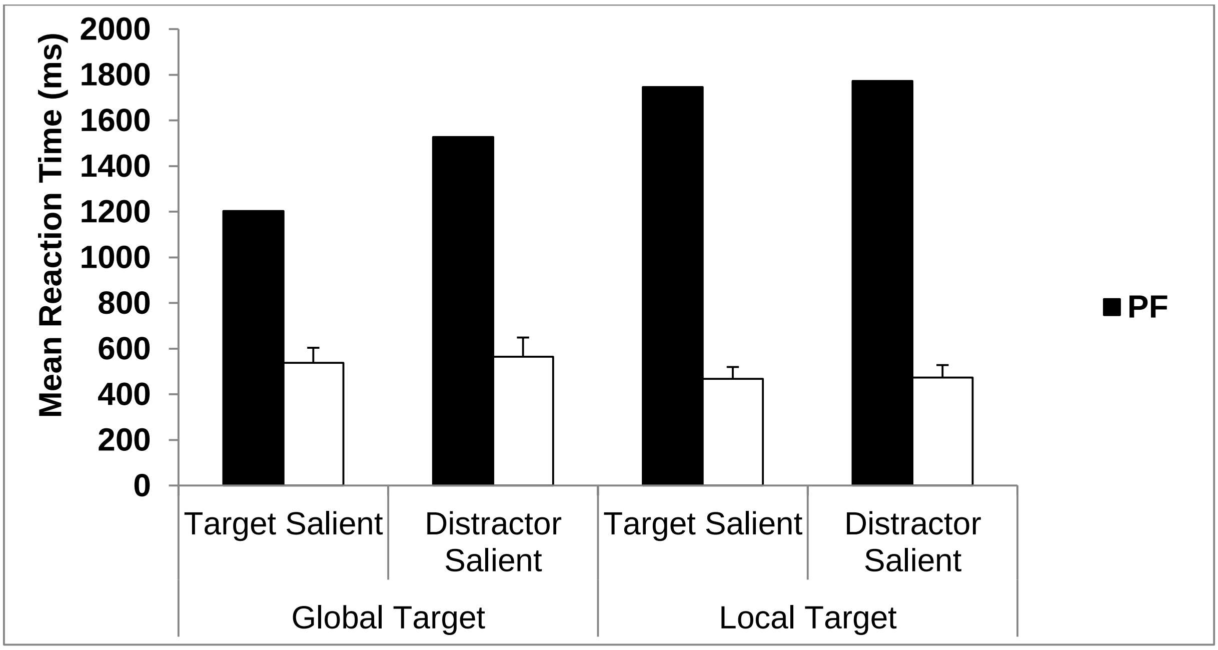

Figure 5.2.2: Mean reaction times (measured in milliseconds) to correctly identified targets in the divided global-local task (Experiment 5.2) between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

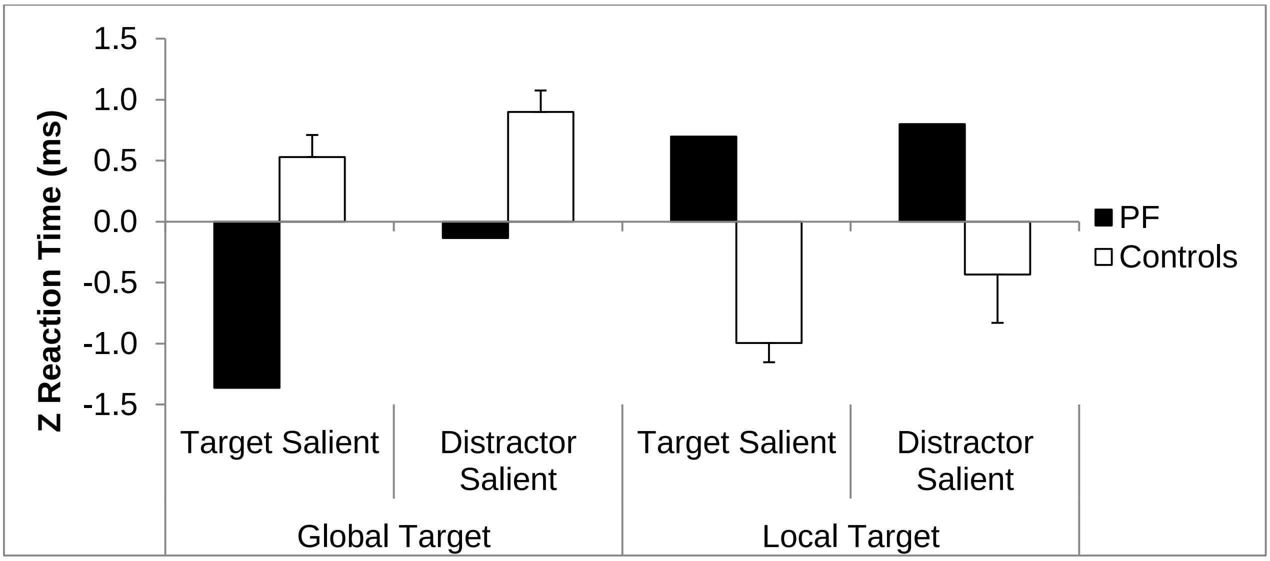

Figure 5.2.3: Mean Z reaction time (measured in milliseconds) for correctly identified targets in Experiment 5.2 between PF and healthy controls. Error bars for control group represent standard error of the mean.

Using the adjusted F calculator (Hulleman & Humphreys, 2007), two main effects were calculated to compare between PF and the control group: level (local targets minus global targets); saliency (distractor salient displays minus target salient displays). The analysis revealed a significant difference in the level effect between Patient PF (*M* = 1.50) and the controls (*M* = -1.43, *SD* = .48) (*adjF*(1,3) = 30.01, p <.001). Thus, PF showed quicker performance with global targets compared to local targets (global precedence) while the controls showed quicker performance with local targets compared to global targets (local precedence). However, in terms of saliency there was no difference in the effect of saliency between PF (*M* = .66) and the controls (*M* = .47, *SD* = .62) (*adjF*(1, 3) = .08, p = .565). Thus, the previously identified atypical saliency effect in PF was eliminated in this experiment and both PF and controls showed a comparable saliency cost (where distractor salient displays were reported slower than target salient ones).

Whilst there were not statistically significant difference in the effect of saliency in the local task between PF (*M* = .10) and Controls (*M* = .56, *SD* = 1.10) (*adjF*(1, 3) = .14, p= .468). PF was significantly more captured by salient displays when identifying global targets (PF *M* = 1.23; Controls: *M* = .37, *SD* = .53) (*adjF*(1, 3) = 2.09, p = .049).

Discussion

The present experiment yielded quite a different pattern of performance in PF compared with the previous one. Particularly, the reversed saliency effect that was reported in Experiment 5.1 was eliminated here as PF showed comparable saliency cost as the controls. In contrast, here a difference in the level effect has emerged, whereby PF showed global precedence while the control showed local precedence. Thus, the data here supports the notion that superior parietal lobule contribution to salience-based selection is important only when the distractors represent a viable alternative to the target. One important aspect to consider, however, is whether the divided attention task used here actually required salience-based selection at all. For example, it could be argued that there was no need to select or suppress a particular level in this task (as the target level is unknown in each trial). Therefore, participants may always first select the salient information and only when this does not hold the target will move to select the other level (less salient one). However, if that was the case, then performance should have always highlighted a selection of salient information first. This was clearly not the case here is I report a level precedence effect (even in the controls) that transcends the relative saliency. For example, when the global information was more salient control participants were actually quicker to report local targets (which was the less salient aspect of the display) than global ones. This suggests that some degree of salience suppression was utilised here too.

In terms of the reversed level precedence effect, it is important to note that in a divided attention version of the task when there is no a-priori instruction to attend a specific level, it could be the case that individuals will elect to focus on a specific level initially as a strategy. Thus, the level precedence effects observed here may reflect a strategy of attending to local letters first for the controls and to global letters first in PF. Alternatively, this could also reflect a real difference in level preference effect (on a perceptual level) that is attributed to PF's lesion. Riddoch et al., (2008) have documented two bilateral occipital patients who showed reversed level precedence effect. Specifically, a patient with bilateral dorsal occipital lesion (SA) showed local preference while a patient with bilateral ventral occipital lesion (HJA) showed global precedence (with the same set of global-local stimuli). SA's lesions were closer in that they do partially overlap in the parietal cortex (SA had lesions extending to the right inferior parietal cortex) to PF's lesions than HJA, which had occipital-temporal lesions extending to the temporal cortex. Despite this proximity, PF does have superior parietal lesions (where SA does not) and also she does not have grey matter lesions in the occipital cortex. Whilst PF does have lesions in the occipital cortex; it is hard to assume that she would have a problem with local processing. She was still able to identify targets in the divided attention variant of the global-local task.

One other possibility for the different level precedence effect between PF and controls here could be that the use of neutral letters (which are taken from the same response category as the targets) affected selection in the patient to some degree. As mentioned above, Shalev et al., (2007) reported that only when the local letters where completely unknown to their Balint’s patient, he was able to identify the global shape. Thus, it could be that while for PF the use of neutral letters facilitated dramatically the ability to select or suppress salient information it still incorporated some difficulty in selection because it was taken from the same response category. As there is also a question of whether salience selection and suppression are utilised in a similar way in both divided and focused attention tasks (see above), in the next experiment I will repeat the same focused attention task as before (Experiment 5.1) but with unfamiliar Hebrew letter as the non-targets. Thus, only the target level (top-down instruction) will contain a valid target letter while the distractor level will always contain a Hebrew letter (unfamiliar to the participants).

Experiment 5.3: Using unfamiliar distractors to enhance typical saliency capture in a patient with simultanagnosia: the strange letter global-local paradigm

The following experiment aimed to test whether using unknown symbols (Hebrew letters) in a focused attention version of the global/local task will facilitate selection in PF so that normal effects of saliency and level will emerge.

Method

Participants

Four female controls of the six (no exclusions) participated in this study. Mean age is 64.6 years (*SD* = 2.3 years). Two of them were left handed.

Design

A focused attention global-local task (in a similar manner as Experiment 4) was run. Like the previous experiment, only neutral displays were used (distractor level included only non-target letters). Other than that change, the design was identical to that of Experiment 2.1, and 5.1 just with 48 trials per saliency*level condition instead of 32 trials per saliency*condition as was the case in Experiment 5.1.

Stimuli

By using two letters which are unknown in the English language (Hebrew- like letter and its inverse), the unfamiliar aspect will interact with saliency to increase the distraction. The size of the stimuli, there inter-elemental letter distance, local salience segmentation and global salient blurring principles were designed using the same criteria used in Experiment 5.2. See Figure 5.3.1 for stimuli presented arranged by level and saliency of targets.

Procedure

Participants were sat at an LCD monitor of which was 36 x 30 cm (width x height) in size, 60cm away from the screen. There was a fixation cross for 505ms. The stimuli were presented for 150ms, and the participants had to identify which target letter was it as fast as possible. Participants could only respond to H or S and no other responses or passes were allowed. The responses were mapped to two keys on a keyboard (m for “H” and k for “S”).

Figure 5.3.1: Compound letter stimuli used for Experiment 5.3. The targets were H and S and the distractor level were the strange letters. Each permutation has a level salient variant.

Results

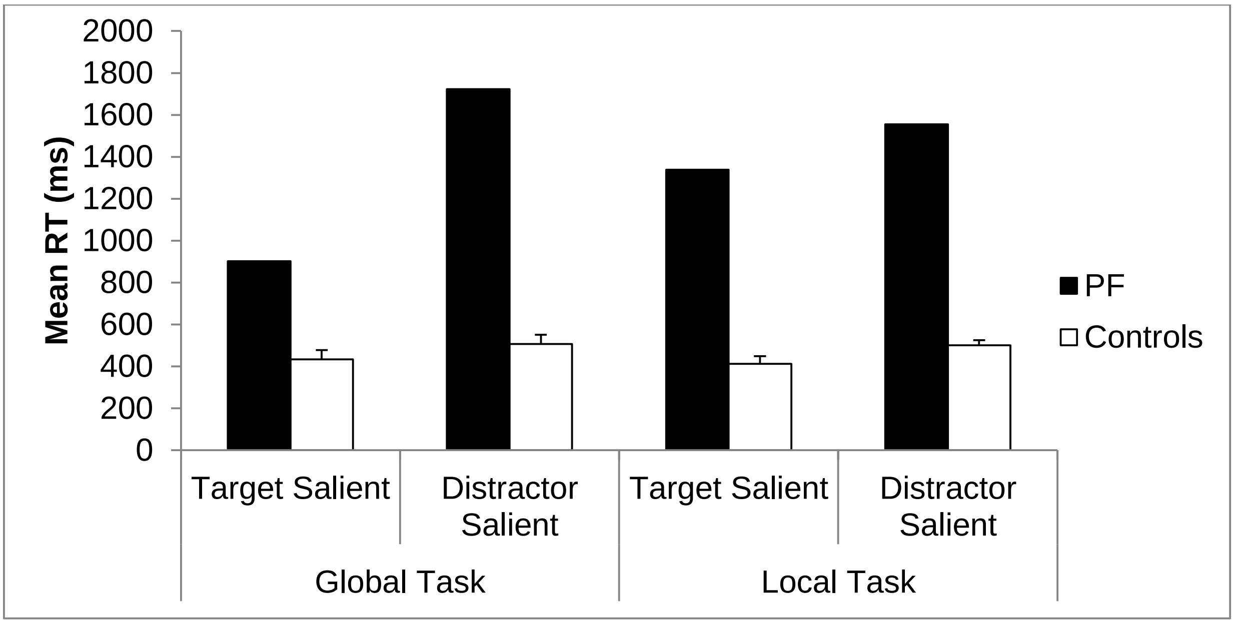

Figure 5.3.2: Mean reaction time (measured in milliseconds) to correctly identified targets in the strange letter global-local task (Experiment 5.3) between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

The mean reaction time to targets across all conditions was significantly longer in PF (*M* = 1379.58ms, *SD* = 355.07ms) than neurotypical controls (*M* = 463.64ms, *SD* = 67.78ms) (*adjF*(1,3) = 146.08, p < .001) (see Figure 5.3.2 for means). Therefore, all mean reaction times for each condition was converted to Z scores using the same method as described in the previous two experiments (see Figure 5.3.3 for Z-transformed mean reaction times).

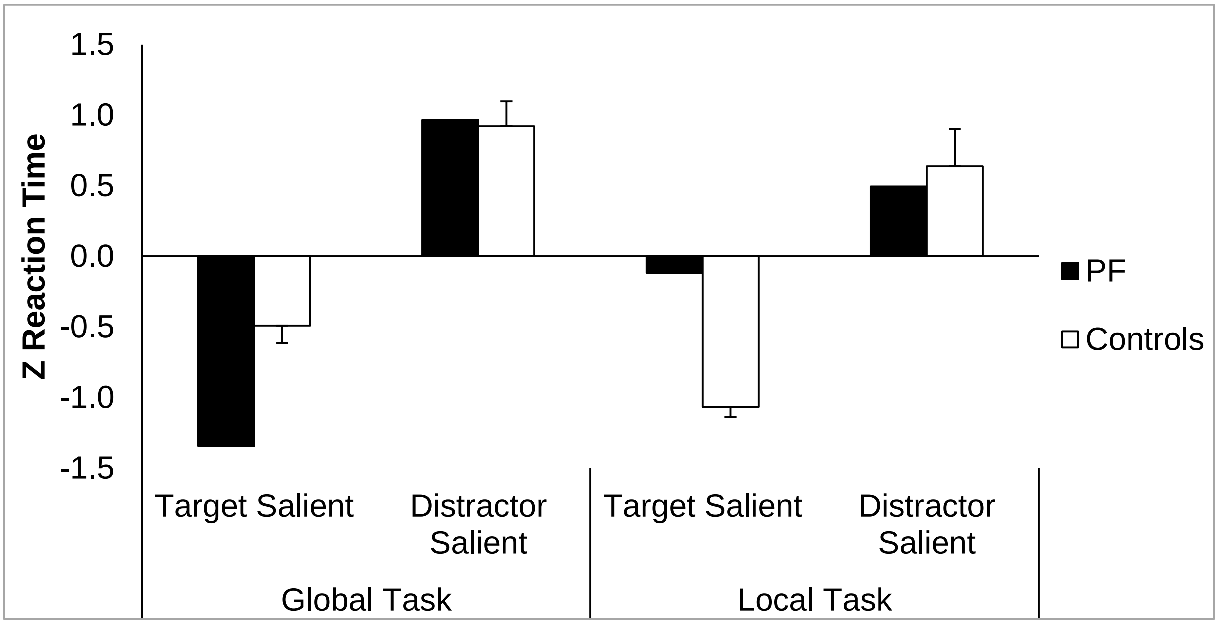

Figure 5.3.3: Mean Z reaction time for correctly identified letter identification in the strange letter global-local task (Experiment 5.3) between Patient PF and healthy control participants. Error bars for control group represent standard error of the mean.

Using the adjusted F calculator (Hulleman & Humphreys, 2007), two main effects were computed in order to compare PF and the control group: level (local targets minus global targets) and saliency (distractor salient displays minus target salient displays). There was a no significant difference in level form (local targets minus global targets) identification between Patient PF (*M* = .04) and to controls (*M* = -.44, *SD* = .33) (*adjF*(1,3) = 1.68, p = ns).

Like the previous experiment there was no overall main effect of saliency between PF (*M* = 1.46) and Controls (*M* = 1.56, *SD* = .2) (*adjF*(1, 3) = .2, p = ns). PF performed similarly to controls in terms of saliency capture; that is to say the distractor salient was slower that target salient conditions (shown by the positive value in the calculation).

Discussion

In this experiment PF performance resembled the performance of the healthy controls. There was no clear level precedence difference between PF and controls (and generally there was no significant level difference for the controls or PF in this experiment). Importantly, PF exhibited a similar salience effect as the controls suggesting here salience-based selection in this experiment did not differ than controls.

General Discussion and Conclusions

The experiments presented in this chapter were designed to test whether the parietal contribution to salience-based selection and suppression is dependent on the information presented in the distractor level. In the first experiment in this chapter (Experiment 5.1) it was first established that PF's parietal lesion is associated with atypical salience-based selection. Indeed, using a similar global local task as I have used in the previous chapters of this thesis, patient PF showed substantially different salience effect compared to healthy controls. While for the controls, distractor salient displays were reported considerably slower than target salient ones, for PF they were actually reported quicker (a reversed salience effect). In the second experiment (Experiment 5.2) I tested whether this abnormal performance could be extinguished when there is no a-priori instruction to select a specific level of form and when the distractor does not represent a viable alternative to the target. Therefore, a divided attention task was used where only one target letter could appear together with a non-target letter. PF's peculiar salience-effect was not observed under these conditions and her performance was similar to controls in this respect. However, there was a marked difference in the level precedence effects shown by PF (global precedence) and controls (local precedence). Such precedence effects may be attributed to different strategies employed by the patient and controls, to select initially a specific level in each trial (and indeed were not evident in the other two experiments). Finally, in the third experiment of this chapter (Experiment 5.3) I used a focused attention version of the global/local task again but included distractors that did not represent a viable alternative to the targets (Hebrew letter/numbers). Once again, PF peculiar salience effect was eliminated and both the salience and the level effects were comparable to controls.

As in both Experiments 5.2 and 5.3 the saliency effect was comparable across the patients and controls (the saliency effect which was different in Experiment 5.1) it seems plausible to conclude that the critical aspect was the identity of the distracting information. In Experiment 5.1 this represented a viable alternative to the targets (as the same letters appeared in the target and distractor level). In Experiments 5.2 and 5.3 the distractor level always included letters (or symbols/numbers) that could not be mapped onto a response. Thus, it seems salience-based selection and suppression in the parietal cortex is called upon only when the distracting information could be mapped onto a response.

While similar effects of salience were observed in Experiments 5.1 and 5.2, it is not clear that similar salience-based selection and suppression processes occurred in both experiments. It has been argued that the left parietal cortex is particularly important in the focused attention version of the task for preparing to suppress salient distractors before they are presented (Mevorach et al., 2008) through a parietal occipital circuit that attenuates early visual cortex response to salient information (Mevorach et al., 2010). However, in the divided attention version of the task (Experiment 5.2) such a preparatory mechanism cannot be utilised as the participant does not know in advance which level (or relative salience) will include the target or the distractor. Thus, one can speculate that in a divided attention task, initial selection can follow the bottom-up cue (and therefore focus on the salient aspect of the display). However, when the salient information is not the target, a reactive disengagement and reorienting process should be called upon. Such a distinction between preparatory and reactive control processes has been previously proposed by Braver (2012; The Dual Mechanism of Control - DMC). While the DMC framework makes little distinction between critical brain regions and focuses mostly on the temporal dynamics of these two modes of control, it could still be the case that the parietal cortex serves different roles. In particular, the parietal lateralisation in selection and suppression of salient information proposed by Mevorach et al., (2006b) seems particularly relevant for the proactive control aspect of DMC and less so for the reactive mode of control. It, therefore, follows that the elimination of the atypical salience effects in PF in the divided attention task might be attributed to utilization of a reactive mode of control in this task which does not critically rely on the parietal cortex (or at least not to the same degree as preparatory proactive control).

Nevertheless, the elimination of the atypical salience effect also occurred in Experiment 5.3 with a focused attention task. This may suggest that the salience-based selection mechanism the parietal cortex is critical for is not only preparatory in nature but also sensitive to the information presented on the distractor level. Thus, the parietal cortex is called upon only when there could be confusion between target and distractor information (i.e., when the distractor information could serve as an alternative to the target). However, these two aspects of the parietal cortex might not represent different aspects of the selection process. Rather it could be the case that proactive suppression is particularly important when confusion between target and distractors may occur. However, when confusion is not possible (when the distractors do not represent a viable alternative), reactive control may be successfully engaged to direct attention towards the target.

Whichever is the case, it is clear that once distractors cannot compete with the target for the response, PF (a bilateral parietal patient) exhibited similar performance pattern to healthy controls suggesting the parietal cortex is critical in salience-based selection particularly when distractors represent a viable alternative for targets.

Patient PF has a small white matter lesion from the parietal areas projecting to the frontal cortex which may imply that her deficit may influence a wider control network. The frontal cortex has been particularly important in proactive control (Braver, 2012 for more discussion about specific functions of the frontal cortex, see Chapter 6). It should be acknowledged that PF’s deficit in proactive control may be due to white matter disconnection in the frontoparietal network as opposed to the bilateral grey matter lesions in the parietal cortex. As mentioned in Chapter 1, the frontoparietal network is particularly pertinent for the control of attention (Ptak, 2012) and in saliency control both the parietal cortex (LIP in the monkey, Kusunoki et al., 2000; Arcizet et al., 2011) and the PFC as part of the dorsal attentional circuit (Vossel et al., 2014).

The PFC and PPC have been argued to represent similar information in attention however at different stages or particular biases (Katsuki & Constantinidis, 2012b). To further this point, in an electrophysiological study on monkeys, it has been found that PFC and PPC represent information at different time points (Buschman & Miller, 2007). One such example is provided by Buschman and Miller (2007) in which they performed a spatial visual search task which was adapted from a delayed matched to sample task on monkeys. In which a target coloured slanted bar was cued sample and then the monkey had to find the sample target in an array of four tilted coloured bars by making a saccade to the target. There were two conditions: a pop-out singleton search in which the singleton was in one feature (colour or singleton) which required bottom-up attentional control; a conjunction search (in which target was a combination of orientation and colour features) which the authors argued required top-down control of attention. Electrodes recorded the LIP, the Frontal Eye Fields (FEF) and the lateral PFC simultaneously while the monkey performed the search task. The coherence in the neural firing rate between the LIP and frontal cortex appeared both in pop-out singleton search as well as conjunction search. Furthermore during conjunction search, frontal neurons fired before the parietal cortex. However, the reverse was seen during the pop-out search. Whilst there was synchronous firing during both bottom-up and top-down search whilst highlights the network and regulation between the two areas, the study also highlights that depends on task demands and whether the control is proactive (top-down) or reactive (bottom-up) can have different time-phased signatures in different parts of the fronto-parietal network.

In relating this back to the case of PF, it may be the case that the right frontal cortex establishes the top-down proactive goal which determines which level should be selected and the appropriate behaviour targets that should be required for search which necesitates the selection of salient information in the parietal cortex later on, but, due the damaged white matter connections to the parietal cortex, this modulation of salience-based selection of relevant items despite the overall goal being complete. Since the connection was severed in mainly the right hemisphere and it has been known in a variant of this task cortex which was involved in the selection of salient targets (Mevorach et al., 2006b; 2008), the proactive selection of relevant salient items could not be done. Likewise the up-flow which evaluates the relevance of the extraneous physically salient feature could not be done due to the severed white matter connectivity. Thus, PF may be able to complete the task using largely the left fronto-parietal network which acted as reactive control took over selection in order to complete the search task as defined frontal goals as the distractors were not a viable alternative to the targets, so, frontal comparator mechanism would not be needed. This speculation should be better tested using control patients with impaired left fronto-parietal connectivity damage.

One aspect of the global/local tasks that were utilised thus far in this thesis is that attention selection is non-spatial. The following chapter (Chapter 6) will continue to investigate the salience-based selection impairment in PF by focusing on spatial aspects of selection. Thus, the following chapter will explore the notion of behavioural relevance in salience-based selection to see whether PF’s inability to select automatically target relevant salient information based on top-down cues extends to the spatial domain.

CHAPTER 6 AUTOMATIC SALIENCE CAPTURE BUT IMPAIRED UTILISATION OF TASK RELEVANT FEATURES IN BILATERAL PARIETAL PATIENT

Introduction

The previous chapter (Chapter 5) revealed that Patient PF showed atypical salience-based selection in a global-local task. The chapter speculated that PF had a problem in proactive control of attention while the reactive mode of control was still intact. Critically, however, her performance resembled that of normal controls once the distractors could not be mistaken for a target (i.e., did not serve as a viable response alternative).

So far in this thesis, I have investigated parietal contribution to selection and suppression of salient features in a non-spatial manner. The global-local task I have used is considered a non-spatial task as spatial information on its own cannot solve the selection problem (e.g., when the global shape is spatially attended so are the local elements). Thus, in this final experimental chapter of the thesis, I will investigate the contribution of the lesioned parietal cortex of PF to salience selection/suppression in a context of a spatial attention task.

It has been recognised that the parietal cortex plays a role in the orientation of attention in space (Yantis et al., 2002). As mentioned in Chapter 1, a key study by Posner et al. (1984) found that patients with lateralised parietal lobe damage had problems in disengaging attention from an invalidly cued location. Indeed, it was argued in a previous chapter (JM from Chapter 4) that bilateral parietal damage may result in problems both in proactively suppressing salient information and reactively disengaging from salient information once it was selected. However, the problems highlighted in PF in the previous chapter seemed substantially different as atypical performance only emerged when distractors could be mistaken for targets.

It is important to know that in order to test whether PF's proactive control problem (in the context of competing distractors) is purely top-down and not merely a problem in allocating attention across all of space, perceptual (bottom-up) saliency should be controlled. The control of perceptual saliency will allow for the explanation of spatial attention to be tested.

This chapter will first assess whether the problem is spatial by using the working-memory guided visual search task by Soto and Humphreys (2007). As mentioned in Chapter 1, the saliency manipulated in this paradigm is top-down. That is, there is no clear perceptual distinctiveness in terms of features in the search task. As mentioned in Chapter 1, the working-memory guidance of attention was described as an automatic process (Soto, Heinke, Humphreys & Blanco, 2005). The brain region most closely associated with this process has been the prefrontal cortex (Soto, Heinke & Humphreys, 2006; Soto, Humphreys & Rotshtein, 2007; Soto, Hodsoll, Rotshtein & Humphreys, 2008). Since Patient PF has intact frontal lobes so it could be hypothesised that working-memory guidance would not be affected by the parietal damage. If working-memory did affect PF's guidance in search differently to healthy neurotypical controls, then it reinforces the notion that PF's deficit is a broader problem of manipulating and selecting salient information. That is to say, the working-memory based cue makes the reappearing feature behaviourally salient to the task (as opposed to perceptually salient like a singleton pop-out feature), thus demanding attentional priority. If PF showed typical working-memory guidance from valid cues in a spatial search task, then findings found in the previous findings would be limited the parietal cortex to compound objects and bottom-up saliency.

Experiment 6.1: Attentional guidance in Patient PF

Method

Control Participants

Five neurologically healthy participants (1 male, M_{Age} = 61.8 years, *SD* = 1.64 years; 1 left-handed) consented to participate in this study.

Design

The working-memory guided search paradigm used in this experiment was based on Soto and Humphreys (2007) and Soto, Humphreys and Heinke (2006) using the same methodological principles for design and implementation of the experiment. The design was a mixed design with a between-subjects factor of group: PF and controls, and two within-subjects factors: prime cue type (verbal cue and visual cue) and cue validity (valid, invalid, and neutral).

Cue type within subjects factor comprised of two levels: the cue was a coloured shape (in which the colour was the attended feature), or the prime was a white word written in font size 24 Cambria font of the colour itself (e.g. red written in white letters). This condition was done to control for mere perceptual repetition of the colour feature and that the participants had to hold the semantic representation of the colour in working-memory. Past studies have shown that this was an effective control for mere perceptual priming repetition and have as strong an attentional guidance effect as visual feature cues (Soto & Humphreys, 2007).

Cue validity was divided into three levels: invalid cue, neutral no cue reappearance and valid target cue conditions. The invalid condition was in which the cue memory-item colour (which acts as a top-down salient cue) reappeared in the search display but with a tilted distractor (non-target bar). This can also be termed as top down distractor salient condition. The neutral condition was which the cue item feature did not reappear in the search display and was replaced by another feature which was not remembered. Thus, there was neither top-down or bottom-up saliency in the search display. The valid condition was when the cue item reappeared in the search display combined with the search bar (white horizontal bar or vertical white bar) in its centre. This acts a top-down target salient feature.

Each block consisted of 48 trials each. There were six blocks in total. Altogether there were 288 trials overall making 48 trials per cell (validity*prime type). Colours for each prime and shape were randomly allocated however no two identical shapes or colours appeared simultaneously in the search task.

Stimuli

The cue shape and the search distractor shapes consisted of five possible geometric outline polygons: circle, triangle, square, hexagon and diamond all of the same dimensions 4.57° by 4.76°. Five possible colours used: red (RGB: 255, 0, 0), yellow (RGB: 255, 255, 0), blue (RGB: 0, 176, 240), green (RGB: 0, 255, 0) and pink (255, 102, 255). In the search task the shapes were positioned 45°from the centre around a clock face (making one object in each corner of the visual array) (7.56° of horizontal visual angle by 5.27° vertical visual angle). A bar in the middle of the shape was a white filled rectangular bar (1.59° height), three of which were rightward tilting lines (+45 degree). The fourth bar was used for the search discrimination task in which it was either horizontal or vertical bar.

Procedure

E-Prime 2.0 (Psychology Software Tools, 2002) was used to program the behavioural experiment and the record the accuracy of correct responses. Participants were sat at an LCD monitor of which was 36 x 30 cm (width x height) in size. They were sat 60cm away from and directly opposite the screen.

There was fixation asterisk for 500ms. The cue item was then presented for 1000ms. Participants were told to actively hold the colour of prime cue item in working-memory upon presentation (after vocalising the colour aloud) and hold it until a memory test after the search task (memory condition). Mask of random noise was shown for 250ms to remove sensory visual aftereffects of the cue presented. Afterwards, participants saw a fixation asterisk for 500ms and then the bar orientation search display was shown until response. Participants had to respond vocally as to the orientation of the target bar (horizontal or vertical) as quickly as possible. The experimenter pressed a button in synchrony with the participants' vocalisation. The m key was for horizontal bar and the k key for vertical bar.

A fixation asterisk was presented for 500ms and then a screen which was the memory test question which had either a shape of the same colour as the remembered prime cue at the start of the trial, or another colour which was randomly selected. Above the cue was a text stating “Same or Different?” The experimenter pressed a button (m for same and k for different) to indicate the response. Once this was done, a blank screen was shown for 250ms. Reaction time and accuracy were collected for the search discrimination and only accuracy for the memory test. Figure 6.1.1 displays what the displayed looked like to the patient and controls.

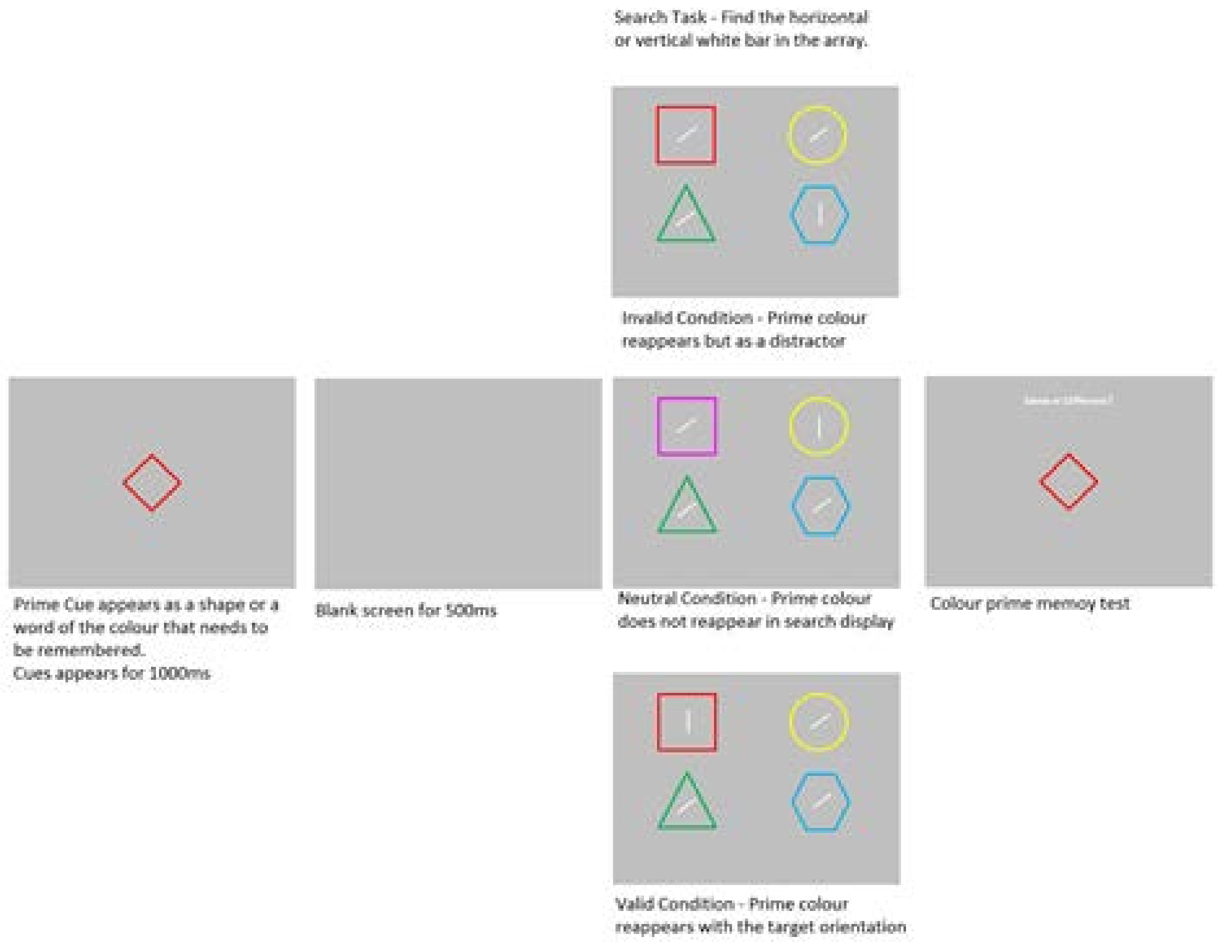

Figure 6.1.1: Schematic of a single trial procedure for Experiment 6.1.

Results

As per the same manner as done in the experiments in Chapter 5, the adjusted F calculator (Hulleman & Humphreys, 2007) was used to allow for statistical analysis between PF and healthy controls. Patient PF and controls were highly accurate in identifying the target in the search task without any errors. PF was, however, significant poorer in working-memory in terms of overall accuracy (*M* = .89) compared to controls (*M* = .99, *SD* = .002) (*adjF*(1,4) = 36.23, p<.001). However since overall accuracy is above 80%, the reaction times of the trials in which the memory item was correctly recalled were analysed.

The median reaction times of correct trials were taken for each participant in each condition. Figures 6.1.2 displays the median reaction times for PF and for the healthy control group.

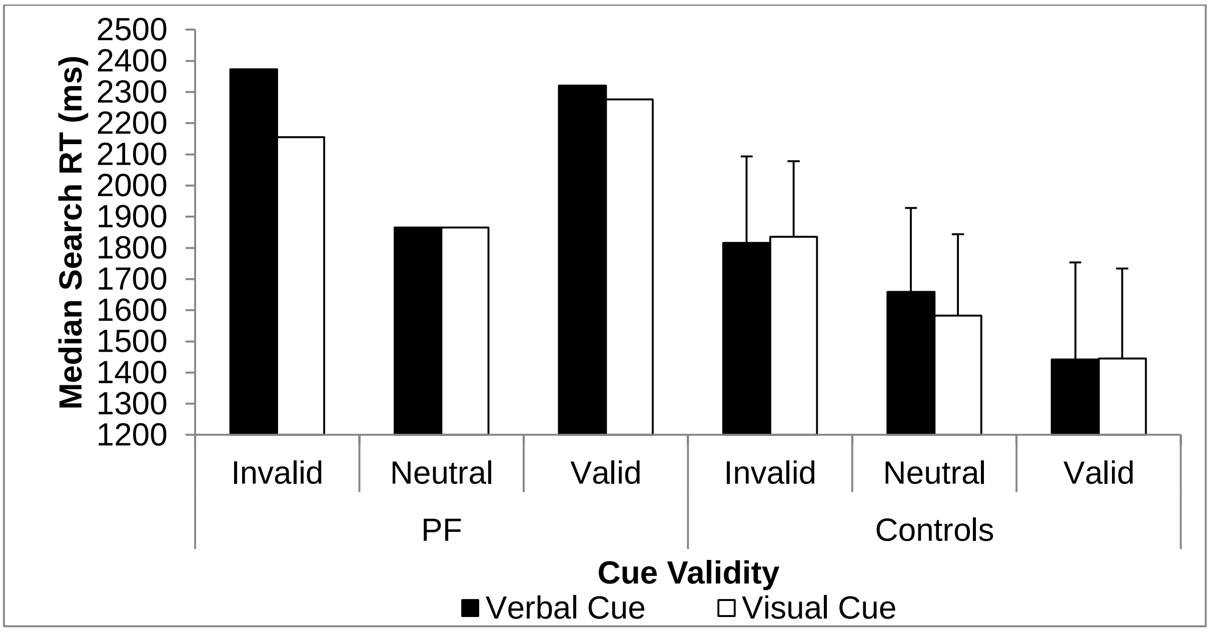

Figure 6.1.2: Median reaction times (measured in milliseconds) for correct search bar identification under different cue validities and whether memory cue verbally or visually presented between Patient PF and the healthy control group in Experiment 6.1. Error bars for the control group represent standard error of the mean.

Overall, there was no significant difference between PF and controls in reaction times in identifying targets across all conditions (PF *M* = 2142.58ms, Controls *M* = 1629.72ms, *SD* = 608.76ms) (*adjF*(1,4) = 0.59, p = ns). Based on this, no transformation of reaction times was run.

To assess the main effect of cue type (verbal vs. visual), the difference in reaction times between these two conditions was calculated for each participant (verbal – visual). There was no significant reaction time difference between PF and controls in detecting targets based on the type of cue (verbal or visual) (PF *M* = 87.5ms, Controls *M* = 17.77ms, *SD* = 67.82ms) (*adjF*(1,4) = .88, p = ns).

To assess the effect of saliency (assessed by cue validity), a cost-benefit approach was taken. The cost of invalid cues (salient memory distractors) was calculated by subtracting the baseline reaction time in the search task in the neutral condition from the reaction time in the search task in invalid condition (e.g. the higher the value, the longer the reaction time in the invalid condition was). The benefit of valid cues (salient memory cue coinciding with the target) was calculated by taking the reaction times in the search task in the valid condition away from reaction times in the baseline neutral condition (e.g. the lower the value the faster the reaction times were in the valid cue condition). Figure 6.1.3 displays the cost-benefit reaction times for PF and controls.

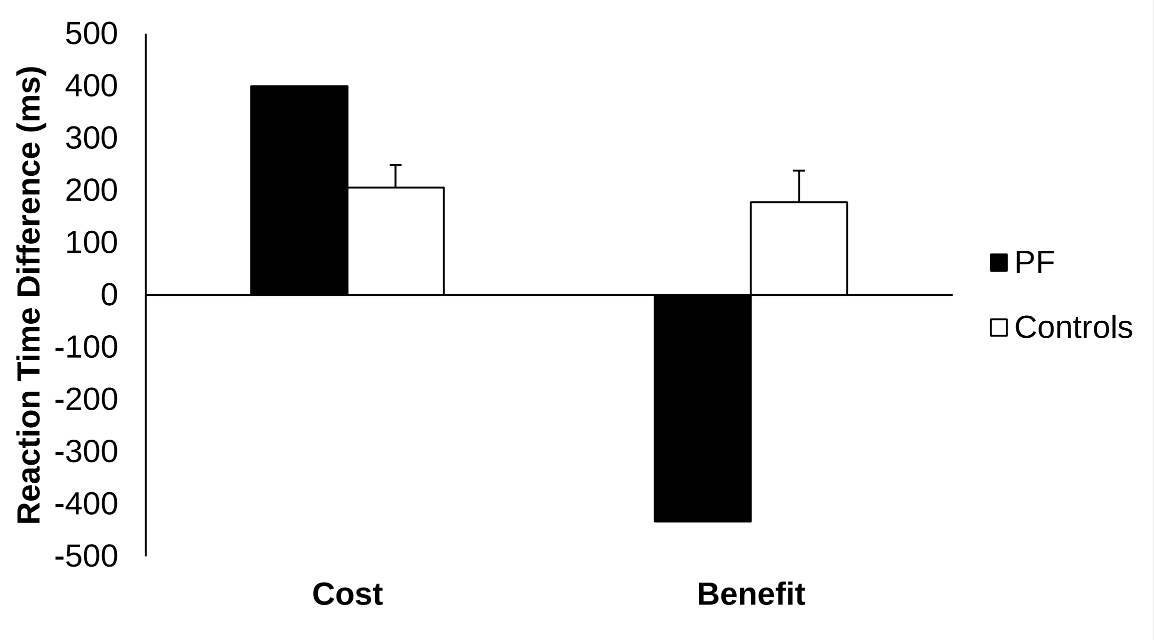

Figure 6.1.3: Cost and benefit in reaction time to target identification in spatial search in Experiment 6.1 between Patient PF and healthy controls (negative values represent reversed cost/benefit). Error bars for control group represent standard error of the mean.

There was a significant difference in invalidity cost between Patient PF and healthy controls (PF *M* = 399.25ms, Controls *M* = 205.35ms, *SD* = 97.83ms) (*adjF*(1,4) = 3.27, p = .012). PF did also show significantly less benefit from valid cues compared to controls (PF *M* = -433.5ms, Controls *M* = 177.1ms, *SD* = 135.8ms) (*adjF*(1,4) = 16.85, p < .001).

Discussion

PF did not show the typical benefit from valid (but irrelevant) cues during visual search. However, PF was still captured by information held by working-memory as her performance with the neutral condition was faster than both the invalid and valid conditions. This result shows that PF's deficit is unlikely to be explained by a problem of orienting to salient information in space but that PF was not benefiting from the additional information that the top-down memory drove saliency was providing when it was joined with the target.

In Chapter 5 I hypothesised that PF's problem may specifically involve conditions in which proactive suppression (or utilisation) of information is available. However, in the current task participants could not rely on proactive control as they do not have pre-knowledge of the salience of the target and the distractors before the search array appears. Thus, it is more likely that reactive suppression should be called upon once the memory item appears as a distractor. Indeed, PF showed evidence for the capture of the reappearing memory item (which seemed to exert an increased cost in her compared with the controls). However, the more striking effect is the cost (rather than benefit) a reappearing memory item exerted when it coincided with the target. This effect is reminiscent of PFs performance in the target salient condition of Experiment 5.1 where target salient displays were slower than distractor salient ones. Thus, rather than an impaired proactive suppression, the data here may suggest a confused reactive suppression mechanism where reactive suppression is triggered whenever a salient item is selected. Moreover, it suggests that the salience-based selection impairment shown in Chapter 5 is not specific to compound stimuli and can be evidenced in the spatial domain.

It should be appreciated that a cognate variant of working-memory guidance had already been run on PF. Soto, Mannan, Malhorta, Rzeskiewicz and Humphreys (2011) ran a simplified version of the working-memory guided search task on patient PF. The task was a simplified version in the sense that there was low perceptual information as it had only two items in the search and distractor items. The procedure of the paradigm was similiar to that of Experiment 6.1. PF had to remember a cue and had to make a target discrimination between the direction of two white bars surrounded by the memory cue shape and another unrelated shape which could be a target (invalid) or not (neutral) or valid (if the target was combined with cue reappearance). However in the particular case, the working-memory cue was positioned either in the ipsilesional location (which for the purposes of that study was determined as the right visual hemifield). The search shapes were positioned either side of a central fixation point (left or right visual hemifield). This study showed that incorporating valid working-memory cued items did show differences in performance (which was assessed by reaction times to make the first saccade to the target) and revealed more than the mere capture of distracting items which were the case in the aforementioned study. However, this was only the case if the validly cued shape appeared in her non-neglected hemifield. The authors concluded that working-memory contents in could guide spatial attention in the contralesional hemisphere.

This links to the Experiment 6.1 in two ways: the fact it was the same patient examined; and secondly it investigated automatic guidance of working-memory primes in visual search. Whilst it appeared to the be the case that the current experiment also revealed some effect of working-memory items on search, it did not show guidance as Soto et al.'s (2011) study found. It should be appreciated that the comparability of the study is difficult to assess due to methodological differences. Firstly, Experiment 6.1 did not investigate eye-movements so there may be a possibility that eye-movements may have shown a different process to the response time once the target is found. Secondly, in both this study and in Soto et al.'s (2011) study, the working-memory cue was placed in one position throughout. However, Experiment 6.1 placed the cue centrally (like Soto & Humphreys, 2007) and not peripherally. The third main difference is that in the Soto et al. (2011) there were only two possible search shapes positioned peripherally along the horizontal meridian, whereas in Experiment 6.1 there were four positioned in quadrants. This increase in set-size may have influenced the strength of the working-memory cue guidance to display different results. Since set-size was not compared in this study, these findings remain speculative.

Furthermore, tests from BCoS (Humphreys et al., 2012) have since shown that she may not experience neglect symptoms. Also, the question aimed at specific visual hemifields which could not explain the results shown in the non-spatial domain (Chapter 5). Therefore, it can be inferred that the parietal cortex does play a more general role in guiding attention from working-memory beyond the role of the prefrontal cortex (as would be suggested by Soto, Humphreys & Heinke, 2006).

The finding from this current experiment (Experiment 6.1) has not been the first instance showing atypical working-memory saliency guidance in visual search in those without prefrontal lesions. de Bourbon Teles et al. (2014) found in a neuropsychological study of a cognate variant of this task that it was not only the prefrontal cortex is responsible for working-memory guidance. Patients with damage to the ventral thalamus had reduced search bias by the contents of working-memory.

Whilst PF does not have damage in the thalamus. However, the de Bourbon Teles et al. (2014) study showed PFC projections to other brain regions affecting the automatic guidance of working-memory salient contents in attentional search. This could mean that a regulatory network between subcortical areas with the prefrontal cortex shows the interplay with different aspects of attentional guidance. It could be plausible that, despite not having thalamic damage, the parietal cortices have a role in direct this non-perceptual saliency based guidance of attention.

On a broader scope, Greene and Soto (2014) in their fMRI study using a similar working-memory guided visual search task as de Bourbon Teles et al. (2014) found connectivity relationship between the effect of priming and working-memory guidance in processing streams. They found that the ventral processing stream is associated with bottom up guidance of attention but it can also be influenced by top down information. This is also supported by additional evidence that strategic guidance in visual search has parietal underpinnings (Soto et al., 2012).

Individual differences in parietal structure could have some explanation as argued in an fMRI study using the working-memory guidance paradigm on a neurotypical sample by Soto, Rotshtein and Kanai (2014). The authors compared grey matter integrity with reaction times in relation to search under cue reappearance from working-memory guidance. For target relevant cases (valid cues), those with increased grey matter tissue integrity in the superior parietal lobe was related to increased correct responses to search targets. Additionally, the authors found that the inferior parietal cortex was associated with distractor salient invalid cues from working-memory biasing attention. Both validity conditions were lateralised to the left parietal cortex.

Whilst the above study demonstrated a potential of the parietal cortices in working-memory guidance of attention, the task was a mere two-choice task. The spatial extent and generalisation would be limited as there was only one alternative stimulus to choose from in the search task. It is hard to say directly due to the nature and breadth of PF's lesions which area of the PF cortex is being damaged. However, it could be supposed based on the results of the previous chapter and the performance in the lack of target relevant validity effect here, that there is supporting corroborating neuropsychological evidence for parietal involvement in attentional guidance by working-memory.

Also, the memory cue can be argued to be behaviourally relevant as the recall of memory information is needed for the recognition memory task. Whilst in the search task, the memory cue is behaviourally irrelevant, the top-down information of the memory item still directed PF's attention to the memory cue which is surrounding the target search bar. It could be speculated that since there were two behaviourally relevant pieces of information on the trial level, PF was not able to disentangle the purpose of the memory cue in the search task.

Until this point, the problem has focussed on top-down saliency from working-memory. Since this has been tested and PF's deficit is similar to that of bottom-up saliency, it can be assumed that her deficit is more generalizable across different types of saliency. Since the task previously was a dual task, it may be hard to disentangle whether her atypical performance is due to managing multiple pieces of top-down information at the same time. Therefore, a simpler search task should be run to reveal whether PF's saliency problem in the spatial domain is attributed to increasing working-memory demand since she did have significantly poorer performance compared to controls. To that effect, the following experiment will test spatial attention in bottom-up saliency using a non-memory based paradigm: the irrelevant singleton task.

Experiment 6.2: Irrelevant distractor task

As mentioned in Chapter 1, a paradigm which combined two different singletons to investigate the effects of bottom-up and top-down saliency effects is the irrelevant singleton task (Theeuwes, 1992). The irrelevant singleton task requires the participant to identify a target feature (e.g. line orientation) in a search display which is accompanied by a surrounding shape (similar to that in Soto et al., 2005). The surrounding shape (like that in the working-memory guidance task) is not an essential part of the search goal. However, it can be salient by a change in shape or in colour, either as a pop-out singleton distractor (equivalent to invalid cue condition) or as part of the target pop-out (equivalent to the valid cue condition). Participants tend to be slower in the condition which the irrelevant distractor is salient and fastest when the target surrounding shape is a salient pop-out (for an example see Theeuwes & Van der Burg, 2007). The bottom-up factors “pop out” and capture attention despite its task irrelevance.

There have been neuroimaging studies that have attempted to localise these capture effects in the irrelevant distractor paradigm. One study has suggested that the bilateral parietal cortex is involved in the low-level capture of attention from distractors in a visual search task (de Fockert, Rees, Frith & Lavie, 2004). This also occurs when the irrelevant singleton is perceptually salient (de Fockert, Rees, Frith & Lavie, 2004). Also Lavie and de Fockert (2006) found from fMRI singleton search task (similar to that of Theeuwes and Van de Burg, 2007) that the frontal lobes controlled irrelevant singleton capture interference in additional to the bilateral superior parietal lobule.

Since these studies implicate both the parietal cortices and the frontal lobes (similar to the previous findings), it would be an ideal candidate to control for any confounds of memory in saliency capture. The following experiments will be based on an adaptation of the paradigm used by Theeuwes and Van der Burg (2007). Using this paradigm adaptation (to make it simpler by removing any additional discrimination whilst maintaining the underlying essence of the task), it can help test predictions as to the spatial generalisability of the salience response relevance notion.

Perceptual saliency will be manipulated by the additional singleton in the search. Theeuwes (1994) argued that the competition of another perceptually salient bottom-up feature will override any top-down information. Since in the previous experiment, top-down information had to be constantly updated on a trial-by-trial basis. However, a possible critique may occur that PF’s deficit was a problem of maintenance and updating of multiple top-down information on a continuous basis.

In order to allow for PF to utilise proactive control, a blocked version of the irrelevant singleton will be used with explicit instructions at the start of each block stating the saliency of each block. This would allow for proactive control because she would have pre-knowledge of what saliency to utilise (if the target is salient) or suppress/ignore (if the distractor is salient). If she has intact proactive control, then she should be able to utilise bottom-up salient information based on such task level knowledge.

If PF has a problem in memory-guided top-down attention only (Experiment 6.1) then in a similar spatial visual search task with no working-memory component (a singleton search task) should show typical effects of invalidity (distractor salient pop out singleton) cost and benefit (from target salient valid pop out singleton) compared to a neutral baseline. If, like in the previous chapter, her capture of saliency is more generalised, then her performance should be equivalent to the findings to Experiment 6.1 and exhibit a problem in utilising target relevant information.

Method

Control participants

The same controls who participated in Experiment 6.1 also participated in Experiment 6.2.

Design

There were nine shapes in a ring of which eight were distractors (circles), and one was the target shape (either a triangle or a square). The experiment was a repeated measured design blocked by saliency: distractor singleton salient (which was an odd colour circle), valid, the salient target was the singleton colour, and neutral, all shapes including the target were the same colour (no singleton). Each block was 52 trials long, and each block was run three times leading to a total of 156 trials per saliency condition for irrelevant distractor task.

Stimuli

All shapes were of the same size 2.85° by 2.85° which was positioned on an imaginary circle centred on the centre of the screen with a radius of 4.75°. A central fixation cross (of size and colour) appeared at the centre of the screen. There was a 1.90° distance between each object. The shapes were either green (RGB: 0, 255, 0) or red (RGB: 255, 0, 0), with a 50% likelihood of being either colour.

Procedure

Discrimination task was run on E-Prime 2 on an LCD computer. A fixation cross was presented for 1500ms. Afterwards, the discrimination search task was run. The discrimination task involved the patient having to find a target in a ring of nine polygons. There were nine polygons, eight of which were outlines of circles which acted as the distracters, and one target shape (either a square or a triangle). Upon display onset, the patient had to decide whether the target was a square or a triangle. Each location could have an equal likelihood of being the target location. The singleton was always the opposite colour. This search display was shown for 1000ms. If the participant did not respond within the period that the search display was present, the search display would disappear with a screen which had each previously item location replaced with random noise to remove afterimage effects. Participants could still make their response within this noise ring and reaction times were recorded taking this into account. The experimenter pressed a button to indicate the appropriate response (m key for square and k key for triangle). Reaction time and accuracy for each trial was recorded. Figure 6.2.1 displays examples of a typical trial within each of the three conditions.

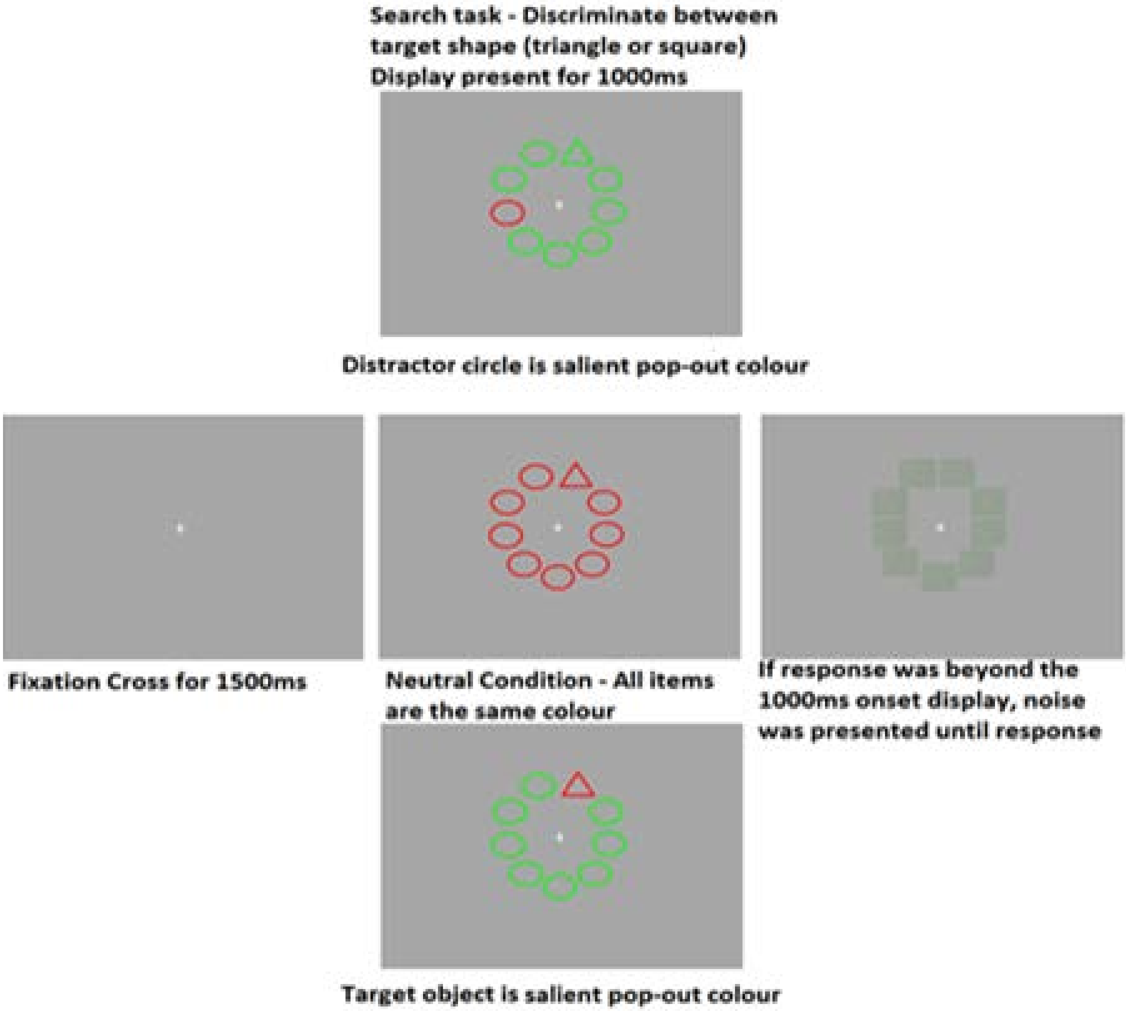

Figure 6.2.1: Schematic of exemplar trial event sequence in the irrelevant distractor task (Experiment 6.2) under the three different saliency conditions.

Results

Both Patient PF and the control group were at ceiling (100%) in correctly identifying the search targets. Only mean reaction measures were analysed (displayed in Figure 6.2.2).

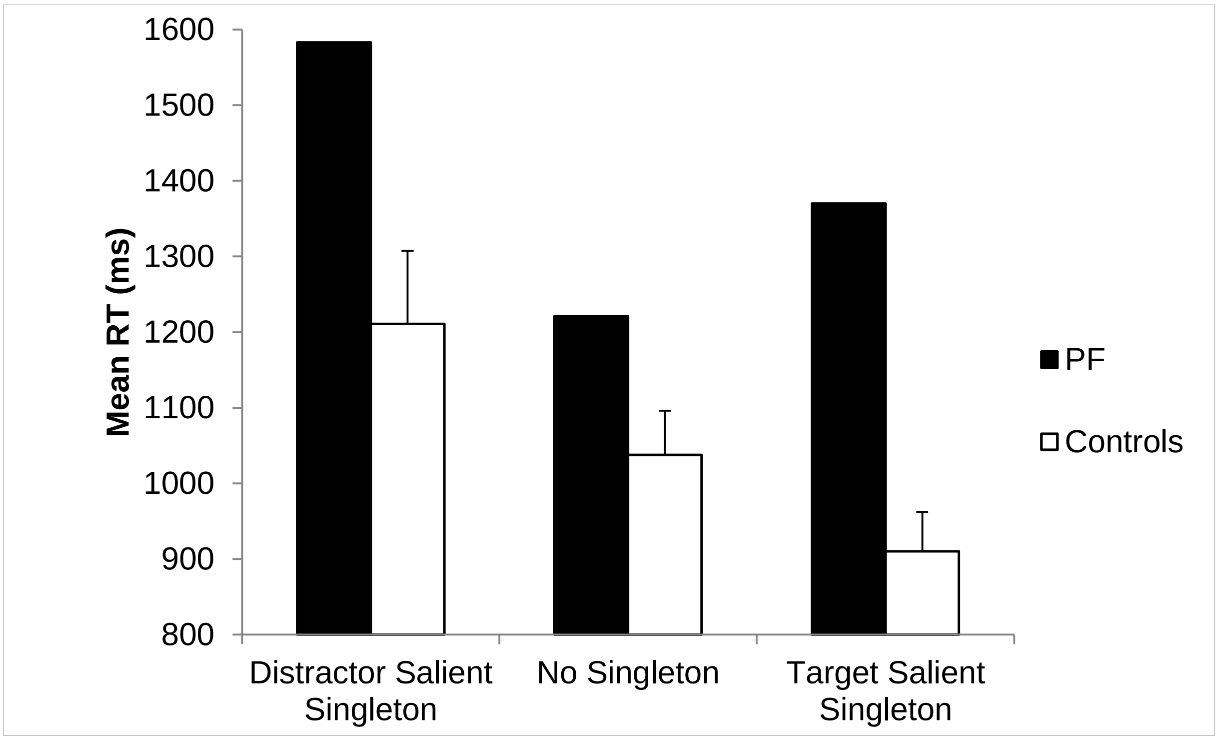

Figure 6.2.2: Mean reaction times for correctly identified targets in the irrelevant distractor task under different saliency conditions between Patient PF and controls. Error bars for control group represent standard error of the mean.

PF was significantly slower at responding to targets (PF *M* = 1391.33ms), compared to controls overall (*M* = 1052.81ms, *SD* = 151.42) (*adjF*(1,4) = 4.17, p = .007). Due to this effect, mean reaction times for each condition for each participant were converted to Z scores in a similar manner to that explained in Chapter 5. After the Z-transformation, saliency distractor cost and salient target benefit were calculated as shown in Figure 6.2.3. The calculation of cost and benefit was performed in the same way as described in Experiment 6.1.

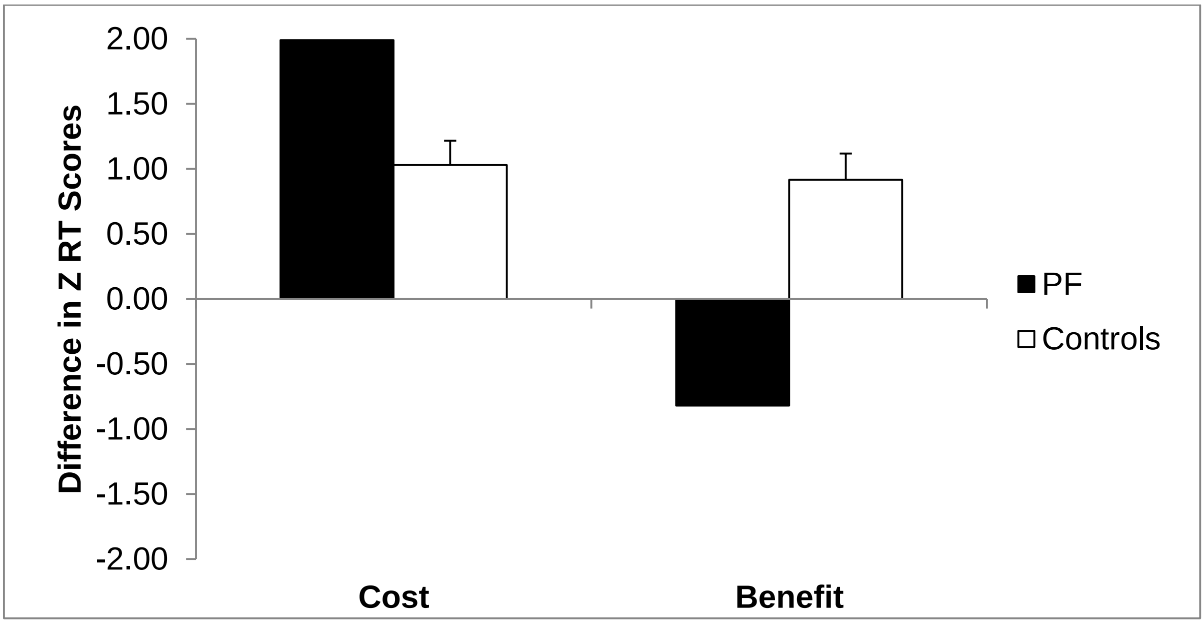

Figure 6.2.3: Cost and benefit in reaction time to target identification in spatial search in Experiment 6.2 between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

Patient PF showed a significantly bigger distractor (invalid) salient pop-out cost than healthy controls (PF *M* = 1.99, Controls mean = 1.03, *SD* = .42) (*adjF*(1,4) = 4.27, p = .01). In addition, PF showed cost for valid target salient pop-out while the controls showed the expected benefit (PF *M* = -.82, Controls *M* = .92, *SD* = .45) (*adjF*(1,4) = 12.62, p < .001).

Discussion

Similar to Experiment 6.1, PF did not show typical benefit from salient cues compared to healthy controls. There were significantly different cost in additional to benefit compared to controls. Whilst salient distractor cost was significantly larger, suggesting potentially more distraction from the invalid distractor salient singleton, it was still the slowest in the overall trends, like the controls. Likewise, the salient target singleton benefit was reversed in PF compared to controls. This phenomenon was similar to the previous experiment. This would mean that the problem of salient capture in visual spatial search was not restricted to top-down saliency.

The problem seen in this chapter based on the two experiments used thus far (i.e. Experiment 6.1 and 6.2) could be used to the perceived relevance of the salient item in spatial search. What could be happening is that PF is considering any salient item an irrelevant distractor which interrupts efficient search. Since the salient feature is not part of the response category (an orthogonal feature which is coincidentally bound to the target feature), it captures attention without any utilisation. By making the salient feature the response feature from an instructional goal level, it would be expected that PF could convert the salient item into a response category and utilise it appropriately.

Experiment 6.3: Salient square task

Method

Control Participants

Three neurologically healthy females (M_{Age} = 66 years, *SD* = 2 years) (1 left handed) consented to participate in the study.

Design

There were six shapes in a ring of which five were distractor circles, and one was the target square. There were four conditions which were divided into separate blocks. These four conditions were: the invalid singleton distractor salient condition (in which one circle was a pop-out, the opposite colour to the target and the remaining circles); neutral no salience conditions (in which half the items were coloured green and the remaining half coloured yellow); equal salience conditions (in which all items were the same colour) and the valid singleton target salient condition (in which the target was a pop-out colour different from the distractor circles. There were 108 trials per saliency per task.

Stimuli

The colours were either yellow or green with an even likelihood of the correct answer being either shape. The shapes were positioned 4.75° around a clock face. The size was the same for each object 2.38° by 2.85°. The inter-elemental distance was 1.90°.

Procedure

In this task PF was required to report the colour of the square singleton in a ring of five circle distractors (either yellow or green). The trial composition was exactly the same in this experiment as in Experiment 6.2. Figure 6.3.1 displays an example of each of the search saliency conditions. A catch trial of a triangle was included in 10% of the trials (excluded from analyses), in which PF had to withhold from making a response. To ensure that PF was actively looking for the square and response to its features as opposed to randomly guessing. The experimenter pressed the button synchronously with the vocalised response (m for green and k for yellow). Reaction times and accuracy were measured.

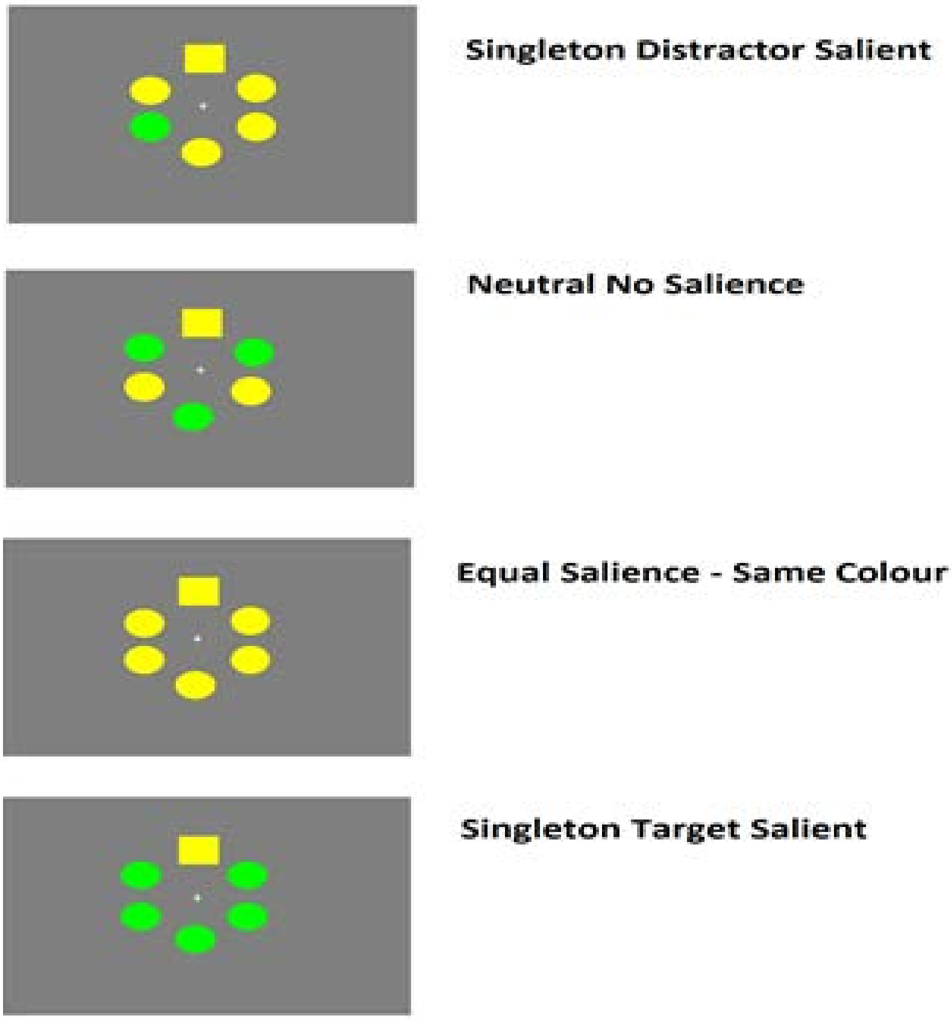

Figure 6.3.1: Exemplars of different trial displays in the four different saliency conditions in the adapted singleton search task – the salient square task (Experiment 6.3).

Results

Patient PF and controls were able to correctly identify all appropriate targets in the search task. Both groups also were able to withhold their responses in all catch trials. Only reaction times were analysed (see means in Figure 6.3.2).

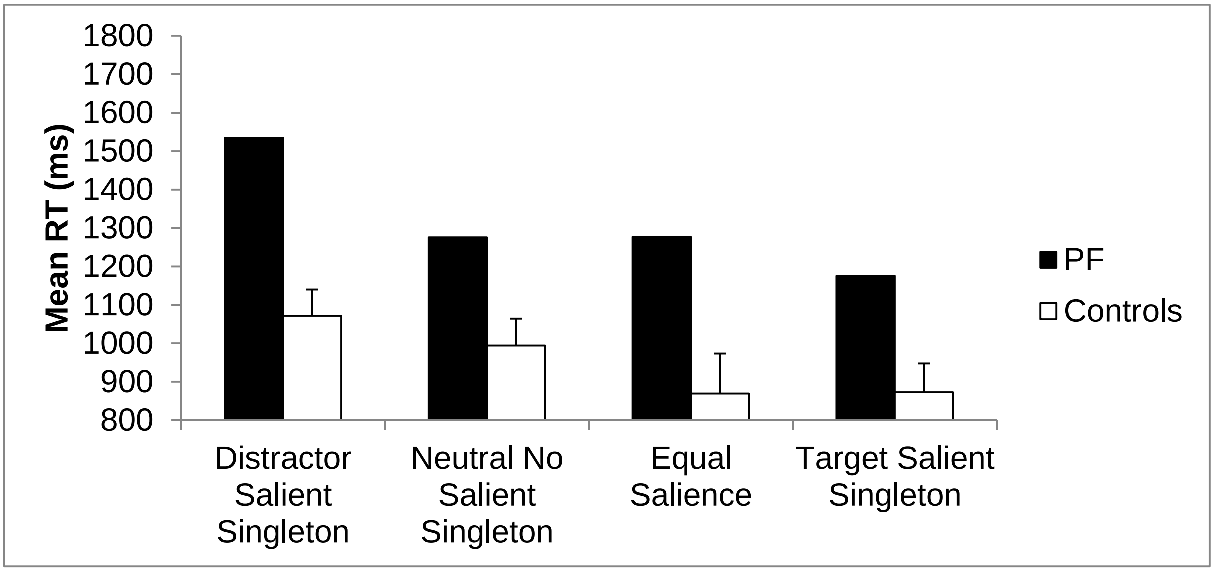

Figure 6.3.2: Mean reaction times (measured in milliseconds) for target identification under different saliency conditions between Patient PF and healthy controls in Experiment 6.3. Error bars for control group represent standard error of the mean.

PF was significantly slower at detecting targets (*M* = 1316ms) compared to controls (*M* = 952.18ms, *SD* = 112.02ms) (*adjF*(1,2) = 6.67, p = .037). Thus, all mean condition reaction times were converted into Z scores in the same manner as described earlier in Experiments 6.1 and 6.2.

In this particular circumstance, as there were two neutral conditions, there were minor alterations to the cost-benefit calculation to accommodate this. The cost was calculated as the distractor salient (invalid) condition subtracted by the mean average reaction times of the two neutral conditions (equal salience and no salience). Likewise for the salient target benefit condition, the same pooled neutral conditions were used to have the target salient (valid) condition taken away from. Please note this exact same calculation was used for subsequent follow-up experiments (Experiments 6.4 and 6.5).

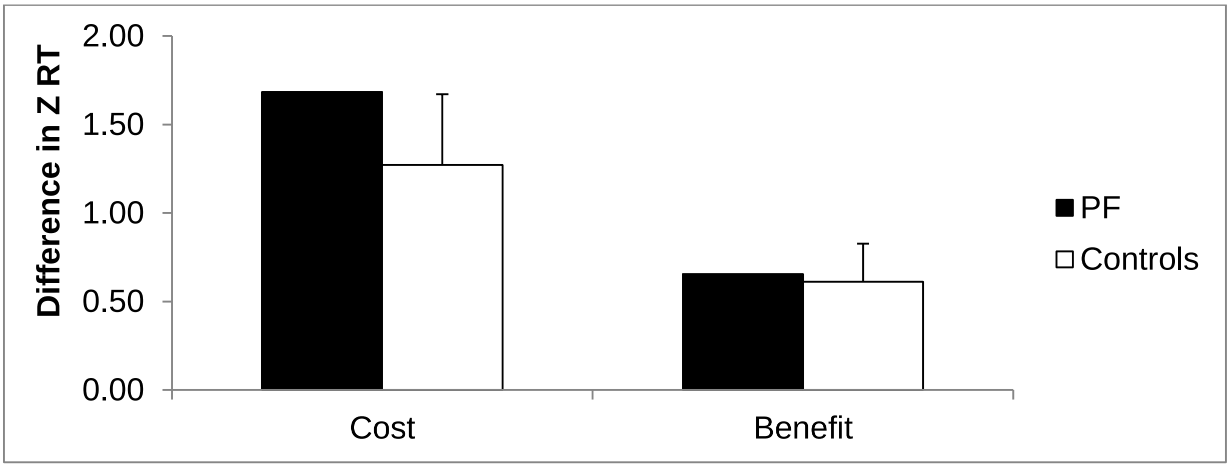

Figure 6.3.3: Cost and benefit in reaction time to target identification in spatial search in Experiment 6.3 between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

There was no significant different in distractor salience cost between Patient PF and controls (PF *M* = 1.68, Controls *M* = 1.27, *SD* = .69) (*adjF*(1,2) = .26, p = .42). Nor were there any significant difference in the target salient benefit between PF and controls (PF *M* = .65, Controls *M* = .61, *SD* = .37) (*adjF*(1,2) = .01, p = .87).

Discussion

Patient PF was able to show typical effects of saliency to pop out targets as would be expected in similar paradigms (e.g. de Fockert et al., 2004; Lavie & de Fockert, 2006). Making the colour which was the salient aspect in addition to the response feature, made PF able to attend to it and utilise it appropriately to solve the visual search task.

Whilst the saliency effect was apparent in PF during this experiment, the aspect which could not be certain was if the colour was a dominant factor in this process. The previous experiment also used colour as a salient feature. So it could be argued that PF is explicitly told to use the colour feature making it more important for the attentional set. However colour in Experiment 6.1, the colour memory cue was a top-down and not bottom-up salient feature. This commonality of colour as a salient feature would only limit explanation to a failure to notice or utilise colour and not relevant response feature which is salient per se. Thus, a subsequent experiment was run to control the effects of colour by manipulating another perceptual feature (filling).

Experiment 6.4 Salient filling

Method

Control Participants

Five female neurologically participants (M_{Age} = 64.6 years; *SD* = 2.41 years) (2 left handed) participated in this experiment.

Design

The design was identical to that of Experiment 6.3.

Stimuli

Six shapes in a ring were used in the display of which five of these were circles, and one was either the target square or a triangle (in catch trials only). As in Experiment 6.3, three geometric polygons were used: square (functioned as the target singleton), circle (distractor), and triangle (catch trial distractor). All shapes were coloured yellow. The shapes were positioned 4.75° around a clock face. The size was equal for each object 2.38° by 2.85°. The inter-elemental distance was 1.90°. The filled shapes were entirely coloured in yellow, and the outline just showed the background grey colour centre.

Procedure

The procedure in this task was the same as Experiment 6.3 in the number of trials and trial length. A triangle was instead of a square in order to act as a catch trial at 10% of trials for which participants had to withhold responses. The trial duration, sequence, number of trials and blocks were the same as Experiment 6.3. The difference in procedure was that, in this task, participants were instructed to report whether the square was a solid filled colour, or an outline (see Figure 6.4.1 for example of the different saliency conditions). The experimenter pressed the button synchronously with the vocalised response (m for filled and k for outline). Reaction times and accuracy were measured.

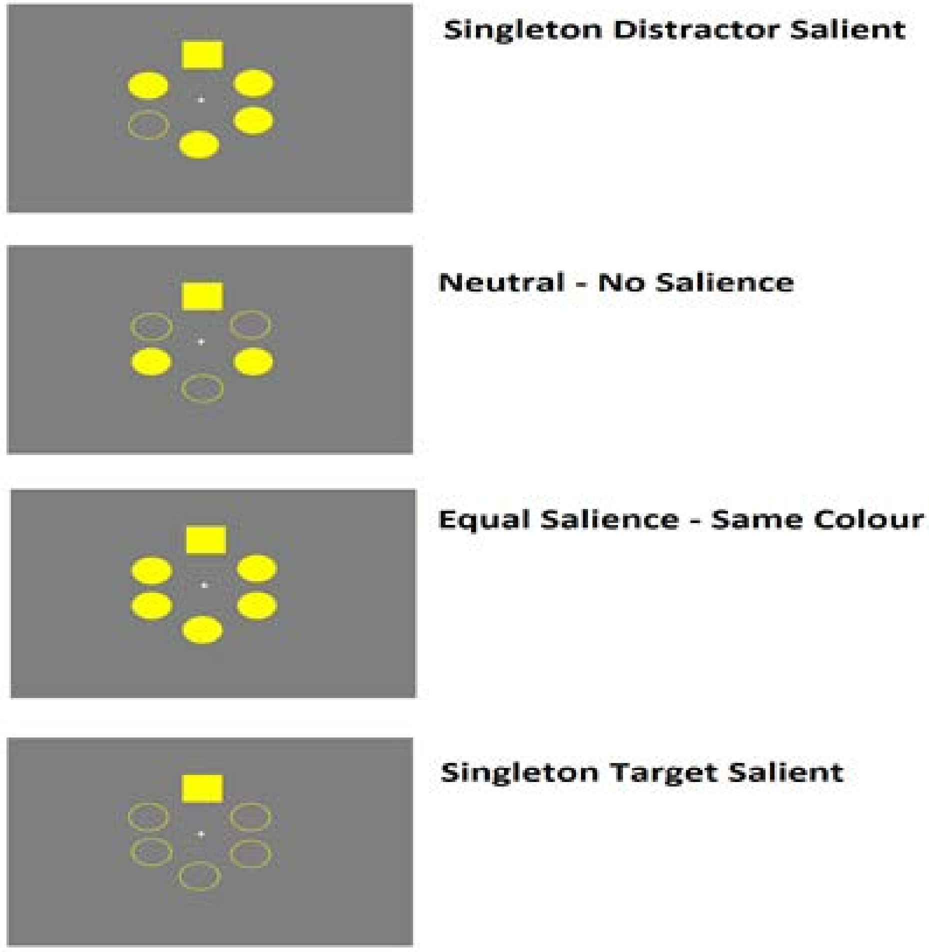

Figure 6.4.1: Exemplars of different trial displays in the four different saliency conditions in the adapted singleton search task – the filled-outline discrimination task (Experiment 6.4).

Results

Patient PF and controls were able to identify all targets and without responses to all catch trials. Only reaction times were subsequently analysed (see Figure 6.4.2 for means).

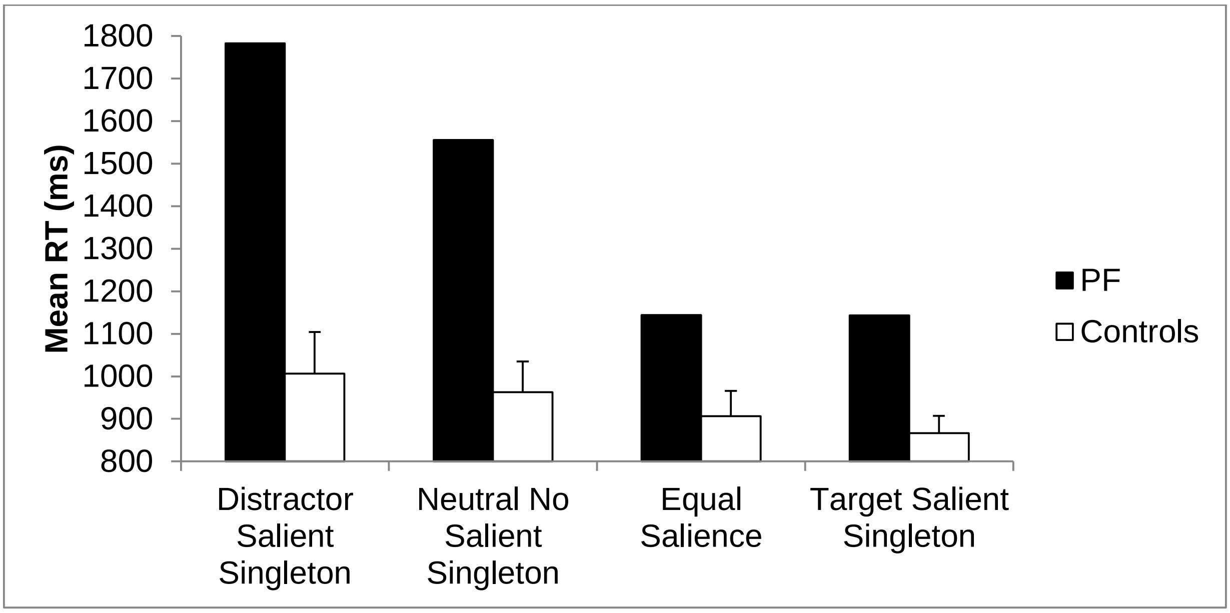

Figure 6.4.2: Mean reaction times for target identification under different saliency conditions between Patient PF and healthy controls in Experiment 6.4. Error bars for control group represent standard error of the mean.

Like before, PF was significantly slower at detecting targets (*M* = 1406.5ms) compared to controls (*M* = 723.62ms, *SD* = 70.33ms) (*adjF*(1,4) = 78.57, p < .001). These condition RTs were transformed to Z scores (due to general slower reaction times of PF compared to controls) and cost and benefit was calculated.

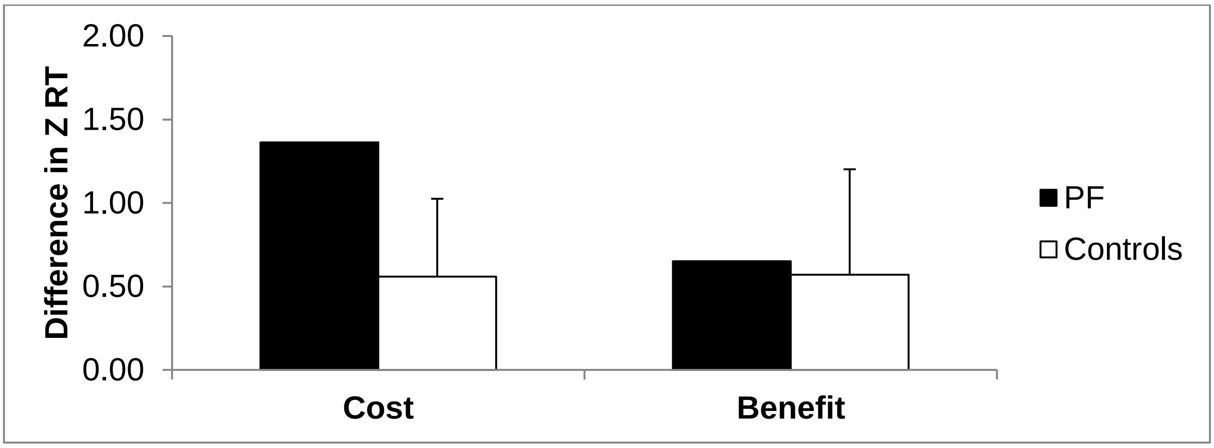

Figure 6.4.3: Cost and benefit in reaction times to target identification in spatial search in Experiment 6.4 between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

There was no significant salient distractor cost difference between PF and controls (PF *M* = 1.36, Controls *M* = .56, *SD* = .93) (*adjF*(1,4) = 0.49, p = ns), nor was there a significant difference in benefit between the two groups (PF *M* = 0.65, Controls *M* = .57, *SD* = 1.23) *(adjF*(1,4) = 0.00, p = ns).

Discussion

In this experiment, it was found that PF did not significantly differ in neither cost nor benefit to saliency capture compared to healthy controls. This result was similar to the previous experiment (6.3). This experiment showed that PF could utilise relevant, salient information beyond simply colour salience. This would mean that the problem seen in the first two experiments of this chapter cannot be explained purely by colour salience but of response set relevance more generally.

The previous experiments (Experiments 6.2; 6.3 and 6.4) all shared the common instruction of searching for a shape. Whilst the shape was a singleton, it was not a salient feature. Whilst the effect of colour was controlled in Experiment 6.4, the utilisation of colour was done at the response selection stage and not the singleton finding stage. Thus, a further control experiment was run to avoid this strong, salient feature. The next experiment (Experiment 6.5) attempted to help test the generality of the saliency relevance notion by controlling for colour at the initial search stage and not at the response selection stage.

Experiment 6.5: Salient yellow task

Method

Participants

Five neurologically healthy females (M_{Age} = 63.6 years, *SD* = 1.52 years) (1 left handed) consented to participate in this experiment.

Design and Stimuli

The design and stimuli were identical to that used in Experiment 6.3.

Procedure

In this task, PF and controls were asked to report the shape which was yellow (either square or circle). The trial and condition format, length and procedure were exactly the same as the Experiment 6.3 paradigm, but with a change of instruction to avoid confound of shape. The experimenter pressed the button synchronously with the vocalised response (m for square and k for circle). Reaction times and accuracy were measured.

Results

Patient PF and the control group were 100% accurate in discriminating the correct targets and withheld responses to catch trials. Only reaction times were subsequently analysed (see Figure 6.5.1 for means).

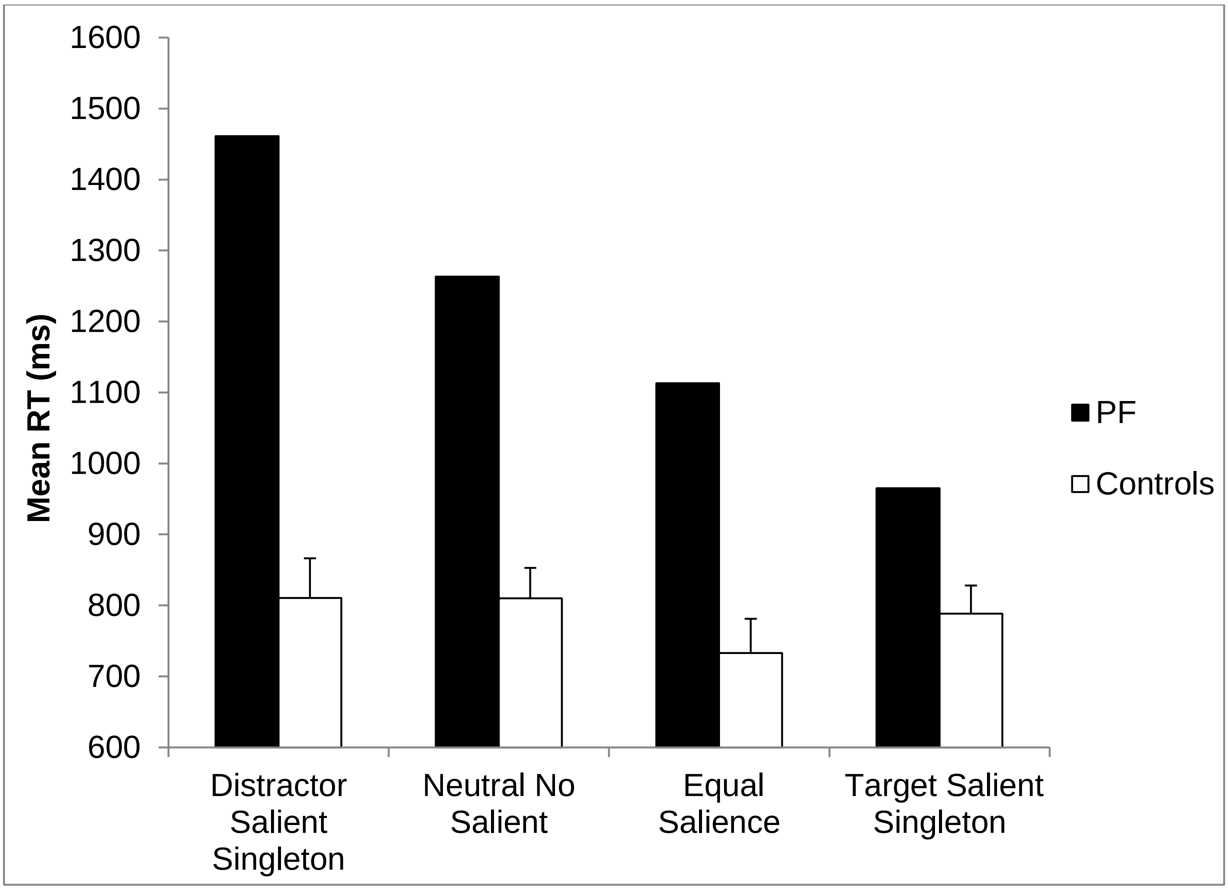

Figure 6.5.1: Mean reaction times for target identification under different saliency conditions between Patient PF and healthy controls in Experiment 6.5. Error bars for control group represent standard error of the mean.

PF was significantly slower at detecting targets across all conditions compared to controls (PF *M* = 1200.5ms, Control *M* = 785.35ms, *SD* = 100.21ms) (*adjF*(1,4) =

14.3, p <.001). Due to this finding, the mean reaction times of these conditions were again transformed into Z scores for subsequent cost and benefit analysis to be made (see Figure 6.5.2).

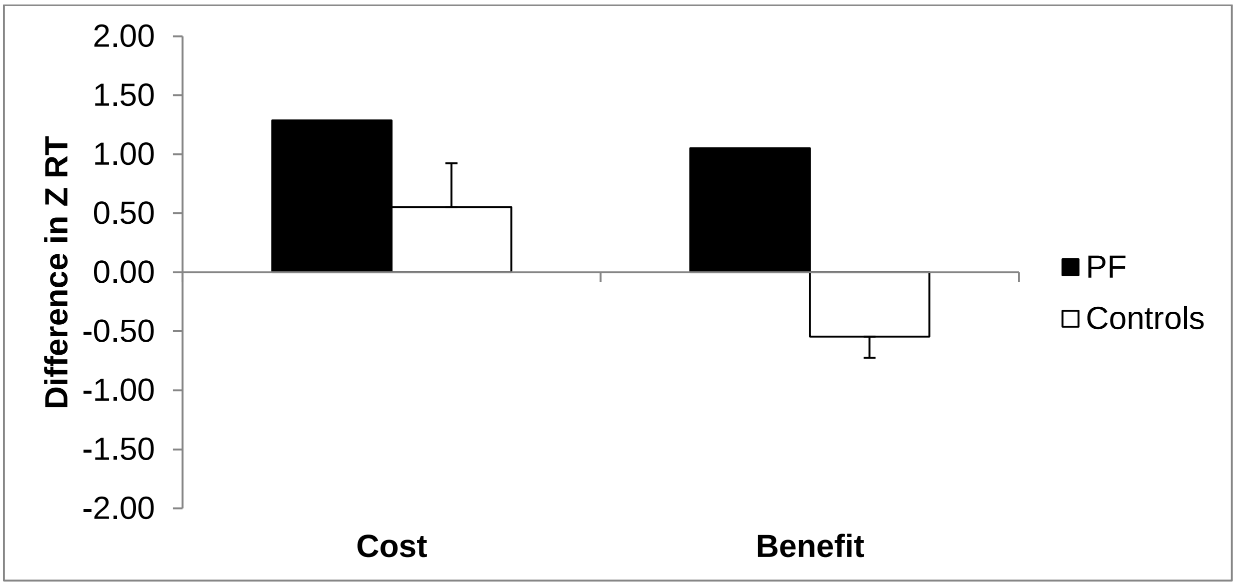

Figure 6.5.2: Cost and benefit in reaction time to target identification in spatial search in Experiment 6.5 between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

In this task, there was no significant difference in distractor cost between Patient PF and controls (PF *M* = 1.29, Controls *M* = .55, *SD* = .82) (*adjF*(1,4) = .67, p = ns). However, Patient PF showed significantly higher benefit than and controls (PF *M* = 1.05, Controls *M* = -.54, SD = .40) (*adjF*(1,4) = 13.17, p < .001).

Discussion

This control experiment showed that Patient PF utilised saliency in similar ways to what was shown in Experiments 6.3 and 6.4. This would mean that specific features (colour, filling, shape) do not overpower the top down capture of saliency. However, this could be explained by the fact that one condition (equal salience) ensured that the responses to the colour were the same (making it easier than singleton pop-out).

The previous studies involved looking for one particular target singleton shape and discriminate upon a salient feature conjoined to the shape. However, this makes comparing this to experiment 6.2 potentially difficult as the discrimination was between two shapes as a response feature. In order to avoid dual-targets being a problem, a further control experiment was run.

Experiment 6.6 Singleton irrelevant distractor (colour-not-shape report only)

Method

<u>Participants</u>

Five neurologically healthy females (M_{Age} = 65.2 years, *SD* = 1.92 years) (1 left handed) consented to participate in this experiment.

<u>Design and Stimuli</u>

The design and stimuli were identical to that used in Experiment 6.2.

<u>Procedure</u>

In this experiment, the format was a repetition of Experiment 6.2 (in trial form, length and structure) however with a change of instruction. The instruction given to Patient PF and controls was to report the colour of the target object (red or green) instead of the shape (target object still being a square or a triangle). The experimenter pressed the button synchronously with the vocalised response (m for red and k for green). Reaction times and accuracy were measured.

Results

Patient PF and controls were 100% accurate in detecting the targets. Only reaction times were subsequently analysed (see Figure 6.6.1 for means).

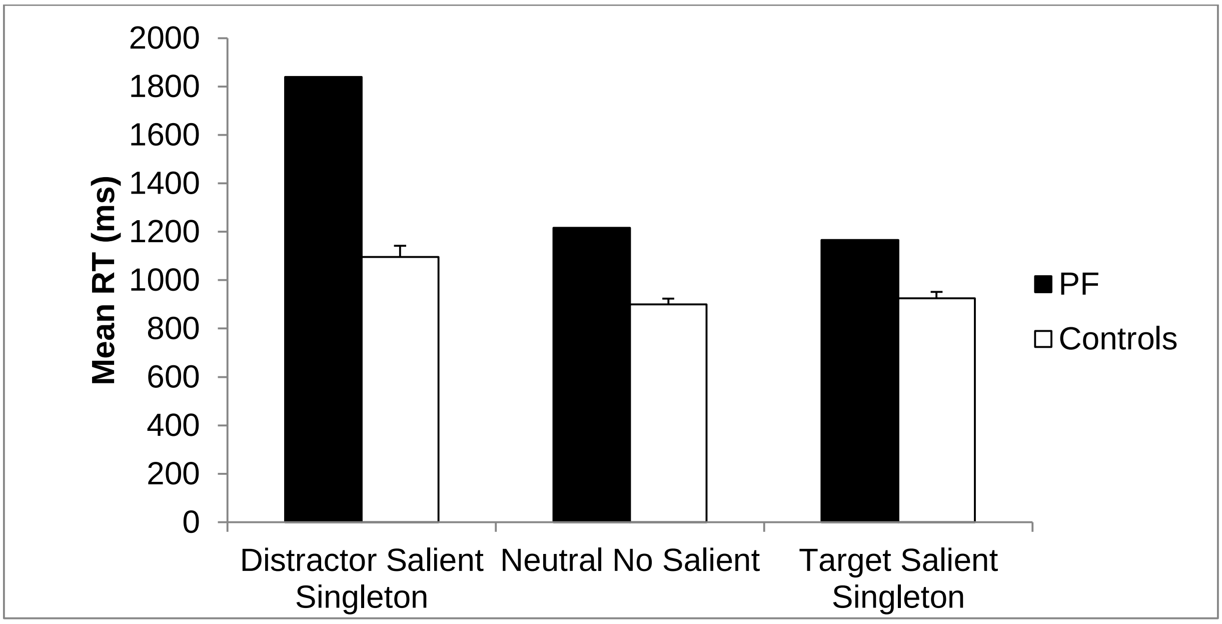

Figure 6.6.1: Mean reaction times for target identification under different saliency conditions between Patient PF and healthy controls in Experiment 6.6. Error bars for control group represent standard error of the mean.

PF was significantly slower at detecting targets overall compared to controls (PF *M* = 1407ms, Control *M* = 973.53ms, *SD* = 55.38ms) (*adjF*(1,4) = 51.06, p <.001). Thus, mean reaction time for each condition per participants was transformed into Z scores using the standard procedure. Like before, cost and benefit were calculated on Z reaction times (Figure 6.6.2).

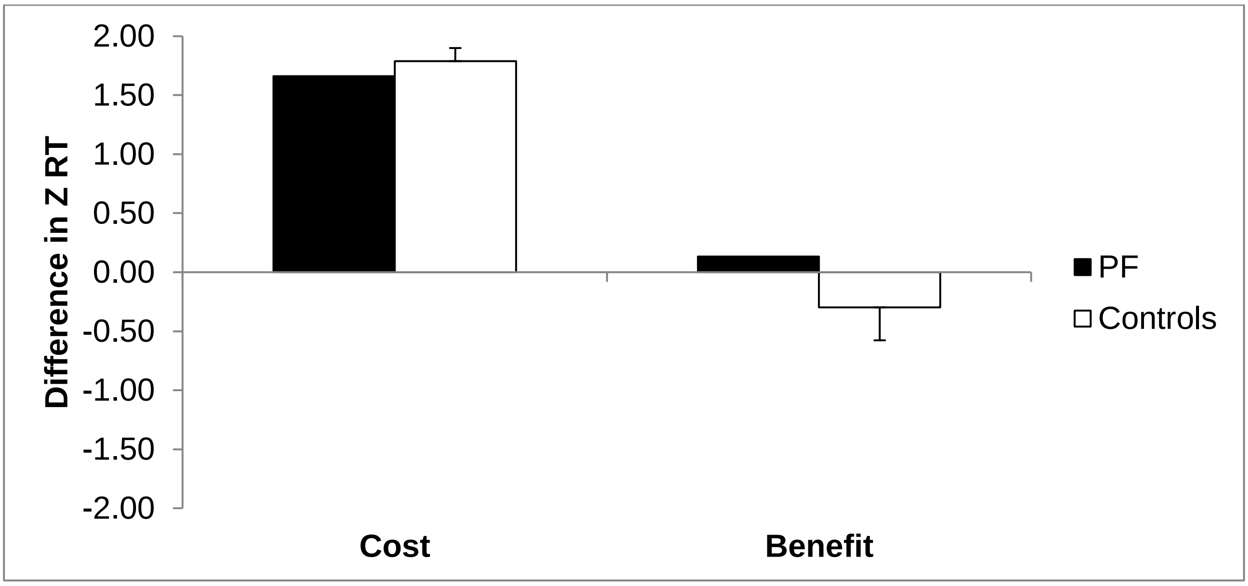

Figure 6.6.2: Cost and benefit in reaction time to target identification in spatial search in Experiment 6.6 between Patient PF and healthy controls. Error bars for control group represent standard error of the mean.

Patient PF did not show any significant difference in cost (PF *M* = 1.66, Controls *M* = 1.79, *SD* = .25) (*adjF*(1,4) = .23, p = ns) or in benefit compared to controls (PF *M* = .13, Controls *M* = -.30, *SD* = .63) (*adjF*(1,4) = .39, p = n.s).

Discussion

The experiment aimed to find out whether holding multiple singleton targets and reporting the salient features would affect saliency cost and benefit in PF. The results showed that PF performed comparably to controls when having to hold multiple targets in the search. This effect could be explained by PF actively utilising the salient information in the response set. This effect is comparable to those seen in Experiments 6.3, 6.4 and 6.5. When the salient information is a target response item, the proactive control can take over in the case of PF.

It should be noted that the benefit was small in both the controls and PF. This could be due to the nature of the neutral conditions of which all the shapes were the same colour. This homogeneity of features between distractor and target would decrease any competition from other salient information. That is to say, since only one colour is perceptually available to PF, then it makes the response as easy to make it as a singleton target.

General Discussion

This chapter aimed to explore PF's behavioural deficit effects found in the previous chapter in the spatial domain, but also to emphasise the importance of top-down task relevance in saliency capture. The initial experiments in this chapter demonstrated that PF, whilst being captured by salient information, was impaired when the target was associated with the independent salient feature. This effect occurred with both memory-guided cues (Experiment 6.1) and bottom-up ones (Experiment 6.2), and both when proactive control could not (Experiment 6.1) and could (Experiment 6.2) be utilised. In the initial two experiments, Patient PF exhibited attention capture without utilisation. That is to say; there was no benefit for using valid target salient features in visual spatial search.

The results of the experiments from this current chapter concur with the general findings shown in Chapter 5 that Patient PF has a deficit in utilising salient information when saliency, which is independent of the task, points towards a target. PF was distracted due to salient cue capture but could not use this information to her benefit if such information coincided with the target. This created competition for a response which in turn delayed processing time. PF was only able to utilise salient information when it formed part of the response set, thus, could only be selected if it was the target. Critically, what has been shown in addition to mere replication of the behavioural performance shown in the previous chapter's experiments are two-fold: 1) the effects of PF's impaired salience-based selection is not due to her impaired spatial orienting; 2) that salience-based selection deficit is not specific to perceptual distinctiveness by bottom-up features.

Also, compared to the previous chapter, the distractors remained constant in all barring Experiment 6.1 of which changed in each case. This shows a clear extension that familiarity of distractors and targets is not an issue per se to allow PF to utilise salient information effectively. Moreover, it is the relationship of salient information to the response set which is the critical issue with PF. This finding has been reflected in the experiments of Chapter 5 and this current chapter.

It must be noted that this case study also complements other studies suggesting the role of other brain areas outside of the frontal cortex in the guidance of attention (de Bourbon Teles et al., 2014; Stoet & Synder, 2007). However, it could provide important information that the parietal cortices acts to make task-relevant information salient from the top-down information provided by the prefrontal cortex.

The strength of this case study and the use of both working-memory-based and non-working-memory-based paradigms is that it rules out dual task effects.

These findings did not only come from working-memory but were identical in a non-memory based tasks. This highlighted the similarity in how the parietal cortex seemed to treat salient items. Both salient bottom-up and salient top-down items were dependent on task relevance.

There is evidence from an electro-neurophysiological study in monkeys by Toth and Assad (2002) to support the notion that the parietal cortex encodes the behavioural relevance of stimuli. Two macaque monkeys participated in a colour-location saccade task in which they had to make an eye-movement to a location (left or right) to one of two circles on a screen which were positioned in two lateral hemifields. The monkeys had to make a saccade to the correct circle following a given rule which was cued by a coloured circle beforehand which was positioned in one of the two lateral hemifields. There were two conditions: location-relevant task and a colour-relevant task. In the location-relevant task, the position (left or right hemifield) was rewarded. In the colour-relevant task colours red or green denoted a specific spatial location regardless of whether the stimulus was positioned in the left or right hemifield during cueing. The monkeys' Lateral Intraparietal area (LIP) neural firing was recorded during the task. There was increased neural firing in the LIP during colour-relevant saccade task independent of the spatial location which represented a selective encoding of behaviourally relevant stimuli. This shows that behavioural relevance can be processed in the parietal cortex. The natural translation from this finding to the case of PF is that saliency has influenced the parietal encoding of behavioural relevance of stimuli.

The findings in this chapter also highlight the difficulties of PF in respect of both reactive control and proactive control. In Experiment 6.1 participants could not draw upon proactive suppression as they possessed no pre-knowledge about the saliency of the distractor. While in the other experiments of the chapter saliency was blocked and therefore, proactive control could have been used, it is still a debate whether such paradigms still give rise to automatic capture (e.g. Woodman & Luck, 2007; Carlisle & Woodman., 2011) by the salient item which is then followed by reactive disengagement (in case the salient item is a distractor).

Thus, it is likely that suppression (at least to a certain degree) was achieved in a reactive manner (i.e., once attention was captured by the salient item). One recurring finding here was an increased saliency cost in PF compared to controls. Thus, one may argue that PF also has a problem in reactively suppressing salient information. However, perhaps a more substantial difference in performance in PF compared with the controls occurred for the salient targets (in a way this was also the case in Chapter 5 where distractor salient displays were identified quicker than target salient ones). This suggests that PF attempted to suppress the salient items on the display regardless of whether these were targets or distractors. This may have been the result of an inappropriately employed proactive suppression (which was triggered even when it was known that targets are salient) or by an excessive use of a reactive suppression (triggered whenever a salient item was selected, be it the target or the distractor).

This atypical behaviour was eliminated in Experiments (6.3-6.6). In these experiments, the participants were asked to report the colour (which was the salient aspect) of the shape-defined target. Thus, it seems that PF's excessive attempt to suppress salient information was only able to be overcome when the salient information itself was response relevant. This may suggest that PF's parietal lesion is critical in making the links between the top-down instruction and irrelevant salience information. When the salient information is irrelevant, she is attempting to suppress it. However, when the salience information *is* relevant, then selection/suppression can occur normally.

A related explanation for this finding could involve problems in binding. It could be that PF had a problem with binding task response demands to salient (but irrelevant) features of the stimuli. The parietal cortex has been associated with feature binding as evidenced in a patient case study with bilateral lesions (Friedman-Hill, Robertson & Treisman, 1995). However the binding being explained here is on an instructional level as opposed to a low-level perceptual one. This top-down view of binding highlights the mapping from the task goal to the physical, perceptual feature. Whereas if the low-level binding was an issue with PF, then atypical performance should have also occurred when the salience information was response relevant (as binding of features is necessary there too). This distinction between low-level and instructional level binding comes from work by Cinel and Humphreys (2006) on Patient GK, who had a simultanagnosia (additionally Balint syndrome – also was mentioned briefly in Chapter 5). It was found that Patient GK could show interference effects in a modified variant of the Stroop (1935) task only when instructed to combine multiple features (an example of explicit binding).

An additional alternative explanation could also be explained her effects in the non-spatial task (Chapter 5) as well as spatial task could be due to problems in the control network between frontal and parietal areas. Since as mentioned in Chapter 5, PF does have white matter lesions in the medial frontal cortex, the top-down control circuit pertaining to the proactive and reactive control networks may be impaired.

The medial frontal cortex has been known to be involved in response selection and conflict and uncertainty (Ridderinkhof et al., 2004). In a meta-analysis of functional imaging studies, Ridderinkhof et al. (2004) found that the medial frontal cortex in the monitoring of performance based on feedback and flexibly adjusting response in cases of uncertainty or conflict. The meta-analytic review found that increase in activation of the left medial frontal cortex was associated with error detection and changing responses when the task demands it. Furthermore, the role of decision uncertainty has been implicated in this brain region based on the findings from the review. In the case of PF, her lesion which extends to the right medial frontal cortex which may reflect impaired decision making of uncertain salient stimuli. That is to say, the salient item is not mapped onto a response in Experiments 5.1, 6.1 and 6.2, but does capture attention leading to uncertainty as to whether it should be responded to. Her lack of appropriate proactive control which allowed for this uncertainty to not be successfully resolved in this frontal area and due to severed connections to the right parietal cortex (which is needed for selection of salient targets), this selection may not have happened. However, in the case of reactively suppressing a salient distractor, in which reactive control is required, since the left parietal white matter lesions were not as impaired as those on the right, the resolution may have already been done.

In visual spatial search, there have been findings to suggest that the prefrontal and parietal cortices work synchronously (Phillips & Takeda, 2009). In their EEG study, participants searched for a target bar of varying orientations and colours among distractor bars. There were two types of search: efficient (singleton pop-out) and inefficient (no singleton, conjunction search) at either a set-size of two or four items while having electrical activity recorded by EEG. During the efficient search, there were both frontal and parietal activities simultaneously. During the inefficient search, there was an increase in electrical activity in both of the frontal and parietal areas which also occurred simultaneously. This increase in activity, according to the authors, represented increased synchrony in the frontoparietal network which was top-down control independent of orientation and set-size.

However, there has been evidence which shows temporal and neural differences in bottom-up pop-out search and top-down conjunction search. An event-related potential study by Li et al. (2010) presented participants with a sample search in which the participants had to match a sample triangle which was either red or green and was in one of eight possible orientations that that to be searched for in a display of four triangles. There were two search conditions: visual pop-out search in which one of the triangle’s features (colour or orientation) was physically salient from its neighbours; and what was defined as visual search in which a conjunction search with no one salient feature in the display. The visual pop-out search tested bottom-up attentional control whereas visual [conjunction] search tested top-down attentional control. Event-related potentials (ERP) were recorded simultaneously. Conjunction visual search time took longer to find the target than pop-out search. With respect to the ERP aspect, both frontal and parietal regions were active in both search and produced P300 amplitudes. However, there were region specific differences depending on the type of visual search. During visual pop-out, the P300 amplitude increased in parietal areas, whereas during visual [conjunction] search P300 amplitude increased in frontal regions. The authors concluded that the frontoparietal network of attention had some specialisation in bottom-up controls (more in parietal cortex) and in top-down (more in frontal cortex).

In relating the above studies' findings to the case of PF, her top-down control may have been impaired, and this impairment was independent of spatial set-size (as the set-size was different in Experiments 6.1 and 6.2 suggesting this may not have been a factor) and spatial search in general (as the same effect was seen in the non-spatial global-local tasks Experiments 5.1 and 5.2). Although set-size was not consistent across all experiments in this chapter, the general control effect remained the same. Her damaged proactive control network may be linked to her impaired left frontoparietal white matter tracts which were not allowing for synchronous interactions between the establishment of goals in the left frontal cortex and assessment of the relevance of features in the parietal cortex. PF was only able to utilise saliency due to an overreliance on reactive control (which was not regulated by the impaired frontoparietal network perhaps due to the damaged left hemisphere tracts and lesioned grey matter in the left parietal cortex). What may be happening in the case of PF is that relevance of salient information is coded in the frontal and parietal cortices synchronously but due to the left hemisphere tracts severed the synchronicity of the encoding of the relevance of the response features and its relationship with the salient information was impaired and segmented. So, this control circuit region had reduced communication about what the updated proactive resolution (top-down goal) of what would be the best way to respond to the ambiguous salient would be. The synchronous associative assessment of relevance and salience helps regulate proactive and reactive control to avoid an overdependence of one or another. PF had impaired regulation of these two control mechanisms perhaps due to these disrupted synchronous white matter network. In order for the ambiguous decision to be resolved, if the saliency matched the response type (i.e. it became relevant), the reliance on reactive control which was unregulated by disrupted frontoparietal network could be done.

It should be acknowledged that in both Chapters 5 and 6, the sample size of the controls was small and inconsistent in number across experiments. Ideally, the same controls should have participated in all experiments in Chapters 5 and 6, but this was not the case. This was largely due to practical reasons of time availability of older controls. However, it would be unlikely that increasing the sample size of the control group would be sufficient to replicate deficits in PF due to high statistical significance once corrected for by the adjusted F calculator (Hulleman & Humphreys, 2007). Although PF perhaps could have done repeated runs per experiment to make an equivalent number of trials to the controls in total to enhance power and reduce variance in PF’s RTs (as opposed to the same number of trials as any one participant).

The contribution to the theory that this case study brings is that it highlights with more precision the role of the parietal cortex in guiding attention towards target relevant information. Like the previous chapter, the problem with PF (and thus the parietal cortex) is that it is not the fact that saliency itself is not effective in capturing attention. Moreover, it is what the parietal cortex does with the information once attention has been captured by the saliency is the most pertinent issue in PF. Previous studies have been broader in this approach, highlighting the general issue that the parietal cortex is important for directing attention towards (and away from) salient items (Mevorach et al., 2006a; Mevorach et al., 2006b). However, this case study shows a specific extension to this issue in highlighting the relation between the salient information and its relevance for the response.

In summary of this chapter, it has been shown that a bilateral parietal patient shows, in the spatial domain, an automatic capture of bottom-up (or top-down) salient information, but seemingly a deficit in correctly utilising suppressive mechanisms. This inappropriate suppression was eliminated when the saliency became response relevant. Her deficit in the spatial domain showed a clear resemblance to that shown in Chapter 5 in the non-spatial domain, suggesting a general impairment in salience-based selection.

CHAPTER 7 GENERAL DISCUSSION AND CONCLUSIONS

The aims of this thesis were, by using the neuropsychological approach, to elucidate the role of the parietal cortex in saliency-based selection and in particular, when it interacts with task-salient information. The thesis used three main paradigms to help explore the relationship of salience-based selection and the parietal cortex, these being: the saliency-mediated global-local task (Mevorach et al., 2009); the working-memory-guided visual search task (Soto & Humphreys, 2007); and the irrelevant singleton distractor search task (Theeuwes & Van der Burg, 2007). Before integrating the different findings reported, I will provide a summary of the key points from each chapter.

Overview of findings

Chapter 2 aimed to find more precisely the neural correlates of global and local form processing in a way which extended knowledge gained from previous studies. In particular, past neuropsychological studies have used highly selective groups of patients either selecting those with specific brain lesions (e.g. Lamb, Robertson & Efron, 1984; Mevorach et al., 2006a) or those with specific neuropsychological deficits such as simultanagnosia (e.g. Riddoch et al., 2008; Huberle & Karnath, 2010). This approach limits explanation to those specific populations, leading to limited generalizability and contradictions in findings. Furthermore, using a VBM approach with a wider range of patients, it could help address the lateralisation debate of global and local processing more directly. This debate has been conflicting as to whether global and local object form processing are directly lateralised to specific cerebral hemispheres, with some in favour of global processing in the right hemisphere and local in the left (e.g. Martin, 1979; Delis, Robertson & Knight, 1986) and converse findings also being the case (e.g. Fink et al., 1997). Finally, there was a third category of findings which refute the notion of lateralisation of level processing due to manipulations of perceptual saliency (Huberle & Karnath, Mevorach et al., 2006a; 2006b). The chapter used the VBM method on a saliency mediated global-local task (Experiment 2.1) and found: firstly, that patients with lesions to the left superior parietal lobule had difficulties in identifying targets when the distractors were salient; and secondly that deficits in identification of local targets was correlated with reduced grey matter tissue in the bilateral precuneus (thus not lateralised).

The contribution of this research is that it adds to the growing literature which refutes the notion that global and local processing were distinctly lateralised. The advantage of this approach is that the diversity of patients helps remove some bias in selection this amplifying the extent and validity of the refutation of global-local lateralisation.

Another key finding from Chapter 2 is that the precuneus (PCu) has a role in resolving conflict from incongruent displays. This finding had not been previously demonstrated in neuropsychological studies relating to global and local processing. It should be acknowledged that response conflict has been traditionally associated with either the prefrontal cortex or (more commonly) the anterior cingulate cortex (ACC) (Botvinick et al., 2001). While it is still likely that these regions are involved in conflict resolution, here we highlight that the precuneus may also play an important role in regulating distractor competition.

The role of the precuneus was further investigated in Chapter 3. Here the aim was to test the validity of the VBM findings in patients in healthy neurotypical participants using reversible transcranial magnetic stimulation (TMS). This offline repetitive low frequency stimulation intended to simulate temporarily lesions in specific brain areas. By comparing performance following stimulation of the right precuneus and a control area (the vertex; Cz), a link was established with congruency interference in the PCu like in Chapter 2 with the patients. Whilst there was a reduction in the congruency interference effect and not an enlargement, a link between congruency interference and the precuneus was still present. It was suggested that the role of the PCu in this phenomena was that this region spread attention towards all distractors in space.

Chapter 4 investigated the effects of saliency in non-spatial search in the case of simultanagnosia, using the same global-local saliency task as Chapter 2. This was investigated with a bilateral occipital and posterior parietal damaged patient with simultanagnosia (Patient JM) performing a global-local letter discrimination task. In this study, Patient JM had an inability to control attention in a top-down manner due to the overwhelming capture of attention from bottom-up perceptually salient distractors. For example, when local elements were salient (e.g. had high contrast), JM could only identify these items, not the global figure. When the global shape was salient (blurred), JM could only identify the global stimulus and was unaware of the local elements. Here, any top-down control (to select the local or global elements) was overridden by strong saliency cues at either the local or global level of the form.

The contribution of this research is that it provides supporting evidence against the notion that those with simultanagnosia cannot process the global form of objects. Balint's syndrome (simultanagnosia) has been classically associated with an inability to process the global form of objects. However increasing evidence suggests that this is not necessarily the case. In a way, the finding from Experiment 4.1 supports the study by Huberle and Karnath, thus complementing the growing evidence against the global form inability claims in simultanagnosia. This is because Patient JM was able (under conditions of which facilitated grouping of local elements) to process the global form.

What this research extends in terms of our understanding of global-local processing in simultanagnosia is that (at least in the case of JM) the level processing is partially driven by perceptual information which compliments a top-down cue. That is to say; JM was driven by bottom-up perceptual features in order to identify level forms and not top-down information (the task goal). This finding is important as it highlights the interplay between top-down and bottom-up attention in the salience-based selection of object forms. Top-down attention is required for directing focus on the task-defined level and appropriately disengages from bottom-up distracting information. Due to bilateral lesions in the parietal-occipital cortices, JM could not disengage and suppress the distracting perceptual information whilst being captured; the bottom-up information took over attentional selection. This allowed her to show seemingly able to process both the global and local object forms but in a reactive manner and not a proactive manner.

The subsequent Chapter 5 explored the findings in another single patient with bilateral parietal cortex damage (Patient PF). It was noted that compared to age equivalent healthy controls, Patient PF did not show the typical utilisation of salient information when it is beneficial (matching) the top-down task. In a global-local task (Experiment 5.1), PF showed slower responses to target salient cues to distractor level salient information. This deficit did not depend on a problem of divided attention. However, the issue was that PF was able to direct attention to salient targets if the distractor items were unrelated to the task's response set (e.g. independent of the response set).

Chapter 6, the final experimental chapter revealed that a similar phenomenon occurred in the spatial domain in PF. She displayed no benefit of target salient (valid) cues in a memory guided search task (Soto & Humphreys, 2007) despite earlier findings suggesting the contrary (Soto et al., 2011). Additionally, the same effect occurred in the bottom-up domain as well as the top-down domain using a modified version of the irrelevant distractor task (Theeuwes & Van der Burg, 2007). This experiment showed that the effects shown in the memory guided tasked, generalised to the singleton search task (which had no working memory component). To resolve this issue, if the target response was the salient response feature, the utilisation of cues (beneficial or otherwise) was made.

It can be argued that there are parallels between PF's performance in Chapter 5 in the non-spatial global-local task and in Chapter 6. Unlike the potential limitation of Chapter 5, the responses that PF had to give in the experiments in Chapter 6 were different in each case. This ruled out the possibility of learning being an alternative explanation for target salient feature utilisation. The top-down could act to bind saliency with a response feature may be a plausible explanation for what is happening. Patient PF without the goal motivation to automatically bind the saliency with the goal would only be distracted by saliency as a bottom-up exogenous feature in search. That is to say; the salient attention regardless of its potential benefit to search is treated as a distractor interrupting search (or its relevance to search). This could explain why the neutral condition was quicker in the original tasks. There was no salient bottom-up information perturb efficient spatial search. It was when the instructions of the task forced binding of saliency to the target defining feature (e.g., shape) as part of the task requirement that utilisation of salient target information occurred.

It has been argued that spatial and non-spatial selection of attention is qualitatively different (Theeuwes & Van der Burg, 2007). Top down information may change bottom up non-spatial perception but this is not the case for spatial attention. However, the findings from the patient study do not confirm this notion as PF showed qualitatively similar results regardless of the spatial domain. Her deficit was task specific. This could both be linked as a non-utilisation of salient information when it is orthogonal to the task demands. That is when the salient information is not directly linked to the task but coincidental to it. Therefore, her deficit could be a control issue as opposed to mere saliency capture.

Lack of distinct level form effects and lateralisation

The experiments run in Chapters 2, 3, 4 and 5 were all global-local tasks based on the classic task by Navon (1977). As mentioned in Chapters 1 and 2, a key aspect of the debate about global and local form processing is that these processes are separate but not necessarily independent (e.g. Navon 1977). As Chapter 1 described, it had been thought that the global form was processed first by the visual system and then afterwards local details were processed (also known as global precedence). Another important concept (that was mentioned in Chapter 1) which proposed by Navon (1977) was the notion of global interference in local processing. Global interference is when distracting global levels (incongruent global) slows down processing of local elements in hierarchical displays.

In terms of accuracy, there were no clear signs of global form being more accurately identified than local targets in patients (Experiments 2.1 and 3.1). In terms of reaction times and efficiency, there were no clear sign of level precedence in young neurotypically healthy populations (Experiment 3.1), in Patient PF as well as older populations (controls in Experiments 5.1, and 5.3). The above findings could be seen to contribute to the growing literature against global advantage and interference in a global-local task. However, it should be noted that this removal of level precedence was due to manipulations of saliency. As mentioned in Chapter 1, there have been studies that have shown that level advantage can be manipulated in accordance with how one level is salient with respect to the other. To elaborate, making one level more perceptually salient facilitates response to that given level, whereas delays responses to the opposite level.

The second main claim in global-local processing is that these levels are discretely lateralised in distinct cerebral hemispheres. As mentioned in Chapter 1 and 2, classically, it has been found via behavioural peripheral hemifield tasks (Martin, 1977; Lux et al., 2004), via neuropsychological studies (Delis, Robertson & Efron, 1986; Lamb, Robertson & Knight, 1990). As explained earlier, there was not clear lateralisation of neither global nor local processing from the VBM study

(Experiment 2.1) which incorporated a wide variety of patients. The incorporation of salient displays may have removed any potential level effects. However, if there was a clear level bias, the VBM study would have found something. Only local processing was found in the VBM and it was bilateral in nature. Additionally, in the neurotypical young healthy population (Experiment 3.1) right stimulation of the PCu did not affect local processing which may also contribute to the general lack of level lateralisation effects shown. It should be noted that the left PCu was not tested in that experiment so it leaves the possibility for local level lateralisation to occur. However left PCu inhibition would be unlikely to have affected local processing since a past study showed TMS inhibition the left posterior parietal cortex facilitated the processing of global targets and not local targets in a non-saliency manipulated global-local task (Qin & Han, 2007).

It should be appreciated that due to the population used, the test of level laterality could not be fully investigated in this thesis. The two case study patients, JM (Chapter 4) and PF (Chapter 5) were bilateral parietal patients. Thus no discrete double-dissociation in terms of level processing could be made (such as those in Delis, Robertson & Efron, 1986). However, it should be noted that both PF and JM both were able to identify both global and local forms, despite both having bilateral lesions. Despite differing presentation, the issue for both of these two patients is that their ability to processes hierarchical levels is highly dependent on the saliency. Both JM and PF showing the ability to process level forms more generally despite having bilateral lesions. Furthermore, both of two these patients follow a similar general pattern of saliency dependent selection of hierarchical level form as shown in studies by Mevorach et al (2006a) in which left parietal patients could show processing of both global and local levels only if the respective target levels were correspondingly perceptually salient.

Thus, the above experiments in this thesis have shown increasing evidence against the notions of level precedence and lateralisation. Although, this evidence should be acknowledged that level processing is influenced by the relative perceptual saliency of the target and distractor levels.

Parietal contributions to the Dual Mechanisms of Control Theory (Braver, 2012)

Chapter 1 identified the role that the parietal cortex had in the past literature in terms of orienting attention to salient information. As a recap, Petersen and Posner (2012) proposed that in the attentional orienting network, the parietal cortex is important in directing attention to different areas of space (either to salient items or goals). Additionally, the authors suggested that the parietal cortex is important for orienting attention to disengage from already captured items in space. Classic neuropsychological evidence by Posner et al. (1984) supported the notion that the parietal cortex was involved in voluntary and involuntary orienting of attention to cued spatial locations.

As part of this orientating network, there are the notions of selection (choosing as appropriate task aspect in search) and suppression (the ability to inhibit distracting items from overriding search) (Mevorach et al., 2008). To link these two concepts to the Petersen and Posner (2012) orienting network, directed orienting is needed for selection since attention needs to be directed towards a task relevant aspect.

Suppression, on the other hand, is also needed for disengagement from salient information. Mevorach et al. (2006a; 2006b) suggested that selection and suppression of salient information were governed by the parietal cortex and can be independent processes. This has also been implicated in spatial search (Hodsoll et al., 2009) and in top-down saliency (Soto et al., 2014). The right parietal cortex is involved in the selection of relevant, salient information (Mevorach et al., 2006b; 2009). The left parietal cortex is involved in the suppression of distracting salient information that capturing attention (Mevorach et al., 2006b; 2009). It is clear from Chapters 5 and 6 that the exact nature of distractor items should be investigated in relation to saliency to elucidate alternative mechanisms of salience-based selection and suppression and that these could be implicated in the parietal cortex. These selection and suppression mechanisms could still be lateralised.

What I have demonstrated so far in this thesis is the importance of the parietal cortex in salience-based selection. A theory that was introduced to describe the effects in Chapters 5 and 6 in relation to this salience-based selection was the Dual Mechanism of Control theory (DMC, Braver, 2012). As a reminder to the reader, Braver (2012) proposed that cognitive attentional control was a dual mechanism. These two mechanisms were: proactive control which is a top-down, sustained goal-driven attention set and reactive control which is transient and is captured by stimulus properties (exogenous). In terms of their localisation, it was argued that the prefrontal cortex was responsible for proactive control due to the deliberative and continually maintains the task goal in order to complete a task accordingly in a planned manner. The reactive control is when the lateral prefrontal cortex is recruited to respond to changes in the environment as a capture. In this mechanism, interference is dealt with retrospectively after the information is presented.

The DMC theory does not focus on the parietal lobes and is mainly focussed on the frontal lobes as the seat of these control mechanisms, largely due to the use of executive control tasks (e.g. Stroop tasks, go no-go tasks) (see Braver, 2012 for examples). It has been known that the frontal lobes are important for executive control and flexible behaviours (Gilbert & Burgess, 2008). However, recent evidence suggests that the parietal cortex does play a role in executive tasks (Stoet & Synder, 2007). I will now attempt to relate the past findings of this thesis to the DMC account to see whether this can adequately explain the parietal cortex's involvement in the attentional control of salient information.

In terms of past studies, it could be the case that in the Mevorach et al. (2006b; 2009) studies on saliency-mediated global-local processing that the task requires proactive control for selection of task suitable salient items and reactive suppression of salient distracting information. In terms of spatial visual search, reactive control may be seen in singleton search tasks in which parietal inhibition of salient irrelevant singleton distractor features is needed (as exemplified by a TMS study by Hodsoll et al., 2009).

Firstly, the VBM analysis did not find any correlation between behavioural performance and the frontal lobes, a key candidate region for reactive and proactive control (as suggested by Braver, 2012). Therefore, direct neuroanatomical comparisons to this theory cannot be made. The VBM found correlations with congruency interference deficits and reduced grey matter tissue integrity in the parietal cortex. This could be applied to problems of proactive and reactive control. This is because incongruent displays there are two competing pieces of information (one from the target level, the other from the distractor level) which need to be processed at the same time in order for a final behavioural response solution to be made. The reactive element is trying to suppress the competing distractor. The congruent displays, on the other hand, are reactive as both levels provide the same response, thus facilitating efficient selection reactively. Whilst proactive control is needed for determining the level which is required for selection, the reactive element from incongruent displays needs to be suppressed (more detail about this will come in the next paragraph). In terms of salient targets, there were no distinct neural correlates were found from the VBM. Thus it is hard to test the full extent of the proactive control of the selection of relevant salient targets.

In reference to the TMS study (Experiment 3.1), the argument was proposed that the PCu was involved in processing all items in space in order to create back-up response commands ready or any online change in the task (based on a combined explanation from the Attentional White Bear hypothesis by Tsal & Makovski, 2006 and the backup command account by Coulthard et al., 2008). The DMC account could be applied to supplement the above explanation. It could be argued that proactive control is needed to perform the global-local task as there needs to be pre-existing knowledge (top-down) of the target to select actively and suppress distracting information which competes with that. What TMS inhibition may have been doing was to inhibit the reactive selection allowing for participants to rely more efficiently on suppressing distractors by proactive control mechanisms only. The reactive control theory could not account for reduced interference after TMS inhibition of the precuneus in the global-local task.

In the two PF case study chapters (Chapters 5 and 6), it could be interpreted that PF had poor control of salient information. This was demonstrated by the fact that in both spatial and non-spatial domains, PF was reactively drawn to salient items. However her utilisation of such saliency capture could not be simply explained by the poor reactive control as even in salient top-down items she was still drawn to it (Experiment 6.1) and even was faster at identifying targets with despite there being salient distractors (Experiment 5.1). Thus, her deficit cannot be simply categorised as simply a problem of proactive or reactive control, as she showed deficits in tasks which require both proactive and reactive control. For example, in non-spatial tasks, she could not proactively select salient targets in the global-local task (Experiment 5.1), but could only do so if the distractors were irrelevant behaviourally (Experiment 5.3).

In the spatial singleton search task (which described earlier rely on reactive control of salient singleton features), PF showed deficits in reactive control in that she could not disengage from targets and distractors which had salient features in visual search which could have been reactively utilised to help aid search despite being behaviourally irrelevant to the task goal (Experiment 6.1 and 6.2). Her reactive control was only utilised when targets and distractors had salient features which mapped on to a behavioural response (Experiments 6.3 and 6.4).

Based on the issues highlight in Chapters 5 and 6, the fact that her problems could be resolved by the manipulation of stimulus relevance means that her saliency selection and suppression deficits are beyond simply categorising it as either proactive or reactive control. Thus, this thesis needs to propose a suitable alternative explanation which can accommodate the notion of stimulus relevance with the DMC model.

It is important to recognise that this thesis presents evidence implicating the role of the parietal cortex in the proactive and reactive control of attention based on single-patient case studies. Of course, Chapters 4 and 5 present patients who, whilst both having lesions in the parietal cortex more broadly, display different behavioural deficits pertaining to different subregions of the parietal cortex (JM and PF). In comparing these two patients, it is clear that both patients have clear problems in controlling the impact of salient information in search. However, whilst both JM and PF show a broadly similar deficit of saliency, the presentation is different in each case. JM could not suppress distracting salient information in order to complete the global-local task; whereas, PF had a difficulty in selecting relevant information which made the target salient easier to find in the global-local task.

The explanation for JM's deficit was that her lesion in the PPC allowed the low-level perceptual information to override the top-down cue goals. Once captured by the bottom-up saliency, she had difficulties in disengaging from the saliency and could not effectively reorient attention to the top-down target cue. This is a similar explanation as stated by Theeuwes (1994) who suggested that in visual search; the bottom-up saliency always overrides the top-down goal. It should be appreciated that this explanation was based on variants of the irrelevant distractor task which was spatial in nature and on singleton features. Unfortunately, JM was not able for further testing to allow for a confirmatory test of this notion. However, if this explanation were to be correct, then it would be expected that JM would show an exaggerated version of the effects of singleton distractors and benefits of singleton targets. That is to say; she would be likely to report the shape of the salient low-level irrelevant distractor feature (colour) instead of disengaging from it. However, unlike PF, JM would be likely not to have a problem in effectively detecting salient targets in that task.

In the case of PF, who had superior parietal lesions, she was clearly captured by salient information like JM. However, the presentation of PF's deficits in saliency control was the opposite to that of JM's. PF was not able to select items which contained a task-irrelevant salient feature that coincidentally pointed to the top-down defined target. Similar to that of Theeuwes' (1994) bottom-up explanation, PF did show the overriding capture of saliency. However, unlike JM, PF was able to disengage from salient distractors and could complete the search task as the distracting feature did not conflict with the task goal *per se*. Whilst in the irrelevant distractor task and the global-local task, PF did show the capture of bottom-up saliency, unlike Theeuwes' (1994) bottom-up capture theory, PF's deficit also applied to top-down saliency from memory items. If bottom-up saliency overrides processing, then PF should have been able to be quick at selecting relevant targets. However, this was not the case. Therefore, the difference in presentation between PF and JM cannot be explained by the bottom-up capture account.

In reference back to the DMC account (Braver, 2012); it appears that saliency is a modulatory feature which can facilitate reactive and proactive control mechanisms. PF's lesions in the superior parietal lobule showed that she could not access the behavioural relevance of the perceptual information provided, thus had a conflict of which information to trust and limited proactive control. The saliency alone was not strong enough to overwhelm her meaning that reactive control is available for her and therefore is unlikely to be seated in the parietal regions which PF lesions. In the case of JM, the salient distractors overrode the need to fulfil the task goal and instead reactively responded with the command (level in this case) which was the most perceptually salient and capturing to her. Like PF, patient JM (despite showing seemingly the opposite behavioural performance) showed a proactive deficit of not utilising top-down cues and shown poor reactive control by not disengaging from the low-level saliency (regardless of whether it was a salient target or distractor). Thus, like PF, JM's inflexible control of salient information cannot easily be categorised as a problem of proactive or reactive control.

The salience-relevance component of proactive and reactive control

In considering the findings between the studies, the neuropsychological evidence from patient studies, it is important to attempt to link any commonalities that were found to produce a single hypothesis of parietal functioning in regards to salience-based selection and control. As mentioned in the introductory chapter (Chapter 1), saliency was defined by Corbetta and Shulman (2011) included two essential properties: perceptual distinctiveness; and behavioural relevance, the latter of which this thesis explored in more detail. It appears from the evidence that I have presented in this thesis that the nature of items in search (spatially or non-spatially) does modulate how saliency is processed and utilised for further processing. The neuropsychological cases shown provide some indication that salience-based selection is not merely based on perceptual/physical features but also their relationship to the task goal and response set, showing the importance of the notion of relevance in saliency. Therefore, if the DMC account were to apply to saliency, important considerations should be made to stimulus relevance and how that will influence the proactive and reactive selection and suppression of saliency. Thus, I will present the notion of the parietal salience-relevance component of control.

The salience-relevance component of control implies that saliency is utilised differentially (proactively or reactively) depending on the precise contents of what is salient. As shown in this thesis, it is not sufficient to necessarily say that saliency is merely perceptual distinctiveness (how something is salient physically speaking), although it could be, but how it is utilised by the parietal cortex depends on what exactly is being made salient (the relevance of the item which is salient to the behavioural task). Whilst the definition of saliency by Corbetta and Shulman (2011) does include both aspects of perceptual distinctiveness and behavioural relevance, the precise nature of what is behaviourally relevant had not been explored in much depth. What this thesis has shown is that perceptual distinctiveness can be separable to behavioural relevance in terms of saliency. Furthermore, there are two stages of control which relate to different types of salience-relevance, the perceptual saliency (the physical feature distinctiveness) which is governed by reactive control mechanisms and are low-level in nature. This can be shown in the case of JM whose parieto-occipital lesions could not allow her to disengage effectively from bottom-up perceptual information once reactively captured and utilise the top-down task goal proactively. The salient distractors were behaviourally relevant for JM, thus, could not disengage from the level since it matches in terms of a response to a predefined response set despite it being incorrect in terms of goal level. Additionally, there were parietal correlates to deficits in disengaging from salient distractors found in the VBM study. The content of what are salient (the target or distractor items themselves) and its relationship to the task goal are governed by top-down proactive mechanisms. This can be shown by the case of PF in which low-level perceptual features and salient top-down items captured attention but successful salience-selection returned to normal when the nature of the salient feature (which admittedly was made low-level salient invoking reactive control) was directly related to what the task was requiring (relevant to goals).

For this hypothesis, it should link appropriate to the findings of the other chapters beyond what was already mentioned (Chapters 4, 5 and 6). In linking this theory back to Chapter 2, it is important to note that the original aim of that particular chapter was not explicitly related to the salience relevance hypothesis. As stated previously, the goal of the chapter was to explore using a more diverse range of neuropsychological patients the lateralisation of global and local processing and attention to saliency. Whilst there was no evidence for level lateralisation, saliency and response conflict were found in the VBM analysis. The findings did show evidence for distracting salient information being lateralised to the left parietal cortex consistent with previous studies using similar paradigms (Mevorach et al., 2006a; 2006b). In terms of relevance since both responses were behaviourally relevant (i.e. both were possible responses).

The VBM analysis did pinpoint the parietal cortex as a source of response conflict resolution, for which relevancy has a clear basis. Since a response neutral option was not provided or display of irrelevant distractors, it is hard to say whether the findings of response conflict in the bilateral PCu would have revealed more specific information.

This issue of lack of neutral response to test the relevancy account also applies to Chapter 3. However, since it was argued that the PCu is spreading attention across all of space reactively to all behaviourally relevant items, it is unclear whether this is just to create backup motor responses for all, or merely identifying what is available in the visual scene more generally. The manipulation of relevance would help resolve this notion. If neutral displays, which present no conflict (no interference from a response level) are also faster responded that congruent displays (or the relative difference between the two types of displays) after TMS inhibition, then it could be suggested that relevant items which are being accommodated by the PCu. Future studies, therefore, could investigate whether this region is more responsible for relevant or irrelevant salient information by modifying displays to ensure the same target but a variety of different types of distractors (such as those used in Experiment 5.3).

This parietal salience-relevance selection mechanism appears to be independent of space. This independence could be argued to be an early process in attentional selection. This is due to past findings (as mentioned in Chapter 1) that feature-based attention occurs at an earlier stage of the time course than the spatial allocation of attention (Zhang & Luck, 2009). However, this speculation should be further supported by electroencephalography which gives an indication of the processing time of this salience-based selection.

It should be made clear that this hypothesis does not discount other brain regions in control. Moreover, it does not challenge the DMC account. What this hypothesis does, however, is an attempt to bridge a gap in the role of perceptual distinctiveness and behavioural relevance aspects of salience-based selection in the parietal cortex and how this relationship requires different control mechanisms (reactive and proactive).

In terms of bottom-up and top-down saliency (as mentioned in Chapter 1), it is clear that both forms are processed in the parietal cortex. What it shows is that top-down control mechanisms can manage bottom-up physical salience if the task goal requires it. However if this top-down mechanism is faulty, bottom-up saliency overrides the goal-directed behaviour.

Overall conclusion

In summary, this thesis aimed to elucidate the role of the parietal cortex in salience-based selection in visual search. Using the neuropsychological approach, this thesis has demonstrated more specific aspects of how saliency works alongside response selection in visual search. Past studies have looked into saliency as a mere capture mechanism within a task but had not considered its relationship with response sets and how it relates to the task. The main finding of this thesis is that the parietal cortex is involved in salience-based selection both in a proactive and reactive sense depending on the relevance of the items in search. The parietal cortex is linked in part, to a proactive control mechanism which assesses this salient information to the top-down goal associated. When there is damage to this area, a more explicitly relevant feature to the task goal is needed for efficient salience-base selection to occur. Additionally, reactive mechanism of the parietal cortex reactively supress salient information according to whatever the top-down goals are and subsequently reorient attention in accordance to such goals. This parietal cortex is implicated as a location for the assessment mechanism for joining the relevance of the salient feature for task completion. The salience-relevance component of parietal control could lead to more precision in assessing the relationship between top-down and bottom-up attention as it shows how instructional level demands influence the utilisation of salient features to help aid efficient search.

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