SEMANTIC AND PHONOLOGICAL CONTEXT EFFECTS IN VISUAL SEARCH

by

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ABSTRACT

Visual search requires participants to search for a pre-specified target amongst a number of distractors. According to theories of visual search, attention is directed towards the target through a combination of stimulus-driven (bottom-up) and goal-driven (top-down) means. For example, when searching for a red car, top-down attention can prepare the visual system to prioritise items with matching visual properties to the target, e.g., red objects. Theories of visual search support guidance according to visual properties, including the Guided Search model (Wolfe, 1994) and Attentional Engagement Theory (AET: Duncan & Humphreys, 1989). However, whether or not attention can be guided according to non-visual properties of the stimulus, such as semantic and name information, remains controversial (Wolfe & Horowitz, 1994). This thesis studied search for a target (e.g., baseball-*bat*) in the presence of semantically related (e.g., *racquet*), phonologically identical (homophones, e.g., animal-*bat*) and phonologically related distractors (e.g., *bag*). Participants' reaction times (RTs), error rates, eye movements and event-related potentials (ERPs) were monitored, and performance compared between young, older adult and brain-damaged individuals. Chapters 2 to 4 report semantic interference for all participant groups; Chapter 5 reports homophone interference in young adults and Chapter 6 reports no interference of phonologically related distractors in search for the target by young adults. The results support search being guided according to semantic and whole-name information about the target only. The mechanisms involved in this interference and contributions of these findings to the theories of visual search will be discussed.

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CHAPTER ONE

INTRODUCTION

1. Setting the scene

Moment to moment, we are faced with a huge amount of visual information. In the supermarket we are presented with hundreds of products that line the shelves. How do we find the items on our shopping list? When driving on a motorway, many signs direct us to other destinations. How do we make sure that we find the sign for the correct exit? We manage effectively to shop, drive and perform other tasks that involve visual processing effectively by directing our attention towards only those items that are relevant to our current goals, i.e., by guiding attention in a top-down manner. By means of top-down guidance, our visual system is prepared to prioritise stimuli that match our required packet of tea or signpost for the A38, for example. Attention can also be captured by bottom-up means, with stimuli being noticed due to their attributes, including their motion (e.g., a flashing sign on the road) or colour (e.g., a granny smith left in amongst a box of pink lady apples). Bottom-up and top-down attention systems interact with one another, with a combination of goal and stimulus-oriented attention being weighed up before action in response to a stimulus occurs (see Egeth & Yantis, 1997, for review).

The visual search paradigm is often used to investigate the influences on the control of visual attention. Nearly all models of visual search propose that attention is guided as the result of both top-down and bottom-up factors (Duncan & Humphreys, 1989, 1992; Müller, Humphreys & Donnelly, 1994; Treisman & Sato, 1990; Wolfe, 1994). In visual search experiments, participants are presented with a target (i.e., our goal), which must then be searched for amongst a set of items. Items could include the target or irrelevant items (called the distractors). Participants decide whether the target is present or absent. The target is usually present on 50% of the trials. Reaction time (RT) and response accuracy are measured.

Before we even begin to search, the visual cortex of the brain is being prepared for the task ahead. Cells in the visual cortex receive messages from the fronto-parietal network of the brain that direct top-down attention (e.g., Corbetta et al., 1998; Corbetta, Miezin, Shulman & Petersen, 1993). Cells that respond to features of the preferred stimulus are primed whereas cells that respond to features irrelevant to the preferred stimulus are suppressed. Upon presentation of the visual search display, items that match the target hold a competitive advantage over the items irrelevant to the current goal, and gain attention. Those items have now been selected as the most likely target. The participant may then respond to it by making an eye movement, and if it is confirmed as the target, presses his or her response button to say so.

However, on some trials, an item is selected as a potential target when it is not the target. For example, a distractor might be selected on the basis of it sharing features with the target. In such a case, distractors that are related to the target in some way can interfere with the search process – perhaps because the related distractor takes longer to reject as not being the target, compared with when the distractor is an unrelated item. Whether search is affected by related distractors would depend on what qualities of the stimulus direct attention. Targets and distractors can be related to one another in many ways. Those relationships that cause interference would provide evidence for that level of information being used to direct visual processing. Therefore, when we are in the supermarket, do we direct search according to the expected colour of our product, e.g., looking for green items on display when searching for granny smith apples? Or could this search also be directed according to more abstract properties; for example, directing search according to conceptual or semantic information about that product. Here, search for apples would cause attention to be directed towards different types of fruit.

2. Purpose of this thesis

The purpose of this thesis is to investigate the type of information that interferes with top-down attention. I investigated whether or not distractors visually unrelated and semantically related to the target (e.g., *saddle – horseshoe*), homophonous to the target (e.g., animal *bat* – baseball *bat*) or phonologically related (e.g., *bed – bell)*, could interfere with target selection.

First, search amongst semantically related distractors were studied in Chapters 2 to 5. In Chapter 2, young adult participants' evoked response potentials (ERPs) were recorded to assess the time course of semantic activation in search, in addition to RTs and error rates. In the remaining chapters, RTs, error rates and eye movements were studied. In Chapter 3, I examined the effects of ageing on top-down guidance of search. Following this, the contribution of areas of the brain that are thought to control the directing of attention were assessed by studying the performance of patients with frontal lobe (Chapter 3) and parietal lobe damage (Chapter 4) in search amongst distractors semantically related to the target.

Second, search amongst objects with homophonous names (Chapter 5) and phonologically related names (Chapter 6) were monitored in young adults, recording RTs, error rates and eye movements.

Prior to the experimental chapters, a background to the research has been summarised. Theories of visual search were reviewed along with the neural basis for those theories, and then previous evidence for interference from semantically related distractors were outlined. Following this, evidence for the performance of older adults and patients with frontal and parietal lobe damage in visual search were assessed. Finally, previous evidence for the interference of phonologically related and homophonous distractors were reviewed.

3. Research background

3.1. Theories of visual attention

3.1.1. Feature Integration Theory (FIT)

This theory proposed that search occurred in two stages: a preattentive and attentive stage (Treisman & Gelade, 1980; Treisman, 1986). At the initial preattentive stage, target stimuli can be identified quickly if they stand out from other items in the array (‘pop out’ items). A target can be selected efficiently if it differs from distractors by one attribute, e.g., by its colour. This occurs by parallel, preattentive registering of visual features and their location on separate spatiotopic feature maps (‘feature search’). The second, attentive, stage occurs when target and distractor share overlapping features (e.g., colour and form) and the target must be distinguished by a conjunction of those features (‘conjunction search’). In this case, attention is needed to combine information from different types of features leading to serial search. Evidence consistent with this has now been reported in many experiments (see Quinlan, 2003, for review).

The FIT (Treisman & Gelade, 1980; Treisman, 1986) holds that the processing of only basic features, including colour, size and orientation are possible during preattentive, parallel searching (e.g., a red circle among black circles), whereas serial attentive search is required when more complex conjunction features must be computed (e.g., to find a red circle among red and black squares and black circles). FIT opposes any early processing of semantic or name information, which ought to be possible only at the attentive stage.

Since the original work of Treisman and Gelade (1980), the requirement for serial search for conjunction targets has been disputed following findings that conjunction stimuli can produce search slopes consistent with parallel search (e.g., Heinke, Humphreys & Tweed, 2006; Humphreys & Müller, 1993; McLeod, Driver & Crisp, 1988; Treisman & Sato, 1990; Wolfe, Cave & Franzel, 1989). Other theories since FIT have proposed more integrated parallel and serial attentional processes.

3.1.2. Attentional Engagement Theory (AET)

This theory describes search efficiency as dependent on grouping relationships between targets and distractors, so enabling more complex visual representations to be coded in parallel (Duncan & Humphreys, 1989; 1992). According to AET, preattentive parallel processing of a scene provides an initial uptake of information that allows selecting of possible targets for serial processing. The theory has three stages: (1) perceptual grouping: a parallel uptake of the visual representation of the items on display (2) selection of possible targets (based on matching to an attentional 'template' of the target held in working memory (WM)) to enter (3) visual short-term memory (VSTM), for perceptual report.

AET holds that each attribute of a stimulus (its colour, orientation, texture, etc.) is represented as a unit and linked to other units. Each unit is weighted according to its similarity to the target template (the representation of the target to be searched for), and the units then compete for access to VSTM. Activation (positive weighting) or suppression (negative weighting) spreads through linked units according to their similarity to one another. Hence, if the target and distractor are very dissimilar, grouping within distractors will be stronger than between target and distractor, allowing the spreading of suppression easily through those distractors. Distractors are then rejected very quickly prior to target detection. However, if the target and distractor are similar to one another, or the distractors are dissimilar to one another, the suppression of distractors will be weaker and less effective in preventing distractors from entering VSTM.

Evidence to support AET was found in a series of visual search experiments that studied the effect of heterogenous (e.g., a mixture of upright and rotated Ts) versus homogenous (e.g., all tilted Ts) distractors in search for target Ts and Ls (Duncan & Humphreys, 1989). For example, Duncan and Humphreys (Experiment 3) showed a significant effect of distractor homogeneity on RTs, where search for the target (inverted T) is much easier when distractors are all upright Ts than when they are a mixture of upright and sideways Ts (see also Humphreys & Müller, 1993; Müller et al., 1994 for simulations of these results in a model utilising parallel grouping).

What properties of the stimuli are used as a measure of similarity to the target? For semantically related or name-related distractors to gain entry to the VSTM, these properties must have been coded prior to selection occurring, at the perceptual grouping stage. However, AET dealt primarily with computing visual representations of stimuli, and it is not clear whether higher-level semantic and phonological properties of stimuli may be computed in a parallel fashion.

3.1.3. Guided Search model

This model also rejects a strict serial / parallel distinction and suggests instead that search proceeds on a continuum, with early parallel processing guiding the directing of a later serial processing mechanism (Cave & Wolfe, 1990; Wolfe et al., 1989; Wolfe, 1994, 2001). According to Guided Search, visual elements activate feature maps in a bottom-up fashion. This bottom-up activation merges with top-down activation, set according to features of the expected target. The target wins the competition between targets and distractors for selection because it is supported both by top-down activity and by bottom-up activation from the display.

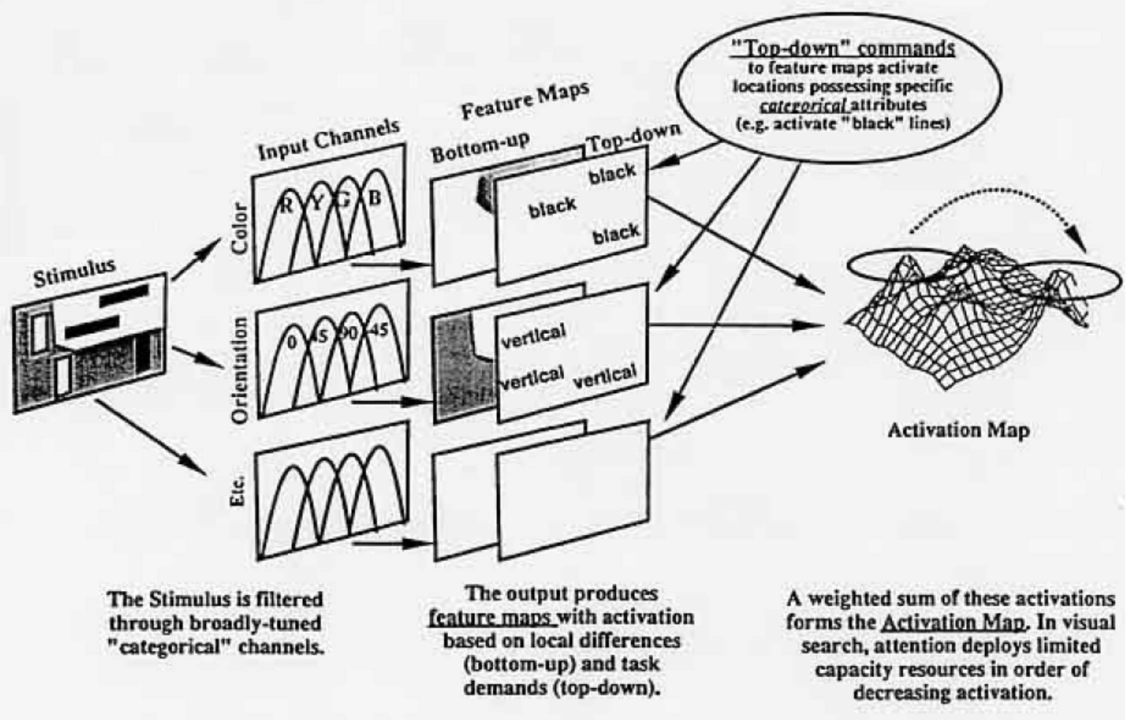

Figure 1. Architecture for the Guided Search model 2.0 (Wolfe, 1994; Fig. 2, p. 205).

Guided-Search proposes that bottom-up and top-down activation are combined to form an activation map (see Figure 1) and attention is directed to the item with the highest activation on that map. If upon inspection that item is not the target, attention will be shifted across to the next highest item until the target is found or ruled out. In feature search, the difference between target and distractor produces such strong activation that the target can be found immediately, so that RT is independent of set size. In contrast, if the target and distractor were more similar, that distractor would receive activation consistent with being a target, resulting in serial search being required to determine which of them is the target.

As with AET, it is unclear whether the attention map is affected by semantic or name information about the target for search, and whether these properties are part of the top-down set for a potential target. Wolfe (1998; Wolfe & Horowitz, 2004) argues that simple features such as colour, orientation, size and motion guide visual search, but suggests that more abstract features are not used (e.g., configural properties of faces, one’s own name or an object’s semantic category). Nevertheless, Wolfe and Horowitz also suggest that distinctive shapes may influence search; for example, when participants find a threatening snake or spider.

Although the AET and Guided Search models provide mostly similar descriptions of the visual search process, with both describing serial search mechanisms being directed according to the weighing up of top-down and bottom-up information, the Guided Search model is more definite that only simple visual features are computed preattentively. In contrast, AET’s emphasis on grouping could enable more complex visual representations to emerge.

3.1.4. Biased Competition model

The Biased Competition model (e.g., Desimone & Duncan, 1995) is an account similar to that of AET, but is more detailed in its neurophysiological framework for search. This model proposes that visual stimuli compete for access to limited capacity mechanisms in the brain, which includes the limited bandwidth for processing multiple stimuli within a single receptive field, along with WM and response execution mechanisms (e.g., eye movements). Attention enhances neuronal responses, biasing competition between stimuli in the visual field through both bottom-up and top-down activation.

For the Biased Competition model, bottom-up competition occurs between stimuli that activate cells in the same receptive field. As with AET, top-down influences are set according to information relevant to a person's goal (i.e., the target for search), which is stored temporarily in WM as an attentional template (Duncan & Humphreys, 1989). Visual processing is then biased towards stimuli with properties matching the attentional template, including its colour, motion or location (Duncan, 1999). Biasing occurs by (a) enhancing the neural response to attended stimuli; (b) filtering irrelevant information by suppressing nearby distractor items and (c) biasing signals in favour of the attended location by increasing visual cortical baseline activity in expectation of a visual stimulus (see Kastner & Ungerleider, 2001). This top-down biasing process is controlled by a fronto - parietal network, which feeds-back activity in the visual cortex to benefit items that share features with the target (see Corbetta & Shulman, 2002; Kastner & Ungerleider, 2000; Kanwisher & Wojciulik, 2000 for reviews). Relevant neural evidence comes from de Fockert, Rees, Frith and Lavie (2004). These authors reported an increased haemodynamic response at the superior parietal cortex and frontal cortex when a singleton distractor was present compared to when it was absent (see also Lavie & de Fockert, 2006). However, when WM was loaded, there was increased prefrontal activity, supporting the role of WM in selective visual attention (de Fockert, Rees, Frith & Lavie, 2001).

Neurophysiological evidence for top-down biasing of attention according to an attentional template held in WM has been shown in single cell recording studies in the anterior and ventral areas of the inferior temporal (IT) cortex of macaque monkeys (Chelazzi, Duncan, Miller & Desimone, 1998; Chelazzi, Miller, Duncan & Desimone, 1993, 2001). The animals carried out a delayed-match-to-sample task after being trained to search for a pre-specified target (e.g., a particular fruit or body part in a search display), and to make an eye movement to it. The target varied in location, requiring the animal to focus on object-based rather than spatial features. On some target absent trials none of the stimuli matched the cue, and the monkey was rewarded for maintaining fixation. By locating which cells responded selectively to a certain target, the activity of those cells could be monitored at the presentation of the target cue, during the delay prior to search array onset (where monkeys gazed at a blank screen) and during search.

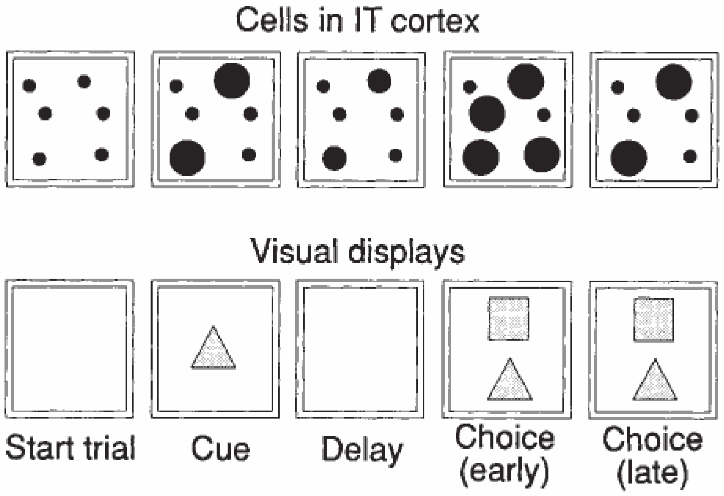

Figure 2. Schematic representations of IT neuron activity in the performance of a task; each dot represents a neuron, with the dot size representing firing rate (top row). An example experimental trial is along the bottom row. From Chelazzi et al. (1993; Fig. 4, p. 346).

Target-cue-specific neurons showed firing rates that were higher than baseline in the 1.5 to 3.0 second interval between the cue and the array onset, providing a neural representation of the maintenance of an attentional template (see Figure 2). Firing rates remained the same for the initial 200 ms of array onset, regardless of whether the target was present or not, suggesting initial parallel activation of cortical representations of all items. About 200 ms after array onset, responses increased when the target was present in the search array, followed by an eye movement to the target 100 ms later. The eye movement provided a foveal view of the target, which increased activity even further at the IT neuron. When the target cue was for another (non-preferred) object (e.g., a square) firing in response to the now distractor (i.e., the triangle) was suppressed. Once initial visual representations have been established (i.e., from 200 ms onwards), the stimuli compete with one another for limited capacity processing. Cells that have been preactivated by the cue and activated once more in response to their target are biased to receive further processing. In contrast, cells responding to an irrelevant distractor are not preactivated by the cue, and are then suppressed from receiving further processing when the distractor appears on the search array.

Kastner and colleagues investigated the neural basis of biased competition in the human visual cortex using functional magnetic resonance imaging, or fMRI (Kastner, De Weerd, Desimone & Ungerleider, 1998a; Kastner et al., 2001). They monitored the haemodynamic response of participants as they carried out a letter counting task (counting the occurrence of Ls and Ts at fixation). During this task, four complex, colourful visual stimuli were presented in the upper right quadrant of the participant's visual field. During the sequential condition, each of the stimuli were presented sequentially, every 250 ms. During the simultaneous condition, all four stimuli were presented at once. Responses were weaker during simultaneous than sequential representations, thought to be consistent with mutual suppression of simultaneous stimuli. The difference between the conditions increased in magnitude from V1 to ventral V4 areas, consistent with larger receptive fields at these neurons, allowing all four stimuli to be processed, compared to at V1 and V2.

Kastner et al. (1998a) monitored participants in the same task, but where attention was directed towards one of the four visual stimuli (attended condition) instead of at fixation (unattended condition). Here, biased competition towards the prioritised stimulus was expected. Compared to the unattended condition, activity at V3, V4 and MT increased significantly for both sequential and simultaneous presentation conditions, particularly within V4. By directing attention to the target, responses to all stimuli increased. However, top-down signals were directed more towards anterior extrastriate areas (V4) than posterior areas (V1 and V2).

Kastner and colleagues also found evidence for the biasing of attention towards a particular location prior to stimulus display onset (Kastner, Pinsk, De Weerd, Desimone & Ungerleider, 1999). The same experiment was carried out as above, but with an expectation period also included. This was akin to Chelazzi et al.'s (e.g., 1993) delay period that was an indicator of WM maintenance. Participants were instructed to direct their attention to the target location and to expect stimulus presentations. Activity in this period was strongest at V4 but also shown in early visual areas, including V1. Activity increased further at display onset, particularly in V4. In this study, the time course of frontal-parietal areas was also monitored. Kastner and colleagues (1999) found increased activity in the FEF, supplementary eye fields (SEF) and superior parietal lobule (SPL) during the expectation period. These areas had been previously shown to be activated during the attended display period (Kastner, De Weerd, Elizondo, Desimone & Ungerleider, 1998b). Other visuospatial tasks requiring directed attention to a stimulus have also reported activations the inferior parietal lobule (IPL), lateral prefrontal cortex in the region of the middle frontal gyrus (MFG) and the anterior cingulate cortex (see Kastner & Ungerleider, 2000, for review). Such regions are thought to make up a network that guides attentional bias.

Returning to the results from Kastner et al. (1999), activity was stronger in the frontal-parietal areas than visual cortical areas (V1 to V4) and this did not increase any further during the presentation of the attended display (unlike visual cortical areas). Sustained activity prior to and during display onset was thought to indicate the involvement of attentional mechanisms in the task, with the frontal-parietal network directing visual cortical areas in preparation of the visual stimuli. In sum, the direction of the attentional network caused (a) above-baseline activity in the visual cortex during the expectation period, followed by (b) higher activity still, once the visual stimuli became available. Kastner et al.'s fMRI experiments showed evidence for enhanced neural response to the attended stimulus (Kastner et al., 1998a; 1998b), and top-down biasing signals in favour of an attended location prior to array onset (Kastner et al., 1999), consistent with the principles of the biased competition model of target selection.

3.2. Semantic activation and search

According to the biased competition model, search for the target is guided by a representation in WM. Evidence supporting this comes from studies where an item held in WM during a task influences visual selection (Downing, 2000; Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; Olivers, Meijer & Theeuwes, 2006; Soto, Heinke, Humphreys & Bianco, 2005). Downing (2000) first tested this assumption by requiring participants to maintain an object in WM during a discrimination task (Experiment 1). Participants were first shown a picture of a face, followed by two faces bilaterally; one of which matched the first face. Next, participants were required to respond as to the orientation of a bracket (⊓), which was either facing up or downwards. The bracket was presented in the location of one of the previously presented faces. After this, participants were presented with a picture of a face and were asked if it matched the one held in memory. Participants were faster to respond and more accurate when the bracket was in a same field as the memory-match face than at the field of the non-matching face. The effects remained when faces were replaced with line drawings of common objects (Experiments 2 and

3) or geometrical shapes (Experiment 4), when the task changed to a motion detection task (Experiments 2 and 3) and when judgements about the memory item (e.g., its symmetry), rather than matching were required (Experiment 4). When participants were not required to maintain the item in memory during the task (Experiment 3), RTs and accuracy were unaffected by the memory object. Downing concluded that active maintenance of an object in WM gives matching objects in the environment a competitive advantage over other objects in gaining access to limited processing resources.

Soto et al. (2005) extended Downing's findings to show that when objects related to the target by shape or colour are held in WM, they can compete with the target for access to processing. Like Downing's experiments, participants were first presented with a memory item (e.g., a picture of a red triangle), next participants were asked to identify a tilted line (target) amongst vertical distractors (distractor) in a search display. Coloured shapes surrounded the lines. In the neutral condition, the memory item did not match any of the shapes in the search task. In the valid condition, the memory item, matched the shape that contained the target. In the invalid condition, the memory item matched a shape that contained a distractor. Search was facilitated in valid trials and inhibited during invalid conditions, compared to neutral trials. In Experiment 2, the relationship between prime and target was manipulated. There were three different match conditions: the prime could either be the same colour or same shape as a search item or the same colour and shape as a search item. During valid trials, RTs were shorter when the prime matched the colour or shape and colour of the target, compared to neutral trials. The opposite occurred during invalid trials, where RTs were slower than neutral trials. Eye movements were monitored and the first saccade made during search was affected by the contents of WM. More fixations landed on the objects that had the same colour or shape and colour as the prime. Soto et al. (2005) concluded that once an item is held in WM, it can guide the search process automatically and regardless of location.

Moores, Laiti & Chelazzi (2003) reported that items that are semantically associated with the target also interfere with the search process, even if those specific items are not held in WM. In Experiment 5 (where the visual search paradigm was used), participants were asked to search for a target amongst a number of distractor items. A distractor semantically associated with the target was present in the search array for 50% of target present trials and 50% of target absent trials. Stimuli were photographs of everyday objects. Semantic associates to the target had a number of types of semantic relationships, for example, they could belong to the same semantic category (e.g., *table* - *chair*); or be semantically associated (e.g., *crash helmet* – *motorbike*). Participants were first presented with the target name (1000 ms), followed by a fixation cross (800 ms) and an array of four photographs (1000 ms or until a response was made). Figure 3 shows an example trial, where the target *motorbike* is absent from the search display, but the semantic associate, *crash helmet* is present instead. Participants' eye movements were monitored during the task.

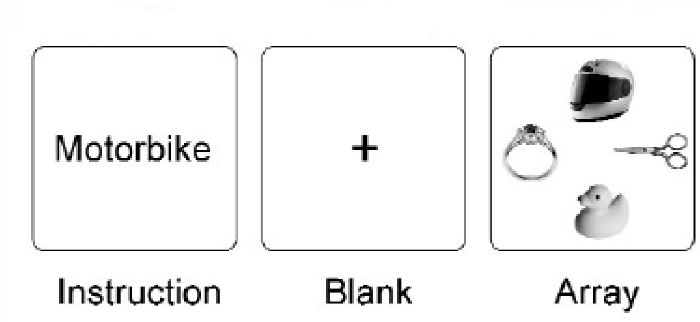

Figure 3. Example experimental trial taken from Moores et al. (2003; Fig. 3a, p. 185).

On target absent trials, accuracy was lower and RTs slower during trials where a related distractor was present rather than an unrelated (filler) distractor. The associate had no impact on behaviour during target present trials. This supports the findings of Houtkamp and Roelfsema (2006), who monitored visual search whilst holding another item in WM. They reported that the guidance of attention by items other than the target is weaker and requires the target to be absent from display to have an effect on behaviour. However, eye movement measures demonstrated that the presence of a related distractor affected first saccades even when the target was present. In the target present condition, when there were only unrelated distractors, significantly more first saccades were directed to the target (47%) than to the unrelated items (9%). During the target present condition, when related distractors were present, first saccades to the target significantly reduced to 41%, compared to unrelated distractor trials. First saccades to the related distractor during target present trials significantly reduced to 12%, compared to target absent trials (23%). During the target absent condition, significantly more first saccades went to the related distractor (23%), than to unrelated control stimulus (17%). First saccades to targets were negatively affected by the presence of an associate, and first gazes to the associate negatively affected by the presence of a target, although associates suffered more than targets. The presence of a semantically associated distractor had no effect on first saccade durations when compared to saccades to the unrelated control (165 ms versus 154 ms). First saccades to targets lasted significantly longer than to other distractors (258 ms).

The experiments of Moores et al. suggest that there can be a spread of activation from the template for the target to the representations of related items, giving semantically related items a competitive advantage over unrelated items in capturing attention. Prior to the first saccade, participants in Moores et al.'s search task had accessed semantic information about the target template, and perhaps also, the items on the search array. Moores and colleagues (2003) proposed a link with semantic priming (Meyer & Schvaneveldt, 1971). The presence of the target and associated representations in WM acts to prime semantically related objects in search so that they are processed more rapidly than unrelated items, contributing further to the attention that they receive.

The finding of semantic interference in first gazes supports early activation of semantic information in visual processing. This is supported by the findings of semantic categorisation studies by Thorpe and colleagues (Kirchner & Thorpe, 2006; Rousselet, Fabre-Thorpe & Thorpe, 2002; Thorpe, Fize & Marlot, 1996; VanRullen & Thorpe, 2001a, 2001b). Participants were able to determine whether an object was an animal or not within 250 ms post stimulus (VanRullen & Thorpe, 2001a); they could also make an initial saccade to the picture where an animal appeared, when two pictures were presented bilaterally, within 120 ms (Kirchner & Thorpe, 2005); and they showed ERP responses to the target over distractor categories 150 ms post stimulus (VanRullen & Thorpe, 2001b).

Eimer (1996) also reported that semantic features of stimuli are used to guide attention towards the target. In Experiment 3, ERP responses were monitored as participants decided which of two words presented bilaterally in a display was the target, ignoring the distractor. The target was either the word LINKS or RECHTS (left or right) and the distractor word was either BRAUN or WEISS (brown or white). A response was required according to either the location or identity of the target word. On trials where responses to the location of the target word was required, the participants should press the left button if the target word was on the left side of the display, and the right button if the target word was on the right side. On trials where the identity of the target was required, the participants should press the left response button if the target word was LINKS, and press the right response button if the target word was RECHTS, regardless of the side of display it appeared on. Eimer (1996) monitored the N2pc response during the task, which is associated with the allocation of attention to task relevant stimuli (e.g., Woodman & Luck, 2003). He found that participants elicited an N2pc response in both conditions, when either spatial location or the activation of semantic properties about the stimulus was required for the task. The latter result shows that this attention-based component was sensitive to selection based on the semantic properties of stimuli, in line with Moores et al (2003).

To sum up, semantic information can be accessed rapidly in two ways. First, upon activation of the target template, semantically related items in long-term memory are also activated and access WM. Second, upon presentation of the search display, items on display may be processed to a semantic level prior to the first saccade being initiated. It is also possible that these two processes interact, with priming from preactivated items in WM benefiting early activation of related parafoveal stimuli presentation in the search array. Unrelated items that have not been preactivated may still be accessed in long-term memory, but later than the primed items. The net result is a competitive advantage for items semantically related to the target for search, consistent with the biased competition model.

However, Moores et al. (2003) is the only published account of semantic interference in search, so replication is needed to support the findings. In addition, Moores et al.'s (2003) semantic associate stimuli included items that were also from the same semantic category (*table-chair; cat-mouse*) rather than just associate items (*chicken-egg; monkey-banana*). Furthermore, visual similarity was not controlled (although "photographs of associated objects which bore as little resemblance as possible to any potential examplar of the paired object" were chosen (see page 1 of supplementary methods, Moores et al., 2003-S1)). Huettig and Altmann (2005) commented on this and designed their 'visual world' experimental stimuli to include members of the same semantic category, e.g. *trumpet* and *piano*; that were semantically but not associatively related target-distractor pairs. They also matched stimuli for name agreement and visual similarity. In this paradigm, participants are presented with a display that contains an item in each quadrant, e.g., a picture of a goat, trumpet, piano and a hammer. Whilst being shown a display, the participants would listen to a sentence, e.g., *'Eventually, the man agreed hesitantly, but then he looked at the piano and appreciated that it was beautiful'.* They were told that they could look at whatever they wanted. In the target condition, the target (e.g., a picture of the piano) was present; in the target and competitor condition, the target and semantic competitor (e.g., a picture of the trumpet) was present; and in the competitor condition, only the semantic competitor was present. At the onset of hearing the target word, there were no differences in the probabilities of fixating on any item. Whilst hearing the target word, however, differences between conditions were reported. In the target condition, more saccades were directed to the target than any other item. In the competitor condition, more saccades were directed to the competitor than any other item. In the target and competitor condition, there were more saccades to the target than competitor, and more looks towards the competitor than towards the unrelated items. The authors concluded that upon hearing the target word, this activated semantic information that overlapped with the competitor item, which activated the competitor representation, leading to a saccade to the competitor. This has not been confirmed in the visual search paradigm, however.

Given that theories hold that visual rather than semantic features will be activated during search (Wolfe & Horowitz, 2004), it is important to control for visual relationships between targets and distractors, and whether any semantic effects emerge independently of this. In this thesis, the same set of target and distractor pairs were used for all experiments. These items were selected to be semantic associates or belonging to the same semantic category. Visual similarity ratings were carried out on the stimuli, to ensure that the visual similarity between target and semantic distractor was equivalent to the similarity between target and unrelated distractor, to rule out any interference due to visual features.

Chapter 2 will aim to support Moores et al.'s (2003) account of semantic processing in visual search by replicating the effects on RTs and accuracy and providing additional ERP evidence, in particular based on the N2pc, which has been linked with semantic activation by Eimer (1996). By monitoring ERP components, evidence for the time course of semantic activation can also be derived, to extend data previously gathered by monitoring first saccades.

3.3. The effects of ageing and brain damage on visual attention

Chapters 3 and 4 will study the effects of ageing and brain damage to the frontal and parietal areas of the brain on the control of visual attention in search amongst semantically related distractors.

3.3.1. Ageing and search

Previous evidence suggests that older adults find it more difficult to bias attention towards relevant information and to ignore irrelevant information in search. Older adults have been found to perform differently to younger adults in conjunction search, where distractors that share some visual features with the target interfere with search in older adults more than search in young adults. Older adults have showed longer RTs (Humphrey & Kramer, 1997; Trick & Enns, 1998), longer fixation durations (Ho, Scialfa, Caird & Graw, 2001; Scialfa & Joffe, 1997) and more rechecks to searched areas of display (Scialfa, Thomas & Joffe, 1994) compared with younger adults. In contrast, performance was no different to young adults in feature search (Trick & Enns, 1998). In addition, performance improved to the same degree as younger adults when targets differed from distractors by two rather than one feature (Humphrey & Kramer, 1997).

Given that older adult participants show a more substantial interference from visually related distractors in conjunction search, Chapter 3 investigated whether or not there is more interference in older than young adults when there is a distractor semantically related to the target during visual search. Older adults have shown increased semantic interference in other paradigms, including semantic priming (e.g., Cameli & Phillips, 2000) and reading tasks where semantically related distractor words were embedded in the text, where there was slower reading and poorer comprehension of the text than in young adults (Connelly, Hasher & Zacks, 1991).

Causes of increased semantic interference in older adults have been linked to the inhibitory deficit (Hasher & Zacks, 1988) and the frontal lobe hypothesis of ageing (Grady & Craik, 2000; Rabbitt & Lowe, 2000; West, 1996), whereby older adults fail to inhibit related items in WM as a result of age-specific decline to the frontal lobes. Although younger adults are still affected by semantic distractors, their top-down biasing could exert more control of attention towards the target than older adults. Alternatively, increased interference could also be due to slower information processing in older adults (Salthouse, 1996), allowing more time for the activation of semantic neighbours in long-term memory and perhaps increasing the strength of that activation. Another explanation might be that semantic information about the items could be weakened with age, similar to effects shown in some patients with dementia of Alzheimer’s type (Chertkow et al., 1994; Chertkow, Bub & Seidenberg, 1989), who show deteriorated semantic memory. A decreasing distinctiveness between items in semantic memory may cause target and distractor representations to be less distinct, affecting target selection in search.

A finding of greater semantic interference from related distractors in search in older adults compared with their younger counterparts would support the theories of attentional decline as a result of prefrontal lobe degradation, slowed processing and / or a decline in semantic memory with increasing age. On the other hand, a lack of difference between young and old participants would suggest that the ageing effects previously reported do not manifest themselves in search amongst semantic distractors. One explanation for this could be compensatory recruitment of additional brain areas in older adults, leading to equivocal performance (Cabeza, 2001; Grady, 2000; Grady & Craik, 2000; Madden et al., 2004; Madden, Whiting, Provenzale & Huettel, 2004; Madden, 2007, for review). Such recruitment, or neuroplasticity, contributes to the cognitive reserve of an individual (see Whalley, Deary, Appleton & Starr, 2004, for review). Cognitive reserve describes individual differences in how tasks are processed and how this impacts on an individual's availability of neural reserve against brain pathology and age-related changes (Corral, Rodríguez, Amenedo, Sánchez & Díaz, 2006; Keller, 2006; Richards & Deary, 2005; Stern, 2006).

Now the influences of the frontal and parietal lobes on controlling attention towards the target (and away from semantic distractors) will be discussed, as a basis for Chapters 3 and 4. Whereas the frontal lobes are associated with directing attention to particular search items, the parietal lobes are associated with directing attention to particular spatial locations (Yantis & Serences, 2003). Patients with lesions to the frontal lobes and to the posterior parietal cortex were studied in separate groups here, in order to investigate how damage to these regions disrupts their search:

3.3.2. Frontal influences on search

The frontal lobes have been shown to be mediators of the top down control of attention in visual search (e.g., Corbetta & Shulman, 2002; de Fockert et al., 2004; Kanwisher & Wojciulik, 2000) including the role of WM in search (e.g., Courtney, Petit, Haxby & Ungerleider, 1998; Roth, Serences & Courtney, 2006; Walker, Husain, Hodgson, Harrison & Kennard, 1998). Lavie and de Fockert (2006) showed evidence for this in an fMRI experiment where irrelevant colour singleton distractors were present on the display when participants search for a target shape. The distractor presence was associated with frontal cortex activity. The presence of the distractor slowed RTs, and interference effects were negatively correlated with frontal activity. This increase in frontal activity as a result of the presence of a distractor showed the importance of the frontal cortex in enabling the participants to overcome the distractor interference and to respond correctly.

Lavie and de Fockert (2005) imposed high, low and no WM load to participants carrying out this search task. Participants were shown a string of 4 or 6 digits for 1.5 seconds prior to the search target and asked to rehearse the string in order to identify whether or not a single digit, presented following the search response, was part of the memory set. During the low load condition, the digit string was always in the same order (e.g., 01234) whereas in a scrambled order during the high load condition (e.g., 03241), making rehearsal more difficult. Behavioural results showed greater interference effects when a singleton distractor was present rather than absent during high versus no WM load (60 ms increase) and high versus low WM (36 ms increase) conditions. Increasing WM load placed additional demands on the frontal lobes, affecting how well top-down control modulated interference from distractors (see de Fockert et al., 2001; Lavie, 2000; Lavie, Hirst, de Fockert & Viding, 2004).

One case study reported that a patient with damage to the frontal lobes performed poorly in visual search. Compared with control participants, there was significantly slower RTs in the performance of frontal patient, YW, in search where a singleton distractor was present compared to when it was absent (Kumada & Hayashi, 2006). It was suggested that YW's target selection was faulty; YW was impaired at weighting the relevant target features over singleton features (cf. Duncan & Humphreys, 1989). Zihl and Hebel (1997) also reported problems in the planning of dot pattern scanning in patients with frontal damage and linked this to a WM deficit.

Soto, Humphreys and Heinke (2006) investigated the relationship between WM contents and visual search. Using the same task as Soto et al. (2005), patients and controls were initially equally affected by the contents of WM, for their fastest RTs and first fixations, with slower RTs and fewer first saccades to the target when the WM item re-appeared as a distractor in the search display. However, later on in processing, frontal patients showed larger overall effects than controls, with more errors, slower RTs and longer latencies to fixate on the target. This suggests that the difficulties with directing attention arose later, whilst the initial selection of the target according to the contents of WM were relatively preserved. At later stages in processing, distinction between the target template and the distractor template in WM was poorer. Patients perhaps found it difficult to disengage from the distractor once selected, being uncertain whether or not it was the target due to a poorly defined goals generated by impaired frontal lobes.

In Chapter 3, patients with damage to the frontal lobes were monitored whilst carrying out visual search when a distractor that was semantically related to the target was present. If activation of the target representation in WM activates further although slightly weaker semantically related representations (Moores et al., 2003), it is possible that patients will find it difficult to separate target template from distractor template as suggested by Soto et al. (2006). If so, then there will be relatively normal effects on overall RTs and initial saccades, but effects may emerge on saccade durations and error rates.

3.3.3. Parietal influences on search

Patients with damage to the parietal cortex can present with visuospatial neglect or extinction. Visuospatial neglect occurs when attention is biased toward one side of space, typically the ipsilesional side, resulting in patients not attending to their contralesional visual field (Driver, 1998; Mesulam, 1999). A milder form of disrupted control of visuospatial attention is shown in patients with visual extinction (though see Karnath, Himmelbach & Kücher, 2003, for a different view). Patients with extinction can orient to single unilateral objects, whether in the contralesional or ipsilesional field. The problem arises when two objects are presented bilaterally, however, when patients may report the presence of an object on their ipsilesional side, but fail to report the contralesional item (the so called 'extinguished' item). It is thought that extinction results from a bias of attention towards the ipsilesional space when competing items are also present (Driver, 1998).

Patients with these neurological conditions have been found to process early visual information, in the absence of it reaching awareness. For example, fMRI studies have reported a haemodynamic response to contralesional stimuli in striate and extrastriate areas of the visual cortex (see Driver & Vuilleumier, 2001; Driver, Vuilleumier, Eimer & Rees, 2001, for review). Thus, an unconscious level of processing can occur in visual extinction, although this is insufficient to generate awareness of that object. Patients have also been reported to process semantic information about contralesional words and objects, despite a lack of awareness. For example, McGlinchey-Berroth, Milberg, Verfaellie, Alexander & Kilduff (1993) reported equivalent semantic priming in patients with neglect for lexical decision when a semantically related picture was presented to their ipsilesional and contralesional sides.

Chapter 4 looked to find out whether or not patients with parietal lobe damage would process semantic information when the distractor was presented in their attended field (where their spatial bias was directed towards) and when it was in their unattended field (where the spatial bias was directed away from). If semantic processing can occur without the need for attention, as suggested by McGlinchey-Berroth et al. (1993), the influence of semantic distractors should be equivalent for both sides. However, if attention is required to process semantic information, then semantic distraction would be more substantial in the patients' attended than unattended field. The intention of this chapter was to understand further the initial processing of information presented in the search display. If semantic information can be processed in the absence of attention, this suggests that semantic information about the search display is activated rapidly and automatically, prior to the first fixation.

3.4. Phonological activation in search

Long-term memory representations of common objects are connected to lexical entries that include name information along with information about an object's semantic-syntactic representation (lemma), morphology and phonology (e.g., Dell, 1986; Levelt, Roelofs & Meyer, 1999). Activation of name information about an object requires conceptual activation first (Johnson, Paivio & Clark, 1996). If visual search experiments have reported evidence for activation of semantic information about the target so that distractors semantically related to targets compete for attention

(Moores et al., 2003), would this activation spread to name information also? It has not been shown whether or not phonological information about the target in search tasks is also activated and whether phonologically related distractors compete for attention. The final experimental chapters of this thesis will investigate the influence of homophone (Chapter 5) and phonologically related (Chapter 6) distractors in visual search.

In other paradigms, information about an object's name has been shown to be activated rapidly. Morgan and Meyer (2005) found that target naming was facilitated when prior processing of a homophone occurred (visually and semantically distinct but phonologically identical stimuli, e.g., animal *bat* and baseball *bat*). In a series of picture-picture interference experiments, Meyer and Damian (2007) found that target picture naming was facilitated when a homophone or phonologically related picture (e.g., target *dog*, distractor *doll*) was also present in a display, overlapping the target picture (see also Jescheniak & Schriefers, 2001; Miozzo & Caramazza, 2005; Navarrete & Costa, 2005).

Although evidence supports name information being activated rapidly in naming tasks, we do not know whether the same occurs in visual search (where no overt naming is required). By assessing the influence of homophone and phonological distractors, a more complete picture of the attributes that guide top down attention can be produced. Little prior evidence exists to suggest the activation of name information in search. The study presented in Chapter 5 provides the first evidence for this.

4. Outline of this thesis

To summarise, this thesis aims to investigate the level of information that directs top-down attention, namely whether semantic and name information is involved in visual search for a target. The semantic interference reported in visual search by Moores et al. (2003) will be replicated in Chapter 2, whilst recording ERP responses in addition to RTs and error rates. In Chapter 3, the contribution of the frontal lobes in directing attention according to the target template will be studied in older adults and patients with frontal lobe damage. In Chapter 4 the distinction between preattentive and attentive semantic activation will be studied by investigating whether semantic interference occurs in patients with visual extinction, due to posterior parietal lobe damage, which causes the biasing of attention to one field only – rendering the other unattended. Finally, whether or not name information is also activated about the target and used to direct search will be studied in the last two experimental chapters. Search amongst homophonous (Chapter 5) and phonologically related (Chapter 6) distractors will be monitored in young adults, recording RTs, error rates and eye movements. By introducing either phonologically identical or related distractors, these experiments clarify whether information is accessed even post-semantic processing (cf. Wolfe & Horowitz, 2004) and used to guide search.

CHAPTER TWO

ELECTROPHYSIOLOGICAL EVIDENCE OF SEMANTIC INTERFERENCE IN VISUAL SEARCH[1]

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[1] Manuscript submitted for publication. Authors: Telling, A. L., Kumar, S., Meyer, A. S. & Humphreys, G. W. Please note: Telling will be Anna Southall's married name, as of 12th July 2008.

1. Introduction

Visual search typically involves looking for a pre-specified target amongst varying numbers of distractors. Current theories suggest that the target for search provides a form of "attentional template" held in working memory, which acts to bias attention towards relevant objects (e.g., Duncan & Humphreys, 1989). Single-unit recordings in monkeys have provided evidence for the maintenance of search targets in working memory and for their influence on target selection. Chelazzi, Miller, Duncan and Desimone (1993) reported that neurons tuned to features of a cued target in the inferior temporal (IT) lobe showed increased neural activity prior to search, consistent with the maintenance of a target template in working memory. Subsequently the monkeys were required to make an eye movement to the target in a choice array of between 2 and 5 items. About 200 ms following presentation of the array, but prior to any saccade being initiated, the activity of neurons tuned to distractors was suppressed and the neurons tuned to the target remained active. This provides the neural basis for selecting a saccadic response to the target rather than to any distractor (see also Thompson, Hanes, Bichot & Schall (1996) for converging evidence on the timing of selection at a neural level). Psychological evidence for the role of top-down knowledge in driving human attention comes from studies showing that the efficient search for targets at the extreme of a stimulus dimension (e.g., for a large target relative to small and medium distractors) depends on foreknowledge of what the target is (Hodsoll & Humphreys, 2001; 2005). Without this foreknowledge, search for targets at the extreme of their dimension becomes much less efficient.

In everyday life, many of the targets that we search for appear not amongst unrelated distractors but rather amongst distractors that can be related to the object we are looking for – as when we search for a cup in a kitchen containing related objects such as saucers, jugs and so forth. What are the consequences on search of having such related distractors present? A first study to assess this was reported by Moores, Laiti and Chelazzi (2003). They had participants search for a known target (e.g., motorbike) and, on some trials, presented a distractor that was semantically related to the target being searched for (e.g., motor bike helmet). Moores et al. found that the initial gaze of participants tended to land more frequently on distractors that were semantically related to the target than on unrelated distractors. Since, in this case, the semantic relation was between the distractor and the item being searched for, the data suggest either of two possibilities: (i) that activity from a 'template' for the target can spread to other semantically related items, or (ii) that the target's template is specified in semantic terms and there is sufficiently rapid extraction of the semantic properties of objects for both targets and distractor to activate the template, causing competition for selection from multiple locations. We return to consider these possibilities in the Discussion.

1.1. The present study

In the present study we use event-related potentials (ERPs) to examine the time course of this effect of semantic bias from a target template to related distractors. ERPs provide a fine-grained means of tracking the time course of visual selection, since they give an on-line measure of when the variable of interest (in this case, the presence of a distractor semantically related to a target) influences processing. Our interest focuses on the N2pc, an enhanced negative deflection in the N2 time window, at posterior sites over the contralateral relative to the ipsilateral hemisphere coded with respect to the target's position. The N2pc is visible at around 175-300 ms post stimulus and is thought to represent the attentional selection and/or the initiation of an orienting response to a target. Thus the magnitude of the N2pc varies according to the difficulty of target selection (Luck & Hillyard, 1994) and it co-varies under the same conditions that determine the neural competition for selection observed in neurophysiological studies (Luck, Girelli, McDermott & Ford, 1997). We ask whether the presence of a semantic distractor is detected early enough in time to influence the N2pc component.

Although the N2pc has not previously been studied in relation to search amongst semantic distractors, Eimer (1996) reported that this component was present in conditions when a target had to be discriminated from distractors on the basis of its semantic properties. In his Experiment 3, Eimer presented participants with two words in opposite locations either side of a display: one target and one distractor. The target words were either LINKS (left) or RECHTS (right) and the distractor words were WEISS (white) and BRAUN (brown). Participants responded according to the content of the location word, i.e., pressing the left button if LINKS was present, pressing the right button if RECHTS was present. A reliable N2pc (i.e., a larger negativity across the hemisphere contralateral to the target) was obtained over the posterior left hemisphere, suggesting that the N2pc can be sensitive to selection based on the semantic properties of stimuli (see also Dell'Acqua et al., 2007). Here we assess if it is sensitive to the semantic relations between a distractor and the target being searched for in a multi-element display.

In addition to the N2pc, we also examined whether other ERP components were affected by the presence of a semantically related distractor. The P1 (first positive wave with a 80-130 ms peak after stimulus onset) and N1 (first negative wave with a 150-200 ms peak) components are typically thought to reflect differences in the early perceptual processing of stimuli (see Hillyard, Vogel & Luck, 1998; Luck & Hillyard, 1995). By evaluating effects on these components we assess whether there are differences in the early perceptual processing of displays when a related distractor is present. The P3 component occurs from 300 ms post stimulus onwards and can reflect decision-making and response selection. For example, the P3 amplitude typically decreases during target absent compared to target present trials in search (e.g., Hopf et al., 2000; Luck & Hillyard, 1990; 1994; Wolber & Wascher, 2003; see Kok, 2001 for review). However, this component may in addition reflect the ease of target selection. For example, Wolber and Washer (2003) reported decreasing amplitudes of the P3 component with increasing set sizes in conjunction search. Note that target selection is more difficult at larger set sizes as the difficulty of search increases.

In the present study, participants were presented with a word specifying the search target followed by a visual search array containing four objects. A picture matching the target word was present on half the trials. During target present trials, the picture of a semantically related distractor (e.g., *fish*) was either (i) presented in the same field as the target (ii) presented in the opposite field to the target or (iii) it was absent from the display (replaced by an unrelated foil picture). During target absent trials, a foil replaced the target and the semantic distractor was either (i) presented in the same field as the foil (ii) in the opposite field to the foil or (iii) it was absent. Table 1 provides examples of the different conditions. An example trial is presented in Figure 4. Trials where both the target and the semantic distractor were present were separated according to whether these items were on the same or opposite sides of space because the strength of the orienting response may differ under these two conditions. In particular, orienting to one side of space should be stronger when the target and semantic distractor are in the same field than when they are in opposite fields (when the stimuli may compete to determine whether orienting is to the left or right visual field). These comparisons are illustrated in Figure 5.

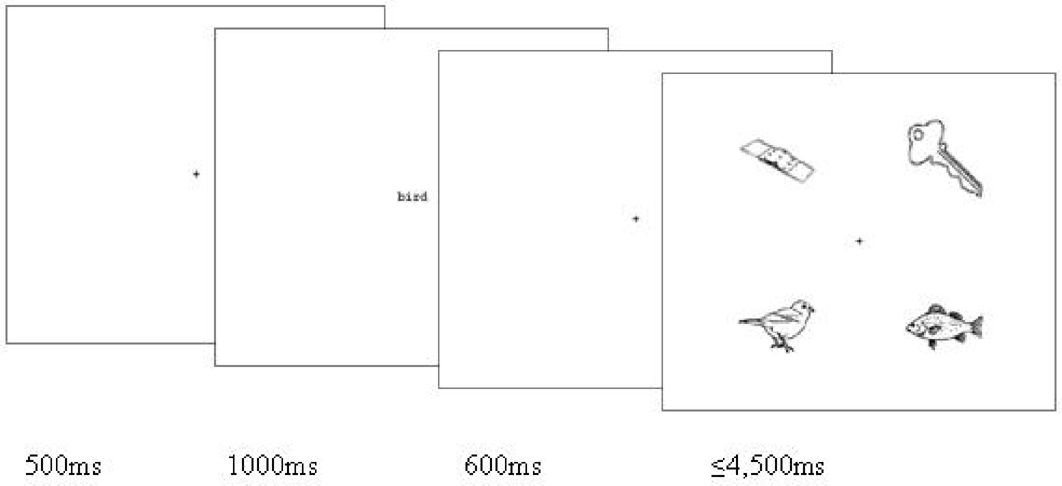
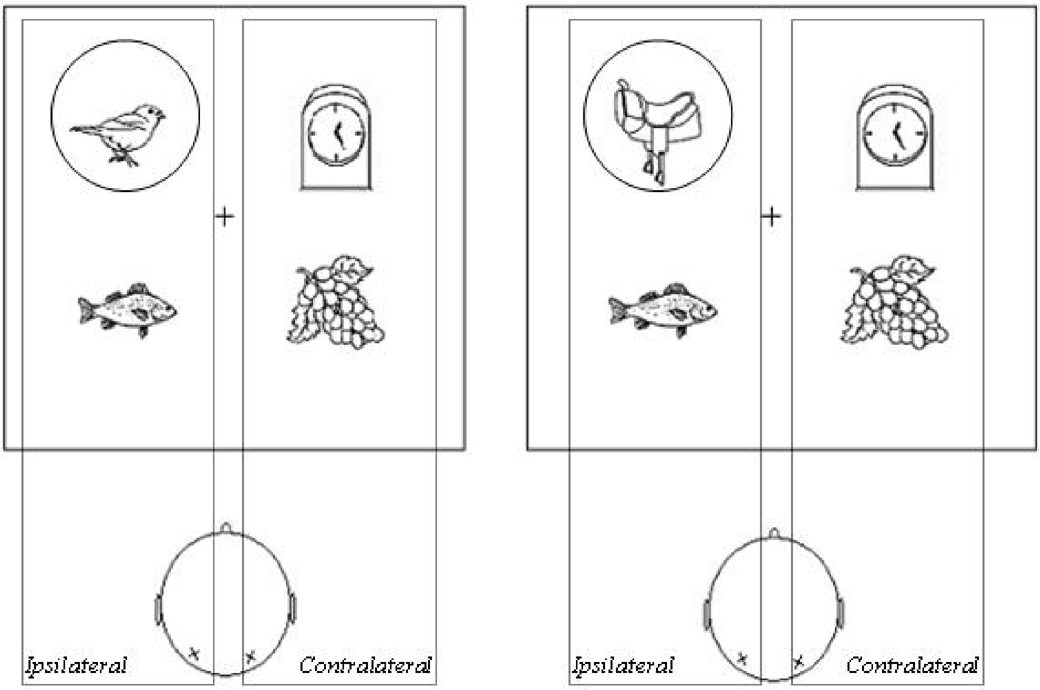


Figure 4. Example trial for Experiments 1 and 2, where the target is *bird* and the related distractor is *fish*.



(a) Target Present N2pc: Difference between activity at contralateral vs. ipsilateral electrodes to the target (bird).

(b) Target Absent N2pc: Difference between activity at contralateral vs. ipsilateral electrodes to the foil (saddle)

Figure 5. Calculating the N2pc (based on the position of the target or foil) during target present and target absent trials.

We expected to find slower responses during trials where the target is absent rather than present and slower responses where the distractor is present rather than absent (Moores et al., 2003). If the semantic distractors influence early perceptual processing, then changes in P1 and N1 amplitude would be expected. Effects of target selection and the initiation of attentional orienting may be expected on the N2pc component, while effects on selection and decision-making may emerge on the P3 component.

2. Experiment 1: Pilot study

Prior studies of the effects of semantic distractors on search have allowed participants to make free eye movements (Moores et al., 2003). To avoid artefacts due to eye movements on our EEG experiment, we used brief display durations. To ensure that semantic effects would occur under these conditions, we first ran a behavioural experiment where we monitored eye movements to ensure that the task could be performed when no eye movements were made.

2.1. Method

Participants. Twelve participants from the University of Birmingham were tested in return for course credits. They were aged between 18 and 26 years (mean age 21, 3 males). They reported their vision as normal or corrected to normal. All were right handed. They were all native speakers of English.

Stimuli. The visual search display contained four objects presented at a distance of 7.5° from a central fixation cross. The objects were 7 cm^2 in size, maintaining a visual angle of 2.4°. The pictures were selected from Snodgrass and Vandervart (1980) and a picture gallery provided by the Max-Planck-Institute for Psycholinguistics, Nijmegen (NL). All stimuli were black and presented on a white background.

Participants were presented with a target word, e.g., *bird*, followed by a four-object search array. Each of the four objects was taken from a set of 16 items, 64 in total: a target set, a distractor set and 2 unrelated filler sets (see Appendix 1). On fifty percent of trials, one of the objects was the target, i.e., a picture of a bird. On the remaining trials, the target was replaced by foil (randomly chosen from the target set), e.g., *saddle*. Semantic distractor objects belonged to the same semantic category as the target, e.g., *fish*, and occurred for fifty percent of all target present and all target absent trials. On remaining trials the distractor was replaced by a foil unrelated to the target (from the distractor set), e.g., *horseshoe*. These represented distractor absent trials. The other two positions on the search display were taken up with objects from two unrelated filler sets. The search items were chosen to minimize visual similarity between the stimuli and previous ratings with this set of items showed no differences in visual similarity between related and unrelated pairs.[2]

Objects were arranged so that the target (or its foil) and distractor (or its foil) were on the same field or opposite field to one another. These objects were positioned in all possible combinations on the display (e.g., target top-right, distractor bottom-left, is an example of an opposite condition). This created four possible positions on the display for each factor of field (same or opposite), target status (present or absent) and distractor condition (present or absent). However, for distractor absent trials, knowledge about the field of the distractor foil in relation to the target or its foil is unnecessary. These conditions were merged to create distractor absent trials. The conditions were thus labelled according to target status (present or absent) and distractor condition (distractor on the same field as target/foil, opposite field as target/foil, or absent), as shown in Table 1.

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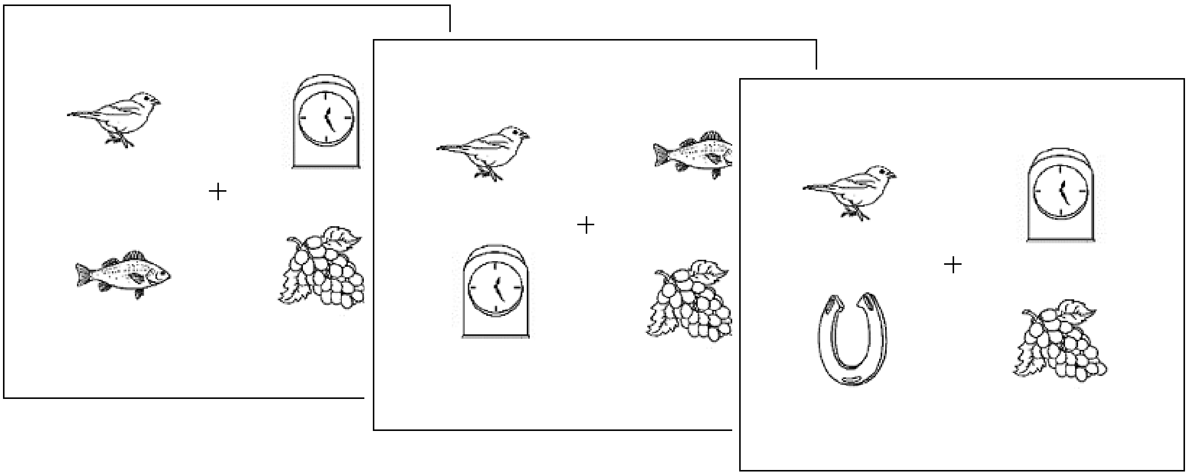
[2] Visual similarity ratings scale, where 1 represents very low and 5 very high visual similarity, yielded no significant differences between semantically related and unrelated target-distractor pairs (Target Present pairs 1.7 vs. 1.5, $Z = -1.86$, $p = .063$; Target absent pairs 1.7 vs. 1.6, $Z = -1.89$, $p = .058$, by Wilcoxon test).

Table 1 *Target status and distractor conditions for Experiments 1 and 2.*

Target present

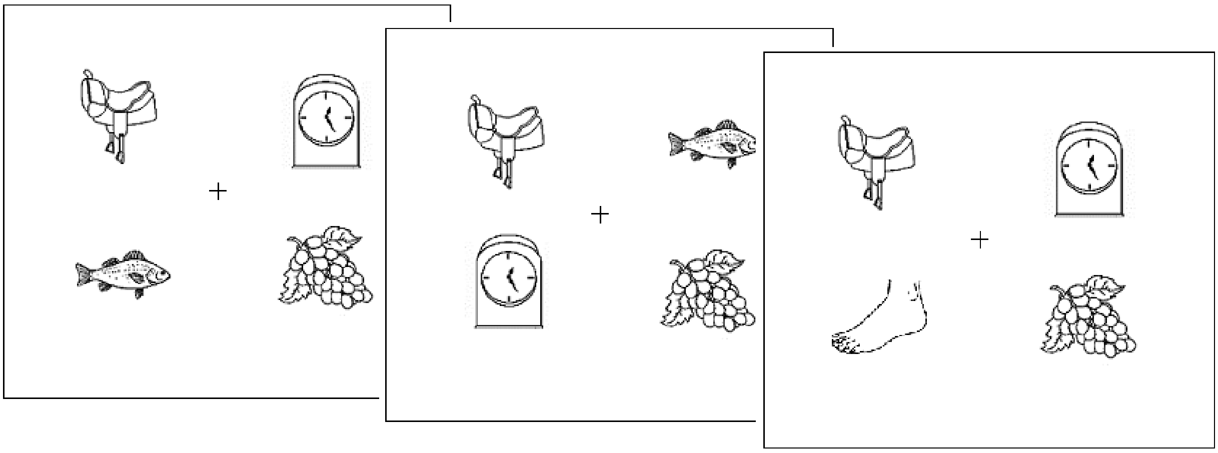
Target = bird, distractor = fish, distractor foil = horseshoe



(a) Distractor same side (b) Distractor opposite side (c) Distractor absent

Target absent

Target foil = saddle, distractor = fish, distractor foil = foot



(d) Distractor same side (e) Distractor opposite side (f) Distractor absent

Procedure. The experimental stimuli were presented on a ViewSonic colour monitor, 80 cm from the participant. First, participants familiarised themselves with a picture booklet, containing pictures with names written beneath them for all stimuli used in the experiment. Next, the participants positioned themselves on a chin rest, which restricted head movements. An SMI Eye Tracker (iView X, v1.6 Build 37) recorded eye movements.

Each experimental trial began with a fixation cross in the centre of the screen for 500 ms, followed by the target word, which lasted for 1 second. Next, a fixation cross was presented for 600 ms. This was followed by the search display, with the fixation cross remaining in the centre, which lasted until a response was given or up to 4.5 seconds (see Figure 4 for an example trial). Following the response, the next trial began after a delay of 1 second.

Participants were asked to search for the target picture amongst four pictures on the screen. Half of the participants were instructed to respond by pressing “z” on the keyboard if the target was present and “m” if absent with their corresponding left and right index fingers. This was reversed for the remaining participants. Participants were instructed to respond as quickly but as accurately as possible and to keep their eyes fixated in the middle throughout. They were informed that any trials where they move their eyes would be repeated at the end.

Each experimental block consisted of 64 trials, and each completed 8 blocks in total (512 trials). Opportunities for breaks were provided in between each block. Any trials where participants moved their eyes away from the centre or kept their eyes closed for more than 75% of the samples per trial were repeated at the end of the 8 blocks. During repeat trials, participants were given one more opportunity to correctly respond without moving their eyes. The number of trials depended on the number of eye errors made. Following the experiment, participants filled out a post-hoc questionnaire. The experiment lasted approximately one hour fifteen minutes.

2.2. Results and discussion

Eye errors consisted of 1.6% missing samples and 14% eye movement error (where an eye movement took place during the trial). Trials where participants did not move their eyes were selected for further analysis (85%). The first five trials of the first block were excluded as practice trials (0.7%). Next, any responses that were outside of three standard deviations from the mean RT by participant were excluded (1.7%). Accuracy rates were analysed before removing incorrect responses and RTs analysed.

Table 2 *Experiment 1: Mean RTs and accuracy, with standard error of mean (SEM) in parentheses.*

Target status	Distractor	Accuracy (% correct)	RT (ms)
Target present	Present, same side	91 (1.1)	653 (33)
	Present, opposite side	82 (3.4)	653 (33)
	Absent	84 (2.3)	640 (32)
Target absent	Present, same side	90 (1.6)	750 (38)
	Present, opposite side	71 (6.7)	745 (38)
	Absent	85 (3.6)	725 (37)

Table 2 presents the RTs and accuracy data observed in Experiment 1. Subject means were compared using a repeated measures analysis of variance (ANOVA) with factors of target status (present, absent) and distractor (same, opposite or absent). A main effect of target status ($F(1, 11) = 34.78$, $p < .001$, partial η^2 (henceforth, η^2) = .76) and a borderline effect of distractor conditions ($F(2, 22) = 3.38$, $p = .060$, $\eta^2 = .24$) was apparent. There was no interaction between target status and distractor condition ($F(2, 22) = 0.30$). The mean RT observed across distractor present conditions (same and opposite) was 700 ms whereas the RT in the distractor absent conditions was 682 ms, suggesting a disruptive influence of the semantic distractor. Planned comparisons showed a significant difference between the conditions where the distractor was on the same side as the target and when it was absent (an 18 ms difference: $t(12) = 2.95$, $p = .013$, $\eta^2 = .44$) only.

A similar analysis of the accuracy data revealed no differences in target present versus absent trials ($F(1, 11) = 3.88$), but a significant difference between the distractor conditions ($F(2, 22) = 7.61$, $p = .017$, $\eta^2 = .41$). Planned comparisons showed significant differences between all distractor conditions (same side as target versus opposite: $t(12) = 2.78$, $p = .018$, $\eta^2 = .41$; same side as target versus absent: $t(12) = 2.21$, $p = .049$, $\eta^2 = .31$; opposite side to target versus absent: $t(12) = 3.21$, $p = .008$, $\eta^2 = .48$). Participants made significantly more correct responses when the semantically related distractor was on the same side as the target/foil (on target absent trials) relative to when the related distractor was absent, whereas more errors relative to this last condition occurred when the related distractor fell on the opposite side of space to the target/foil.

This experiment confirms the effect of the semantic distractor reported by Moores et al. (2003) but under conditions with limited display durations and without eye movements. These same display conditions were then used in Experiment 2, where EEG recordings were also taken.

3. Experiment 2: Main ERP experiment

3.1. Method

Participants. Twelve participants from the University of Birmingham were tested in return for course credits or cash. They were aged between 18 and 26 years (mean age 21, 5 males). They reported their vision as normal or corrected to normal. All were right handed. They were all native speakers of English. All participants provided informed consent and confirmed that they had not consumed alcohol or recreational drugs in 24 hours prior to testing and that they were not on any prescriptive medications that may affect cognitive processes.

Stimuli. The experimental stimuli used in Experiment 2 were identical to those used in Experiment 1.

Procedure. The experimental procedure carried out Experiment 2 was identical to that in Experiment 1, with the following exceptions. The participants sat 75 cm from an SVGA colour monitor with the keyboard on their lap. No chin rest was used. No trials were repeated on occasions where eye movements occurred, unlike Experiment 1. The participants were asked to keep as still as possible during the blocks, keeping eye movements, swallowing and blinking to a minimum.

3.1.1. Recording and analysis

Electroencephalogram (EEG) was recorded continuously with Ag/AgCl electrodes from 128 scalp electrode locations. The electrodes were placed according to the 10 - 5 electrode system (Oostenveld & Praamstra, 2001) using a nylon electrode cap. Horizontal and vertical eye movements were monitored by unipolar electrodes placed at outer canthus and infra orbital area of the left eye respectively. Additional electrodes were applied to right and left mastoid areas, and were used as references and ground. EEG and electro-oculogram (EOG) signals were amplified with a band pass of 0 - 128 Hz by BioSemi Active-Two amplifiers and sampled at 1024 Hz. The continuous EEG recordings were off-line referenced to the average of the left and right mastoids and band pass filtered between 0.01 and 35 Hz, with a 50 Hz notch filter. Eye movement correction was carried out using the Gratton, Coles and Donchin (1983) method as part of the Brain Vision Analyzer software. This method corrects blinks, horizontal and vertical eye movements and adjusts for ERPs (see Croft, Chandler, Barry, Cooper & Clarke, 2005). Continuous EEG signals were segmented into epochs from 200 ms before trial onset to 1100 ms after trial onset for each of the conditions for each subject. Epochs were discarded if the voltage exceeded ±100 µV. Pre-stimulus 200 ms was used as baseline, and activities reported here were baseline corrected.

3.2. Results

3.2.1. Behavioural results

The first five trials of the first block were excluded as practice trials (0.7%). Next, any responses that were more than three standard deviations from the mean RT by the participant were excluded (1.7%).

Figure 6 and Table 3 present the means for the accuracy and RT data observed in each condition of Experiment 2. Statistical analysis was carried out as for Experiment 1. Whether the target appeared on the left or right hemifield was not introduced as a factor, only whether the distractor was on the same or opposite side as the target or its foil. Preliminary analysis of target hemifield showed that this had no impact on participant performance[3].

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[3] Additional analysis was carried out on conditions where the distractor was absent, but the target or its foil was in the left versus right hemifields. This was carried out so that any effect of target hemifield could be ruled out. ANOVA yielded a main effect of target status, with shorter RTs and reduced accuracy during target present, distractor absent trials than target absent, distractor absent trials (660 vs. 720 ms, $F(1,11) = 39.50, p < .001, \eta^2 = .78$; 93 vs 97%, $F(1,11) = 46.07, p < .001, \eta^2 = .81$). However, there was no main effect of target hemifield (RTs: $F(1,11) = 1.47$; accuracy: $F(1,11) = 0.00$) and no interaction (RTs: $F(1,11) = 0.98$; accuracy $F(1,11) = 0.32$).

Table 3 *Experiment 2: Mean RTs and accuracy, with standard error of mean (SEM) in parentheses.*

Target status	Distractor	Accuracy (% correct)	RT (ms)
Target present	Present, same side	93 (1.0)	673 (28)
	Present, opposite side	93 (1.4)	662 (27)
	Absent	93 (0.7)	654 (27)
Target absent	Present, same side	96 (1.7)	764 (32)
	Present, opposite side	96 (0.9)	746 (32)
	Absent	97 (0.6)	721 (28)

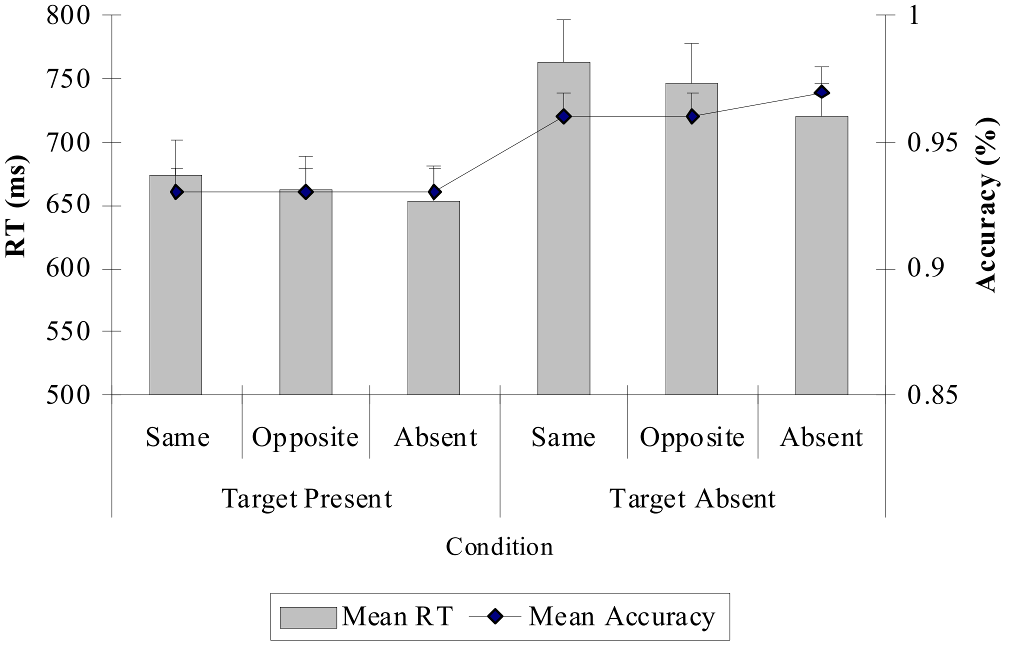

Figure 6. Experiment 2: Behavioural results (error bars represent standard errors, SEM, by participants).

Accuracy rates showed no effect of distractor, only of target status ($F(1, 11) = 26.68, p < .001, \eta^2 = .71$). The mean accuracy across subjects was 93% for target present trials and 96% for target absent trials, averaged over the distractor conditions.

RTs showed a main effect of target status ($F(1, 11) = 46.09, p < .001, \eta^2 = .81$) with responses being 81 ms slower during target absent than present trials. There was also a main effect of distractor ($F(2, 22) = 10.95, p = .001, \eta^2 = .50$). Planned comparisons between the distractor conditions showed that the RTs were significantly longer for trials where the related distractor was on the same side of fixation as the target/foil relative to when it was absent (a 31 ms difference: $t(12) = 5.64, p < .001, \eta^2 = .74$), and RTs were also longer on trials where the related distractor was on the opposite side of fixation to the target/foil, compared with when it was absent (an 18 ms difference: $t(12) = 2.63, p = .023, \eta^2 = .39$). There was no interaction ($F(2, 22) = 1.03$).

3.2.2. Electrophysiological results

The main component studied in this experiment was the ***N2pc***. The N2pc component was analysed at posterior and lateral occipital electrodes (O1 / O2 and PO7 / O8) and parietal electrodes (P3 / P4 and P7 / P8), consistent with electrodes reported for previous N2pc research. Figure 7 shows a series of topographic maps of electrode activity, grand averaged across participants. Here the map during the N2pc time period (260 ms) demonstrates the activity of electrodes in the posterior and occipital regions measured. N2pc activity was calculated by subtracting ipsilateral activity from contralateral activity on the scalp electrodes in relation to the target for target present distractor conditions (same, opposite, distractor absent) and on scalp electrodes in relation to the foil for target absent distractor conditions (same, opposite, distractor absent).

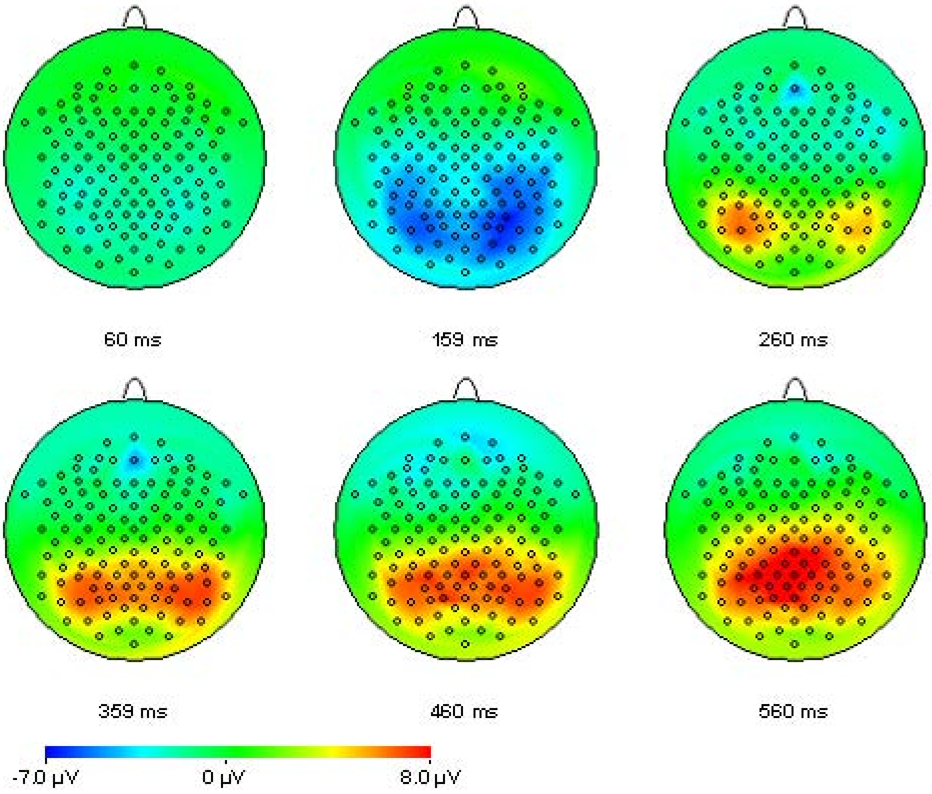

Figure 7. Topographic maps for the target present, distractor present (same field) condition. Taken from the grand average across all subjects and partitioned into 100 ms time windows. Occipital and posterior activity can be shown for the N1 (155 - 195 ms), N2 (255 – 295) and P3 (450 – 750 ms) time periods. A similar pattern was found for the other 5 conditions.

Figure 5 shows sample displays during target present and absent conditions, with a representation of electrode position. In (a) the target is on the left, so the contralateral electrode would be located on the right side of the subject's head, and the ipsilateral electrode on the left side (indicated by cross marks). Here, activity at the left electrode would be subtracted from the activity at the right electrode, across all distractor conditions. During trials where the target is on the right, the calculation would be reversed. In (b) the target is absent, so has been replaced by a foil. The position of the foil was used as a basis for electrode laterality: So the contralateral electrode to the foil here is on the right and ipsilateral on the left. Dividing the results in this way provides a target absent control to target present distractor conditions. If there is an effect of the related distractor, then the N2pc should be greater when the distractor falls on the same side as the foil (i.e., activity should increase for the hemisphere contralateral to the foil) compared with when the related distractor is absent, while the N2pc should be reduced when the semantic distractor falls on the side of space opposite to the foil.

Visual inspection of the waveforms for the different electrodes during different conditions showed that the N2pc occurred between 225 and 325 ms (see Figure 8). The mean area of activity (µV) was examined for each condition.

Three different methods of analysis were used on the data: (1) comparing activity at PO7 / PO8 electrodes only; (2) comparing activity at separate electrode sites O1 / O2, PO7 / PO8, P3 / P4 and P7 / 8 with electrode site as a within-subjects factor; (3) pooling activity across the four electrode sites. These were carried out across the larger time window of 225 – 325 ms, but also by separating the time windows into 225 - 275 ms and 275 - 325 ms, with time window as an additional factor. Differences in target status (target present versus target absent) and distractor condition (same, opposite or absent) were assessed using repeated measures analyses of variance (ANOVA) with additional factors of electrode site (4 levels) and time window (2 levels) where applicable.

The results of the pooled electrodes, for the two time windows only will be reported. There were no interactions between electrode site and distractor. All other analyses yielded essentially the same effects. The analysis including the effect of electrode site did yield an interaction between electrode site and target status, however when analysed separately for each site, all showed effects of target status in the same direction.

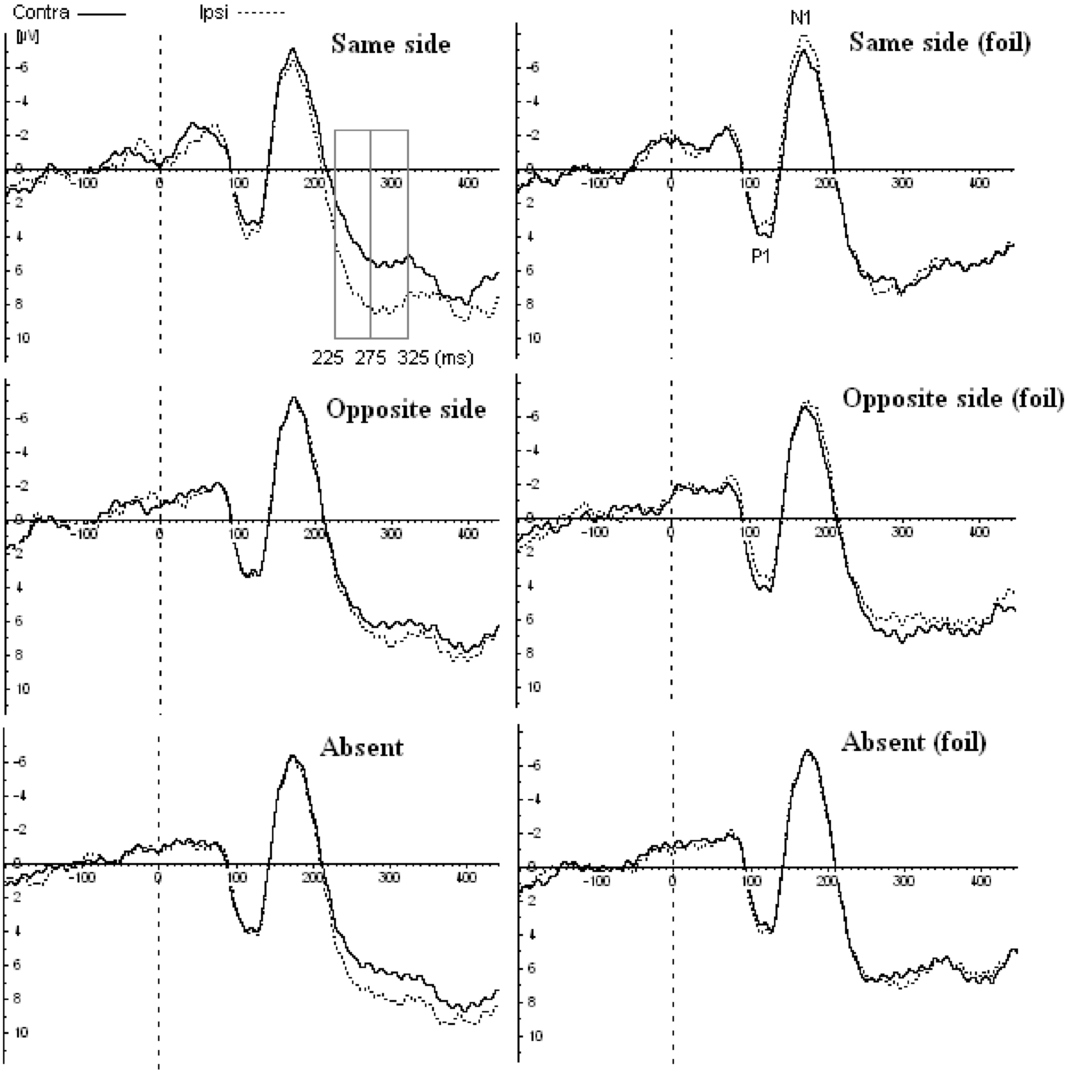

Figure 8. Activity at PO7 / PO8 electrodes contralateral versus ipsilateral to the target or foil. The difference between them represents the N2pc. The left side of the figure lists target present conditions, and the right column lists target absent conditions. The time course of activity is indicated on the x-axis and the amplitude of electrode activity (µV) on the y-axis. The negative is plotted upwards, and stimulus onset was at 0 msec.

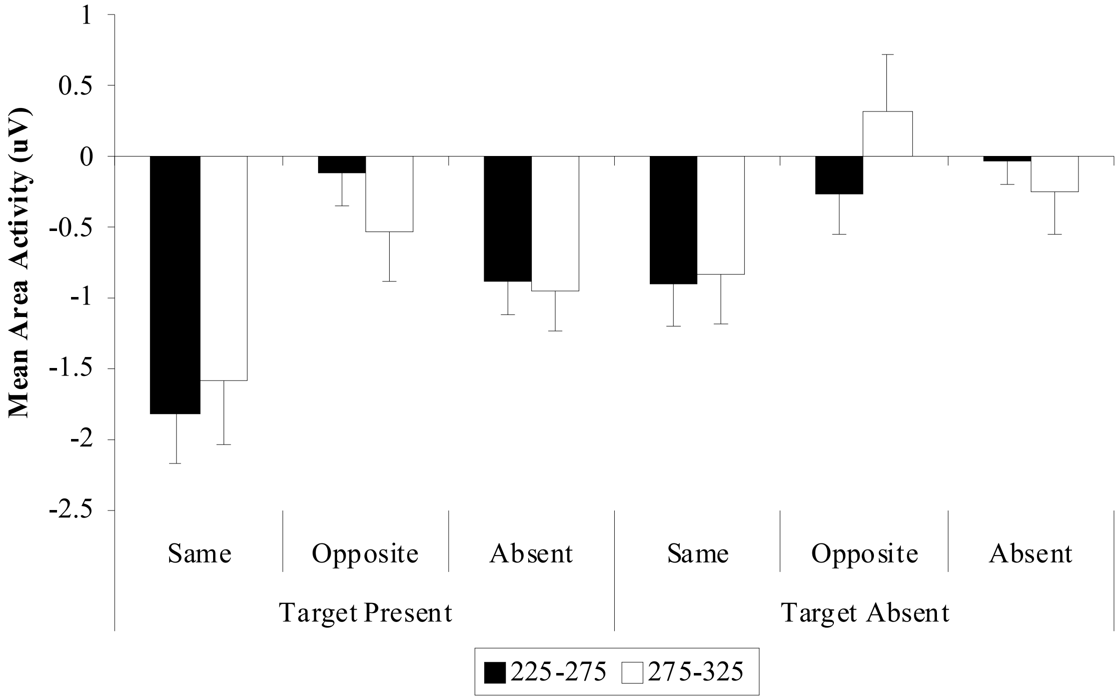

Figure 9. Mean N2pc activity across electrodes O1 / O2, PO7 / PO8, P3 / P4 and P7 / P8 (error bars indicate SEM, by participant).

To elicit an N2pc, the difference between activity on electrodes contralateral to the target and electrodes ipsilateral to the target is typically more than –0.3 μV (see Woodman & Luck, 2003). Figure 8 and Figure 9 show that according to this standard, the N2pc was elicited most notably during target present trials where the semantic distractor was in the same field (-1.7 μV), when compared to target present trials where the distractor is absent (-0.92 μV), and it was elicited to relatively the same degree on target absent trials when the related distractor was on the same side as the foil relative to when the target was present without the related distractor (-0.88 μV). Trials where the distractor was in the opposite field to the target or foil varied in activity with time. During target present trials an N2pc was elicited in the later time window (-0.11 μV, earlier versus -0.53 μV, later), although both to a reduced amount compared to the other target present conditions. During target absent trials, when the distractor was in the opposite field to the foil, the reverse activity (i.e., a positive response, indicating an N2pc being elicited in response to the distractor field) occurred during the later time window (+0.31 μV). Activity during trials where no target or distractor was present showed the least activity, i.e., no N2pc (-0.25 μV).

An analysis of variance with the factors of time window (early: 225 - 275 versus late: 275 - 325), target status (target present versus absent) and distractor condition (same, opposite or absent) showed reliable main effects of target status ($F(1, 11) = 10.71, p = .007, \eta^2 = .49$) and distractor condition ($F(2, 22) = 8.66, p = .005, \eta^2 = .44$). Target present trials were significantly more negative in activity than target absent trials (-0.65 μV difference). There was an interaction between time window, target status and distractor ($F(2, 22) = 5.71, p = .016, \eta^2 = .34$). The interaction was broken down by analysing target present and target absent trials separately:

Target present trials yielded a main effect of distractor condition only ($F(2, 22) = 8.95, p = .004, \eta^2 = .45$). There was no interaction between distractor and time window. Planned comparisons showed that the N2pc was greater when the related distractor was in the same field as the target compared with when it was in the opposite field ($t(12) = 3.40$ $p = .006, \eta^2 = .51$) a difference of –1.39 μV, and compared with when the related distractor was absent ($t(12) = 3.13, p = .001, \eta2 = .47$), a difference of –0.78 μV. The difference between the conditions when the related distractor was opposite to the target and the condition where it was absent was not significant ($t(12) = 1.96, p = .076, \eta^2 = .26$).

Target absent trials yielded no effect of distractor condition, but there was an interaction between distractor condition and time window ($F(2, 22) = 4.08$, $p = .036$, $\eta^2 = .27$). Both time windows yielded borderline effects of distractor condition (Early: $F(2, 22) = 3.16$, $p = .074$, $\eta^2 = .22$; Late: $F(2, 22) = 3.22$, $p = .069$, $\eta^2 = .23$). Planned comparisons showed that during the early time window, the N2pc was larger when the related distractor was in the same field as the foil compared with when the related distractor was absent ($t(12) = 2.81$, $p = .017$, $\eta^2 = .42$) There was no difference between the other distractor conditions (same versus opposite field to the foil, $t(12) = 1.47$; opposite field versus distractor absent, $t(12) = 0.73$). During the late time window there was a significant difference between trials where the distractor was in the same field as the foil relative to when it was in the opposite field ($t(12) = 2.79$, $p = .044$, $\eta^2 = .32$). The differences between the same and opposite distractor conditions and the condition where the related distractor was absent were not reliable (same versus absent $t(12) = 1.69$; opposite versus absent $t(12) = 1.15$).

Table 4 *P1 and N1 pooled means, with SEM in parentheses.*

Target status	Distractor	P1			N1		
		Area of activity (µV)	Peak amplitude (µV)	Peak latency (ms)	Area of activity (µV)	Peak amplitude (µV)	Peak latency (ms)
Present	Same side	2.06 (0.75)	4.06 (0.82)	116 (1.87)	-5.20 (0.86)	-7.70 (1.10)	170 (3.41)
	Opposite side	1.49 (0.69)	3.51 (0.72)	117 (1.53)	-5.62 (0.75)	-7.86 (0.87)	172 (3.32)
	Absent	2.17 (0.83)	3.99 (0.90)	116 (1.77)	-4.89 (0.95)	-6.85 (1.07)	173 (3.44)
Absent	Same side	1.80 (0.39)	3.80 (0.72)	116 (1.65)	-5.77 (1.02)	-7.96 (1.19)	173 (2.96)
	Opposite side	1.51 (-0.27)	3.62 (0.82)	118 (1.79)	-5.46 (0.94)	-7.54 (0.99)	174 (3.24)
	Absent	1.71 (0.21)	3.63 (0.76)	118 (1.65)	-5.22 (0.98)	-7.27 (1.09)	172 (3.53)

Prominent ***P1*** (110 ms) and ***N1*** (175 ms) component peaks were visible on the electrodes studied for the N2pc component (i.e., PO7 / PO8, O1 / O2, P3 / P4, P7 / P8) as shown in Figure 8.

The mean area of activity, latency and amplitude of the peaks were analysed for the P1 using within-subjects analyses of variance, with factors of target status, distractor condition. The data were collapsed across electrode field (contralateral or ipsilateral to the target or foil)[4] and we used the three methods carried out for the N2pc. The results remained consistent for all three methods: No main effects or interactions occurred. Table 4 shows the means when pooled across electrode sites.

The same analyses were carried out for the N1 component. This resulted in the same findings: For all three methods of electrode selection, no significant main effects or interactions were shown. The presence of a target or a semantic distractor had no effect on either the P1 or the N1.

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[4] Analysis had previously been carried out including this factor, but no interactions with electrode field occurred.

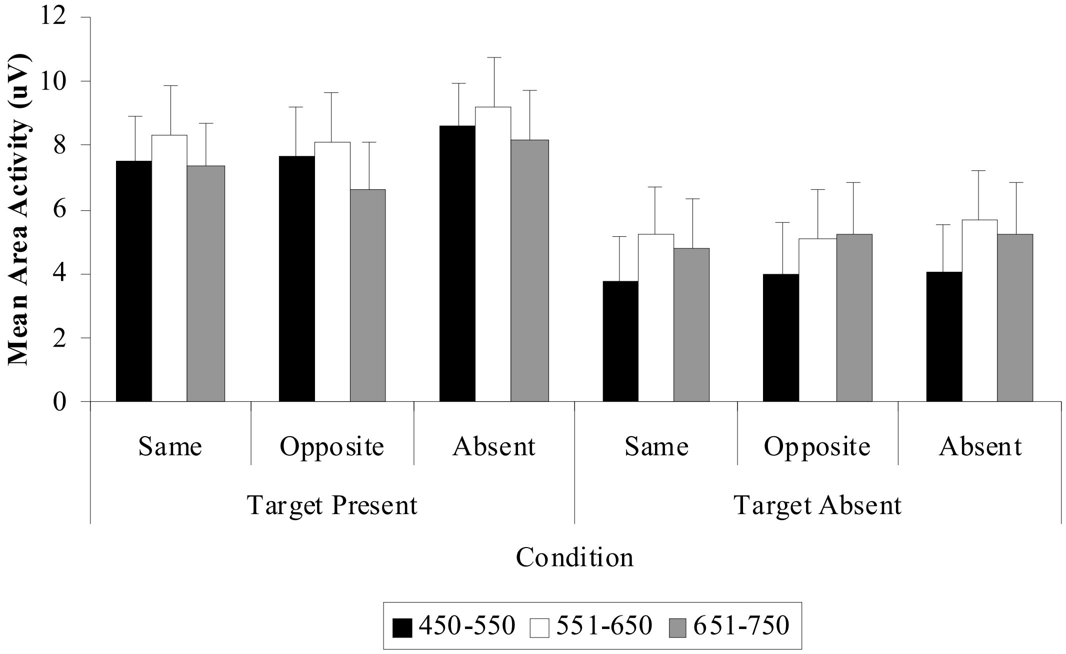

Figure 10. Mean P3 activity across the conditions, divided between the three time windows (error bars represent SEM, by participants).

Finally, the ***P3*** component was analysed. Isopotential contour maps for each condition indicated a bilateral central-posterior activity for the P3 component. The period of positive deflection began at around 450 ms and shifted towards a negative deflection after 750 ms. Electrodes were selected for pooling according to which electrodes had the largest and most consistent positive deflections for all conditions: CPP1h, P1, P3 and PO3h (Left); CPP2h, P2, P4 and PO4h (Right). Due to the lack of a defined peak, only the mean area of activity was analysed, dividing the data into three 100 ms windows. A within-subjects ANOVA was conducted with the factors being target status (present/absent), distractor condition (same, opposite, absent), electrode group (contralateral or ipsilateral electrodes to the target/foil) and time window (450 - 550, 551 - 650, 651 - 750 ms). Irrespective of whether the analysis was carried out on pooled electrodes or with electrode site as an additional factor, target present trials generated a larger P3 response than target absent trials (an effect of 3.17 μV; $F(1, 11) = 48.69$, $p = .004$, $\eta^2 = .82$, for the analysis with electrodes as a factor; $F(1, 11)= 48.68$, $p < .001$, $\eta^2 = .82$, for the analysis with pooled electrodes; see Figure 10). There was also a consistent trend for an interaction between time window, target status and distractor (separate: $F(4, 44) = 2.70$, $p = .065$, $\eta^2 = .20$; pooled: $F(4, 44) = 2.70$, $p = .064$, $\eta^2 = .20$). There was a trend for the P3 on trials where the related distractor was absent to be greater than on trials where the related distractor was present (on either the same side or on the opposite side of fixation to the target/foil). This effect was larger on target present trials, though it tended to emerge at the longer time windows when the target was absent.

3.3. Discussion

This experiment examined the time course of semantic interference in visual search. The behavioural data show that the presence of a distractor that was semantically related to the expected target slowed RTs and it also tended to increase the error rates (particularly when the distractor was on the opposite side of space to the target, Experiment 1). This replicates the study of Moores et al. (2003), while also showing that the results hold even when eye movements are precluded. The EEG analysis demonstrated that the effects of the related distractor emerged at around 225 ms and influenced the magnitude of the N2pc component. The N2pc was greater when the related distractor fell on the same side of space as the target (or the foil, on target absent trials) than when it either fell on the opposite side of space or was absent. There were no reliable effects of the related distractor on the P1 and N1 components but there were some trends for effects on the P3 component.

The earliest components measured in this experiment, P1 and N1, showed no differences in activity according to the presence of the related distractor or even the target (on target present versus absent trials). Luck and Hillyard (1994) reported differences in both the P1 and N1 components on target present versus absent trials in a search task where targets could be discriminated from distractors by a simple feature. However, the present results indicate that, with complex pictorial displays, the differences between targets and distractors are not sufficiently discriminable to influence these early ERP components. Instead the data suggest that there needs to be more protracted processing of the displays (taking around 225 ms) for differences between the various pictures to be utilized.

In contrast to this, there were clear effects on the N2pc. In general the N2pc was greater on trials where the target was present relative to when it was absent. Given that target absent trials yield longer RTs, this result is consistent with the N2pc reflecting the ease of selecting the target rather than the difficulty of search per se. Previous studies indicate that the N2pc may reflect the attentional effects found in area V4 and the inferotemporal cortex of monkeys (see Hopfinger, Luck & Hillyard, 2004), with the N2pc increasing when the allocation of attention to one hemifield increases. This is the case when the target is present, and this effect of the target was further modulated by the presence of a semantically related distractor. Here the data suggest that attention is allocated to one hemifield more easily when both the target and the related distractor are there, compared with when the related distractor is either absent or on the opposite side of space. Interestingly, the magnitude of the N2pc was similar when the target was present without any related distractor (target present, distractor absent condition) and when the related distractor was present without the target and on the same side as the foil. This suggests that the selection of an item, and the orienting of attention to that stimulus, did not differ in these two cases – there was only a small gain to the specified target over a related distractor.

Although the N2pc was greater for trials when the related distractor appeared on the same side of space as the target, compared with trials where the related distractor was absent, RTs were slower. This indicates a discrepancy between the time taken to select a side of space for visual orienting and the time subsequently taken to select the target on the side initially selected. Although having the related distractor on the same side of space as the target facilitates the initial selection of that side, the presence of the related distractor then slows the selection of the target. This is not surprising, given that a related distractor will activate the target's template to some degree and hence create competition in the decision about whether the target is present or absent (cf., Bundesen, 1990). However, when the related distractor is on the same side as the target, there is additional evidence for stimuli on that side matching the template, leading to a stronger spatial bias in selection. The N2pc appears to represent this bias.

Following the N2pc component, the P3 was studied. The P3 may reflect aspects of target selection along with decision processes (Desmedt, 1981; Nieuwenhuis, Aston-Jones & Cohen, 2005). Our results showed that P3 activity from 450 to 750 ms decreased during target absent trials, in line with the P3 reflecting either the ease of target selection or the ease of making the final decision (target present decisions being easier than absent; see Chun & Wolfe, 1996). In addition, conditions where the distractor was present tended to have decreased activity compared to when the distractor was absent; consistent with target selection/decision making being easier when the semantic distractor was not competing with the target. The magnitude of any P3 effect was not sensitive to whether the related distractor appeared on the same or the opposite side of space relative to the target.

3.3.1. The visual search process

The present results suggest the following analysis of the process of searching for a target picture amongst pictures of distractor objects. For an initial 200 ms or so, visual analysis of the items proceeds in a manner that is relatively immune to the definition of an item as a target or distractor and also to whether any distractor is semantically related to the target for the search task. Following this, enough information is extracted from the items in the display to enable contact to be made with a template for the target, and for target selection to begin. This process is influenced by the presence of distractors that are semantically related to the target. We can conceptualise interference from a related distractor occurring in at least two ways. On one view there is a spread of activity from the template held for the target to templates for other, related items. These other templates may be activated by the related distractor, when present, creating competition between templates for selection. An alternative is that the template for the target is created in relatively abstract semantic terms, so that it is activated by distractors that are semantically related to the target (e.g., containing similar semantic features). This activation of a semantic template then leads to one stimulus being selected and this must then be subsequently verified in order for participants to make the correct response. There is some recent evidence suggesting that search may be directed by relatively abstract, semantic information held in working memory. Soto and Humphreys (2007) asked participants hold in mind a verbal label (e.g., red triangle) whilst they performed a visual search task. The search items (oriented lines) could appear within different shapes, one of which could correspond to the stimulus held in memory (the red triangle). Search times were strongly affected by the match between the verbal label and the search display, even though the memory stimulus was irrelevant to the search task. Soto and Humphreys proposed that there was relatively rapid semantic processing of search displays which allowed extracted features to be matched to a semantically specified template for the target. The same may hold here. Indeed, we note that the target in the present experiments was defined by a verbal label rather than an image, and this may encourage participants to use a relatively abstract template to guide search. It would be of interest to examine whether similar effects would arise if the target was defined by being a particular picture – effects based on matching information from the search display to a semantic template might decrease under this circumstance.

The present data also indicate that participants first select a side of space to orient to, rather than a specific item within that space, given that the N2pc effects varied according to whether the related distractor fell on the same or opposite side of space relative to the target. If there was selection of one item for search, rather than selection of the side of space, then it should have mattered less whether the related distractor (when present) was on the same or opposite side to the target. Rather the results suggest a hierarchical process in which the side of space is selected prior to selection of an object within that area. Whether this is dependent on the complexity of the stimuli and by the properties defining the target is another question for future research.

Our failure to find effects of the presence of either the target or the related distractor within the first 200 ms or so of the display stands at odds with recent work suggesting that at least some types of stimuli can make rapid contact with stored knowledge to direct search processes. For example, Bacon-Mace, Kirchner, Fabre-Thorpe and Thorpe (2007) have recently shown that there can be selection of a saccade to an animate target on one side of space when displays are exposed for just 40 ms under backward masking conditions. There are several differences between our experiment and theirs: They used full colour images of natural scenes, the targets were animate objects, and only two stimuli were presented per trial. It may be that the processing of animate objects, supported by more fully specified visual images, is sufficiently rapid to lead to selection within a shorter time period than that revealed here. Interestingly, Belke, Humphreys, Watson, Meyer and Telling (in press) used the same paradigm as that employed here and found that the effects of the semantic distractor was equally large when displays of 8 rather than 4 items were presented, suggesting that there is parallel extraction of the semantic features that may ‘drive’ the current effects. Hence the failure to find evidence here for selective responses to targets and related distractors within 200 ms was not because critical features cannot be extracted in parallel, but apparently any parallel processing needs to operate across this time period before target selection emerges.

Finally, at later stages of processing effects of target presence/absence arise (on the P3 component). The magnitude of the P3 may reflect the difficulty of the final decision process along with the ease of target selection. There were minimal effects on the P3 of whether related distractors were on the same or opposite side to targets. This suggests that, if there is a component of the P3 influenced by the related distractor, this does not reflect the selection of one side of space, but rather whether any selected item is the target or not.

CHAPTER THREE

DISTRACTED BY RELATIVES: EFFECTS OF AGEING AND FRONTAL LOBE DAMAGE ON SEMANTIC DISTRACTION[5]

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1. Introduction

In visual search participants are asked to give a response as to the presence or absence of a pre-specified target on the screen. Many theories assume that search is guided to a target by an “attentional template” held in working memory. Evidence for such a template comes from a number of sources. Chelazzi, Miller, Duncan and Desimone (1993) trained monkeys to make a saccade to an item in a search display that matched a stimulus held in working memory (using a match to sample task). They found that cells in the inferior temporal lobe responding to the cued item maintained their activity during the interval between the cue and the search display, with the cells then showing an enhanced rise in activation when the cued item re-appeared in the search display. Chelazzi et al. proposed that the activity maintained during the interval between the cue and the display represented a template that biased activity in earlier cortical regions to favour features consistent with the target.

Evidence from human search comes from a number of sources. For example, several investigators have reported that there are asymmetries in visual search, with some search tasks varying in difficulty according to which item is the search target and which the distractor (e.g., a large target vs. small distractors generates efficient search, whereas a small target amongst large distractors generates inefficient search; Wolfe 1998). Hodsoll and Humphreys (2001) showed that this search asymmetry was modulated by fore-knowledge of the target: The asymmetry was larger when participants knew what they were searching for relative to when they searched for a target that was the odd one out (see also Hodsoll & Humphreys, 2005, for similar evidence from orientation search asymmetries). Hodsoll and Humphreys proposed that the search asymmetry was partially dependent on the match between the stimulus and the search template (some stimuli are matched more quickly than others) and not just on bottom-up differences between the stimuli.

Moores, Laiti and Chelazzi (2003) provided other evidence for a template by assessing the effects of semantic distractors on search. They asked participants to search for a familiar target object (e.g., motorbike) and, on some trials, they presented semantic distractors in the display (e.g., motorbike helmet). They found that RTs were slowed on these trials. On target-absent trials in particular, the first eye movement tended to go to the semantically related distractor rather than to unrelated distractors. These data suggest that activation of a memory template for a target also excites the representations of related items, which can then in turn guide search to matching (but in this case, distractor) stimuli. The data from Moores et al. (2003) show that there is a spread of activation from one template to another and that this associative activation influences attention. In the present paper, we examine whether the semantic effects are mediated by the age of participants and whether frontal lobe lesions affect semantic distractor effects on selection.

1.1. Effects of ageing on search

Several groups have found that visual search is affected by ageing. Trick and Enns (1998), for example, compared feature and conjunction search in young and older adults. Whereas the slopes of the search functions for RTs were comparable for both age groups in feature search, older adults had a much steeper slope in conjunction search. Similar effects are found when eye movements are measured. Scialfa and Joffe (1997) reported that fixation durations during conjunction search were longer for older than younger adults (see also Ho, Scialfa, Caird & Graw, 2001). This suggests a problem in matching a selected stimulus to the memory template used to direct search. Consistent with this, Scialfa, Thomas and Joffe (1994) reported that older adults made more rechecks of searched areas of the display than young participants (see Maltz & Shinar, 1999). In addition to this, older adults may be slower at guiding their attention to stimuli. Madden (1990) cued participants to the location of the target in a visual search task, varying the interval between the cue and the display. The benefit from the cue occurred at a longer cue-display interval for old relative to young adults. These effects of ageing, though, can be counter-acted when the differences between targets and distractors are enhanced. Humphrey and Kramer (1997) examined search when stimuli were defined by three rather than two features, with targets differing from distractors by two rather than one property. No effects of ageing were found. Null ageing effects could be explained by theories of a cognitive reserve (see Whalley et al., 2004, for review) in some older adults, which limits the effects of aging and brain pathology due to recruitment of additional brain areas as compensation (neuroplasticity).

Given that both matching to a template and attentional guidance may become less efficient with ageing, it is possible that older adults may be strongly affected when search displays contain distractors that are semantically related to targets (cf., Moores et al., 2003). This follows because poor guidance could lead to a semantic distractor being selected when it falls closer than the target to a current fixation. In addition, inefficient matching to a template could make semantic distractors harder to reject. Strong effects of semantic distractor may also be predicted based on evidence that older adults tend to show increased effects of semantic distractors on other tasks.

For example, Connelly, Hasher and Zacks (1991) asked young and older adult participants to read passages of text that contained embedded distractor words, which could be semantically related or unrelated to the passage. Older adults were more affected than younger participants by the semantic distractor, with slower reading times and a poorer comprehension of the sentences when questioned after the task (see also Carlson, Hasher, Zacks & Connelly, 1995; Dywan & Murphy, 1996). Similarly, semantic priming effects tend to be larger in older than in younger participants (Cameli & Phillips, 2000; Laver, 2003; Laver & Burke, 1993; Myerson, Hale, Chen & Lawrence, 1997), though this result is not uncontroversial (see Burke, 1999; Duchek & Balota, 1993; Kemper & McDowd, 2006; Madden, 1988; Madden, Pierce & Allen, 1993; Phillips & Lesperance, 2003 for counter evidence). The effects of semantic distractor condition may be larger on older than on younger participants because of the generally slower information processing of the older participants (Salthouse, 1996), which increases any effect of spreading activation between semantic neighbours. Alternatively, it may be that degradation of the semantic distinctiveness of items could increase priming between neighbours (a mild form of the effect found in semantic dementia; see Chertkowet al., 1994; Chertkow, Bub & Seidenberg, 1989; Iragui, Kutas & Salmon, 1996). Whichever account is offered, we may expect stronger effects of semantic distractor condition for older than for younger participants. Two different effects could arise. One is that semantic distractors may exert a greater “pull” on attention (e.g., because it is a stronger competitor with the target template) for older participants. This should influence not only overall RTs but also the first eye movement made to displays. The second is that even if there are no effects on the selection of the distractor, the distractor could be harder to reject, once selected. This predicts no age effect on first eye movements, but longer fixation durations, longer RTs and perhaps also increased errors to semantic that to unrelated distractors.

1.2. Effects of frontal lobe damage on search

In addition to examining whether age increases semantic effects on search, we also assessed whether semantic effects were modulated by frontal lobe damage in neuropsychological patients. Adequate functioning of the frontal lobes is necessary for the mediation of visual search (de Fockert, Rees, Frith & Lavie 2004; for a review: Corbetta & Shulman, 2002; Kanwisher & Wojciulik, 2000). In an fMRI study of healthy participants, Donner et al. (2000) found that the frontal eye fields (FEF) showed increased activation during conjunction search when compared to feature search. FEF activation was linked to the selection of targets during search. This FEF requirement is supported by an rTMS study comparing feature and conjunction search in normal subjects. Muggleton, Juan, Cowey and Walsh (2003) found that magnetic stimulation over the FEF (TMS condition) led to more false positive errors during conjunction search when compared to when no magnetic stimulation was applied (no TMS condition). No differences were found between the TMS and no TMS conditions for the feature search task, and intermediate differences in error rates for an interleaved feature search task, where target and distractor items varied between trials. It was concluded that the FEFs were necessary in visual selection of the target, particularly when the target was not very salient.

Visual search performance is not restricted to the FEF region, however. A wider requirement of the frontal lobes has been implicated in singleton search using fMRI and working memory load experiments. In their fMRI experiment, Lavie and de Fockert (2006) found evidence for increased frontal activity during search for a target in the presence versus absence of an irrelevant singleton distractor. In a behavioural experiment, a working memory load task was introduced, where participants held a 5-digit string in working memory before carrying out a search task. Participants were required to manipulate those numbers afterwards. Here, the increased working memory load increased singleton interference compared to no load. Effective use of working memory to direct visual search is therefore dependent on the healthy operation of the frontal lobes.

Frontal lobe damage has been associated with poor performance in visual search. Kumada and Hayashi (2006) studied a patient with frontal-temporal lobe brain damage, YW, and compared his results to normal controls. Participants either searched for a target amongst non-targets (no singleton condition, where the target from the non-targets by orientation or colour) or for targets where a singleton distractor, defined by an irrelevant feature, was presented (the singleton condition, where the distractor differed from the target and non-targets by orientation or colour). YW's search RTs increased abnormally for the singleton compared to the no singleton condition. Kumada and Hayashi reported that YW's selection of the target over singleton features was faulty; YW was impaired at weighting the relevant target features over singleton features.

Zihl and Hebel (1997) also reported problems in the planning of dot pattern scanning in patients with frontal damage and linked this to a working memory deficit. Problems in task control based on the active maintenance of working memory representations could impact on search in various ways. For example, there might be less top-down control from a template of a target held in working memory, or there may be impaired representation of previous inspected locations so that search becomes more generally disorganized.

However, the requirement of frontal lobe functioning for competent search has not been observed universally. For example, Humphreys, Hodsoll and Riddoch (in press) reported no difference between patients with frontal lobe lesions and age-matched controls when search slopes were examined for feature and conjunction search tasks. They used brief presentation conditions, where working memory load may be reduced. The data suggest that search can be relatively normal when working memory is not loaded (see also Walker, Husain, Hodgson, Harrison & Kennard, 1998).

The relation between WM and visual search through small arrays was examined by Soto, Humphreys and Heinke (2006). Soto et al. found increased effects of irrelevant objects held in working memory on search in frontal patients compared with age-matched controls. They had participants hold an item in memory prior to carrying out a search task. The search task required participants to point to a tilted line target amongst vertical line distractors, and an irrelevant shape surrounded each line. Normal participants are influenced when the memory re-appears as a surrounding distractor in the search display; reactions to the target line are delayed and the likelihood that the first saccade goes to the target is reduced. Soto et al. reported that these effects were equivalent in frontal patients and controls, indicating that the influence of the working memory on the initial stages of selection was relatively preserved. Nevertheless, the patients made more errors when the memory item re-appeared around a distractor, and they were subsequently slower to select the target. This last result suggests that frontal lobe damage affected the ease of disengaging attention from a distractor, once it was selected. Soto et al. proposed that frontal patients had difficulty maintaining separate the template for the target from other information held in working memory. They were thus confused about whether they should respond to a selected item, even if it was a distractor.

If we extend Soto et al.'s (2006) results to the present situation, where we assess the effect of semantic distractors on search, then we may predict that (i) effects of the semantic distractor on the initial selection of stimuli should be unaffected by the lesion, and (ii) there may be impaired disengagement from an associated distractor, once selected. Thus the patients should not differ from older adult controls on first fixation behaviour, but RTs may be slower, fixation durations longer and more errors may arise when the patients select semantic distractors.

We report data from young controls, elderly controls and patients with frontal lobe damage. To address the influence of normal ageing on semantic effects in search, we report the results from normal young and elderly participants in Experiment 3. To address the effects of frontal lobe damage, we present the results from the elderly controls and frontal patients in Experiment 4.

2. Experiment 3: Effects of age and semantic distractors on search

2.1. Method

Table 5 *Experiment 3: Participant details.*

Measure	Young (n = 16, 5 males)		Young-old (n = 16, 5 males)		Old-old (n = 17, 3 males)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age	20.3	2.5	61.1	5.0	73.7	3.7
Vocabulary[a]	16.6	3.2	23.5	4.2	24.9	4.7
Age left school	18	0.0	17.1	1.1	15.9	1.3

[a] Raw scores on the multiple-choice section of the Mill Hill Vocabulary test (Raven, Raven and Court, 1998; maximum score = 33).

Participants. All participants gave their informed consent prior to taking part in the study. The young group comprised of sixteen students from the University of Birmingham, who participated in return for payment in cash or course credits. The older adult groups volunteered from the West Midlands region and were paid for their time. The older adults had reported themselves to be in good health, with no known neurological conditions. Both age groups were native British English speakers and were tested for 20/20 normal or corrected vision. Background details for participants are shown in Table 5. Vocabulary scores reflect increased levels of crystallized intelligence with age (see Craik & Bialystok, 2006). The handedness of the participants was not recorded.

Stimuli. The visual search display contained four objects, positioned at 12, 3, 6 and 9 o'clock on the visual array and at a distance of 7.4 degrees of visual angle (170 pixels) from the midpoint of the screen. All pictures were selected from Snodgrass and Vandervart (1980) and a picture gallery provided by the Max-Planck-Institute for Psycholinguistics, Nijmegen (NL All stimuli were black and presented on a white background. The stimuli were 100 by 100 pixels, with a horizontal and vertical resolution of 72 dpi, corresponding to 4.6 by 4.6 degrees of visual angle when viewed 60 cm from the monitor. Randomisation software was used to create the visual search arrays (StimulusGenerator, © D.G. Watson), with objects being randomly assigned to a screen quadrant.

Participants were presented with a target word, e.g., *bird*, followed by a four-object search array. Each of the four objects was taken from a set of 16 items, 64 in total: a target set, a semantic-competitor set, a semantic-associate set and an unrelated filler set (see Appendix 2). The items were chosen to minimise visual similarity between the stimuli and previous ratings with this set of items showed no differences in visual similarity between related and unrelated pairs (see footnote 2, Chapter 2).

In each block, half of the trials were target present (where the target object was in display), and the remaining trials were target absent (where the target was replaced by a foil randomly chosen from the target set). Two thirds of the trials also had a semantically related distractor present (in addition to the target or foil). Half of these related distractors were semantically associated to the target (e.g., *feather* for the target *bird*) and half were categorically related competitors to the target (e.g., *fish*). Associates held either a "part-whole" (e.g., *finger - hand*) or "tool-object" (e.g., *bow – arrow*) relationship with the target. Competitors were drawn from the same category members of the target. Synonyms or antonyms were not included. In the remaining third of trials, no related distractors were present. In this case, the related associate or competitor was replaced by an unrelated member of the associate or competitor set (foil). For example, Figure 11 shows a target-present, associate-present trial, with a member of the competitor set related to the target probe (*fish*) and a member of the associate set unrelated to the target probe (*key*), and the target (*bird*). Thus, each search display featured a member of the target set, a member of the associate set, a member of the competitor set and an additional filler object, which were semantically and phonologically unrelated to the remaining objects in the display.

This generated six conditions, with within-subjects factors of target status (present or absent) and distractor condition (associate-related, competitor-related and unrelated). One search array was produced per item, per condition, per block. There were 96 trials per block and four blocks in total (384 trials). Participants were exposed to all objects, four times per condition. Two different orientations of the object were used so that searching was not based on specific local features. Half of all stimuli in each block were in one orientation and half in the opposite orientation. In the target present condition, the search target was always shown in the same orientation as corresponding object in the search display. The experimental conditions were presented in a mixed order across participants.

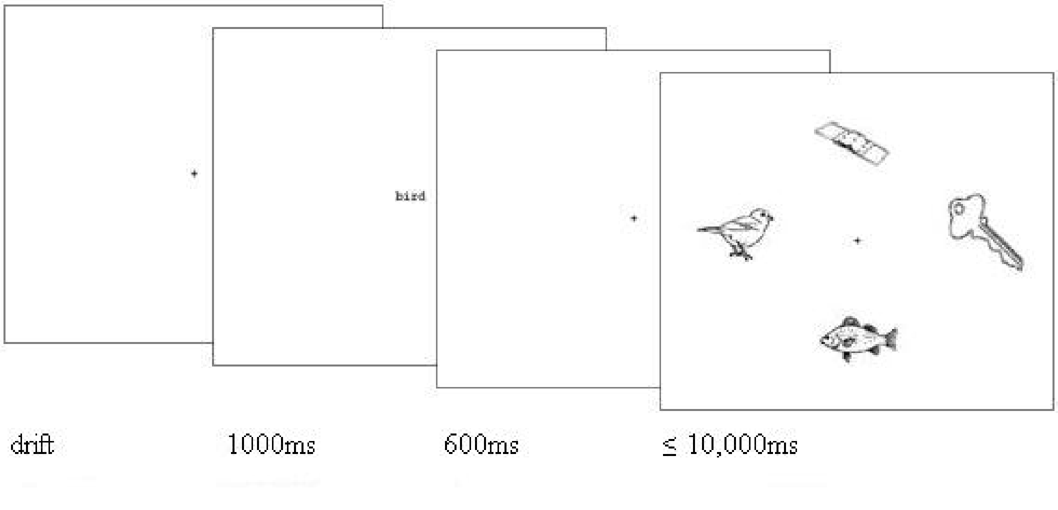

Figure 11. Example trial for Experiments 3 to 5, where the target is *bird* and the related distractor is *fish*.

Apparatus. The experiment was controlled using a Pentium IV (1.5 GHz) PC. The stimuli were displayed on a Triniton Multiscan G240 monitor (17”), with a screen resolution of 600 by 800 pixels. Eye movement data were processed using an Eyelink SensoriMotoric Instruments (SMI) v 2.04 head mounted eye-tracker from SR Research Limited.

Procedure. First, participants familiarised themselves with a picture booklet, containing pictures with names written beneath them for all stimuli used in the experiment. The participants assumed a suitable viewing position from the monitor (typically 60 cm) in the laboratory, which was dimly lit for the duration of the experiment. The eye tracker was positioned on the participant’s head, camera aligned so that one eye was in focus and the system calibrated. Eye position data were gathered from the right eye.

Each trial began with a fixation cross at the centre of the screen participants were asked to look at the cross so that drift correction could be made, correcting for any change in head position during the previous trial. The young adult participants managed drift correction themselves by pressing a button on their hand-held control pad whilst looking at the fixation point. However, for the older adult participants the experimenter managed drift correction. These participants were only required to fixate on the centre point and the experimenter chose when fixation was aligned correctly. Immediately after drift correction, the target word was presented in the centre of the screen for 1000 ms (e.g., “*bird*”) followed by a fixation cross for 600 ms. Next, a the search display was presented until the participant responded, for a maximum duration of 10 seconds. Participants were asked to search for the target picture amongst the four pictures on the screen (see Figure 11). The participants were instructed to respond by pressing the left green button of a hand-held control pad when the target was present and the right red button when the target was absent. Upon pressing the button, the next fixation point appeared (drift) indicating the start of a new trial.

The total time to run the experiment was 60 minutes, including 15 minutes for instruction and calibration and 45 minutes of testing (with breaks and optional removal of headset in between blocks included). Following the search task, participants completed Set B of the Mill Hill Vocabulary Scales and took part in a visual acuity test. Following completion of all tasks, participants were verbally debriefed.

Analyses. The first five trials of the first block were considered as practice and excluded from the data set. Incorrect responses accounted for a further 3.3% of responses. Outlying RTs were removed by eliminating those responses that were beyond three standard deviations from a participant's mean (1.9%).[6] A further reduction to the behavioural data set was made by coding any instances at display onset where eye gaze did not land in an area 2 degrees of visual angle around the centre of the screen (drift errors, 10.8%).[7] This prevented cases occurring where the participant's gaze was inclined towards one quadrant more than another because of the off-centre starting point. Correct responses only were selected and used as a basis for RT analysis and eye data preparation (85.3%).

Eye movement data were selected from correct trials only (i.e., 85.3% of the trials). The mean saccade durations (i.e., duration between offset from current fixation to onset of next fixation) were calculated for each group: on average, the

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[6] Young participants had more outliers than older adults: 3.9% (young adults), 1.0% (older adults)

[7] Older adults made more drift errors than young adults: 4.6% (young), 13.7% (older adults).

saccades made by young adults lasted for 55 ms and those for older adults lasted for 48 ms. In addition, gaze durations were calculated to include multiple fixations to the same object. Trials were excluded when gazes were not made to the middle region until after 150 ms (e.g., due to blinking so that eyes were not at the middle point at trial onset). The remaining trials were those that were initiated following a gaze to the middle region. Trials where no eye movement were made away from the middle region before making a response were coded and subsequently removed for the eye movement (but not for the behavioural analysis): 5.9% of trials.[8]

Offset time of gaze to middle region (time taken for eyes to leave the middle region after trial onset), the proportion and duration of first gazes (to the target, associate, competitor and unrelated filler) were analysed for each trial. First gazes were the proportion of first gazes made away from the middle region after trial onset to one of the four objects. On target absent trials, first gazes to the foil were studied. In the semantically unrelated trials, first gazes to the unrelated filler object were studied. Due to merging the semantic associate and semantic competitor object conditions, 50% of were selected from the unrelated associate set and 50% from the unrelated competitor set.

A split plot ANOVA, with a between-subjects factor of group (2 levels - young adults and older adults), within-subjects factors of target status (2 levels – target absent and target present) and distractor condition (2 levels – related, based on

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[8] Young participants had more trials where no eye movement made away from middle prior to response than older adults 14.3% (young), 1.4% (older adults).

averaging of associate and competitor distractor present conditions, and unrelated, where no distractor was present) was carried out on the subject means.[9]

2.2. Results

The main results can be summarised as follows:

The young adults made increased numbers of errors when the semantic distractor was present compared with when it was absent from the display. This was the only difference between the groups in their response to the semantic distractor. Although the older adults were slower overall to decide whether the target was present or absent, RTs for both groups were slowed to an equal degree when the semantic distractor was present. When directed to the target, the initial gazes of the older adults lasted longer than those of the young adults, although were no differences in gaze durations to the distractors. The presence of a semantic distractor increased the frequency and duration of first gazes to the distractor. These results will now be described in more detail, with the standard behavioural measures of search (error rates and RTs) followed by the analyses of eye movements.

2.2.1. Behavioural results

Error rates. Analyses of variance showed that more errors occurred on target present trials than on target absent trials (4.9% versus 2.1%: $F(1, 47) = 72.18, p < .001, \eta^2 = .61$), and on trials where related distractors were present compared with when the distractors were unrelated (3.8% versus 3.2%: $F(1, 47) = 3.97, p = .052, \eta^2 =$

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[9] Preliminary analyses of the data indicated that there were no differences between associate and competitor distractors (see also Belke et al., in press). Hence this difference is not highlighted and we use the term semantically related distractors to refer to both types of semantic relation.

.08). The distractor condition effect was greater for young than older adults, as shown by a significant interaction between group and distractor condition (*F*(1, 47) = 4.09, *p* = .049, η^2 = .08). When broken down between groups, only the young adults yielded a main effect of distractor condition, with a 1% difference between related and unrelated conditions (*F*(1, 15) = 9.22, *p* = .008, η^2 = .38).

Table 6 *Experiment 3: Mean RTs (ms) across the age groups, with SEM in parentheses.*

Target status	Distractor	Young adults	Older adults
Target present	Related	803 (43)	918 (30)
	Unrelated	791 (38)	896 (27)
Target absent	Related	1018 (64)	1185 (44)
	Unrelated	969 (62)	1136 (43)

RTs. Analyses of variance showed that older adults took longer to respond than young adults (1034 ms versus 895 ms: *F*(1, 47) = 5.09, *p* = .029, η^2 = .09). Both groups showed slower RTs during target absent than present trials (1077 ms versus 852 ms: *F*(1, 47) = 166.58, *p* < .001, η^2 = .78); and during semantically related than unrelated distractor trials (981 ms versus 948 ms: *F*(1, 47) = 39.14, *p* < .001, η^2 = .45). The effect of the distractor condition was most pronounced during the target absent trials, as shown by a significant interaction between target status and distractor condition (*F*(1, 47) = 8.31, *p* = .006, η^2 = .15). When broken down between target present and target absent conditions, both states yielded a main effect of distractor condition, though to differing degrees (17 ms difference during target present trials: *F*(1, 47) = 8.67, *p* = .005, η^2 = .15; 49 ms difference during target absent trials: *F*(1, 47) = 39.42, *p* < .001, η^2 =.45).

2.2.2. Eye movements

The results obtained from one older participant were excluded from the eye movement analysis due to a high proportion of missing cases, which affected the calculation of the rate and duration of first gazes to the target and distractor.

Offset of gaze from middle region. Analyses of variance yielded a main effect of target status only ($F(1, 47) = 17.77$, $p < .001$, $\eta^2 = .27$). The time taken to initiate the first gaze away from the middle region was longer for target absent than present trials (240 versus 230 ms).

First gaze to the target. Analyses of variance yielded no significant main effects or interactions. The average first gaze to the target was made 52% of the time.

First gaze to the distractor. There were significant main effects of target status ($F(1, 46) = 129.93$, $p < .001$, $\eta^2 = .74$) and distractor condition ($F(1, 46) = 56.92$, $p < .001$, $\eta^2 = .55$). There were no interactions. There were more initial saccades to related distractors (26%) than to unrelated distractors (21%), and more on target absent (29%) than target present trials (19%). These effects did not vary with age.

First gaze duration to the target. Analyses of variance showed a main effect of group ($F(1, 46) = 8.30$, $p = .006$, $\eta^2 = .15$). There were no interactions. First gazes to the target were of a longer duration for the older than the young adults (379 versus 306 ms).

First gaze duration to the distractor. Analyses of variance yielded significant main effects of target status ($F(1, 46) = 60.78$, $p < .001$, $\eta^2 = .57$) and distractor condition ($F(1, 46) = 16.36$, $p < .001$, $\eta^2 = .26$). Gazes were longer to related (170 ms) than to unrelated distractors (156 ms), and they were longer on absent (177 ms) than present trials (149 ms). There were no significant interactions.

2.3. Discussion

As is typically the case in visual search, target present RTs were faster than target absent RTs. In addition, the time to initiate search (the time to offset gaze from the centre) was reduced on target present relative to absent trials. Thus targets exerted a greater pull on attention than distractors. In addition, there were effects of the distractor condition on search. Semantically related distractors slowed RTs and increased error rates, particularly during target absent trials. The frequency and duration of first gazes were also increased to the related distractor relative to unrelated distractors. This supports the findings of Moores et al. (2003) in demonstrating a semantic interference effect on search. The semantic interference effect can be accounted for in at least two ways. One suggestion is that there is a spread of activation from the target's representation in long-term memory to the representations of semantically related distractors. The "template" activated for related distractors then competes with the "template" for the target, disrupting target selection (see Duncan & Humphreys, 1989). An alternative is that the "template" for the target is not specified purely in terms of the target's visual features, but rather also includes information about the semantic properties of stimuli. If semantic features are derived from the related distractor, then these may draw attention to the distractor rather than the target, slowing target selection.

2.3.1. Search as we get older

Interestingly, none of the above effects were differentially affected by increasing age; there were main effects of age on performance, however. Older adults were significantly slower to respond than the young participants (100 ms difference) and they gazed at the target for longer than the young adults (see also e.g., Scialfa &

Joffe, 1997). This may reflect the older adults adopting a more cautious search strategy – an argument supported by the smaller error rate in the older adult group. However, unlike some studies, we did not find any greater effect of ageing on RTs for absent compared with present trials (cf., Hommel, Li & Li, 2004). This might reflect the small display sizes used here, where any re-checking processes were minimized.

The overall lengthening of RTs in older adults is consistent with the general slowing account of ageing (Salthouse, 1996), though it should be noted that specific effects on memory or on inhibitory effects in search might also have been masked by the small display sizes. The older adults also gazed for longer durations at the target, which is also indicative of a poorer focus of attention with age (Greenwood & Parasuraman, 2004, Madden, 1990; Trick & Enns, 1998), and there may also be slowed target recognition (Viggiano, Righi & Galli, 2006). Importantly, there was no evidence that semantic interference increased with age. Hence there was no indication of semantic effects increasing in size because of the generally slower processing of information by the older adults, and there was no indication of semantic effects increasing due to a loss of semantic distinctiveness between targets and related distractors (cf., Chertkow et al., 1994)[10].

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[10] It should be noted that the older adults recruited had particularly high levels of education and crystallised intelligence (see Table 5). Such factors can be contributory factors to an increased cognitive reserve and higher cognitive ability, limiting the effects of aging that may have been found if older adults from a different educational background were studied (Stern, 2003).

3. Experiment 4: Effects of frontal lobe damage and semantic distractors on search

In Experiment 4 we examined search in a group of patients with damage to the frontal lobe. The data from the patients were compared with those from the older adults, in Experiment 3.[11]

3.1. Method

Participants. The patient group comprised of eight right-handed patients with a range of lesions, but all including damage to the frontal cortex (see

Figure 12 and Table 7). There were four patients with unilateral right hemisphere damage (JQ, AS, TT and PW), and two with unilateral left hemisphere damage (PH and DS). In these cases, damage was to lateral areas of frontal cortex. There were also three patients with bilateral medial frontal damage (GA, FK and SP). In seven patients, the damage extended to and included the temporal lobes (the exceptions being DS and TT). The patients were between 32 and 73 years old (mean age 57, all males). All patients had normal or corrected-to-normal vision. All patients gave their informed consent prior to taking part in the study.

The older adult group was derived from Experiment 3, i.e., sixteen young-old adults (mean age 62, 5 males) and seventeen old-old adults (mean age 74, 13 males). These groups were merged to create the older adult group (see Experiment 3).

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[11] Note that the older adults were, if anything, older than the patients. This contrast, then, represents a cautious treatment of the data. If the patients are worse than the controls, then it reflects the effect of the lesion over and above any effects of age.

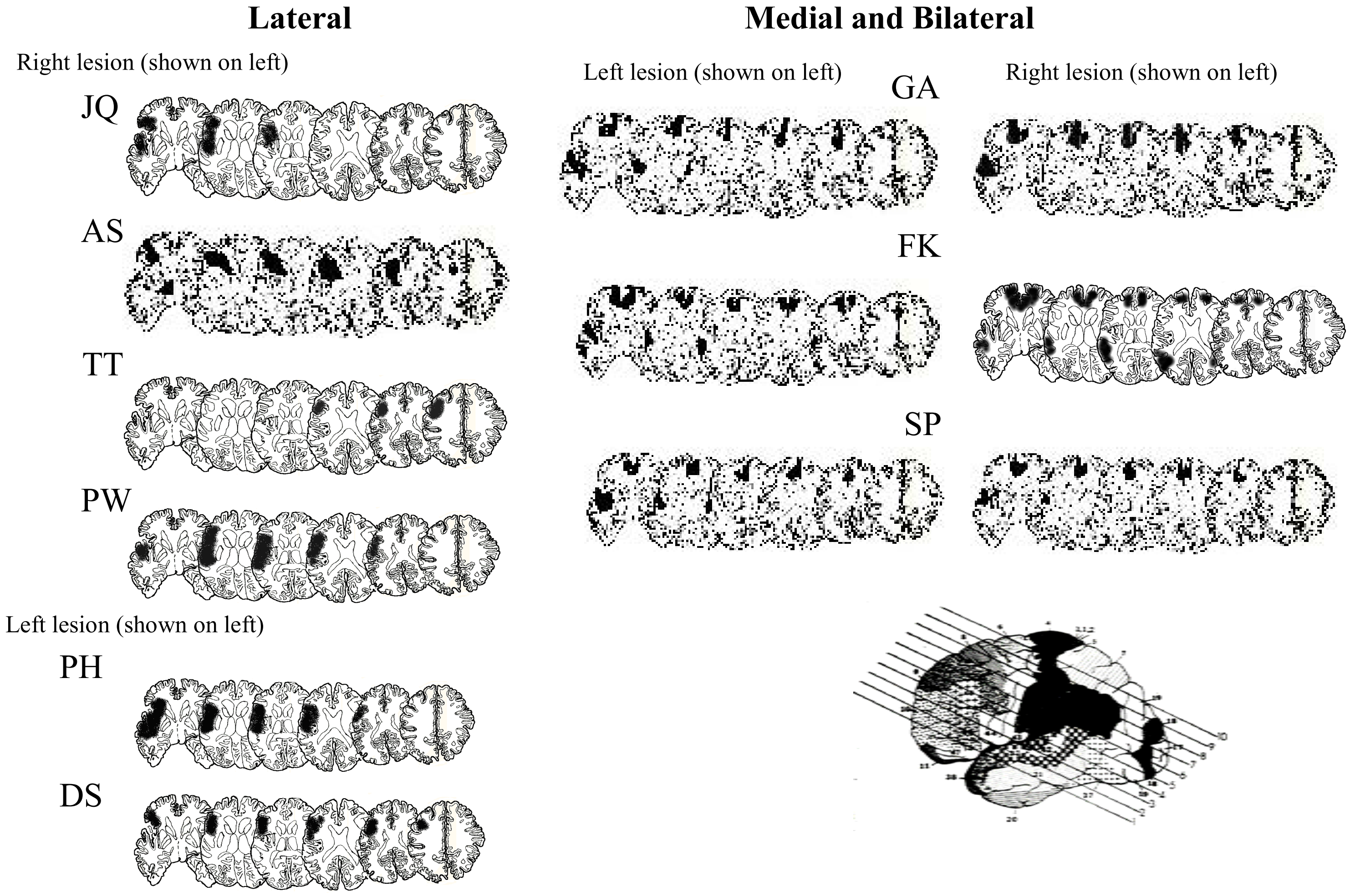

Figure 12. Lesion reconstructions for the patients from their MRI scan. Lesions have been drawn onto standard slices from Gado, Hanaway and Frank (1979). The bottom right figure shows the 10 slices used. Only slices 3 to 8 are depicted here.

Table 7 *Experiment 4: Patient list, including lesion site and clinical details.*

Patient	Sex/Age/ Handedn.	Years post lesion	Main lesion site – frontal –	Aetiology	Clinical deficit	NART IQ equiv.**	Brixton test raw score†	Pyramids & palm trees visual*	Pyramids & palm trees auditory*	Corsi blocks	Digit span F (B)
JQ	M/59 /R	3	Right frontal and temporal	Stroke	Elements of dysexecutive syndrome	115	26	50	50	3	5(3)
AS	M/70 /R	4	Right middle frontal gyrus and medial temporal cortex	Stroke	Impaired sustained attention, left extinction	102	26	50	50	5	6 (4)
TT	M/67 /R	2	Right middle frontal gyrus	Stroke	Impaired working memory and dual task performance	110	21	51	51	4	5 (3)
PW	M/73 /R	5	Right inferior and middle frontal gyri, right superior temporal gyris	Stroke	Aspects of dysexecutive syndrome	105	27	50	49	3	5 (3)
PH	M/32 /R	5	Left medial and superior temporal, left inferior and middle frontal gyri	Stroke	Non-fluent aphasia, deep dyslexia, impaired verbal short term memory	80	21	49	50	2	2(0)
DS	M/72 /R	14	Left inferior, middle and superior frontal gyri	Stoke	Non-fluent aphasia, impaired verbal short term memory	105	20	48	48	3	4 (4)
GA	M/51 /R	12	Bilateral medial and anterior temporal lobes extending into left medial frontal region	Herpes simplex enceph.	Aphasia, amnesia, category specific recognition disorder, aspects of dysexecutive syndrome*	102	20	40	41	4	6 (2)
FK	M/37 /R	12	Bilateral, superior and medial frontal regions; bilateral superior and medial temporal gyri, bilateral lateral occipital gyri	Anoxia	Agnosia, aphasia, dysexecutive syndrome*	112	38	36	37	4	5 (4)
SP	M/52 /R	11	Bilateral damage to middle and anterior temporal regions extending into the frontal lobes	Herpes simplex enceph.	Amnesia, category specific recognition disorder, aspects of dysexecutive syndrome*	110	20	42	40	5	8 (5)

* *FK, GA and SP all have some problems with Pyramids & Palm Trees, a test of semantic access from words and pictures - and thus some recognition difficulties.*
***The NART (Nelson & Willison, 1991) is a reading test that provides a IQ-related score. PH's performance on this test was hampered by the presence of a significant reading deficit (respectively deep and neglect dyslexia), which lowered his score. PH was a law graduate. GA and SP both presented with some degree of surface dyslexia (PALPA reading test regular words both 30/30, irregular words 24 and 25/30 respectively). No other patients had any reading difficulty.* † *The Brixton test of executive function (Burgess & Shallice, 1997) provides a measure of non-verbal executive function. A raw score above 26 indicates a clinical abnormality.*

Procedure. The procedure was identical to Experiment 3, except for the following additions: (i) Prior to the experiment, the experimenter explained the task verbally. The patients were also asked to go through and name each of the pictures in the picture booklet, which had the names written beneath. Any mistakes were corrected. The opportunity to re-name any picture was offered, if the patient wanted to double-check any of the names. (ii) The experimenter managed the patient's drift control. (iii) The hand held control pad was responded to using the left and right coloured buttons. Whereas most participants responded with a one finger from their left and one from their right hand, PW responded using their active hand only, due to hemiparesis. (iv) The patients carried out blocks within testing sessions of up to one hour. Four blocks of data were gathered for each patient over a number of sessions. (v) To assess whether all the patients could recognize the stimuli, the patients were shown all target-distractor pairs of pictures used in the visual search experiment and were asked to point at the target picture. The distractors were either related (semantic competitor or associate) or unrelated to the target picture. No time limit was given. The pairs were presented in a randomised order. All of the patients pointed to the target on at least 93% of the trials. All patients could identity all of the target objects used in this experiment.

Analyses. The data were prepared in the same way as for Experiment 3. Incorrect responses accounted for 14.9% of patient responses. The outlying RTs were removed (1.3%) along with drift errors (16.5%). Correct responses only were selected and used as a basis for RT analysis and eye data preparation (70%).

Saccades for the patients lasted for 59 ms on average. Six patient trials were excluded where gazes were made to the middle region after 150ms. Trials were removed where no eye movement was made away from the middle region before making a response: 3.0% of patient trials. The remaining fixations for further eye analysis were merged with the correct trials data, eliminating all eye errors, which left 87% of correct trials for the patients.

Split plot ANOVAs were carried out on the subject means, with a between-subjects factor of group (two levels), within-subjects factors of target status (2 levels) and distractor condition (2 levels).

3.2. Results

The results can be summarised as follows:

Relative to the older control participants, the frontal patients showed a stronger effect of semantic distractors on errors, with increased numbers of false positive responses when the semantic distractor was present rather than absent. On error trials, the RTs of the patients were slower when the semantic distractor was present rather than absent. There was no effect of distractor condition on RTs on correct response trials, although the patient group responded much more slowly than the controls. The first gaze durations of the patients to the target were shorter when the semantic distractor was present rather than absent, while the older adults showed no effect of the distractor on this parameter. Both groups gazed for longer at the semantically related relative to the unrelated distractor on target present trials only. The size of this effect was slightly larger for patients versus controls. There were no semantic effects on the time to offset fixation or on the percentage of first gazes to either the target or the distractor. However, the controls made more first gazes to the target, and fewer gazes to the distractor (regardless of whether the distractor was semantically related to the target).

Table 8 *Experiment 4: Mean error rates (%) by the control and patient groups, with SEM in parentheses.*

Target status	Distractor	Older adults	Patients
Target present	Related	4.5 (0.6)	16.2 (1.2)
	Unrelated	4.6 (0.9)	17.2 (1.6)
Target absent	Related	1.5 (1.0)	15.5 (2.0)
	Unrelated	1.3 (0.5)	8.7 (1.0)

3.2.1. Behavioural results

Error rates. Analyses of variance showed the patients making more errors than controls (14.4% versus 3%: $F(1, 40) = 10.72, p < .001, \eta^2 = .72$); there were more errors during target present than absent trials (10.6% versus 6.8%: $F(1, 40) = 16.19, p < .001, \eta^2 = .29$) and more errors during related than unrelated distractor conditions (9.4% versus 8%: $F(1, 40) = 6.92, p = .012, \eta^2 = .15$). There were significant interactions between distractor condition and group ($F(1, 40) = 6.99, p = .012, \eta^2 = .15$), target status and distractor condition ($F(1, 40) = 13.35, p = .001, \eta^2 = .25$) and a 3-way interaction between target status, distractor condition and group ($F(1, 40) = 11.52, p = .002, \eta^2 = .22$). Separate analyses of variance were performed for target present trials and target absent trials. Target present analysis showed a significant effect of group only ($F(1, 40) = 74.07, p < .001, \eta^2 = .65$). Target absent analysis yielded main effects of group ($F(1, 40) = 46.17$ $p < .001, \eta^2 = .54$), distractor condition ($F(1, 40) = 20.86, p < .001, \eta^2 = .34$) and an interaction between the two factors ($F(1, 40) = 19.26, p < .001, \eta^2 = .33$). This interaction was broken down by looking at the patient and older adult groups separately for target absent trials, running an analysis of variance with a within-subjects factor of distractor condition only. The patient group alone showed a main effect of distractor condition ($F(1, 8) = 6.42$, $p = .035$, $\eta^2 = .45$), with a greater number of errors during target absent related (15.5%) than unrelated (8.7%) trials.

RTs for correct responses. Analyses of variance showed the patient group responding more slowly than the controls (2440 ms versus 1034 ms: $F(1, 40) = 49.72$, $p < .001$, $\eta^2 = .55$) and slower RTs during target absent than present conditions (1983 ms versus 1491 ms: $F(1, 39) = 115.20$, $p < .001$, $\eta^2 = .74$) only. The distractor condition had no reliable effects across the groups. There were no interactions.

RTs for incorrect responses. The incorrect responses for the patients were also analysed. Analyses of variance found a significant difference between incorrect responses when related distractors were present than when absent (3323 ms versus 2976 ms: $F(1, 8) = 8.73$, $p = .018$, $\eta^2 = .52$).

3.2.2. Eye movements

Offset of gaze from middle region. Analyses of variance showed that there were longer gazes to the middle region on target absent (244ms) compared to present trials (237 ms) only ($F(1, 40) = 5.36$, $p = .026$, $\eta^2 = .12$). There were no interactions.

First gaze to the target. Analyses of variance showed that the controls made more first fixations to the target than the patients (53% versus 36%: $F(1, 40) = 23.92$, $p < .001$, $\eta^2 = .37$). There were no significant differences between the other variables.

Table 9 *Experiment 4: Mean first gazes to the distractor (%) by the control and patient groups, with SEM in parentheses.*

Target status	Distractor	Older adults	Patients
Target present	Related	20 (0.8)	26 (1.5)
	Unrelated	15 (0.8)	20 (1.6)
Target absent	Related	32 (0.9)	31 (1.7)
	Unrelated	26 (0.6)	26 (1.2)

First gaze to the distractor. The patients made more fixations than the controls (26% versus 23%: $F(1, 40) = 7.27, p = .010, \eta^2 = .15$), with both groups making more first gazes to the distractor during target absent than present trials (29% versus 20%: $F(1, 40) = 76.20, p < .001, \eta^2 = .66$), and for the related relative to the unrelated distractor condition (27% versus 22% $F(1, 40) = 40.02, p < .001, \eta^2 = .50$). There was a significant interaction between target status and group ($F(1, 40) = 11.40$, $p = .002, \eta^2 = .22$). When this was broken down between target present and absent trials, only target present trials showed a main effect of group, with patients looking to distractors more frequently than the controls (23% versus 18%: $F(1, 40) = 15.45, p < .001, \eta^2 = .28$). There was no difference in the distractor condition effects between the groups.

Table 10 *Experiment 4: Mean duration of first gazes to the target (ms) during target present trials only, by the control and patient groups, with SEM in parentheses.*

Distractor	Older adults	Patients
Related	383 (16)	421 (31)
Unrelated	375 (16)	460 (30)

First gaze duration to the target. Analyses of variance found a main effect of distractor condition ($F(1, 40) = 5.21, p = .028, \eta^2 = .12$) and a reliable interaction between group and distractor condition (*F*(1, 40) = 11.84, *p* = .001, η^2 = .23). When broken down between the groups, a borderline effect of distractor condition was shown for patients only (Patients: *F*(1, 8) = 4.67, *p* = .063, η^2 = .37; Older adults: *F*(1, 32) = 2.26). For the patients, gazes to the target on related trials were 39ms quicker than on unrelated trials. There was no effect of distractor condition for the controls.

Table 11 *Experiment 4: Mean duration of first gazes to the distractor (ms) by the control and patient groups, with SEM in parentheses.*

Target status	Distractor	Older adults	Patients
Target present	Related	153 (7.3)	252 (13.9)
	Unrelated	130 (5.5)	199 (10.5)
Target absent	Related	183 (6.3)	236 (12.1)
	Unrelated	170 (6.5)	235 (12.4)

First gaze duration to the distractor. The patients gazed at distractors for longer than the controls (231 ms versus 159 ms: *F*(1, 40) = 43.41, *p* < .001, η^2 = .52), with both groups gazing for longer on target absent than on present trials (206 ms versus 184 ms: *F*(1, 40) = 14.84, *p* = .001, η^2 = .27), and on trials when there was a related rather than an unrelated distractor (206 ms versus 184 ms: *F*(1, 40) = 22.28, *p* < .001, η^2 = .36). Significant interactions occurred between target status and distractor condition (*F*(1, 40) = 13.43, *p* = .001, η^2 = .25), between target status and group (*F*(1, 40) = 4.55, *p* = .039, η^2 = .10) and there was a 3-way interaction between all of the factors (*F*(1, 40) = 6.87, *p* = .012, η^2 = .15).

The three-way interaction was broken down by comparing the target present and target absent trials separately. Target present trials yielded a significant main effect of distractor condition only (203 ms versus 165 ms with related relative to unrelated distractors: *F*(1, 40) = 27.56, *p* < .001, η^2 = .41). There was no interaction between distractor condition and group, though the effect of the distractor condition tended to be larger for patients (53 vs. 23 ms). Target absent trials yielded no effect of distractor condition and no interaction between group and distractor condition.

3.3. Discussion

In Experiment 4, the frontal patients as a group performed differently from the older controls in the following ways:

(a) The patients made more false positive errors during related than unrelated trials.
(b) The patients' incorrect responses took longer on related relative to unrelated trials.
(c) The patients made fewer first gazes to the target overall.
(d) The patients made more first gazes to distractors (regardless of the distractor condition), particularly on target present trials.
(e) The patients' gazes to targets tended to be quicker on trials where related distractors were present.
(f) The patients made longer lasting first gazes to related relative to unrelated distractors, particularly on target present trials.

These data indicate that the frontal patients were more vulnerable to competition from semantic distractors, when compared with the elderly controls. This had a clear impact on the ability of the patients to reject a semantic distractor once it had been selected; leading to increased error rates when a semantic distractor was present and the target was absent. Analysis of RTs for incorrect responses only highlighted the distinction between the effects of semantically related and unrelated distractors on the patient's decision making. Incorrect RTs were longer on related relative to unrelated trials, illustrating the competition between the target and the related distractor prior to the response. In addition, during correct responses, the patients showed longer gaze times to related distractors than the controls, when targets were present. These results fit with those of Soto et al. (2006), who reported that patients with frontal lobe damage were strongly affected by attending to distractors matching an item held in working memory, finding it difficult to reject such distractors once they were selected.

However, the initial selection processes did not appear to differ between the patients and the controls. The time to offset fixation may be taken as a measure of initial selection. There was no difference between groups, regardless of the distractor condition. There was also no evidence for problems due to initial first selection of the related distractor (indexed by the proportion of first gazes to related distractors), with patients showing an equivalent pattern to the controls for gazes to the related compared to the unrelated distractors. Instead, patients made a lower proportion of first gazes to the target (regardless of distractor condition) and a higher proportion of first gazes to both related and unrelated distractors than the controls, suggesting a weaker general control of attention during the search task.

Table 12 *Experiment 4: Mean error rates (%) by the two lesion groups of the patients, with SEM in parentheses.*

Target status	Distractor	AC / AT	Lateral	Older adults
Target present	Related	20.5 (3.0)	14.1 (2.1)	4.5 (0.6)
	Unrelated	17.3 (5.3)	17.3 (3.8)	4.6 (0.9)
Target absent	Related	27.8 (5.3)	9.3 (3.8)	1.5 (1.0)
	Unrelated	13.3 (2.6)	6.3 (1.8)	1.3 (0.5)

Table 13 *Experiment 4: Mean first gazes to the distractor (%) by the two lesion groups of the patients, with SEM in parentheses.*

Target status	Distractor	AC / AT	Lateral	Older adults
Target present	Related	29 (2.7)	24 (1.9)	20 (0.8)
	Unrelated	17 (1.8)	22 (1.3)	15 (0.8)
Target absent	Related	32 (3.1)	30 (2.2)	32 (0.9)
	Unrelated	25 (1.8)	26 (1.3)	26 (0.6)

Although we have presented the frontal patients as a single group, it should be borne in mind that the patients had a diverse set of lesions. While the majority of the patients had relatively lateral lesions affecting ventro- or dorsolateral prefrontal regions (the lateral group, Figure 12), three patients (SP, FK and GA) had damage to the anterior cingulate plus also damage to anterior temporal regions (the AC/AT group). Although the patients showed impairments as a group, an analysis of sub-groups of the patients indicated that the patients with AC/AT damage were particularly affected by the related distractor. This difference was most pronounced for the error data, with the AC/AT patients being particularly prone to making false positive responses to related distractors on target absent trials. A sub-analysis revealed an interaction between distractor condition and sub-group for errors ($F(1, 7) = 16.66$, $p = .005$, $\eta^2 = .70$). While the lateral sub-group also showed an effect of related distractors on errors when compared to controls (effect size 3.0% vs. 0.2%), this effect was particularly large for the AC/AT sub-group (effect size 14.5%) (see Table 12). This fits with the arguments that the AC is involved in error monitoring (Carter, et al., 1998; Blasi et al., 2006). The data suggest that patients with AC/AT damage have difficult in refraining from responding to a related stimulus that they have experienced a strong orienting response to.

Furthermore, this group all show difficulties with the Pyramids and Palm Trees standardised test, and so, with recognition (see comments below Table 7). It still could be that the difficulty in recognition led to more errors when the AC/AT patients oriented to the distractor rather than the target, when compared to the lateral and older adult group. This is especially so if their lesion also resulted in problems in error monitoring.[12]

However, the propensity to make an orienting response to the related distractor (e.g., as indicated by the tendency to saccade to related distractors) did not differ significantly across sub-groups of patients. The interaction between distractor condition and sub-group failed to reach significance ($F(1, 7) = 4.85$, $p = .063$, $\eta^2 = .41$), although there was a trend for an increased proportion of first gazes to the related distractors by the AC/AT patients compared to the lateral sub-group (effect size, 10% vs. 3%; see Table 13), with both sub-groups showing a main effect of distractor condition, in addition to the elderly control group (who had an effect size of 6%). Thus, the effects of semantic competition on orienting were not strikingly abnormal in either frontal group, compared with the controls, but the monitoring of the error in orienting to the distractor was more specifically deficient in the AC/AT patients.

Given that the patients showed a good ability to identify targets when the pictures were screened, the cause of increased distractor interference for the AC/AT sub-group cannot simply be attributed to poor target recognition (indeed the patient who made most errors in the screen test was in the lateral rather than the AC/AT sub-group). Also, consider the finding that there were decreased gaze times to targets for the frontal patients when the distractor was present. This is more consistent with the patients being more affected by semantic activation between related items rather than

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[12] In addition, these three patients are non-stroke cases and have bilateral anterior temporal damage (associated with semantic dementia). It is possible that recognition problems in the Pyramids and Palm Trees (see Table 7) is indicative of semantic problems, which, combined with error monitoring trouble, has impacted on their task performance moreso than the lateral patient group.

target recognition being impaired. When the target is selected, this increased activation may facilitate the ‘present’ response. When the target is not present, however, it may lead to false positive errors (where differences between both sub-groups of patients and elderly controls were shown). In addition, first gazes were proportionately lower to targets and higher to distractors (related and unrelated) in the patient group relative to the control group. This suggests a weaker control of search towards targets over other objects on the screen for the patients, despite no difficulty in recognizing the targets once they found them.

4. General discussion

We replicated the effects of a semantic distractor on target selection, as shown by higher error rates, longer RTs and more frequent and longer lasting first gazes to the distractor during trials where the distractor was related rather than unrelated to the target. Such changes are consistent with search being affected by spreading activation between templates of targets, or with participants searching on the basis of semantic descriptions of targets. These semantic descriptions are activated by distractors semantically related to targets as well as by target themselves.

One implication of this study concerns the level of activation that occurs during search prior to participants initiating their first saccade. The disruptive impact of related distractors, which attracted the first gaze more frequently than unrelated distractors, provides evidence for parallel access to semantic information from objects. Semantic properties are activated quickly enough to influence first eye movements in displays, supplementing findings in previous work by Moores et al. (2003). These effects held across the different groups of participants.

We also confirmed that older adults were slower to carry out search than young adults. Effects were found on RTs and first gaze durations to the target, consistent with processing speed generally being slower for older adult participants (Salthouse, 1996). Despite this, there was no evidence for the effects of semantic distractors being larger on the older adults than the younger adults. This fits with data where semantic priming has been shown to be additive with effects of ageing (e.g., Laver & Burke, 1993). The data suggest that access to semantic knowledge is relatively normal in older adults.

The data from the frontal patients indicated that the patients were more affected by semantic distractors than older control participants. This was not due to impaired recognition, as pair-wise matching data showed that patients were successful at identifying the target over related and unrelated distractor pairs. The effects of related distractors manifested themselves particularly on 'late' errors (false positives to related distractors on target absent trials, longer incorrect RTs and first gaze durations to distractors during related than unrelated trials). In addition, the frontal patients were overall less likely to initially fixate the target, suggesting a weaker overall control of spatial orienting. Patients with AC/AT damage showed particularly strong effects on errors, consistent with these patients having a problem in monitoring whether an orienting response is correct or not. The data indicate that the effects of semantic competition on target selection are not increased after frontal lobe damage, suggesting that semantically-based competition between targets and distractors may take place in more posterior brain regions associated with semantic representation (e.g., see Price & Friston, 2002, for one overview).[13] On the other hand, the frontal lobes do seem involved in keeping separate information about the item that should be selected (the specified target) from other information that may be activated during a task (e.g., if "templates" for semantically related stimuli become activated along with the "template" for the target). Hence frontal patients have difficulty rejecting semantically related distractors that have been selected (see also Soto et al., 2006). The frontal lobes seem critical for maintaining task-relevant goals independently of other information that may enter working memory during task performance.

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[13] It might be noted that there was tendency for the first gaze to go more often to a related distractor for the AC/AT group than for the other frontal patients and the older controls (Table 13). On the other hand, these patients also had damage to anterior temporal cortices, which may heighten initial semantic competition for selection.

CHAPTER FOUR

NEUROPSYCHOLOGICAL EVIDENCE FOR IMPLICIT SEMANTIC DISTRACTION IN SEARCH

1. Introduction

There is now considerable evidence that attention is controlled by a fronto-parietal network, which modulates the processing of visual information in the brain (e.g., Corbetta et al., 1998; Corbetta, Miezin, Shulman & Petersen, 1993). Hopfinger, Buonocore and Mangun (2000) used fMRI to study the effect of a spatial cue (directing participants to the left or right side of the screen) on search for presence or absence of grey checks in a checkerboard, presented bilaterally to the participant. BOLD responses to the cue should reflect the top-down control signals in preparation for the target, whereas BOLD responses to the target should reflect the consequential visual processing of this stimulus. Hopfinger et al. reported cue-based responses from the fronto-parietal areas (left superior frontal gyrus, bilateral midfrontal gyrus, bilateral superior parietal lobule, bilateral inferior parietal sulcus and superior temporal gyrus) followed by target-based responses from extrastriate areas of the visual cortex (see also Corbetta, Kincade, Ollinger, McAvoy & Shulman, 2000; Pessoa, Kastner & Ungerleider, 2003, for review). The evidence suggests that fronto-parietal regions prime activity so that there is referential visual processing of attended targets in visual cortex.

1.1. Changes in visual attention as a result of brain damage

Neuropsychological studies of visuospatial neglect and extinction have provided support for attention being guided by a fronto-parietal network. Neglect is observed most typically following damage to posterior parietal cortex (Mort, Malhotra, Mannan, Rorden, Pambakian, Kennard et al., 2003). Neglect patients are impaired at directing attention to the contralesional visual field even when only a single stimulus is present (Driver, 1998). In contrast to this, patients with visual extinction can detect single objects in their contralesional field, but not when an ipsilesional stimulus appears simultaneously (to ‘extinguish’ the contralesional item). Both disorders can be accounted for in terms of a spatial bias in attention, which is stronger in cases of neglect (see Heinke & Humphreys, 2003, for simulations (though see Karnath, Himmelbach & Kücher, 2003, for an alternative view)).

Despite patients with neglect and extinction often denying the presence of stimuli on their contralesional side, and paying minimal attention to that side, there is evidence for stimuli still being processed. For example, extinction can be reduced when items on the contralesional side group with ipsilesional stimuli, indicating that contralesional stimuli are at least processed to a level where they enter into grouping relations with other items (Gilchrist, Humphreys & Riddoch, 1996; Humphreys, 1998; Mattingley, Davis & Driver, 1997; Ward, Goodrich & Driver, 1994). On the other hand, there is physiological evidence that activation in early visual regions is not normal.

Rees et al. (2002) presented patient GK with either a picture of a house or a face to his left or right visual field, or both a face and a house bilaterally. GK had suffered an infarction to the right inferior parietal lobule following a stroke 18 months previously. GK was asked whether he saw a picture on the right side, left side or both sides. Trials with extinction (i.e., reporting a bilateral trial as a right side only trial) showed unconscious processing of the extinguished left side picture at the ventral visual cortex, including the right fusiform gyrus when the picture was of a face. Nevertheless, trials without extinction (where items were reported on a bilateral trial), showed greater activity in ventral visual cortex than extinction trials, along with additional activity in left parietal and pre-frontal areas. Thus an unconscious level of processing can occur in visual extinction, although this is insufficient to generate awareness of that object. ERP studies confirm attenuated early ERP components during bilateral extinction versus non-extinction trials (e.g., Marzi, Girelli, Miniussi, Smania & Maravita, 2000; Vuilleumier et al. 2001).

Despite evidence for the reduction in early visual processing in neglect and extinction, other results suggest that stimuli are processed to a level at which stimuli can activate semantic representations of stimuli (Bertiet al., 1992; Berti & Rizzolatti, 1992; Làdavas, Umiltà & Mapelli, 1997; McGlinchey-Berroth, Milberg, Verfaellie, Alexander & Kilduff, 1993; Vallar, Rusconi & Bisiach, 1994). McGlinchey-Berroth et al. (1993) examined semantic priming in four patients with left-sided visuospatial neglect and one patient with left-side hemianopia (blindness to their left side) without neglect. Participants were presented with a prime and scrambled filler object, one in each visual field, for 200 ms. After a delay of 400 ms, the target word appeared centrally and a response was required as to whether it was a real English word (yes or no). Half of the trials contained real words (e.g., BALL), half were replaced with nonwords (e.g., SKEB). During real word trials, one third of picture primes were semantically related to the target (e.g., a bat), the remaining were semantically unrelated. The neglect group showed a significant 1032 ms advantage for lexical decision on semantically related relative to unrelated trials. There was no significant difference between priming on trials when the prime was in the ipsilesional versus contralesional visual field. Primes in the neglected visual field were as effective as those in the intact visual field at activating semantic representations of targets. These results matched those of the control group. In contrast, the hemianopic patient showed a greater priming effect in his ipsilesional than his contralesional field. These data suggest that, unlike hemianopic patients who are impaired at receiving afferent information, neglect patients can process contralesional stimuli to a high level.

In a review of unconscious visual processing, Köhler and Moscovitch (1997) suggested that although patients may neglect primes when a task requires explicit processing, when a task does not involve explicit processing, the primes may be processed implicitly to a semantic level (cf., McGlinchey-Berroth et al., 1993; Berti & Rizzolatti, 1992; Làdavas et al., 1997). Vuilleumier and colleagues tested four patients with left-side neglect and extinction in an implicit and then an explicit perceptual learning task (Vuilleumier, Schwartz, Clarke, Husain & Driver, 2002b). In the implicit task, participants were shown pictures to their left side, right side or both sides of the screen, and asked to locate and name the items (e.g., duck on the right, nothing on the left). Participants were then tested with fragmented versions of the previous pictures (‘old’) and new, previously unseen pictures, to the left or right side. These pictures gradually become more complete whilst being displayed, until they were identified. Once identified, the picture would appear complete and the participant was asked if they had been shown it in the study phase. In the explicit task, participants were told that their memory would be tested after studying and that they must also name and categorise the objects as indoor or outdoor on their initial presentation, to encourage deeper processing. For both implicit and explicit tasks, the patients were able to identify old, extinguished pictures (i.e., left-side pictures described by the patient as not present on bilateral picture trials) at a more fragmented level (so more quickly) than new objects. Old, seen pictures (i.e., left-side pictures described by the patient as present on bilateral picture trials) could be identified at even greater levels of fragmentation, however. The patients' memories of seeing the old, extinguished objects in the study phase were also low and no different from false positives on new pictures. Vuilleumier et al. (2002b) suggest that the extinguished stimuli are processed to a stage of object categorization despite contralesional inattention, consistent with McGlinchey-Berroth and colleagues' semantic priming study (1993). This implicit processing can remain online to influence the later processing of related stimuli.

Other studies have shown effects of the emotional valence of neglected or extinguished stimuli in patients, providing additional support for residual processing that can occur in spared brain regions (Marshall & Halligan, 1988; McIntosh et al., 2004; Vuilleumier, 2000; Vuilleumier et al., 2002a; Vuilleumier & Schwartz, 2001a; 2001b). Using fMRI, Vuilleumier and colleagues (2002a) provided unilateral or bilateral exposures of faces and houses, with the faces having a fearful or neutral expression. The patient had to state whether the pictures appeared to the left or right side only or on both sides. On bilateral trials, a right-only response occurred on 65% of the trials. A distinction between neutral and fearful faces was shown during earlier sessions however, with less extinction for fearful faces than neutral faces in sessions one and two (72% versus 88% left-side faces missed). Furthermore, fMRI during the task showed that the patient's left amygdala was active during seen and extinguished trials in response to the fearful face.

The lack of awareness of stimuli that are processed to semantic levels has been suggested to be due to conscious awareness requiring activated object representations being bound to spatial representations, with the spatial representation being defective in patients with visuospatial neglect (see Buxbaum, 2006, for review).

1.2. Semantic processing in visual search: the effect of visual extinction

In prior studies, experiments have examined whether unattended (contralesional) stimuli activate higher-level representations in a bottom up manner, when items appear in the contralesional field of patients showing neglect and / or extinction. In the present study, whether there is evidence for high-level (semantic) processing of unattended stimuli in patients with neglect and / or extinction when the semantic properties of stimuli are activated in a more top-down manner was examined. Top-down cues were varied by guiding participants with different targets in a visual search task. Studies with healthy adults have shown semantic interference when a distractor (e.g., *chair*) semantically related to the search target (e.g., *table*) is presented on display (Moores, Laiti & Chelazzi, 2003; Telling, Kumar, Meyer & Humphreys, 2008 – see Chapter 2). In particular, participants are slower to decide the presence or absence of the target and they make more first gazes to the distractor, when it was semantically related rather than unrelated to the target.

These semantic interference effects may arise because there is spreading activation from the ‘template’ that participants hold for the target (cf., Duncan & Humphreys, 1989) to the semantic representations of related items. These related items then compete for selection, attracting first saccades and slowing RTs. For the competition to arise, the semantic distractors must be processed to a level at which they make contact with their stored representations.

Here the patients carried out a visual search task where the target was present on half of the trials, as was the related distractor. Each display was arranged vertically around fixation (one above and one below fixation), another item appeared in the left and the remaining item in the right visual field. The effect of the distractor was measured when it appeared in either the attended or unattended field for the patient, and which field was designated ‘attended’ was determined by measuring performance as a function of the field of the target when the (competing) semantic distractor was absent. The ‘attended’ field was diagnosed as the side where RTs were faster and more first gazes made to the target.

If semantic processing of visual search stimuli proceeds without the need for attention, the related distractors should disrupt performance irrespective of whether they fall in the attended or unattended fields of the patients. However, if attention is required to process the semantic features of visual search stimuli then semantic distractors will be more effective when they fall in the attended compared to unattended field.

2. Method

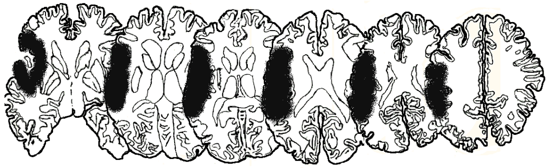
Participants. The participants comprised of five patients with a range of lesions, but all including damage to the posterior parietal cortex, and all patients presented with visual extinction (see Table 14 and Table 15). There were two patients with unilateral right hemisphere damage (JB and MP), and three with unilateral left hemisphere damage (RH, DB and MH). JB and MP also showed some evidence of left neglect. The patients were aged between 55 and 74 years old (mean age 67, one female). All patients had normal or corrected-to-normal vision. All patients gave their informed consent prior to taking part in the study.

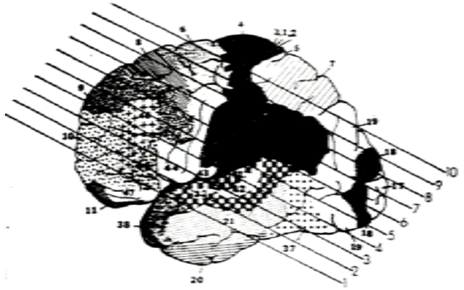
Table 14 *Experiment 5: Patient list, including standardised test performance.*

Patient	Sex/Age/ Handedness	Years post lesion	NART IQ equivalent*	Brixton test (raw score)**	Pyramids & palm trees (visual)	Pyramids & palm trees (auditory)	Corsi blocks	Digit span F (B)
JB	F/71/R	10	105	20	50	50	3	5 (3)
MP	M/61/L	12	105	21	51	51	3	5 (2)
RH	M/74/L	8	85	32	50	47	4	2 (0)
DB	M/72/R	12	95	20	48	48	4	6 (4)
MH	M/55/R	10	104	34	49	50	2	4 (3)

* *The NART (Nelson & Willison, 1991) is a reading test that provides an IQ-related score. RH's performance on this test was hampered by the presence of a significant reading deficit (respectively deep and neglect dyslexia), which lowered his score. RH was a former successfully self-employed plumber. JB initially presented with left neglect dyslexia but this had resolved by the time of testing. No other patients had any reading difficulty.* ** *The Brixton test of executive function (Burgess & Shallice, 1997) provides a measure of non-verbal executive function. A raw score above 26 indicates a clinical abnormality.*

Table 15 *Experiment 5: Patient list, including lesion reconstructions from MRI scan. Lesions have been drawn onto standard slices from Gado, Hanaway and Frank (1979). The end right figure shows the 10 slices used. Only slices 3 to 8 are depicted here. The right of each slice represents (a) the left hemisphere for JB and MP; (b) the right hemisphere for RH, DB and MH.*

Patient	Main lesion site – parietal –	Aetio-logy	Clinical deficit	Lesion reconstruction from MRI scan
JB	Right angular and supramarginal gyri, right inferior frontal and postcentral gyri	Stroke	Left neglect on word reading, and left extinction with short exposures	
MP	Right angular and supramarginal gyri, right superior temporal, inferior frontal and postcentral gyri	Stroke	Left neglect and left extinction with longer exposures	
RH	Left angular and supramarginal gyri, left superior temporal gyrus	Stroke	Word finding, right neglect dyslexia and right extinction with short exposures	
DB	Left angular gyrus, left superior and middle temporal gyri	Stroke	Word finding; right extinction with short exposures	
MH	Left angular and supramarginal gyri, lentiform nucleus	Anoxia	Optic ataxia. Right extinction with short exposures	



Stimuli and apparatus. These were identical to that of Experiments 3 and 4 (cf. Chapter 3).

Procedure. This was identical to Experiment 4. Patients with hemiparesis responded using their active hand only (MP and JB). However, in this experiment, the patients carried out eight blocks, which were gathered for each patient over a number of sessions. This provided twice as many cases as for Experiments 3 and 4 (192 per condition: target status (present vs. absent) x distractor condition (semantically related vs. unrelated)).

Design. The field of the target and distractor were labelled in relation to the patient's lesion, i.e., contralateral or ipsilateral to the individual patient's hemisphere of damage. Due to the circular positioning of items, only two of the four objects were in the contralateral or ipsilateral fields, with two in the centre. In Figure 11 (see Chapter 3) the target, *bird,* is in the right field and the related distractor, *fish,* is central). For analyses where target field was the factor (see Defining field bias), cases where the target was in the centre of the screen were removed (50% of all cases). For analysis where the distractor field was the factor (see Main analysis), cases where the distractor was in the centre of the screen were taken out (50% of all cases). Subsequent repeated measures factors for analysis were *field* (either target field or distractor field: ipsilateral or contralateral to the patient lesion, depending on the analysis), *target status* (target present or target absent), *distractor condition* (distractor semantically related or unrelated to the target). The random factor was patient (JB, MP, RH, DB and MH).

Analyses. The first five trials of the first block were considered as practice and excluded from the data set (0.6%). Incorrect responses accounted for 11% of the remaining responses. Correct responses only were selected and used as a basis for RT analysis and eye data preparation (89%). Next the data was prepared for eye movement analysis. The mean saccade durations lasted for 55 ms on average. Trials were excluded when gazes were not made to the middle region until after 150ms and when no gaze was made away from the centre before making a response. Once eye error trials were removed from the set 78% of correct response trials remained. The proportion of first gazes (to the target or distractor) were analysed for each trial (see Chapter 3, Experiment 3 for more information).

3. Results

3.1. Defining field bias

Inspection of the data indicated that the patients behaved in two separate ways, with most showing a bias towards the target when it was in their ipsilesional field (JB, MP, RH and DB) and MH showing a bias towards the target when it was in his contralesional field (see Table 16).[14] The contralesional bias might have been adopted as a compensatory strategy. These different field biases were assessed by taking the behavioural and eye movement data for target present, unrelated trials, where there should be an unambiguous orienting response to the target (not affected by competition from the related distractor). These analyses show interactions between target field and field bias, confirming distinct patterns.

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[14] Note that patients with posterior parietal lesions can show compensatory effects when they attend to the contralesional side in order to help overcome the bias operating to the ipsilesional side. However, this can then lead to reduced attention to the ipsilesional side (see Robertson, 1994). This was the case for one of the present patients, MH.

3.1.1. Bias detection analysis

Target present, unrelated distractor trials were analysed with a repeated measures factor of target field (contralesional or ipsilesional) and between-subjects factor of field bias (contralesional bias, i.e., MH, or ipsilesional bias, i.e., JB, MP, RH, DB)[15].

Table 16 *Differences in bias towards the target (target present, distractor unrelated trials only).*

Field Bias	Error rate (mean %)		RT (median ms)		First gaze to target (median %)	
	Target Field					
	Contra	Ipsi	Contra	Ipsi	Contra	Ipsi
Contra						
MH	2.3 (5.4)	11.0 (5.6)	1169 (162)	1537 (102)	65 (11)	11 (14)
Ipsi						
JB	3.5 (5.4)	0.0 (5.6)	2424 (59)	1159 (64)	29 (11)	50 (13)
MP	8.0 (5.4)	8.3 (5.6)	3560 (125)	3604 (657)	21 (11)	48 (10)
RH	15.3 (5.4)	12.8 (5.6)	1853 (174)	1706 (331)	55 (11)	50 (14)
DB	4.3 (5.4)	0.0 (5.6)	1830 (74)	1384 (139)	14 (11)	67 (14)
Mean	7.8 (5.4)	5.3 (5.6)	2417 (119)	1963 (277)	30 (11)	54 (13)

Error Rates. Analysis of variance for error rates showed a borderline main effect of target field ($F(1, 3) = 7.64, p = .007, \eta^2 = .72$); 3.3% fewer errors were made when the target was in the patient's ipsilesional than contralesional field. There was no main effect of field bias. There was a significant interaction between the target field and field bias ($F(1, 3) = 24.92, p = .015, \eta^2 = .89$). MH made fewer errors when the target was contralesional rather than ipsilesional; whereas the ipsilesional bias

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[15] Where possible, median values were calculated for this chapter: RTs, offset times, first gaze proportions and durations. This was not possible for error rates due to coding of errors (1 correct, 0 incorrect), so mean errors were calculated instead. Medians were used due to patients MP and DB, having a positively skewed distribution, compared to the other patients, which might have distorted the mean scores. This was not necessary for Chapter 3, due to the patients' normal distribution.

group made fewer errors when the target was ipsilesional rather than contralesional (see Table 16).

RTs. Analyses of variance of RTs showed no main effects or interactions. There was a trend towards MH having a contralesional and the remaining patients having an ipsilesional bias however (interaction between target field and field bias: $F(1, 3) = 1.62, p = .293, \eta^2 = .35$). Table 2 shows that MH responded more quickly during trials where the target was in his contralesional field than when in his ipsilesional field; in contrast, the ipsilesional-bias group responded more quickly when the target was in their ipsilesional rather than contralesional field.

First gaze to the target. Analyses of variance of first gazes to the target showed no main effects, but a clear trend to an interaction between target field and field bias ($F(1, 3) = 8.59, p = .061, \eta^2 = .74$). MH made more first gazes to the target when it was in his contralesional rather than ipsilesional field and the ipsilesional-bias group did the opposite (see Table 16).

To summarise, the patients showed different field biases towards the target. When the target was in their attended field rather than unattended field, patient errors lowered, RTs tended to speed up and first gazes tended to increase to the target.

3.2. Main analysis

The subsequent data were analysed to assess the effects of the related distractor, defining the field in terms of where the different patients showed their attentional bias, i.e., merging the attended field for MH with the attended field for the ipsilesional group. For the main analysis, the effect of *distractor* field rather than the target field was assessed. The new field factor had two levels, attended field and unattended field. The field of the unrelated distractor (i.e., when the related distractor was absent) was determined according to the position of the unrelated foil, which replaced the location of the related distractor. Analyses of variance were carried out on the patient data with within-subjects factors of target status (present or absent), distractor field (attended or unattended) and distractor condition (distractor related or unrelated to the target). Performance in the visual search task was measured according to “late” behavioural measures (RT and error rates), and early “eye” movement measures (per cent first gaze to the target and per cent first gaze to the distractor), taken 0.25 seconds after trial onset. Please note: For target present trials, in cases where the distractor was in the patient’s attended field, the target would be in their central or unattended field; when the distractor is in the patient’s unattended field, the target would be in the central or attended field.

3.2.1. Behavioural results

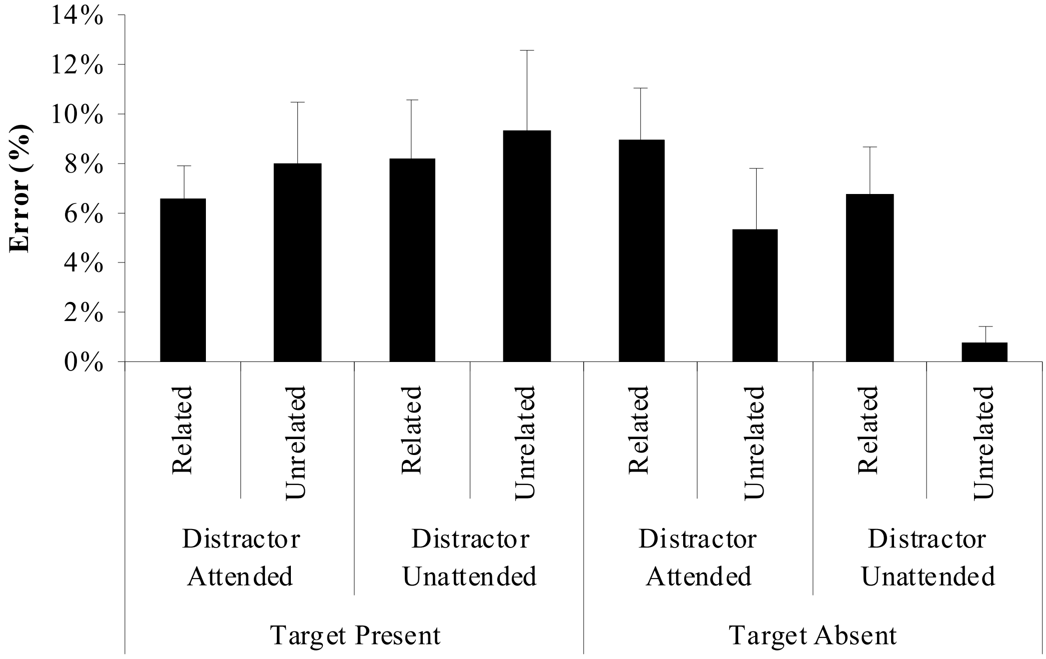

Figure 13. Mean error rates across patients tested with SEM (by participants).

Error rates. An analysis of variance was carried out on mean error rates (see Figure 13)[15]. A main effect of distractor field was found, with more errors when the distractor was in the attended than unattended field ($F(1, 4) = 8.30, p = .045, \eta^2 = .68$). A main effect of distractor condition failed to reach significance, though more errors tended to occur when the distractor was related relative to when it was unrelated to the target ($F(1, 4) = 4.60, p = .099, \eta^2 = .53$). There was an interaction between target status and distractor condition ($F(1, 4) = 6.43, p = .064, \eta^2 = .62$), although this failed to reach significance. A main effect of distractor condition was shown for target absent conditions only, with more errors during trials where the distractor was related than unrelated to the target (target present: -1.3% difference,

$t(5) = 0.83, p = .454, \eta^2 = .15$; target absent: 4.8% difference, $t(5) = 3.61$, $p = .022$, $\eta^2 = .77$). There were no other interactions.

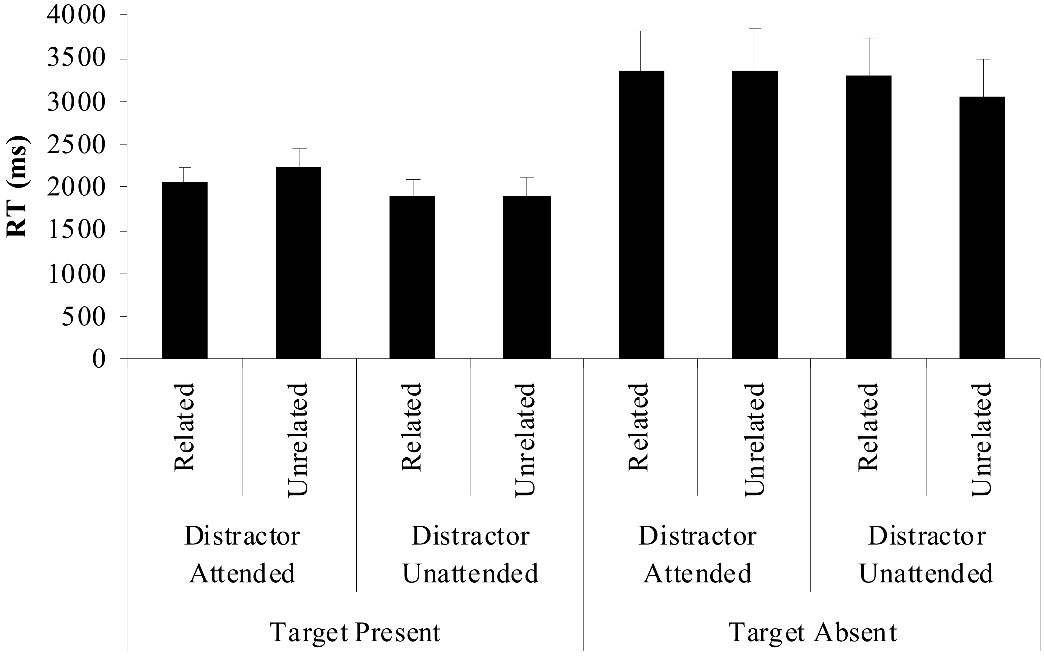

Figure 14. Median RTs across patients tested with SEM (by participants).

RTs. An analysis of variance was carried out on the median RTs (see Figure 14)[15]. There was a trend for a main effect of target status with patients responding more slowly during target absent than present trials ($F(1, 4) = 6.66, p = .061, \eta^2 = .63$). There was also a main effect of distractor field, with slower responses during trials where the critical distractor was in the attended versus unattended field, averaged across related distractor and foil trials ($F(1, 4) = 13.40, p = .022, \eta^2 = .77$). There was a significant interaction between target status and distractor condition ($F(1, 4) = 9.16, p = .039, \eta^2 = .70$). A main effect of distractor condition was shown for target absent conditions only, with slower RTs during trials where the distractor was related compared with when it was unrelated to the target (target present: $t(5) = 1.14$, $p = .317$, $\eta^2 = .25$; target absent: $t(5) = 2.87$, $p = .045$, $\eta^2 = .67$). There were no other interactions.

3.2.2. *Eye movements*

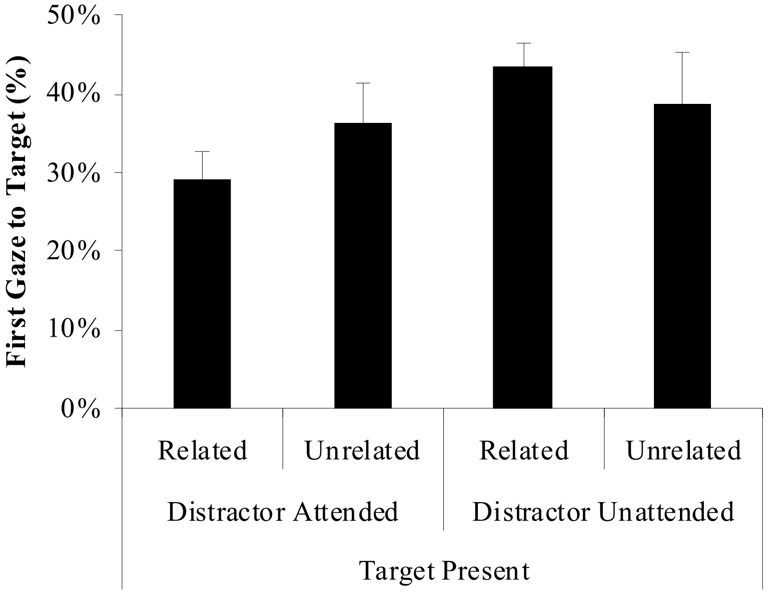

Figure 15. Median first gazes to the target across patients tested with SEM (by participants).

First gaze to target. The percentage of first gazes made to the target was compared across the patients (see Figure 15). A significant main effect of distractor field was found, with 8% more gazes to the target when the distractor fell in the unattended (and so target in the midline or attended field) than the attended field (when the target fell at midline or in the unattended field) ($F(1, 4) = 17.31, p = .014$, $\eta^2 = .81$). There were no other interactions.

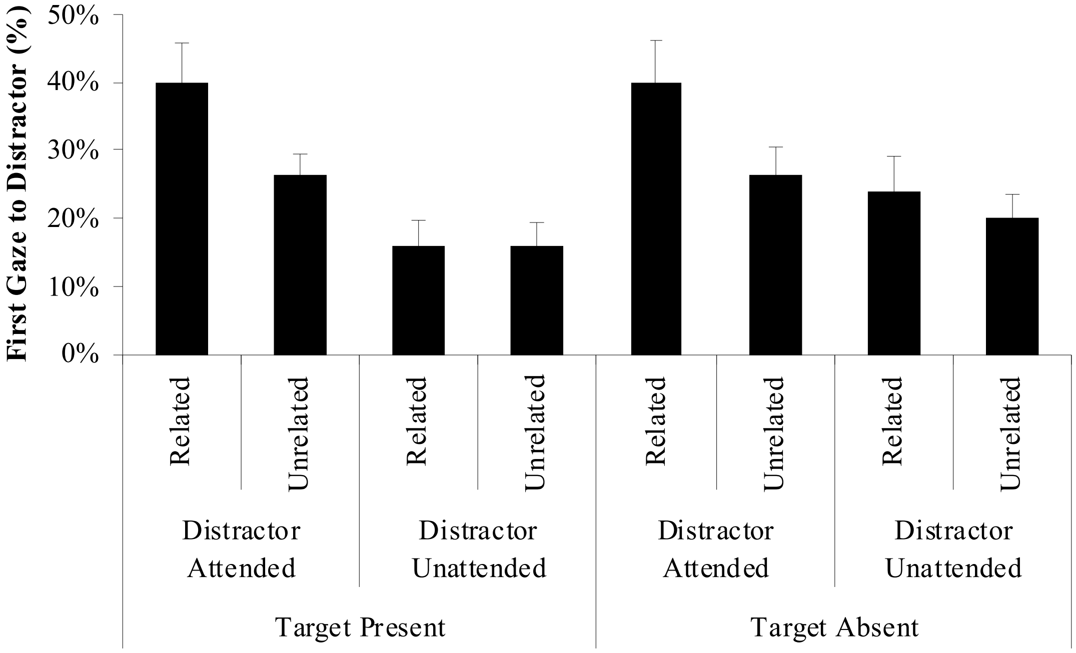

Figure 16. Median first gazes to the target across patients tested with SEM (by participants).

First gaze to distractor. The percentages of first gazes made to the distractor were compared across patients (see Figure 16). Analysis of variance yielded a main effect of distractor condition, with more gazes to the distractor when it was related than when it was unrelated to the target ($F(1, 4) = 122.24, p < .001, \eta^2 = .97$). There were no other main effects or interactions.

4. Discussion

Regardless of their lesion location (left or right hemisphere), all patients showed a preference to one side over another, when searching for the target. The majority performed the task better when the target was on their ipsilesional side, although MH performed better when the target fell on his contralesional side (possibly for strategic reasons). The preferred side was relabelled as the attended field and the other side as the unattended field. Visual search for the target was faster, more accurate and supported by more frequent first gazes to the target, and fewer first gazes to the unrelated distractor when the target fell in a patient's preferred field. This supports previous findings that visual attention is controlled by a fronto-parietal network, which for patients with lesions in this area, is biased towards one side of space (Driver, 1998). The side subject to bias can be changed, however, if the patient adopts a policy to strategically attend to the opposite side. In the latter case, stimuli on the ipsilesional side can then be unattended (see Robertson, 1994).

The main analysis assessed the effect of the semantically related distractor being in the patient's attended versus unattended field. First, the effect of target presence or absence will be summarised. Patients showed differences in their responses to the presence or absence of the target, with faster RTs during target present than absent trials, similar to the behaviour of healthy adult participants (Moores et al., 2003; Telling et al., 2008 – Chapter 2). A difference to the healthy controls was, however, that first gazes to the distractor were unaffected by target presence or absence: participants usually make fewer first gazes to distractor items during target present than absent trials (see Chapter 3, Experiment 3). The lack of target presence effects on first gazes to the distractor suggests a weaker control of attention towards the target by the fronto-parietal network.

Second, a semantic interference effect was found. There were slower RTs and more first gazes to distractors that were semantically related than unrelated to the target. These findings occurred irrespective of whether the related distractor fell in the attended or unattended field of the patients. Search was disrupted when the target was absent but the semantic distractor was present in the display, with more errors and slower responses than on unrelated trials. This replicates the behaviour of normal adults (e.g., Moores et al., 2003). The fact that this result held across both visual fields suggests that distractors that were related to the template activated their representations equally when the distractors appeared in the attended and unattended fields.

First gazes to the target showed no main effect of distractor condition and no interaction with distractor field. On target present trials, first eye movements to the target were unaffected by the presence or absence of a semantically related distractor. Eye movements only showed a spatial bias towards reflecting the presence of the target. There were more saccades to the target when it fell in the patient's midline or attended field, compared with when it fell in a patient's unattended field. This confirms our assignment of whether each field was attended or unattended, and it confirms that targets were assigned a stronger "attentional weight" than distractors (cf., Duncan & Humphreys, 1989).

The present results provide evidence for implicit processing of semantic information of items in search, with semantic interference occurring regardless of the field of the related distractor. This supports previous findings indicating processing to the semantic level of stimuli coded implicitly by normal adults (Merikle, Smilek & Eastwood, 2001; Kouider & Dehaene, 2007 for review) and patients with visual extinction (Berti & Rizzolatti, 1992; Berti et al., 1992; Làdavas et al, 1997; McGlinchey-Berroth et al., 1993; Vallar et al., 1994). This provides evidence for semantic processing of items in visual search without requiring attentional control from the fronto-parietal network, i.e., semantic processing in search occurs implicitly.

It may be that the semantic activation, from an attended stimulus, is particularly strong because there is top-down generation of activity from the template of the target. Whether this is stronger than ‘pure’ bottom-up activation needs to be tested in the same patients. The present results demonstrate, however, that top-down activation of semantic knowledge can be effective in matching stimuli in both the attended and unattended fields of posterior parietal cortex patients.

CHAPTER FIVE

EARLY ACTIVATION OF OBJECT NAMES IN VISUAL SEARCH[16]

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[16] Published manuscript: Meyer, A. S., Belke, E., Telling, A. L., & Humphreys, G. W. (2007). Early activation of object names in search. *Psychonomic Bulletin & Review, 14 (*4), 710 – 716.

1. Introduction

In many everyday tasks (e.g., reading, driving), we must direct our visual attention to appropriate stimuli at the appropriate times. The control of visual attention has often been studied in visual search paradigms, wherein participants decide as quickly as possible whether or not a target is part of a search display. Current models of selective visual attention assume that search performance is determined by competition among visual stimuli, which is moderated by bottom-up and top-down influences (see Desimone & Duncan, 1995; Duncan & Humphreys, 1989). Top-down influences can be modulated by a 'template' for the target, which can prime the representation of an object in a search display, biasing attentional selection towards it (Chelazzi, Miller, Duncan, & Desimone, 1993; Hodsoll & Humphreys, 2001, 2005; Soto, Heinke, Humphreys, & Blanco, 2005).

The working memory representation of the target will often be linked to knowledge about the object stored in long-term memory. Moores, Laiti, and Chelazzi (2003) demonstrated the existence of associative effects on the allocation of visual attention during visual search. They showed participants four-object displays that could include an associate to the target, for instance a *crash-helmet* when the target was a *motorbike*. The presence or absence of an associate did not affect the participants' response speed or accuracy on target-present trials, but on target-absent trials, they responded more slowly and less accurately when the associate was present. Eye movement analyses showed that, on target-present and target-absent trials, the first saccade after display onset was more often directed to the associate than to an unrelated control object. On target-present trials, most initial saccades were directed to the target, but the likelihood of first saccades to the target was reduced by the presence of an associate. These findings suggest that activation spreads from targets to associatively related representations. Due to this, the related object in the display is primed and competes with the target more efficiently, relative to unrelated objects, for the allocation of visual attention (see also Dahan & Tanenhaus, 2005; Huettig & Altmann, 2005).

The long-term memory representations of most common objects are connected to lexical entries specifying their names. A lexical entry consists of a semantic-syntactic representation of a word (the lemma) and representations of its morphological and phonological form (e.g., Dell, 1986; Levelt, Roelofs, & Meyer, 1999). Several studies have shown that names of common objects become rapidly activated even when the objects are presented extrafoveally (e.g., Morgan & Meyer, 2005) and when speakers do not intend to name them, but plan to name other simultaneously present objects (Meyer & Damian, 2007; Morsella & Miozzo, 2002; Navarette & Costa, 2005). However, in all these studies, participants were engaged in naming tasks. It is as yet unclear whether lexical representations become activated in search as well and influence competition with the target for selection. This issue was examined here.

In the experiment reported in this article, participants saw target objects, followed by four-object search displays, half of which included the target. On a quarter of these target-present displays and a quarter of the remaining, target-absent displays, one of the objects was conceptually unrelated to the target, but had a homophonous name (e.g., *bat* (animal) and (baseball) *bat*). Homophones have distinct conceptual representations and lemmas, but their lexical representations are closely linked because they share all phonological segments and possibly the morphological representation (Jescheniak & Levelt 1994; Miozzo & Caramazza, 2005). In order to compare the effects of homophonous competitors to those of semantically related ones, we included trials wherein the search display featured an associatively or categorically related competitor or an appropriate control object. If the objects presented in visual search activate their names, a strong lexical relationship between homophonous targets and competitors might have similar effects to a strong semantic relationship: The presence of homophonous competitors might delay responses, and participants' first saccades might be directed at such competitors more often, relative to unrelated control objects. By contrast, if access to object names is not an automatic consequence of object recognition but occurs only when the task requires verbal labelling of the objects (e.g., Zelinski & Murphy, 2000), only the presence of semantically related, but not homophonous competitors should affect participants' response latencies and eye movements.

2. Method

Participants. Fourteen undergraduate students of the University of Birmingham participated in exchange for payment. They all reported having normal or corrected-to-normal vision and were native speakers of English. The handedness of the participants was not recorded.

Design and materials. On each trial, participants saw a target picture followed by a four-object search display. On half the trials (target-present), the display included the target. On half of these trials and on half of the remaining (target-absent) trials, related competitors were present. There were two types of related competitors: objects with homophonous names and semantically related objects.

Two sets of 56 pictures each were selected from Snodgrass and Vandervart (1980) and a picture gallery provided by the Max-Planck-Institute for Psycholinguistics, Nijmegen (NL; see Appendix 2). In the *homophone set*, 14 pictures served as targets and 14 others, with homophonous names, as related competitors. The remaining 28 pictures were used as unrelated fillers. The *semantic set* also included 14 targets, 14 competitors (members of the same semantic category or associates to the target), and 28 unrelated fillers. The visual similarity of 25 of the 28 target-competitor pairs had been assessed in a paper-and-pencil rating study by Belke, Humphreys, Watson, Meyer & Telling (in press), wherein 14 participants rated the visual similarity of object pairs on a scale ranging from 1 (very dissimilar) to 5 (very similar). The ratings for the target-competitor pairs were low (median ratings: 1.25 for semantically related pairs and 1 for homophones), and significantly different from the ratings for 24 pairs, such as *pencil-needle*, that had been specifically selected to be visually similar (median rating: 4.25; $z_1 = 3.34$, Wilcoxon Signed Rank Test; $z_2 = 4.55$, Mann-Whitney U-Test, both $p < .001$ for the comparison of semantically related vs. visually similar pairs; $z_1 = 3.32$; $z_2 = 4.62$, both $p < .001$ for the comparison of homophones and vs. visually similar pairs). The median rating for the semantically related pairs was slightly, but significantly higher than the median rating for 12 pairs, such as *tie-swan*, that had been specifically selected to be conceptually and visually as dissimilar as possible (mean ratings: 1.25 and 1, $z_1 = 2.34$, $z_2 = 2.40$, both $p < .05$). The median ratings for the homophones and the visually dissimilar pairs were both 1.

In the condition where target and competitor were present, the related target-competitor pairs were shown, along with two fillers. In the target-absent conditions, the target was replaced by another member of the target set, i.e., a picture serving as a target on a different trial. Analogously, in the competitor-absent conditions, the related competitor was replaced by an unrelated member of the competitor set (see Table 1). Thus, each search display featured a member of the target set, a member of the competitor set, and two filler objects, which were semantically and phonologically unrelated to the remaining objects in the display.

Table 17 *Experiment 6: Materials used in the four experimental conditions (example from the homophone set).*

Target status	Distractor	Target	Search set
Target present	Competitor present	boy	Boy, buoy, ant, leaf
	Competitor absent		Boy, flour, chair, scissors
Target absent	Competitor present		Flower, buoy, necklace, horseshoe
	Competitor absent		(fish) tank (garden) spade, clock, plug

For each target and condition, two different fillers were selected. In addition, two versions of each display were created that differed in the left-right orientation of the objects. This yielded 448 different search displays (28 targets x 4 conditions x 2 sets of fillers x 2 orientations). In the target-present condition, the search target was shown in the same orientation as the corresponding object in the search display.

The line drawings were scaled to fit frames of 100 x 100 pixels, corresponding to 4.6° x 4.6° at a viewing distance of 60 cm. The four objects shown together in a display were similar in visual complexity, measured as the proportion of black pixels in the 100 x 100 pixel frames. They were positioned in a circle around the midpoint of the screen (see Figure 17), at a distance (midpoint screen to midpoint picture) of 7.4º. The objects were randomly allocated to the four screen positions.

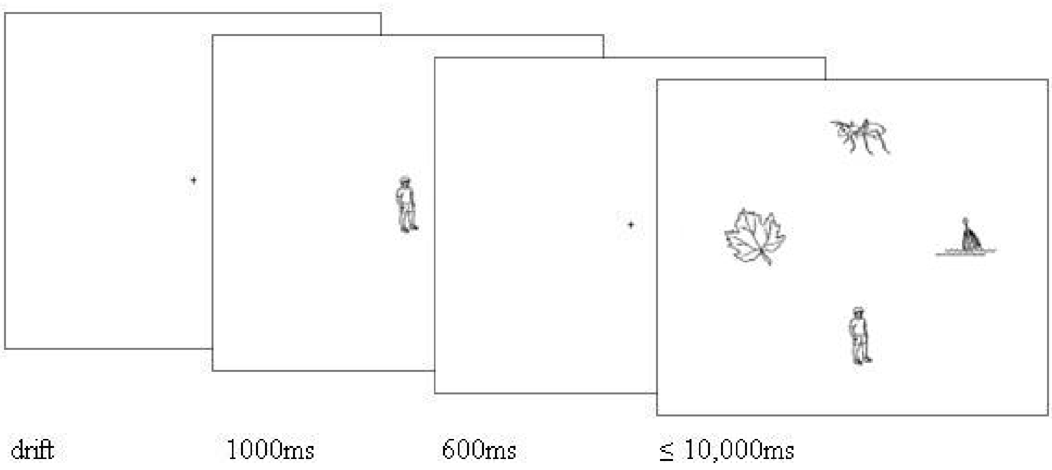

Figure 17. Experiment 6: Example trial, where the target is *boy* and the distractor is *buoy*.

The 448 displays were distributed over four blocks of 112 trials each. In each block, all targets were shown once in each condition. The same orientation of the objects was used in blocks 1 and 2 and in blocks 3 and 4, and the same fillers were used in blocks 1 and 3 and in blocks 2 and 4. A different random order of the displays was used for each block and each participant.

Apparatus. The experiment was controlled by a Pentium IV, 1.5 GHz computer. The stimuli were displayed on a Triniton Multiscan G240 monitor (17”) with a screen resolution of 600 x 800 pixels. Eye movements were recorded using a head-mounted eyetracker (SMI Eyelink V2.04; SR Research Ltd.) at a sampling rate of 250 Hz. Responses were registered using a hand-held response pad (SR Research).

Procedure. The participants read the instructions and familiarised themselves with the materials by studying a booklet showing all objects appearing in the experiment and their names. Then the eye tracker was positioned on the participant's head, the system was calibrated, and the experiment began.

Before each trial, the participant looked at a central fixation point, which allowed the experimenter to carry out a drift correction. The participant pressed a button to initiate presentation of a search target, which appeared in the centre of the screen for one second, followed by another fixation point presented for one second, and a search display, which was shown until the participant responded. Participants pressed the left or right button of the response pad to indicate target presence or absence. Each test block took approximately ten minutes. There were short breaks between blocks.

After the experiment, the participants were given another booklet showing the materials and were asked to write down the names of the objects. In order to establish whether there were any effects of name relatedness between targets and competitors, it was crucial that the objects were primarily associated with the expected names. Therefore, we excluded from the analyses all trials of the main experiment featuring targets or competitors that a participant had named incorrectly in the post-test (4.9% of the trials). The first five trials of the experiment were considered practice trials and were also excluded from the analyses.

3. Results

Errors. Participants were significantly more likely to make errors on target-absent than on target-present trials (4.3% vs. 1.7%; by-participants analysis: $F_1(1, 13) = 17.43, p < .001, \eta^2 = 0.57$; by-items analysis: $F_2(1, 26) =21.67, p < .001, \eta^2 = 0.46$), and that they made more errors on trials using the semantic than the homophone set (3.5% vs. 2.4%; $F_1(1, 13) = 10.04, p < .01, \eta^2 = 0.44, F_2(1, 26) = 4.14, p < .06, \eta^2 = 0.14$). The error rate was not affected by the presence or absence of a related competitor (3.0% for both conditions), and there were no interactions. Error trials were excluded from further analysis, as were all trials wherein a participant's response latency deviated from his/her overall mean by more than 3 SD (1.6% of the trials).

RTs. For the RTs very similar results were obtained for the semantic and the homophone set (see Figure 18). Responses were significantly faster on target-present than on target-absent trials ($F_1(1, 13) = 44.93, \eta^2 = 0.78, F_2(1, 26) = 208.67, \eta^2 = 0.89$, both $p < .001$), and on competitor-absent than on competitor-present trials ($F_1(1, 13) = 45.19, \eta^2 = 0.78, p < .001, F_2(1, 26) = 11.91$, p < .01, $\eta^2 = 0.32$). Reactions were faster in the homophone than the semantic set, but this effect was significant by participants only ($F_1(1, 13) = 5.29, p < .05, \eta^2 = 0.29, F_2(1, 26) = 2.64, p < 0.12, \eta^2 = 0.09$) and did not interact with the effect of competitor presence or target presence. There were no other interactions. In sum, responses were delayed by the presence of semantically related as well as homophonous competitors.

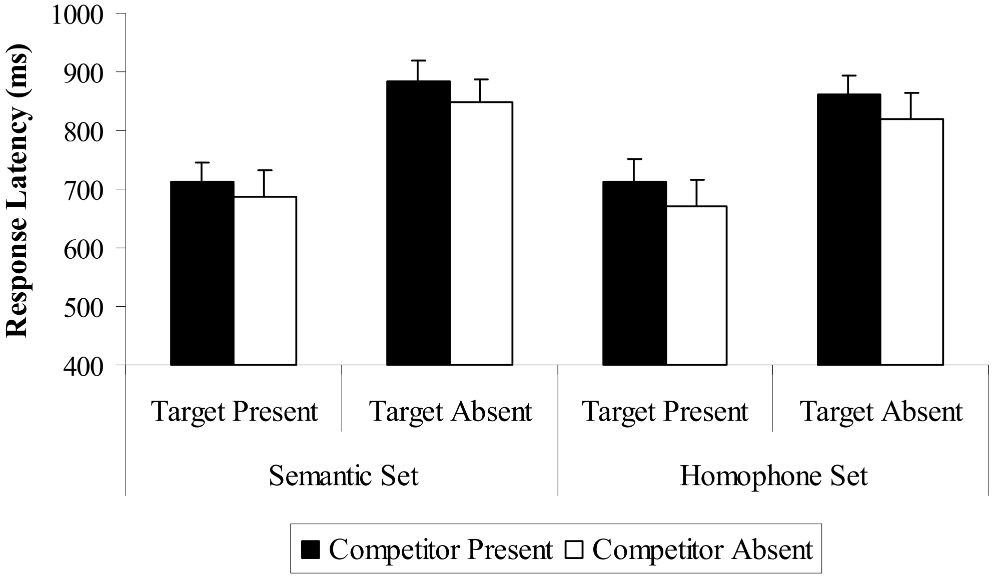

Figure 18. Mean response latency per condition with SEM (by participants).

Eye movements. For the analyses of eye movements, five regions of interest were defined: a circular region around the fixation point (24 pixels in diameter) and a square (108 x 108 pixel) region around each of the four objects. Eight percent of trials were excluded from the analyses because participants did not look at the fixation point at trial onset and a further 4% because participants inspected none of the object regions before responding. For the remaining trials, we examined when the first saccade to an object was initiated, which object was fixated first, and how long each object was inspected.

The first saccade towards an object was initiated significantly earlier when the target was present than when it was absent (211 vs. 225 ms after trial onset; $F_1(1, 13) = 25.20$, $\eta^2 = 0.66$, $F_2(1, 26) = 26.89$, $\eta^2 = 0.51$, both $p < .001$). It was initiated earlier in the competitor-present than in the competitor-absent condition, but this difference (216 vs. 220 ms) was only significant in the analysis by participants ($F_1(1, 13) = 4.99$,

$p < .05$, $\eta^2 = 0.28$). There were no other main effects on saccade latencies or interactions.

Figure 19 shows the percentages of all first saccades that were directed at the targets in the target-present condition or at the foils replacing the targets in the target-absent condition. As noted above, these foils were targets on other trials. The results were again very similar for the semantic and the homophone set. As expected, there were far more fixations to the targets on target-present trials than to the foils on target-absent trials (63% vs. 22%; $F_1(1, 13) = 193.53$, $\eta^2 = 0.94$, $F_2(1, 26) = 245.66$, $\eta^2 = 0.94$, both $p < .001$). More interestingly, targets and foils were significantly less likely to be fixated after the first saccade in the presence (relative to the absence) of a related competitor (40% vs. 45%; $F_1(1, 13) = 14.74$, $p < .01$, $\eta^2 = 0.53$; $F_2(1, 26) = 7.58$, $p < .02$, $\eta^2 = 0.23$). There were no interactions.

The rates of first fixations to the competitors showed a complementary pattern (see Figure 20). The rate of first fixations to the competitors was much lower in the target-present than in the target-absent condition (16% vs. 32%, $F_1(1, 13) = 72.23$, $p < .001$, $\eta^2 = 0.85$; $F_2(1, 26) = 46.47$, $p < .001$, $\eta^2 = 0.64$), and the related competitors were more likely to be fixated than the unrelated control objects replacing them on competitor-absent trials (26% vs.22%), though this difference was significant across participants only ($F_1(1, 13) = 18.85$, $p < .001$, $\eta^2 = 0.59$; $F_2(1, 26) = 2.42$, $p < .15$, $\eta^2 = 0.09$).

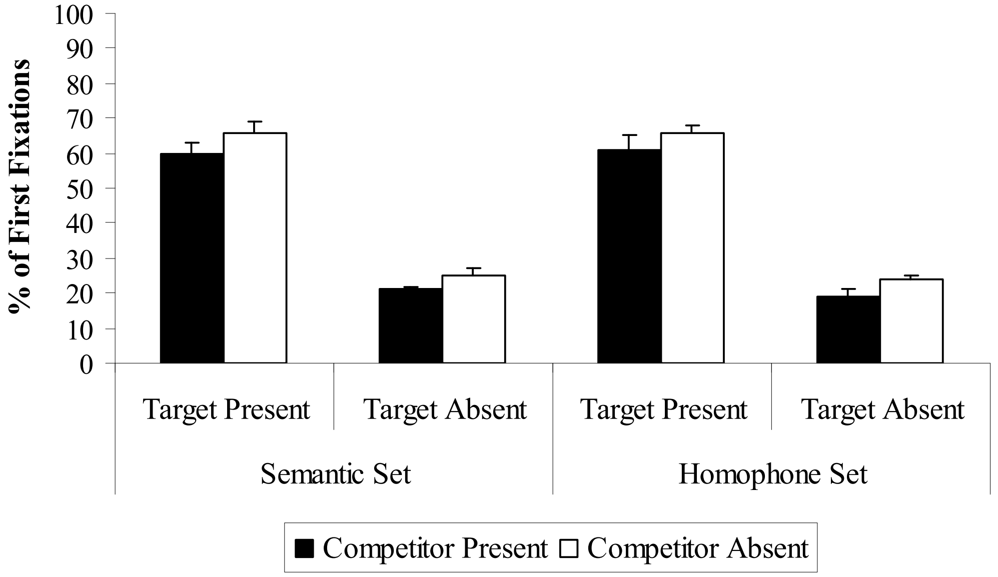

Figure 19. Mean proportions of first fixations to targets (target-present condition) and foils (target-absent condition) with SEM (by participants).

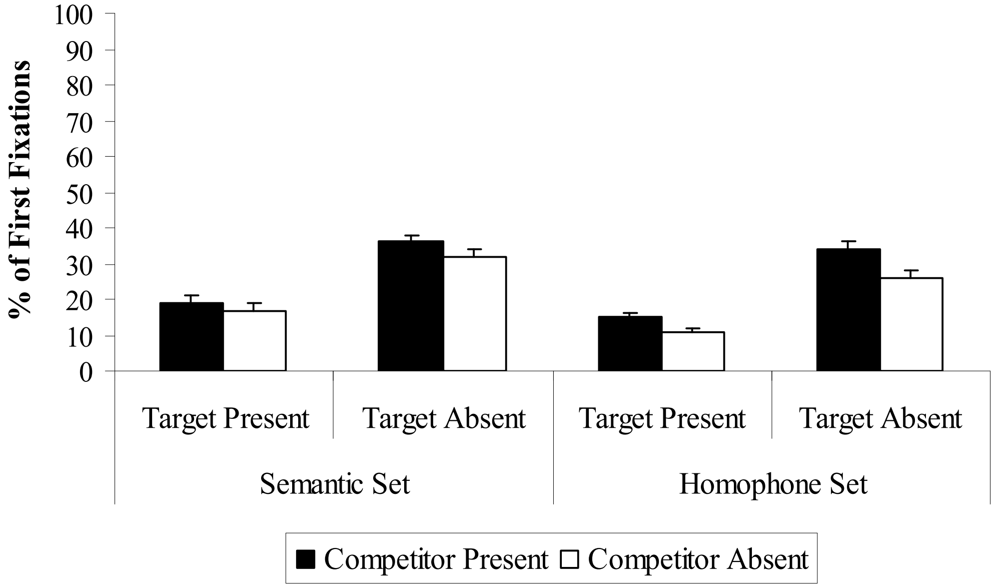

Figure 20. Mean proportions of first fixations to related competitors (competitor-present condition) and unrelated control objects (competitor-absent condition) with SEM (by participants).

The final analysis examined how long the objects were inspected. The first gaze duration was defined as the interval between the onset of the first fixation and the end of the last fixation in a set of successive fixations to an object. First gaze durations were substantially longer for targets than for the unrelated foils replacing them in the target-absent condition (means: 309 vs. 156 ms, $F_1(1, 13) = 101.97$, $\eta^2 = 0.89$, $F_2(1, 26) = 536.53$, $\eta^2 = 0.95$, both $p < .001$). First gaze durations to competitors (whether related or unrelated to the target) were significantly longer in the target-absent than in the target-present condition (165 vs. 125 ms; $F_1(1, 13) = 39.03$, $\eta^2 = 0.75$, $F_2(1, 26) = 20.94$, $\eta^2 = 0.45$, both $p < .001$). Finally, related competitors were inspected for longer than the unrelated control objects taking their place in the competitor-absent condition (152 vs. 138 ms; $F_1(1, 13) = 19.10$, $p < .001$, $\eta^2 = 0.60$; $F_2(1, 26) = 4.73$, $p < .05$, $\eta^2 = 0.15$).

4. Discussion

The present study yielded further evidence for the existence of semantic relatedness effects in visual search (see also Belke et al., in press; Moores et al., 2003): Participants responded more slowly in the presence than in the absence of a semantically related competitor, their first saccade after display onset was more likely to be directed toward a related competitor than toward an unrelated control object, and the target, if present, was less likely to be fixated after the first saccade when a related competitor was present than when it was absent. As Moores et al. (2003) noted, such semantic relatedness effects in visual search are likely to be based on semantic priming but cannot be exclusively due to priming. This is because priming should facilitate the processing of one of the objects in the display and should therefore lead to increased response speed and accuracy. However, semantically related competitors have the opposite effect – delaying responses and, in some studies, reducing accuracy. This suggests an effect of competition in the allocation of visual attention, which is increased when a competitor to the target is primed.

The novel result of the present experiment is that homophonous competitors had exactly the same competitive effects as semantically related ones. This demonstrates that in a visual search task linguistic knowledge associated with the objects becomes activated and affects the search in the same way as knowledge about the semantic properties of the objects.

Given that the experiment used repeated presentations of items, it is possible that participants became aware of the relations between the homophone competitors and targets and adopted the strategy of trying to name all the items present – even though the presence of a homophone disrupted search performance. Note that, even if participants did adopt this strategy, the results are still of interest since they show that the homophone competitors tended to attract attention (influencing the first saccade made during search), suggesting that the names of the objects were accessed prior to the allocation of overt attention in the displays. To test this possibility, we analysed the data for the first block of trials only. The pattern of performance matched that found when all the data were included. The reactions in the first block were slower in the presence than in the absence of a homophonous competitor (means: 880 vs. 840 ms; compared to 788 vs. 746 ms for the complete data set); the first saccade was less likely to be directed at the target or the unrelated foil replacing it when a homophonous competitor was present than when it was absent (35% vs. 39%, compared to 40% and 45% in the complete data set), and the first fixation was more likely to be directed at the homophonous competitor than at the unrelated control object (24% vs. 20%, compared to 24% vs. 19% in the complete data set; footnote 2)[17]. These results suggest that the homophone effect was not contingent on participants strategically naming objects as the experiment progressed.

Our results contrast with findings reported by Zelinsky and Murphy (2000). They carried out a search experiment in which participants decided whether or not a display of four faces included a target face. Prior to the experiment, the participants learned to associate a monosyllabic or a trisyllabic name with each of the faces. Zelinsky and Murphy found that the length of the names did not affect how long the participants looked at the faces during the search task, suggesting that the names did not become automatically activated. A possible reason for this difference to our results is that the recently acquired names did not become activated as readily as the overlearned names of the objects we showed. In addition, Zelinsky and Murphy considered the effect of name length, which would arise during phonological encoding, whereas we considered the effects of homophony, which would arise slightly earlier, during access to the morphological forms of the object names.

Further research is necessary to determine exactly how the homophone effects arose. A much debated issue in current psycholinguistics is whether every activated concept automatically activates the corresponding lexical representations, which is the view held by proponents of cascaded models of lexical access (e.g., Caramazza, 1997; Dell, 1986), or whether lexical access is restricted to those units that the speaker

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[17] The reaction time analysis for the first block revealed a main effect of target presence, with longer reaction times on target-absent than target-present trials (952 vs. 801 ms; $F_1(1, 13) = 40.70$, $\eta^2 = 0.76$, $F_2(1, 26) = 62.94$, $\eta^2 = 0.71$, both $p < .001$) and a main effect of competitor presence, with longer reaction times in the presence than in the absence of a related competitor (896 vs. 857 ms; $F_1(1, 13) = 13.77$, $p < .01$, $\eta^2 = 0.51$, $F_2(1, 26) = 11.88$, $\eta^2 = 0.31$, $p < .01$). The eye movement analyses did not yield any significant differences between the conditions.

selects to be part of an utterance plan, as proposed in serial stage models of lexical access (e.g., Bloem & La Heij, 2003; Levelt et al., 1999). One account of the homophone effects is that both the search target held in working memory and the objects in the search display activated their associated linguistic knowledge, as predicted by cascaded models of lexical access. The homophonous competitor would attract visual attention because it shared an important property – the name – with the target, which was primed when the search target was viewed. Unrelated objects in the search display may also activate their names, but since these items were not primed, they were less potent competitors for the allocation of visual attention. Recent studies (Meyer & Damian, 2007; Morsella & Miozzo, 2002; Navarrete & Costa, 2005) have shown that in object naming tasks, the names of distractor objects can become activated and affect how fast people name target objects. The present experiment suggests that the names of task-irrelevant objects may become activated even when the viewer does not intend to formulate any utterance at all.

Alternatively, the point of contact between the representations of the target and the homophonous competitor might be at the conceptual, rather than the lexical, level. According to this view, activation spread from the visual representation of the target to the target lemma (e.g., *animal bat*) and its morphological and phonological forms. From these representations activation spread to the lemma and conceptual representation of the competitor (*baseball bat*), which were therefore primed when the search display was shown. This view does not presuppose that the lexical representations of the items in the search display become available quickly enough in a bottom-up manner to affect search upon display presentation, or, indeed that there is bottom-up access to these representations at all. It does, however, presuppose that, when the target is processed, activation spreads from its word form to the competitor lemma and conceptual representation. Serial models of lexical access do not assume such bottom-up spreading activation within the speech production system. However, they can account for the results on the assumption that the participants in the visual search task engaged not only the speech production, but also the speech comprehension system: They first generated the target name in inner speech and then comprehended it, just as inner speech is comprehended in other situations (e.g., when we memorise a speech or shopping list). In the comprehension system, there are, of course, bottom-up links from word form representations to lemmas and conceptual representations.

For both of these accounts, the data suggest that there is sufficiently rapid access to conceptual information from distractors for this information to influence the first fixations made during search. It may even be that there is sufficiently rapid access to name information from distractors that this too affects the earliest saccades. It is for future research to assess the constraints on access to these high-level representations in search, and whether, for example, distractor names are activated in parallel across the items present.

5. Author note

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CHAPTER SIX

EVIDENCE AGAINST AUTOMATIC PHONOLOGICAL ACTIVATION IN VISUAL SEARCH

1. Introduction

Visual attention allows us to filter out the irrelevant visual information and focus on the relevant visual information. For example, this helps us to find somebody in a crowd of people; or a destination on a map. The visual search paradigm demonstrates this control of visual attention. In visual search, participants decide whether or not a target is present amongst other search items. The target for search is presented in advance of the search items and this pre-activated representation, or template, is held in working memory to guide the top-down allocation of visual attention towards the target (e.g., Chelazzi, Miller, Duncan & Desimone, 1993; Downing, 2000; Houtkamp & Roelfsema, 2006; Soto, Heinke, Humphreys & Blanco, 2005).

However, in cases when one of the search items is semantically related to the target, the control of attention has been found to be weakened, with the semantic distractor also receiving attention. Moores, Laiti and Chelazzi (2003) first demonstrated this with distractors semantically associated to the target (e.g., *motorbike - crash helmet*). In the presence of an associate, participants were slower to respond and less accurate; their initial gazes were more frequently directed to the associate than to unrelated items and less frequently directed to the target when the associate, rather than unrelated distractor, was also on the screen. Whilst holding the target in working memory, information about it is retrieved from long-term memory, spreading to semantically associated representations. This primes search towards the associate as well as the target. When the search display appears on the screen, competition for visual attention between associate and target then causes the reported effects (see also Belke, Humphreys, Watson, Meyer & Telling, in press; Huettig & Altmann, 2005; Meyer, Belke, Telling & Humphreys, 2007 – Chapter 5; Telling, Kumar, Meyer & Humphreys, 2008 – Chapter 2).

The level of activation was taken further in a study carried out by Meyer et al. (2007, see Chapter 5). We replicated the interference of semantic distractors in search and demonstrated the same interference when homophones to the target were presented. Homophones are phonologically identical, but conceptually dissimilar to one another, e.g., animal *bat* – baseball *bat*. Interference from a distractor with the same name as the target was thought to indicate that, as well as semantic representations; lexical representations are also activated whilst the target is held in working memory. The lexical representation consists of a semantic-syntactic representation of a word (a lemma) and its morphological and phonological representation (Dell, 1986; Levelt, Roelofs & Meyer, 1999). Although the homophone does not share its lemma with the target, it does share phonology and perhaps also morphology (Jescheniak & Levelt, 1994; Miozzo & Caramazza, 2005).

Meyer and colleagues (2007 - Chapter 5) were unable to confirm the mechanisms by which the homophone affected search for the target. One suggestion was that linguistic knowledge about the target and the other items on display was activated prior to the first eye movement (parafoveally). Early conceptual activation of display items lead to the spreading activation to linguistic information about those items. So, upon seeing the target animal *bat* rapid spread of activation to the concept then activates its lexical entry (lemma, morphology and phonology) priming search towards those representations. Upon viewing the search items, activation spreads to the lexical entries for those items also. However, only the homophone baseball *bat* attracts visual attention as it shares its name *bat* with the primed target.

A second suggestion was that bottom-up spreading of activation occurred following comprehension (using inner speech) of the search target. Upon seeing the target (e.g., a picture of an animal bat), it's conceptual representation is activated. From here, activation spreads to the lemma (animal *bat*), then morphological (BAT) and phonological (/bæt/) representations in the lexicon, enabling the participant to inwardly name the target to be searched. Activation then feeds back up to the corresponding homophone (baseball bat) via shared phonological and / or morphological representations to the lemma and concept for baseball *bat*. Whether this feedback occurs at the morphological or phonological level depends on the model of homophone representation (see Figure 21).

According to the Shared Representation model, homophones have individual conceptual and syntactic representations (lemmas) but shared morphological and phonological representations (Biederman, Blanken & Nickels, 2002; Cutting & Ferreira, 1999; Dell, 1990; Jescheniak & Levelt, 1994; Levelt, Roelofs & Meyer, 1999). According to the Independent Representation model, homophones have individual conceptual and morphological representations (no lemma level) and shared phonological segments (Caramazza, 1997; Caramazza, Costa, Miozzo & Bi, 2001; Caramazza & Hallis, 1991; Caramazza & Miozzo, 1997, 1998). Bottom up feedback to activate the homophone distractor's concept in search may cross over from the phonological level only, according to the IR model, or the phonological or morphological level, according to the SR level.

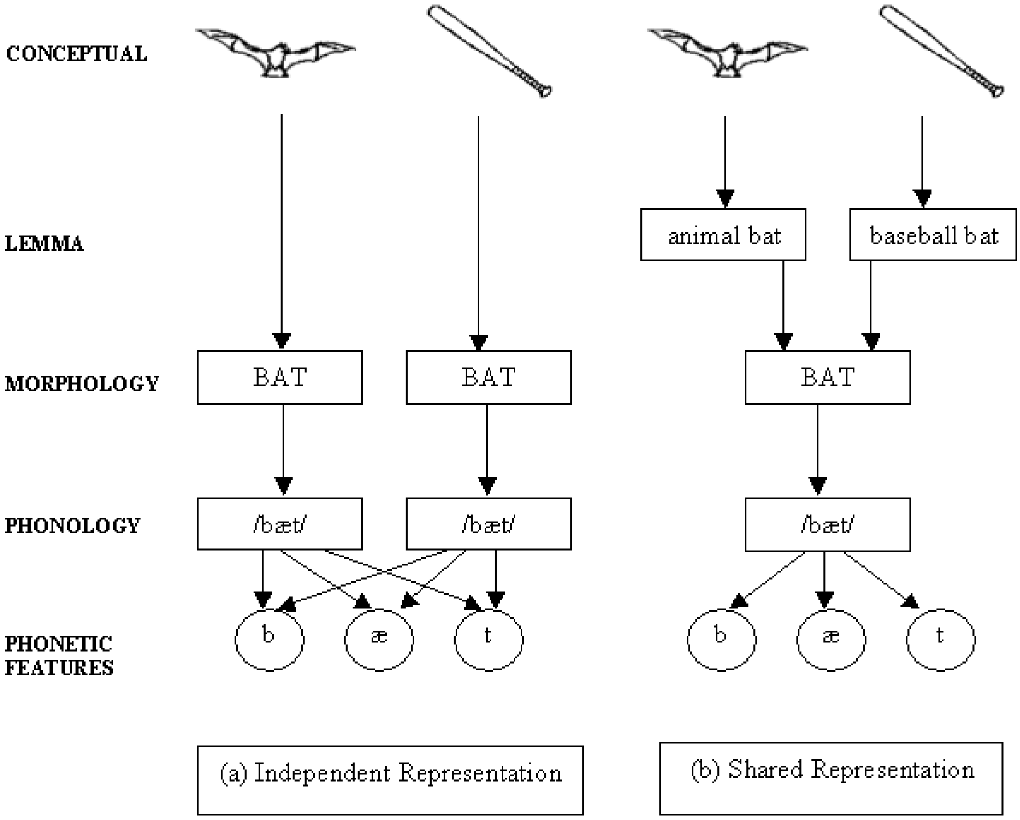

Figure 21. Independent and Shared accounts of homophone representation.

These models also have implications for whether phonological information is activated for all items in search, or whether homophones are a special case. To test this, phonologically related distractors were introduced, which only partially share phonology with the target, for example be̲d̲ – be̲ll but have distinct lemmas and morphological representations. If phonological information is activated for all items in search, then an interference effect should be shown between target and phonologically related distractor. Upon presentation of the target, if target phonology is activated, then search is primed toward those phonological segments, which overlap with a phonological distractor. If phonological information about the items on display is activated parafoveally, prior to the first gaze, then an item with a related phonology to the target should also be primed for search, and compete with the target for visual attention. Furthermore, this would provide evidence to support the IR model of homophone representation, where shared phonology, rather than morphology, is critical. However, if no interference from phonologically related distractors are found, this suggests that phonological information is not activated for the target. Instead, access to the phonological form of the homophone occurred due to shared morphology (which phonologically related distractors do not share with the target). If the morphological representation, rather than phonological representation were the critical level for phonological activation, the SR model of homophone representation would be supported.

The existent evidence for automatic phonological activation is inconsistent. In the overlapping pictures paradigm, participants are asked to name a target picture of one colour (e.g., a green bed) and ignore the distractor picture in another colour (e.g., a red hat). The distractor with phonologically related names (Morsella & Miozzo, 2002; Navarette & Costa, 2005) or a homophone (Meyer & Damian, 2007) have been shown to facilitate naming of the target, compared to unrelated trials (supporting the IR model). In the changing targets paradigm, participants name three pictures arranged on the screen with two on the top and one centrally at the bottom. Upon their eye gaze across to the second picture (the interloper), this is replaced with a target picture (to be named). Trials where the interloper was a homophone to the target have been shown to facilitate naming (Morgan & Meyer, 2005; Meyer, Ouellet & Haecker; in press), although there is currently no published data to show the same effect from phonologically related interlopers, perhaps supporting the SR model.

It is difficult to predict outcomes for visual search amongst phonologically related distractors based on different paradigms, however as both paradigms used naming tasks. A series of experiments were carried out with phonologically related distractors to compare against Meyer et al.'s (2007 - Chapter 5) finding of homophone interference in visual search. Experiment 1 looked at search where one phonologically related distractor could be present on the screen and Experiment 2 looked at search where multiple phonological distractors could be present on the screen.

2. Experiment 7: Single phonological distractor

The first experiment was identical to the experiment by Meyer et al. (2007 - Chapter 5), except that phonologically related distractors replaced semantically related and homophone distractors. The distractors shared either initial segments (e.g., *bed - bell*) or final segments (e.g., *snake - cake*) with the target. In speech production tasks, distractors that share initial or final segments affect the participant's performance similarly (e.g., Meyer & Belke, 2006; Meyer & Damian, 2007) but in speech comprehension tasks, differences have been shown between segment types (e.g., Dufour & Peereman, 2003; Radeau, Morai & Segui, 1995). Both types of distractors were tested to assess whether there were any differences.

In addition, the experiments were split according to whether or not a picture booklet was provided for participants to familiarise them with the pictures used for the task. Meyer et al. (2007 - Chapter 5) familiarised their participants with the pictures prior to carrying out the task. I aimed to investigate whether a phonological effect would only be obtained when the participants had seen the objects and their names, or whether it would be seen when the participants carried out the search task without prior familiarisation. The latter outcome would provide stronger evidence for activation of picture names in a non-linguistic task. In Experiment 7a, participants had no picture booklet; in 7b, participants were shown a picture booklet.

2.1. Method

Participants. Students from the University of Birmingham participated in return for payment in cash or course credits (n = 32, mean age 22, 7 males). 12 participants took part in Experiment 7a, 20 in Experiment 7b. Participants reported themselves to be native British English speakers (not bilinguals), with normal or corrected vision. The handedness of the participants was not recorded.

Design and materials. Participants first saw a target picture (e.g., *pie*) followed by a four-object display. In each block, half of the trials were made up of target present trials (where the target is on display) and the remaining of target absent trials (where an unrelated object from the target set is displayed as a foil). Half of the target present and absent trials had a phonologically related distractor present (in addition to the target or foil), with half sharing the initial consonant and vowel with the target (e.g., *pie* - *pipe*) and half sharing the final vowel and consonant with the target (e.g., *clock* - *sock*). For the remaining trials, a phonologically unrelated distractor was present instead.

In the target present, phonologically related condition, the related target-phonological distractor pairs were shown, along with two fillers. In target absent conditions the target was replaced by another member of the target set (foil). Analogously, in the phonologically unrelated conditions, an unrelated member of the phonological set replaced the related phonological distractor. For example, in a target present, phonologically related trial, a member of the phonological set related to the target would be present (e.g., *pipe*), in addition to the related target (e.g., *pie*) along with two unrelated filler items (see Figure 22). Thus, each search display featured a member of the target set, a member of the phonological set, and two additional filler objects, which were semantically and phonologically unrelated to the remaining objects in the display.

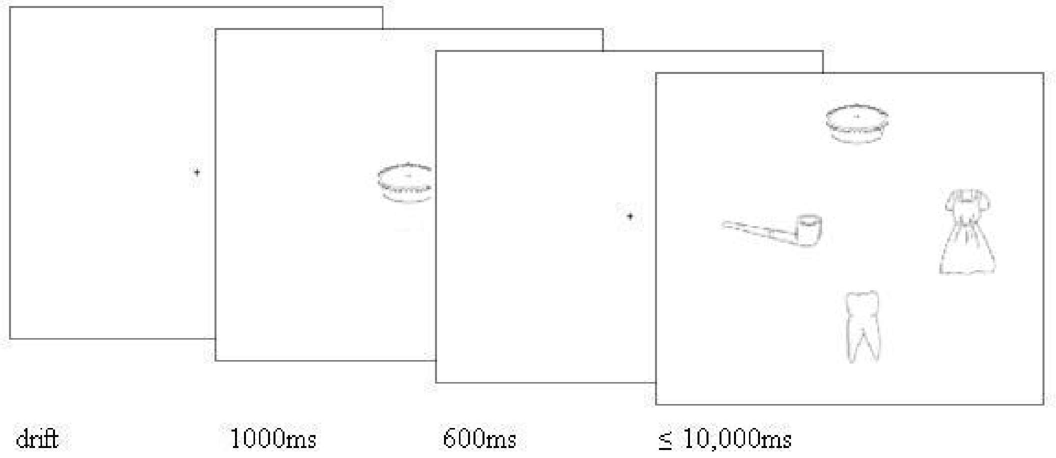

Figure 22. Example trial for Experiment 7, where the target is *pie* and the distractor is *pipe*.

Visual search stimuli consisted of 80 black and white line drawings of everyday objects, 20 of each set (targets, phonologically related, filler groups 1 and 2). Target and related distractors were pre-tested for minimum 80% name agreement native British English speakers (n = 12, mean age 23 years, 9 males). Stimuli were 100 by 100 pixels, with a horizontal and vertical resolution of 72 dpi, which meant 4.6 by 4.6 degrees of visual angle when viewed 60cm from the monitor. If the display were a clock face, the four stimuli were positioned at 12, 3, 6 and 9 o'clock on the visual array, at 7.4 degrees of visual angle (170 pixels) from the midpoint of the screen. Please refer to Appendix 3 for a stimuli list. Randomisation software was used to create the visual search arrays (StimulusGenerator, © D.G. Watson), with objects being randomly assigned to a screen quadrant. One search array was produced per item, per condition, per block. There were 80 trials per block and four blocks in total. Participants were exposed to all objects, which occurred four times on each condition. The experimental conditions were presented in a mixed trial and block order across participants.

Apparatus. The experiment was managed through the Subject PC (Pentium IV, 1.5 GHz), stimuli were displayed on a Triniton Multiscan G240 monitor (17”), with a screen resolution of 600 by 800 pixels. Eye movement data was processed using an Eyelink SensoriMotoric Instruments (SMI) v 2.04 head mounted eye-tracker from SR Research Limited.

Procedure. Prior to beginning the task, participants were asked to read through the instruction sheet. In Experiment 7b participants also read through a picture booklet, which familiarised participants with all of the pictures and their picture names. Participants assumed a suitable viewing position from the monitor (typically 60 cm). The eye tracker was positioned on the participant’s head, camera aligned so that the eye was in focus and the system calibrated. Eye position data was gathered from the right eye.

Participants were completed four blocks, lasting ten minutes each, with rest and recalibration in between and optional removal of headset. Each trial started with a fixation point and participants were asked to look at the point so that drift correction can be made, allowing for any adjustment in head position during previous trial. The participants managed the pace of the experiment, pressing a button on their hand-held control pad whilst looking at the fixation point (drift control) to move on to the next trial. Next, the picture of the target appeared in the centre of the screen for 1000 ms, followed by the presentation of a fixation cross for 600 ms before a four stimuli array, which was displayed until the participant responded and for a maximum duration of 10,000 ms. Participants selected whether a target was present or absent using a hand-held control pad with 4 different colour-coded buttons. They pressed the green button if the target was present and the red button if absent.

Following the search task, participants from Experiment 7b took part in a picture booklet test, where printed pictures from the experiment were asked to have their names written beneath. Finally, all participants were verbally debriefed. The total time to run the experiment was 60 minutes, including 15 minutes for instruction and calibration and 45 minutes of testing.

2.2. Results

Data from one participant were excluded because he rarely fixated on any of the objects shown in the display. The first five trials of the first block were practise trials and excluded from the data set (1.6%). The following errors were removed from all other analysis. Incorrect responses were coded first and provided the basis for error analysis (7a: 2.1% and 7b: 2.7%). Outlying RTs beyond three standard deviations from a participant's mean were excluded (7a: 1.9%, 7b: 1.7%). Any target or distractor pictures incorrectly labelled in the picture booklet test after carrying out the task were excluded for each participant (Experiment 7b only: 1.2%). Next, fixations made to the middle region were coded, i.e., the first fixation made in a trial was to a fixation point, before the eyes moved to one of the four pictures. Participants had been asked to fixate the centre of the screen at trial onset. Trials in which they failed to do so (i.e., did not fixate at a circular interest area (radius: 50 pixels) were removed (drift errors, 7a: 4.0% 7b: 4.2%).

Correct responses only were selected for eye movement analysis. Fixations that occurred within the RT period and to one of four interest areas were examined. The interest areas on the screen were slightly larger than the stimuli appeared on the screen (108 by 108 pixels). Trials where no eye movement was made away from the middle region before making a response were coded and subsequently removed from eye data analysis (7a and 7b: 25.4% of trials). Offset time of gaze to middle region, percent first gaze and gaze duration to the target or its foil and to the phonologically related or unrelated distractor were analysed. The offset of gaze to the middle region was the time taken for the participant to initiate their first eye movement away from the middle region after trial onset. In addition, gaze durations were calculated to include multiple fixations to the same object. The first gaze was the first fixation to one of the four interest areas away from the middle region and before a button response is made.

A mixed ANOVA, with a between-subjects factor of picture booklet group (2 levels), and within-subjects factors of target status (2 levels), relatedness (2 levels) and segment type (2 levels) was carried out on the subject means. A mixed ANOVA with the same factors of picture booklet group, target status and relatedness, and a between items factor of segment type (2 levels) was carried out for the items means, as half of the items were begin related and end related. Analysis of variance found no significant interactions between type of relatedness and any other variables for the measures reported. For this reason, the results have been collapsed across data across segment type.

2.2.1. Behavioural results

Error rates. Analysis of variance showed a main effect of target status only, with increased error rate during target present than target absent trials (4 vs. 1.7%, by subjects analysis: $F_1(1, 30) = 36.66, p < .001, \eta^2 = .55$; by items analysis: $F_2(1, 36) = 24.27, p < .001, \eta^2 = .40$). There were no other effects or interactions.

RTs. Analysis of variance yielded a main effect of target status only, with shorter RTs for target present than target absent trials (711 vs. 808 ms: $F_1(1, 30) = 56.63, p < .001, \eta^2 = .65$; $F_2(1, 36) = 226.16, p < .001, \eta^2 = .86$). There were no other effects or interactions.

2.2.2. Eye movements

Trials where no eye movement was made away from the middle interest area before making a response were removed prior to eye data analysis (7a & 7b: 25.4% of trials, condition breakdown: 22% target present, distractor present; 23% target present, distractor absent; 26% target absent, distractor present; 28% target absent, distractor absent).

Offset time from middle region. Analysis of variance showed a significant effect of target status only, with gazes leaving earlier during target present than absent (236 ms) trials (236 vs. 279 ms: $F_1(1, 29) = 54.93, p < .001, \eta^2 = .65$; $F_2(1, 36) = 115.03, p <. 001, \eta^2 = .76$). There were no other effects or interactions.

First gaze to the target. Analysis of variance yielded a main effect of target status only, with significantly more first gazes to the target than its foil (77% vs. 27%: $F_1(1, 29) = 581.71, p < .001, \eta^2 = .95$; $F_2(1, 36) = 536.43, p < .001, \eta^2 = .94$). There were no other effects or interactions.

First gaze to the distractor. Analysis of variance yielded a main effect of target status, with target fewer first gazes to the distractor (whether related to the target or not) during target present than absent trials (7 vs. 24%: $F_1(1, 29) = 204.18$, $p < .001$, $\eta^2 = .88$; $F_2(1, 36) = 93.63$, $p < .001$, $\eta^2 = .72$).A main effect of relatedness, with participants less likely to look at the phonologically related than unrelated distractor, was significant by items only (14 vs. 16%: $F_1(1, 29) = 2.26$, $p = .144$, $\eta^2 = .72$); $F_2(1, 36) = 7.31$, $p = .010$, $\eta^2 = .17$). There were no other effects or interactions.

First gaze duration to the target. Analysis of variance yielded a main effect of target status, with longer first gazes to the target than to the foil (366 vs. 196 ms: $F_1(1, 29) = 104.21$, $p < .001$, $\eta^2 = .78$; $F_2(1, 36) = 671.80$, $p < .001$, $\eta^2 = .95$). There were no other main effects or interactions.

First gaze duration to the distractor. A main effect of group was found by items only, with participants in Experiment 7a gazing less at the distractor (whether related to the target or not) than those of Experiment 7b (162 vs. 185 ms: $F_1(1, 29) = 1.25$, $p = .273$, $\eta^2 = .04$; $F_2(1, 36) = 5.73$, $p = .022$, $\eta^2 = .14$). There was a main effect of target status, with shorter first gazes to the distractor during target present than target absent trials (164 vs. 206 ms: $F_1(1, 29) = 17.73$, $p < .001$, $\eta^2 = .38$; $F_2(1, 36) = 13.96$, $p = .001$, $\eta^2 = .28$). Figure 23 shows that first gazes to the distractor were shorter during related than unrelated target present trials (28 ms difference) and longer during target absent trials (9 ms difference). However, an interaction between target status and relatedness failed to reach significance ($F_1(1, 29) = 2.98$, $p = .095$, $\eta^2 = .09$; $F_2(1, 36) = 3.08$, $p = .088$, $\eta^2 = .08$). There were no other effects or interactions.

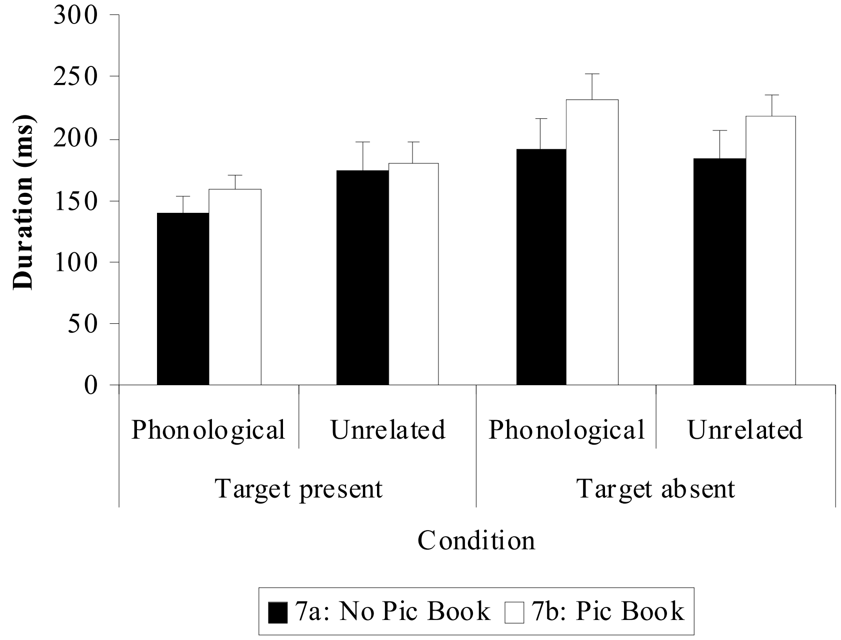

Figure 23. Experiment 7: First gaze durations to the phonological distractor with SEM (by participants).

2.3. Discussion

Following a pictorial target cue, search for a target has been unaffected by the presence of phonologically related distractors (sharing either initial or final segments, e.g., pie-*pipe*, brain-*train*). There were also no significant differences found between participants who were familiarised with experimental stimuli and those who were not. The effect of target presence or absence has been the only effect shown throughout. Participants made more errors, had shorter RTs, shorter offset times from the middle region, more frequent and longer lasting first gazes to the target than the foil, and fewer and shorter lasting first gazes to the distractor during target present than absent trials.

Based on the understanding that homophones have shown a significant effect on search (Meyer et al., 2007 – Chapter 5), it could be that the phonological influence was undetectable, due to partial phonological activation. For example, seeing the target “pie”, only weakly activates related words, including “pipe” prior to search whereas full activation occurred for a complete phonological match as found with homophones (e.g., animal *bat* - baseball *bat*). Such boosting from partially phonologically related to fully related homophones has been successful in picture naming experiments. Cutting and Ferreira (1999) reported a lack of a phonological effect in experiments with partially related auditory primes (replicating Schriefers, Meyer & Levelt, 1990) was explained by replacing these primes with homophones to maximise the effect.

In the next set of experiments, a different technique of boosting a phonological effect was used, based on summation priming (Balota & Paul, 1996; Beeman et al., 1994). Beeman et al. (1994) looked at larger versus small semantic field effects on target naming when items were presented to the left or right visual field. Subjects were asked to name a target word (e.g., *cut*), preceded by three semantically related, summation prime words (e.g., *cry, foot, glass*), or three unrelated words (e.g., *dog, church, phone*). The target words were presented half in one visual field, and half in the other. Accuracy was emphasised in instructions, so latency data was not a valid measure. Irrespective of hemifield, target words were named significantly more accurately following summation primes than unrelated (64 vs. 54%). Balota and Paul (1996) carried out naming, lexical decision and relatedness judgement experiments using multiple related primes. Primes were either unambiguous to the target, e.g., TIGER lion stripes, or ambiguous, e.g., ORGAN kidney piano. All 6 experiments supported additive effects, i.e., the effect of three related primes would equate to the sum of the effect of each related prime presented separately.

Given the benefits of summation priming, multiple phonological distractor triplets were presented with or without the target during visual search. The intention of the next series of experiments was to clarify whether or not a phonological effect was too small to be detected in Experiment 7 or if there was never any phonological activation during search.

3. Experiment 8: Multiple phonological distractors

The second series of experiments used multiple phonological distractors, where three, one related or no related distractors were presented alongside the target or foil. As for Experiment 7, such distractors were conceptually unrelated and only partially phonologically related to the target. Three different summation experiments were carried out. Experiment 8a, replicated Experiment 7's target presentation (i.e., as a pictorial cue); Experiments 8b and 8c, presented the target as a word, and Experiment 8c also asked the participants to name the target out loud (if they see it on the screen) after pressing the response button. Experiment 8a's picture target cue could impact on the detection of phonological effect. Presenting participants with a picture cue followed by four pictures may not require processing to go beyond the visual level (though semantic and phonological effects were found in Meyer et al., 2007 - Chapter 5, when the target was also a picture). Wolfe, Horowitz, Kenner, Hyle and Vasan (2004) reported faster RTs when picture rather than word cues were used in search for targets that were a particular colour and orientation. They concluded that an identical picture cue to the upcoming target leaves no ambiguity, compared to word cues. By presenting participants in Experiment 8b and 8c with a word target cue, this might encourage access to the phonological stage prior to creating a visual representation of the target for search. Reading of the word encourages participants to encode the name of the target and store it in working memory, rather than just the visual image. Experiment 8c also required participants to name the target out loud when it was present on the screen. This forced the participants to activate the name of the target, which may enhance the spreading of activation to phonological units. Requiring the participants to name the target aloud (not just in inner speech) may be the switch required to induce a phonological effect.

Since the presence or absence of a familiarisation phase did not affect participants in Experiment 7, all Experiment 8 participants were familiarised with the materials. Due to lack of difference between the effects of initial- or final-segment related effects, an arbitrary selection of initial-segment related distractors only was chosen for Experiment 8.

3.1. Method

Participants. Sixty undergraduate students of the University of Birmingham were tested, twenty participants in each of the three sub experiments (16 males, mean age 21 years) participated in exchange for payment. They all reported having normal or corrected-to-normal vision and were native speakers of English and not bilingual.

Design and materials. On each trial, participants saw a target picture followed by a four-object search display. On half the trials, the display included the target (target present) and on the remaining half, the display included a foil (target absent).

Either three phonologically related distractors, one phonologically related and two unrelated distractors or three unrelated distractors took up the remaining positions on display. The distractors were all begin-related, sharing the initial segment of the word with the target (e.g., *<u>win</u>dow*- *<u>win</u>dmill*).

A set of 72 pictures was selected from the Snodgrass and Vandervart (1980) picture gallery and a picture gallery provided by the Max Planck Institute for Psycholinguistics, Nijmegen (NL; see Appendix 3). Additional pictures were adapted from those available through the Google Image Search facility. 18 pictures served as targets and 54 others as either phonologically related distractors, or unrelated distractors (fillers). All stimuli were tested for name agreement[18] prior to usage. In the three-related distractors condition, the related target-distractor triplets were shown (selected from each of the three distractor sets). The unrelated distractors were from the distractor set but unrelated to the current target. Each search display featured a member of the target set (target or foil), and a member of each of the three distractor sets, which were either phonologically related or unrelated the current target. For example, where the target was window, *saxophone* was an unrelated filler item during the 1-related and unrelated distractor conditions, when the target was sandwich, *saxophone* was a related distractor during the 3-related condition.

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[18] 20 participants (6 males, mean age 24 years) were asked to name pictures with the first name that they could think of. Those pictures with an accuracy of 80% and above were accepted for usage in the experiment.

Table 18 *Experiment 8: Sample of stimuli used in target present conditions.*

Condition	Target name	Target	Distractor 1	Distractor 2	Distractor 3
3-Related	Window	WINDOW	WHISTLE	WINDMILL	WHISK
1-Related		WINDOW	WHISTLE	**Saxophone**	spoon
Unrelated		WINDOW	bomb	**Saxophone**	spoon
3-Related	Sandwich	SANDWICH	SADDLE	**SAXOPHONE**	SACK
1-Related		SANDWICH	SADDLE	Windmill	pepper
Unrelated		SANDWICH	train	Windmill	pepper

The line drawings were prepared in the same way as for Experiment 7. There were 18 items and 6 conditions: target status (absent or present) crossed with relatedness (3-related, 1-related or unrelated). This yielded 108 different search displays. There were four blocks in total. Trials and blocks were presented in random order for each participant. At the beginning of each block, two additional practise trials were appended; these were made up of trials used in the practise block, i.e., unrelated to the experimental design. This gave the participants the opportunity to familiarise themselves with the task ahead. In total, each block had 110 trials.

Apparatus. The same apparatus was used as in Experiment 7. For Experiment 8c, a Sony TCD-D8 DAT tape recorder and microphone recorded target naming.

Procedure. The same procedure was used as in Experiment 7b, except in Experiments 8b and 8c the target was presented as a word and in Experiment 8c, participants were asked to name the target if they saw it on the screen after pressing the correct button. The experimenter reminded participants to name the target after their response, whenever naming was made simultaneously with the button press during the practise block. Responses were recorded onto a DAT tape and any errors marked down by the experimenter. Any trials where participants misnamed the target, did not name it when present or named it when target absent, were recorded. A picture booklet was provided after the experiment for participants to label the names of each picture seen in the experiment.

3.2. Results

Participants with at least 30% of cases missing from their correct scores (minimum of 288 cases correct) were excluded. Three participants each were excluded from Experiments 8a and 8b and four participants from Experiment 8c. In addition, one participant was withdrawn from Experiment 8a for technical reasons. The remaining participants' mean errors are reported in Tables 5 to 7. The first five trials were excluded as practise trials (1.8%). Incorrect responses (e.g., saying target present when absent and vice versa) accounted for 8a: 2.6%, 8b: 2.1% and 8c: 1.1% all responses. This provided the basis for error analysis. Next, the outlying RTs beyond three standard deviations from a participant's mean (8a: 1.7%, 8b: 1.4%, 8c: 1.6%); drift errors (8a: 3.4%, 8b: 3.1%, 8c: 3.0%) and any target or distractor pictures incorrectly labelled in the picture booklet test after the experiment were excluded from the remaining data (8a: 6.6%, 8b: 11.8%, and 8c: 8.7%). In Experiment 8b, there was a technical error with trials being skipped, leading to blank trials being reported in the output files (0.9% of trials). In Experiment 8c, trials where participants incorrectly or misnamed the target were also excluded from the data set (0.3%). Remaining trials were then used for RT and eye data analysis.

Eye movement data were prepared in exactly the same way as for Experiment 1. Trials where participants initiated no eye movement away from the middle region before making a response were removed. In Experiment 8c, where participants had to name the target, fewer trials occurred where no eye movements were made compared to participants in Experiments 8a and 8b, where no naming was required (8a: 25.1%, 8b: 21.9%, 8c: 7%). In Experiment 8a, participants 11 and 14 were excluded as they made an average of 14 fixations during the experiment where remaining participants made 282 fixations, SD: 60.8. Offset time of gaze to middle region, proportion of first gazes and gaze duration were analysed for each trial.

The three multiple phonological distractor experiments were analysed in a two (target status: absent or present) by three (relatedness: 3 related, one related or unrelated distractors) within-subjects ANOVA with a between-subjects factor of experiment (8a*,* where the target was a picture; 8b*,* where the target was a word; 8c, where the target was a word and included naming out loud when present on display). For the item analysis, experiment group was a within-subjects variable.

3.2.1. Behavioural results

Error rates. Analysis of variance yielded a main effect of group with more errors by participants of Experiments: 8a, where the target was a picture, than 8b, where the target was a word, and 8c, where the target was a word and a naming task required (3 vs. 2 vs. 1%: $F_1(2, 46) = 7.96$, $p = .001$, $\eta^2 = .26$; $F_2(2, 34) = 21.96$, $p < .001$, $\eta^2 = .56$). There was a significant effect of target status, which increased error during target present than absent trials (3 vs. 1.3%: $F_1(1, 46) = 52.43$, $p < .001$, $\eta^2 = .53$; $F_2(1, 17) = 25.07$, $p < .001$, $\eta^2 = .60$). No other effects or interactions were found.

RTs. A main effect of experiment group was found, with RTs getting slower from Experiment 8a to 8c (619 vs. 738 vs. 774 ms: $F_1(2, 46) = 4.61$, $p = .015$, $\eta^2 = .17$; $F_2(2, 34) = 337.31$, $p < .001$, $\eta^2 = .95$). A main effect of target status showed faster RTs during target present than absent trials (653 vs. 768 ms: $F_1(1, 46) = 93.28$, $p < .001$, $\eta^2 = .67$; $F_2(1, 17) = 167.30$, $p < .001$, $\eta^2 = .91$). A main effect of relatedness did not reach significance ($F_1(2, 92) = 2.45, p = .095, \eta^2 = .05; F_2(2, 34) = 0.74, p = .433, \eta^2 = .04$), with similar RTs during the three related and one related conditions (707 ms and 708 ms), and slower RTs in the unrelated condition (715 ms). There were no interactions between experiment and relatedness.

3.2.2. Eye movements

Offset time from middle region. A main effect of target status, with offset times starting earlier during target present than absent trials (212 vs. 229 ms: $F_1(1, 44) = 34.91, p < .001, \eta^2 = .44; F_2(1, 17) = 109.90, p < .001, \eta^2 = .87$). There were no interactions.

First gaze to the target. A main effect of group, with Experiment 8a (pictures) making more first gazes to the target than Experiment 8b (words) or Experiment 8c (words and naming) (59 vs. 52 vs. 52%: $F_1(2, 44) = 4.01, p = .025, \eta^2 = .15; F_2(2, 34) = 13.26, p < .001, \eta^2 = .44$). There was a main effect of target status, with more first gazes to the target than to the foil (70 vs. 39%: $F_1(1, 44) = 372.31, p < .001, \eta^2 = .89; F_2(1, 17) = 162.48, p < .001, \eta^2 = .91$). There were no interactions with relatedness.

First gaze to the main distractor. Because of the presence of multiple distractors, in conditions with three related distractors first gaze to all three distractors could not be measured at the same time, as participants can only focus on one of those distractors. For this reason, I concentrated analysis on the level of gaze direction the main distractor: the distractor that appears in both the one-phonological and three-phonological distractor conditions, for the related and unrelated conditions. First gazes to the main distractor were significantly different between experiments with fewer gazes during Experiment 8a than 8b and 8c (15 vs. 18% vs. 17%: $F_1(2, 44) =$

3.59, $p = .036$, $\eta^2 = .14$; $F_2(2, 34) = 4.26$, $p = .038$, $\eta^2 = .20$). A main effect of target status found fewer gazes to the distractor during target present than absent trials (11 vs. 23%: $F_1(1, 44) = 196.19$, $p < .001$, $\eta^2 = .82$; $F_2(2, 17) = 41.45$, $p < .001$, $\eta^2 = .71$, $\eta^2 = .02$). There were no other main effects or interactions.

First gaze duration to the target. Gazes to targets were significantly longer than to foils (292 ms vs. 166 ms, $F_1(1, 44) = 133.04$, $p < .001$, $\eta^2 = .75$; $F_2(1, 17) = 491.02$, $p < .001$, $\eta^2 = .97$). The durations of first gazes to the target were 9 ms shorter during target present 3-related and 1-related conditions (both 288 ms) than unrelated (299 ms). A significant interaction between target status and relatedness confirmed this by subjects only ($F_1(2, 88) = 4.27$, $p = .019$, $\eta^2 = .09$; $F_2(2, 34) = 0.42$, $p = .634$, $\eta^2 = .02$). There was no effect of relatedness and no difference between experiments 8a, 8b and 8c.

First gaze duration to the main distractor. Analyses of variance yielded a main effect of group ($F_1(2, 44) = 5.86$, $p = .006$, $\eta^2 = .21$; $F_2(2, 34) = 28.03$, $p < .001$, $\eta^2 = .62$), with longer durations to the object (whether related or unrelated to the target) by group 8b (176 ms), than 8c (151 ms), then 8a (141 ms). There was also a main effect of target status, with shorter gazes to the distractor during target present than absent trials (138 vs. 174 ms: $F_1(1, 44) = 46.45$, $p < .001$, $\eta^2 = .51$; $F_2(1, 17) = 23.97$, $p < .001$, $\eta^2 = .59$). An interaction between relatedness and group was significant by subjects only ($F_1(4, 88) = 3.96$, $p = .007$, $\eta^2 = .15$; $F_2(4, 68) = 0.88$, $p = .457$, $\eta^2 = .05$), see Figure 24.There was no main effect of relatedness.

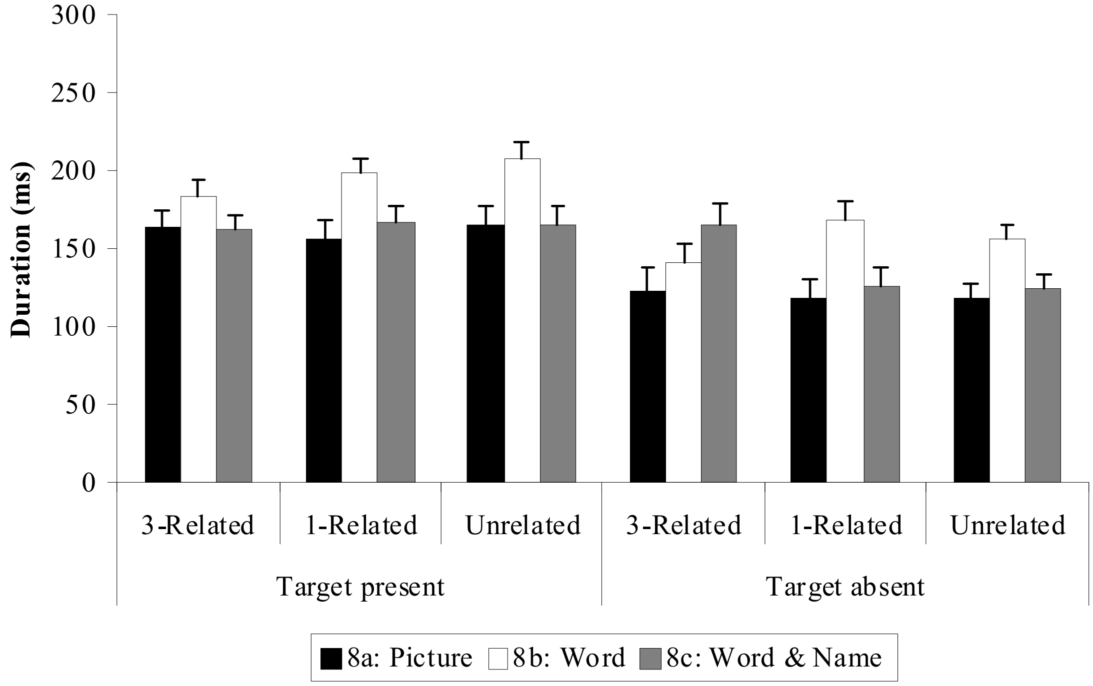

Figure 24. First gaze durations to the main distractor (Experiment 8) with SEM (by participants).

3.3. Discussion

In the second experiment of this chapter, I was looking to see whether multiple phonological distractors would affect visual search for the target. Following no effect of relatedness in Experiment 7, additional phonological distractors were introduced to the search display. In addition to one-related distractor, there was also a three-related distractor condition, here, the target was accompanied by three begin related distractor objects, e.g., window, *windmill, whistle, whisk.* If the phonological effect was undetectable with one distractor, presenting multiple phonological distractors could have boosted the phonological effect so that it was detectable. Three experiments with multiple distractors were carried out, each with different variations of target presentation and experiment instruction. Experiment 8a presented the target cue as a picture and Experiments 8b and 8c as a word. In Experiment 8c, participants were also asked to name the target picture when it was present in the screen, after giving the button response.

In all three experiments, no main effects of relatedness were found. Despite presenting multiple distractors to the participants (in some cases, all pictures on the screen were phonologically related) the effect found when using homophone distractors (Meyer et al., 2007 - Chapter 5) could not be replicated. These results do not support (1) the activation of phonological information about all objects in parafoveal view or (2) bottom up activation of phonological representations related to the target. I will return to this in the General discussion.

3.3.1. Different types of input affect search

The effect of experiment group highlighted the differences between the target cue being a picture (8a) or a word (8b), and adding the target-naming task (8c). When the target was a picture, participants made more errors, shorter RTs, and made more frequent and shorter lasting gazes to the target, than when the target was a word. This was perhaps due to participants focussing on visual information only, not accessing higher levels of information in long-term memory. When the target was a word, participants asked to name the target were more careful in their search for the target, with slower RTs and fewer errors than participants who did not carry out target naming. However, the need to name the target also meant participants moved their eyes away from the target faster during target present trials, with shorter gazes to the objects compared to participants without a naming task.

4. General discussion

The results of the two experiments are clear: the presence of a phonologically related distractor does not significantly influence participant's search for the target, regardless of whether additional "boosts" are applied to the task. The result shows a difference between the relationship between target and a homophone and target and a phonologically related distractor. The results did not show a sliding-scale effect, where perhaps phonologically related distractors would show a weaker interference than homophones, as found in the Meyer and Damian study (2007), instead homophones distracted viewers and phonologically related objects did not distract.

Results did show a difference between target presence or absence on search, with the effects being replicated for Experiments 7 and 8. RTs were longer when the target was absent than present, showing the need for participants to inspect additional items to confirm its absence. This was also supported by the error and eye data. There were more errors and eye gazes were initiated sooner during target present than absent trials. Participants took more time in target absent than present trials and so made fewer mistakes. First gazes were directed to the target 41% more, and lasted 148 ms longer than to the foil. The presence versus absence of the target also reduced first gazes to distractors by 15% and 39 ms in duration. In Experiment 8, the different target presentations and tasks did have an effect on behaviour. For example, shorter RTs and gaze durations when the target was a picture rather than a word demonstrated that this affected the search process, just no impact on phonological activation.

4.1. Implications of this study

Upon the finding that homophones affected search as semantically related distractors did, Meyer et al. (2007 - Chapter 5) suggested that as well as rapid activation of target and distractor conceptual information, name (phonological) information might also be activated. If the target and distractor names were activated, distractors that share some elements of the name (just like semantically related distractor share overlapping semantic features with the target) would be able to compete with the target for visual attention. Despite carrying out five experiments with both single and multiple phonologically related distractors on display, which included introducing a number of conditions to 'induce' phonological activation (e.g., presenting the target as a word compared to presenting the target as a picture), search for the target was unaffected. This suggests that name information is not automatically activated for the target or distractors. At least in this task, automatic activation of an object's name is not necessary.

However, homophones that share their name with the target have been shown to affect search, in this case the target and homophone must have competed for visual attention at a phonological level. Returning to the models of homophone representation, it could be that target and homophone compete at the morphological level of representation instead of phonological. According to the SR model of homophone representation, homophones share morphological and phonological levels of representation. Shared morphological activation may then have led to phonological activation also, priming search for objects with the target name. Phonologically related distractors are morphologically distinct from the targets, and therefore would not be affected by such activation. This would go against the IR model of homophone representation, which sites the critical level at the phonological representation (where phonological distractor effects would have been expected to occur in this task).

4.2. Further points to consider

Alternatives or contributions to the reported homophone effect and absence of interference from phonologically related distractors will now be discussed.

First, there is a possibility that the choice of materials and limited familiarisation of participants with those materials caused any phonological effects to be undetectable. In our experiments, the phonological overlap between target and distractor occurred for the first few segments of the word (e.g., *clown – crown*). In Morsella and Miozzo's (2002) overlapping pictures paradigm phonologically related pairs were selected with the greater degree of overlap, e.g., *pig - pin*. In a pilot study prior to the reported experiment initial-segment related pairs similar to those in our experiment found "negligible effects" (e.g., *skirt* - *skull*). Careful selection of suitable materials may have contributed to their phonological effect. However, some of the pairs selected for the experiment were not ideal, for example, rake-*rain* (rain is not very easily depictable); mouth-*mouse* (mouth could be mistaken for "lips"), affecting name agreement. However, phonological facilitation of naming still occurred and was replicated in later studies. Morsella and Miozzo (2002) also provided participants with an extensive training period: first, subjects named all pictures twice and were corrected if named wrongly; second, participants carried out two training blocks, in order to familiarise themselves with the task, where they saw each picture twice. In our experiment, participants were not trained or tested, they were only asked to familiarise themselves with the pictures. Incorrectly named pictures were only eliminated from analysis based on a post-task picture booklet test.

Second, Meyer et al. (2007 - Chapter 5) presented semantically related and homophone distractor conditions within blocks, not in separate blocks. Participants were presented with a combination of semantically related and homophonous distractors in each block. Semantic distractors with no other distractor conditions produce an inhibitory effect in search (Belke et al., in press; Moores et al., 2003; Telling et al., 2008 - Chapter 2). It is not known whether or not homophone distractors can interfere with search when presented alone. However, Meyer et al. (2007 - Chapter 5) carried out block-by-block analysis, which showed a reliable inhibitory effect for homophone and semantic conditions on RTs and eye movements even after the first block. This provides evidence against the development of strategy in the presence of semantic distractors.

Finally, there is a possibility is that the homophone pictures were more distinctive than the other pictures used in our experiments. The homophone picture pairs were created by hand, as line drawings of the different homophones were not available from standard sets (Morgan & Meyer, 2005). In addition, because of the special status of the homophones, name agreement was not as high as for other pictures so more care was taken in familiarising participants with the pictures (see Figure 25). In order to address this, an experiment replicating Meyer et al. (2007 - Chapter 5) could be carried out with new homophone stimuli (e.g., in German *Fliege* (fly) – *Fliege* (bow-tie)) and tested with native speakers. Replicating the homophone effect with a new set of stimuli and a new group of participants would help to confirm the activation of name information at in search.

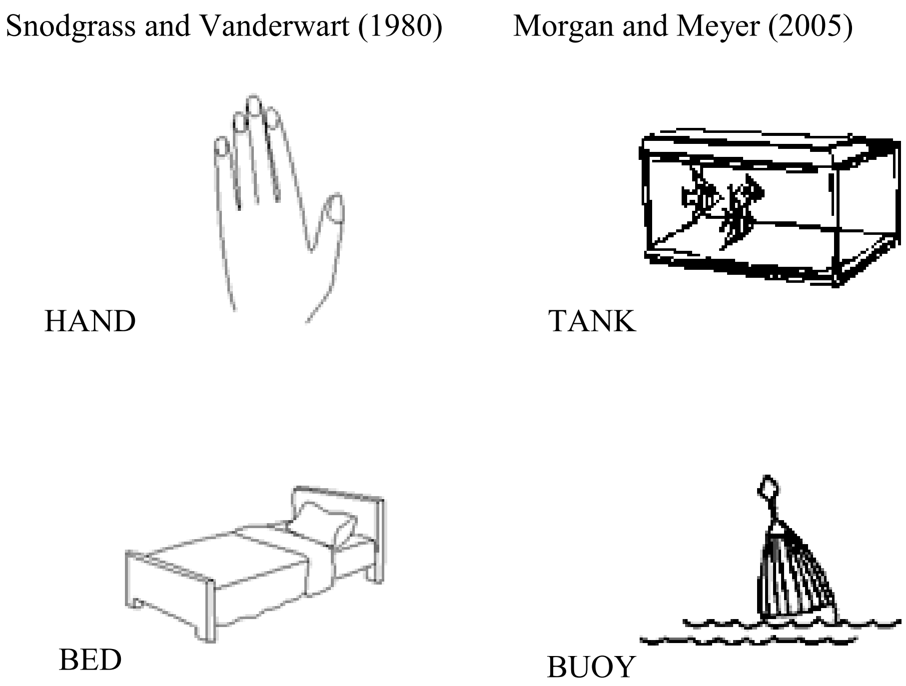

Figure 25. Examples of experimental stimuli used in Chapter 5

For now, I shall assume that the relationship between target and homophone caused the effects reported in Meyer et al. (2007 - Chapter 5), but not between target and phonologically related distractors. Upon presentation of the target, activation does not spread automatically to the phonological representation of the target; upon presentation of the search display, phonological information about the search items are not automatically activated. Instead, homophones shared a unique relationship with their target, sharing their morphological and phonological representations, and this cannot be generalised to phonologically related items, which only share partial phonological representations.

CHAPTER SEVEN

GENERAL DISCUSSION

1. The motivation for this thesis

The visual search paradigm involves searching for a pre-specified target amongst a number of distractor items. The speed and accuracy of deciding whether or not a target is present on display provides researchers with information about how a target is selected and unrelated distractors rejected. The paradigm is used to represent our search for objects in everyday life, e.g., a pilot searching for the right button on the flight deck, or a doctor finding the location of a fracture on an X-ray.

What attributes of the target are used to direct attention? Whereas the majority of visual search theories, including Guided Search (Wolfe, 1994) and AET (Attentional Engagement Theory; Duncan & Humphreys, 1989) agree that search for a target can be guided according to visual properties of the stimulus, e.g., looking for items that match the colour of the target, theories are not so confident about whether other non-visual properties can guide search. FIT (Feature Integration Theory; Treisman, 1986) and Guided Search state that only visual properties can guide search, and that more complex, abstract properties do not. Wolfe and Horowitz (2004) reviewed a selected number of visual search studies and concluded that any evidence for attention being directed according to higher levels of information, including the semantic categories of stimuli, were likely to be due to guidance from visual rather than semantic properties per se. The AET and Biased Competition models do not rule out such higher-level influences, however.

Previous evidence supporting the possibility that search is not only guided according the visual properties of the target has come from a visual search experiment that required participants to search for a target (e.g., *motorbike*) when a semantic associate (e.g., *crash* helmet) may also be present on the screen (Moores, Laiti & Chelazzi, 2003). Moores et al. (2003) reported significant differences between RTs, accuracy and initial saccades when an associate distractor was on display, particularly when the target was absent. On these trials, participants were slower to decide whether the target was present or absent, less accurate and made fewer first saccades to the target and more first saccades to the associate than when the associate was absent.

The authors concluded that activation of a target template for search upon presentation of the target cue, also lead to spreading activation to semantically associated representations held in long term memory, which created further, although weaker, templates for search. Search was then not only guided according to the properties of the target template, but the associated items as well. When one of the associate items was on display, this caused competition to emerge between target and associate, which must then be resolved before a decision could take place, affecting RTs and initial eye movements and in some cases accuracy too. Furthermore, there could have been priming of the initial uptake of information from the search display before the first saccade was made, based on the properties of the representations held in WM. Consistent with semantic priming studies, early processing of objects would occur more quickly for items already accessed in long-term memory, contributing to the biasing of competition towards target and semantic associate items.

The finding of semantic interference in search suggests two phases where the target competes with semantic distractors for attention (i) when semantic representations are activated in WM (ii) when semantic associates on display are recognised more quickly during the initial, parallel uptake of the items on display prior to the first eye movement. I will return to these phases later on in this chapter.

This thesis aimed to investigate further the evidence provided by Moores et al. (2003), carrying out experiments that (i) assessed the impact of distractors semantically related to the target in young, older adult and brain damaged individuals; and (ii) extended the finding of semantic interference in healthy young adults to test the impact of distractors phonologically identical to or related to the target in that group also. These experiments clarify what non-visual attributes are, or are not used to direct our top-down search for the target.

A summary of these experiments will be provided next, before discussing the contribution of these results to the theories of visual search for the target.

2. Summary of experimental chapters

2.1. The time course of semantic access in visual search: Evidence from Chapter 2

Chapter 2 monitored participants' neural activity during visual search when a distractor that was semantically related or unrelated to the target was present on the same or opposite side of the display. By measuring changes to any ERP components that were produced during the task in the different conditions, conclusions could be made with regards to if and when semantic properties about the target are being activated and used to guide search. Four ERP components were studied in particular: the P1, N1, N2pc and P3. The P1 occurs earliest, at around 110 ms, following this was the N1 at around 175 ms, then the N2pc at 225 ms and the P3 at around 450 ms post display onset. Each component is associated with different events in the time course of visual processing and visual attention. The P1 and N1 are linked to early perceptual processing based in the striate and extrastriate areas (see Hillyard, Vogel & Luck, 1998; Luck & Hillyard, 1995). The magnitude of the N2pc is associated with the allocation of attention to task relevant stimuli (e.g., Woodman & Luck, 2003) and has been found to previously be affected by semantic properties of the stimuli (Eimer, 1996). The P3 can reflect decision-making and response selection (e.g., Hopf et al., 2000).

P1 and N1 were unaffected by target presence or absence, semantic relatedness or unrelatedness to the target. At such an early stage of processing, 110 – 175 ms post display onset, visual information was insufficient to generate recognition of any items on display. A little later on, however, the magnitude of the N2pc response showed significant differences between target present and absent, and semantically related and unrelated conditions. Of particular note was the finding that on trials where a semantically related distractor was on the same side as the target (or it’s foil) the magnitude of the N2pc was larger than when the distractor was on the opposite side or absent altogether. On target present trials, the presence of a semantically related distractor to the target increased the N2pc to a level greater than when the target appeared without a related distractor in the same field. On target absent trials, the N2pc (now measured to the foil) was not elicited at all, unless the semantically related distractor was present in same field. This suggests that the allocation of attention to a field increased in the presence of a distractor, consistent with attention being oriented to the related distractor. The RT data however, showed slower responses when the related distractor was present on the same side as the target, and when the related distractor was present on the same side as the foil, compared to distractor absent trials. This later effect on RTs may arise because, after it has been attended, the related distractor takes time to be rejected as not being the target.

These results suggest that search for the target proceeds untouched by semantic details of the target template or display items until visual processing has reached a sufficient stage by which semantic information can be accessed. This starts at 225 ms after the search display has been presented, around the same time that initial eye movements would begin in a normal search task. Here, the presence of a semantic distractor enhances the level of attention being directed to that field (containing the distractor and either the target or irrelevant foil). It is not until after that that the competition between distractor and target is resolved, as more and more information about the scene can be processed to decide target status. Although the presence of a semantic distractor delayed RTs, participants were able to overcome having attended the distractor, to provide an accurate response.

2.2. The contribution of the frontal lobes in limiting the competition between semantically related distractor and target: Evidence from Chapter 3

In this chapter the direction of attention according to the contents of working memory was studied in older adults and patients with frontal lobe damage. These two groups were put together in the same chapter due to previous evidence from frontal ageing (e.g., West, 1996), suggesting that both groups may show the same pattern of performance, though to differing degrees (the older adults being less impaired, but in the same direction as the patients). However, when carrying out search for the target amongst four objects, one of which could have been semantically related to the target, older adults did not differ from young adults in their response to semantically related distractors. Older adult RTs and first gazes were similar to young adult behaviour, with slower RTs and increased first gazes to the distractor during semantically related than unrelated conditions. In fact, younger adults showed a greater increase in error rates than older adults during trials where a semantically related distractor was on display. Older adults were significantly slower than young adults overall, however, in line with the general slowing account of ageing (Salthouse, 1996).

In contrast to the lack of effect of ageing on performance, there were effects of brain lesion - differences did emerge between the older adults and patients with frontal lobe damage. The frontal lobes contribute to the control of top-down attention, which includes the maintenance of the contents of WM (e.g., de Fockert, Rees, Frith & Lavie, 2001, 2004; Lavie & de Fockert, 2006). In this study, patients with damage to their frontal lobes were found to differ from older adults, especially in the later stages of target selection. The patients carried out more false positive responses (selecting a distractor as the target), took longer to make incorrect responses, made fewer and shorter-lasting first gazes to the target, and longer lasting first gazes to the distractors during trials where the distractor was semantically related than unrelated to the target. However, at early stages of selection (indexed by the frequency of first gazes to the distractor and time to initiate first fixation), the patients performed no differently to the older adults.

Altogether, these results suggest that the frontal patients had the same difficulty in biasing competition towards the target and away from semantic distractors at early stages, and that this difficulty increased later on in processing (when healthy older adults were able to resolve this competition in favour of the target). Such a distinction fits with the findings of Soto, Humphreys and Heinke (2006) who examined attentional cueing from working memory. Soto et al. also reported evidence for a dichotomy between early stages of the direction of visual attention being intact in patients with frontal lobe damage, and later stages, where the patients were disrupted in rejecting the irrelevant distractor cued from WM. In Chapter 3, errors were shown to be particularly high in a sub-group of frontal patients with damage involving the anterior cingulate cortex (ACC) as well as anterior temporal regions. Prior work suggests that the ACC is involved in response monitoring (Blasi et al., 2006; Carter et al., 1998). Apparently patients with lesions to the ACC are impaired at monitoring any inappropriate orienting response to a related distractor, and are then prone to respond to it. In contrast to these patients, the control participants were able to reject the distractor and focus attention towards target items only at this later stage.

2.3. The lack of contribution from the parietal lobes in processing semantic information about the target: Evidence from Chapter 4

In this chapter, patients with posterior parietal damage were assessed as they performed the same visual search task as the frontal patients in Chapter 5. These patients presented with visual extinction, a deficit in biasing spatial attention to one field over another when presented with stimuli to both fields (Driver, 1998). Evidence from previous chapters supports rapid, automatic activation of semantic information to guide top-down search for the target, e.g., Chapter 2 reported semantic interference effects on participant's neural activity from 225 ms post stimulus. By monitoring whether there are any differences in the performance of patients when the distractor was in their attended versus unattended field, further support for such automatic activation could be provided. If patient performance was unchanged when the semantic distractor appears in their attended and unattended fields, automatic activation would be supported; if semantic interference differs according to the field of distractor presentation, the automaticity of spreading semantic activation would not account for these differences.

Previous semantic priming research in patients with visual neglect supports early, semantic activation. McGlinchey-Berroth, Milberg, Verfaellie, Alexander and Kilduff (1993) reported equivocal semantic priming in lexical decision making when the picture prime was presented in their ipsilesional (attended) or contralesional (unattended) fields. Our findings supported this. A group of five patients with visual extinction made significantly more errors and longer RTs during trials where a semantically related distractor was present rather than absent from display, and this did not interact with whether the distractor was in their attended or unattended field. In addition, their first gazes to the distractor were more frequent on trials where the distractor was related than unrelated to the target. Again, this did not interact with the distractor field.

Although the parietal lobes play a role in directing visual attention to a particular side of space as part of the fronto-parietal network, this does not influence the early processing of semantic information, either when stored as part of the WM template or processed upon presentation of the search display.

2.4. Activation of whole, but not partial, name information in visual search: Evidence from Chapters 5 and 6

So far, Chapters 2 to 4 have supported the contribution of semantic properties of the target in directing search. This level of representation was tested further in a series of experiments assessing whether or not name information about the target can also direct search. In Chapter 5, participants searched for the target where in some cases, a distractor that was homophonous to the target was present (i.e., had an identical name to it, e.g., animal *bat* – baseball *bat*). Participants were found to react in exactly the same direction and to the same degree as when distractors semantically related to the target were present. RTs were slower and first eye movements showed initial attention taken away from the target and towards the distractor moreso when it was a homophone than when it was unrelated to the target. The homophones share their phonological and morphological segments (e.g., Jescheniak & Levelt, 1994; see Figure 21) with the target. If homophones can compete with the target for attention, competition must have occurred at these shared levels of representation. Therefore, upon presentation of the target word, morphological and also phonological information about the target must have been activated, spreading activation to the representation of the homophone item. Such rapid activation of name information then affected the direction of first gazes and RTs as the competition as resolved between the target and distractor.

Next, evidence for activation of morphological and phonological information about the target to guide search was taken further, by assessing the influence of distractors phonologically related to the target (e.g., *be*<u>*d*</u> – *be*<u>*ll*</u>). If the activation of a target representation can spread to semantically related items, and to items with identical names to the target, would activation spread to items that share initial (e.g., *bed* – *bell*) or final (e.g., *brain* – *train*) phonological segments with the target? Five experiments all with null effects of phonologically related distractors suggest that this is not the case. Experiments were carried out to try to encourage processing of the target to a phonological level: Comparing experiments where the stimuli were familiarised in a picture booklet rather than when participants were not aware of the materials before the task (Experiment 7a and 7b); where the target was presented as a word rather than a picture cue (Experiment 8a and 8b); comparing experiments where the target was to be named out loud when it appeared in the display with when it was not requested (Experiment 8c and 8b); and when multiple phonological distractors were on display, compared to just one (Experiment 2).

The finding that homophones but not phonologically related distractors can affect search suggests that the morphological and phonological representations must be shared with the target for these related representations to be activated and affect search. Phonologically related distractors have distinct morphological representations and activation does not spread to them because of this (see Figure 28). Therefore, in addition to semantic information about the target being activated, morphological and phonological information can also be activated, but only items that share these units of representation can interfere with search, i.e., homophones.

3. Contribution to the theories of visual search

I can now confirm that semantic and name (morphological and phonological) information about the properties of the target are used to guide search. Exactly when in the search process this occurs will now be discussed in more detail.

3.1. Theories of semantic processing

3.1.1. Spreading Activation Theory (SAT)

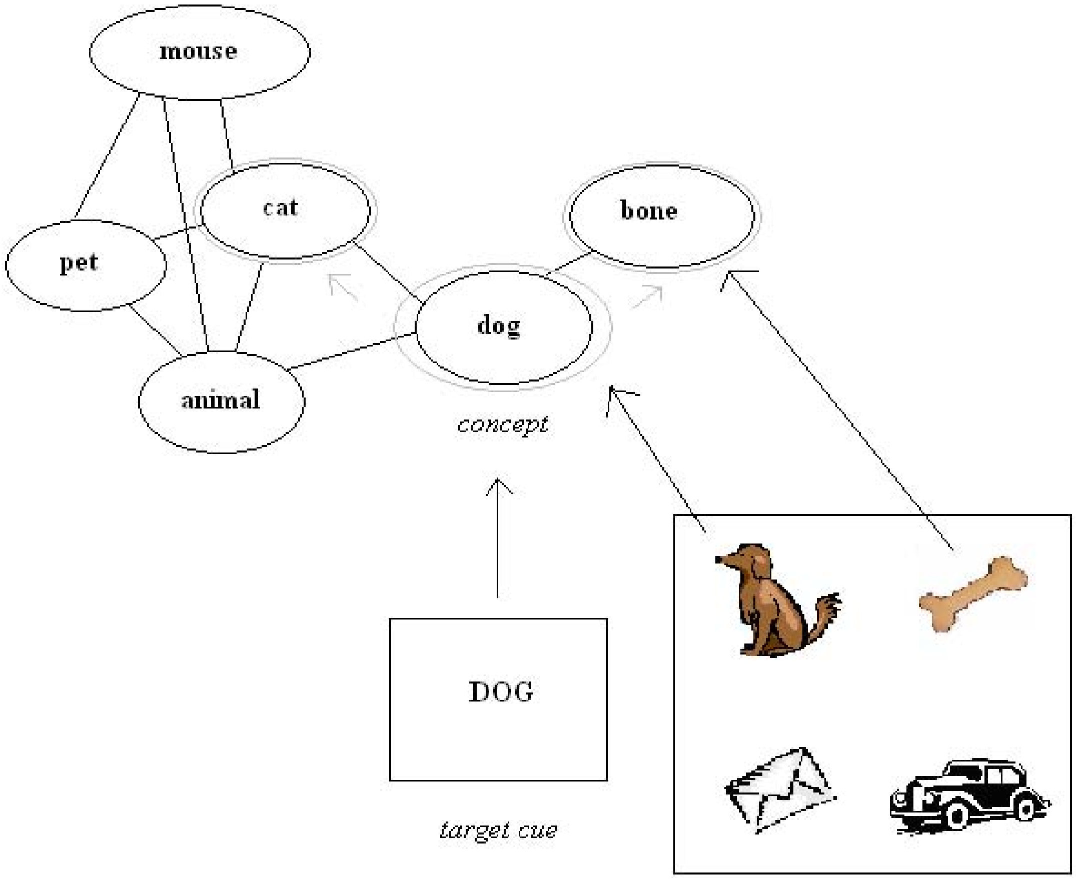

Figure 26. Spreading activation and the visual search task, where the target is *dog* and the related distractor is *bone*.

Collins and Loftus' (1975) SAT, proposes a semantic network as part of long-term memory, with conceptual nodes that are linked in terms of semantic and associative relationships. When an item is processed, nodes connected to it become active and activation spreads along the links of networks so that neighbouring nodes are also activated. Processing is then facilitated for those nodes that are appropriate to items that appear on the search display. Figure 26 shows that in our experiment, activation of the target concept (e.g., *dog*) can then spread to associated items (including *bone*). When the search display appeared with these items in them, initial processing of those items was facilitated in contrast to unrelated items elsewhere on the network (e.g., *envelope* and *car*) that were not activated. By activating the distractor concepts, these conceptual representations then enter working memory, to act as an attentional template. Just as visual and semantic properties of the target have been activated; visual and semantic properties of the distractor activate to direct search.

3.1.2. Parallel Distributed Processing (PDP)

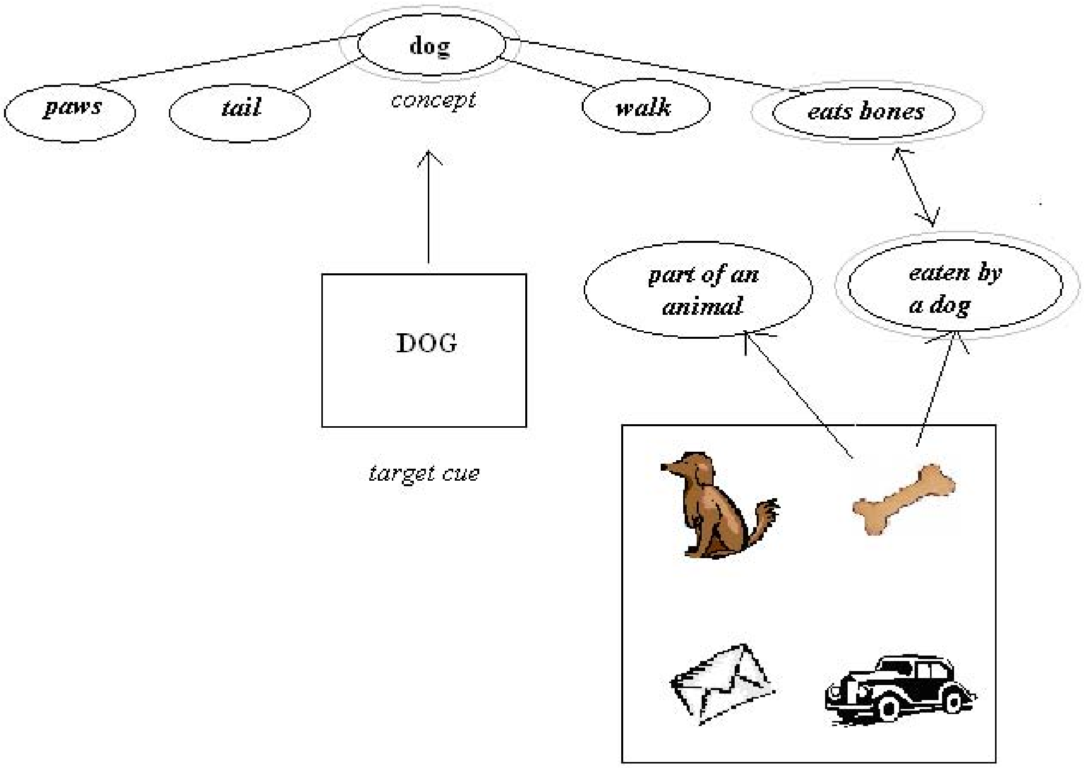

Figure 27. Distributed coding and the visual search task, where the target is *dog* and the related distractor is *bone*.

McClelland and Rumelhart's (1986; Rumelhart & McClelland, 1986) theory of parallel distributed processing (PDP) models the semantic network according to distributed representations (see McClelland & Rogers, 2003; Rogers et al., 2004, for a more recent review of the account). The representation of one item is represented as a pattern of activity across a number of units. Processing of information involves activation of many units at once. For example, Figure 27 shows the distributed coding of a dog (has paws, a tail, goes for a walk, eats bones etc.) and how it links to the coding of a bone (part of an animal, eaten by a dog). The distributed representation of different items creates opportunities for overlapping activation in visual search. Here, activation of the representation of the target (e.g., *dog*) includes units shared by the distractor (in this case, *bone*). Initial processing of the items in the search display would encounter an item with features included in the representation of the dog to cause facilitated processing, compared to the unrelated items, which do not include any overlapping features.

In summary, *a spreading activation account* of semantic activation would explain our findings of semantic interference in visual search at early (eye movement and ERPs) and later stages (RTs and error rates) of processing as due to (1) activation of a semantically related representation (e.g., *a bone*) in addition to the target (e.g., *a dog*) causing attention to be directed according to the properties of these items and (2) upon presentation of the search array, target and distractor processing to be primed by initial activation of their representations in the semantic network, unlike the unrelated distractors which have not been primed. Alternatively, a *distributed coding account* of semantic activation would explain our findings of semantic interference as due to (1) initial activation of semantic units belonging to the target (e.g., a dog → *eats bones*);

upon presentation of the search display (2) initial processing of the items on the screen activates their semantic representations also. Pre-activation of target units facilitates processing of the target (i.e., a picture of the dog) but also the semantically related distractor (i.e., a picture of a bone), albeit to a lesser extent, as fewer units overlap between the target template and the distractor item than the target template and the target item itself.

3.2. When does the semantic activation take place and how does the interference occur?

Throughout this thesis, two stages of information have been referred to where semantic interference can take place. Both spreading activation and distributed coding theories can account for these two stages.

Prior to the presentation of the search display. First, at the working memory stage, before the search display appears and after the target cue has been presented. Upon seeing the target cue (e.g., the word "dog") information is retrieved from long-term memory about that word and used to help search for it on the upcoming search display. A conceptual representation of the dog is activated along with information about its visual features (typical shape, colour etc) so that search for it can be geared towards such features. Information retrieved from long-term memory is held temporarily in working memory and used to guide search (the attentional template; Duncan & Humphreys, 1989). The qualities of the template or templates generated can affect search when a distractor semantically related to the target is present. It could be that more than one template may be activated – templates for search may be generated as a result of the spreading activation to representations nearby to the target in the semantic network. Moores et al. (2003) also suggested this, stating that the degree of distractor activation in an intermediate between the target and unrelated distractor activation. Alternatively, the target template may include semantic features of the target that overlap with the distractor representation (distributed coding theory). Here, if search for the target is based on one template that includes semantic features of that target, in addition to visual features, search is then affected when items on the search display share such features.

Upon presentation of the search display. Once the search display has been presented, initial processing of the display proceeds for around 200 ms before the pictures on the screen can be differentiated between and any eye movements begin (see Chapter 2, where the N2pc shows conditional differences from 225 ms post onset; Chapter 3, where initial eye movements offset from the centre from 230 ms). In the small time window after initial perceptual processing has occurred and before the first eye movement is made, items of the screen have been identified as potential targets. The information used to guide this decision is based on the contents of working memory and bottom-up visual and, perhaps also, semantic properties of the stimuli. By way of spreading activation, a distinct distractor template might guide search to look for visual and semantic properties of that representation in the items available, in addition to search being guided according to properties of the target template. Search would therefore be biased towards the related distractor and the target compared to the unrelated distractor. By way of distributed coding, search would be biased according to the target template only, with search based on semantic as well as visual properties of the target, causing the semantic distractor, that shares semantic features with the target, to benefit from attention.

3.3. Relevance to lexical activation

As well as semantic networks, information regarding the names of items are held in long-term memory and connected to conceptual representations held in the semantic network. The names are stored in a mental lexicon and just as semantically related items are connected to one another, lexical items that share, for example, phonological segments, are connected to one another. Upon seeing the target picture (in Chapter 5 the target cue was presented as a picture in order to distinguish homophone pairs) the activated concept might be converted into inner speech, with the participant saying the name internally prior to the search display appearing. In this case, as well as activating semantic information about the target, lexical access, leading to automatic activation of syntactic, morphological and phonological information may also occur. The spreading activation theory of lexical access (Dell, 1986) and the WEAVER++ model (Word-form Encoding by Activation and VERification; Levelt, Roelofs & Meyer, 1999) both include these stages of activation. In Chapter 6, the level of homophone (e.g., animal *bat* – baseball *bat*) representation was discussed to be at either the morphological or phonological level, according to Shared and Independent theories of homophone representation (Jescheniak & Levelt, 1994; Miozzo & Caramazza, 2005). The lack of any interference from phonologically related distractors in search (e.g., search for a target *bat* in the presence of a distractor *bag*) supports a morphological level of representation (i.e., the Shared Representation theory, e.g., Jescheniak & Levelt, 1994).

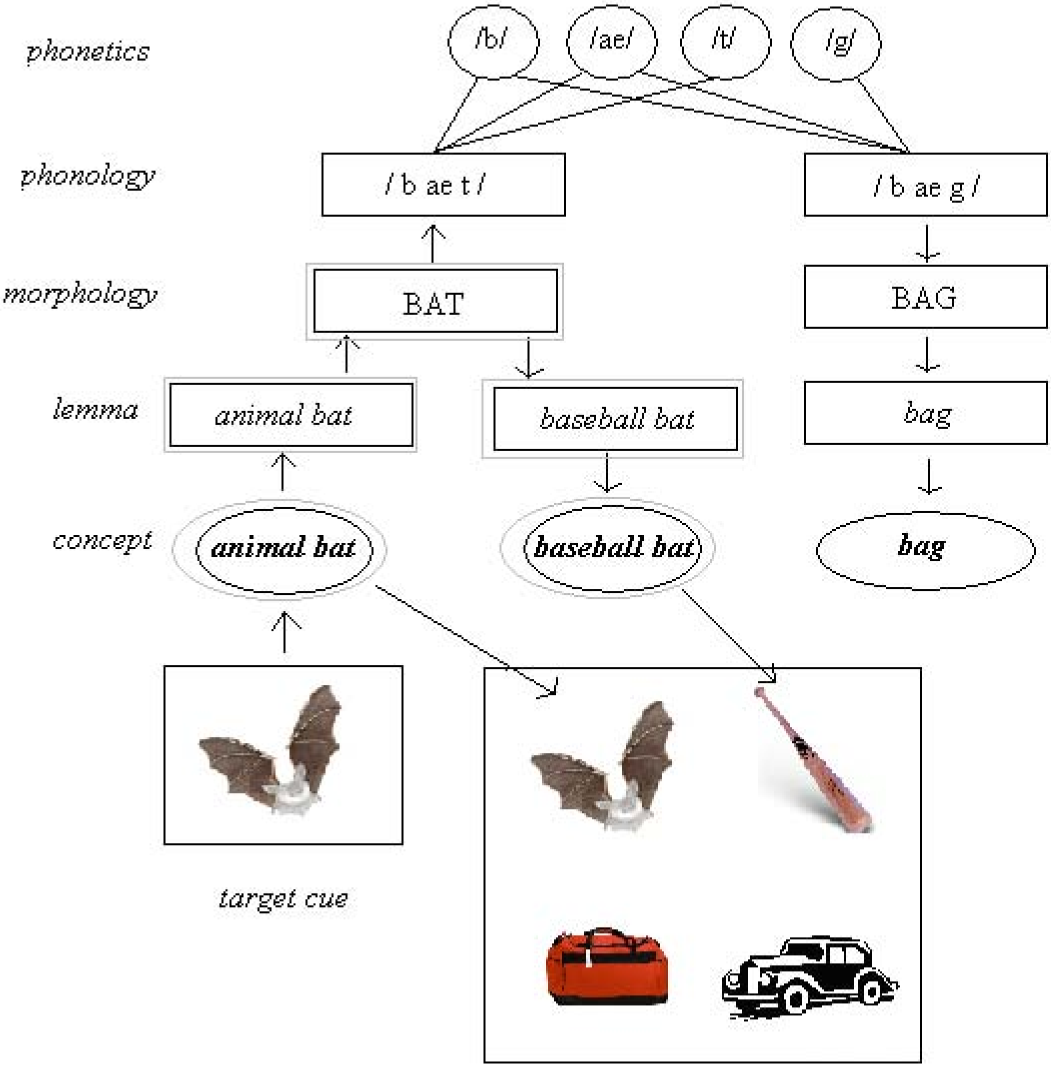

Figure 28. Spreading activation from the homophone representation animal *bat* to baseball *bat*, but not to phonologically related, *bag*.

Figure 28 accounts for the homophone distractor but not phonological distractor affect as spreading activation from the concept 'animal bat' to its syntactic-semantic representation (or lemma), which is distinct from the lemma representation for 'baseball bat' to the morphological representation, which is shared. This connection causes activation to flow back to the lemma and conceptual levels of representation for the baseball bat homophone distractor, causing attention to be directed towards it. This activation does not continue to items that share phonological segments (e.g., *bag*), however.

3.4. What does this mean to the current theories of visual search and visual attention?

In Chapter One, four theories of visual search were introduced: the FIT (Feature Integration Theory; Treisman & Gelade, 1980), Guided Search (e.g., Wolfe, 1994), AET (Attentional Engagement Theory; Duncan & Humphreys, 1989) and the Biased Competition model, associated with AET (Duncan & Desimone, 1995).

Preattentive search is guided by visual features alone? The first two have stated that non-visual properties, including semantic and name information, cannot guide search preattentively. In a review of the attributes that direct top-down attention, Wolfe and Horowitz (2004) suggested that interference from distractors that are related to the target by more abstract features, e.g., the finding that search can be affected by a scary snake or spider. This interference was suggested to be due to search being directed according to visual properties of those stimuli, rather than semantic. By reviewing the mechanisms by which semantic activation may occur, the spreading activation theory (Collins & Loftus, 1975) supports this. Upon activation of the target, this spreads to activation of nearby, semantically related representations, which then generate additional templates for search. Although activation has spread between representations in the semantic network, search may then be guided according to visual properties of those templates. This would support preattentive search being guided only according to visual properties of those items, with search being primed towards objects that share visual features of the target or distractor.

Early activation of properties of the stimulus could be restricted to visual not semantic properties, supporting Guided Search in particular.

In the case of homophone distractors, spreading activation to the target ‘s morphological representation (e.g., animal *bat*) feeds-back to its associated distractor representation (e.g., baseball *bat*), where conceptual and visual information is activated. Search is then guided not only according to visual properties of the target, but also according to visual properties of the distractor.

Preattentive search can be guided both by visual and semantic features? Alternatively, the AET and Biased Competition models have not ruled out that search could be guided according to semantic features (Duncan & Humphreys, 1989; Duncan & Desimone, 1995). Instead, during the initial perceptual processing of the search display, semantic properties of the target or distractor may be biased towards according to the semantic properties held in working memory. Both the spreading activation and the distributed coding accounts of semantic activation would support this. Although the spreading activation to generate a distractor template would cause search to be directed according to visual features, it could also be directed towards semantic properties of the stimulus, utilising any of available attributes to guide search. Search could also be directed towards any items that hold semantic features associated with the target (distributed coding account, see Figure 26). Initial processing of the display must recognise which items include those features, with those item(s) being selected as a potential target. In Figure 27, search for the target *dog*, could lead the viewer to select the distractor *bone*, due to overlapping semantic features.

The finding that homophones to the target can also affect search suggests that initial processing may continue to the morphological level, with homophones potentially feeding-back to the target representation through spreading activation, causing that items to be selected as a potential target (see Figure 28).

Both accounts of visual search amongst semantic and homophonous distractors are possible, however, so it is difficult to categorically state whether any of the theories are supported or unsupported by the findings. However, both spreading activation and distributed coding explanations of semantic and homophone distractor effects support rapid preattentive activation of semantic and name information in visual search.

4. Suggestions for future research

4.1. Compensatory mechanisms with older age?

Chapter 3 reported that older adults were no more affected by the presence of semantic distractor in search for the target than young adults. However, theories of aging suggest that older adults are able to recruit previously unused areas of the brain to counteract any deterioration of other brain areas. Monitoring behavioural results in older adults cannot confirm whether or not this was the case in our experiment. Two possible experiments could be carried out to assess this.

One is to put additional stress on the frontal lobes so that the limits of any compensatory recruitment can be tested (de Fockert et al., 2001). The cost of working memory load on search amongst semantically related distractors has been assessed in young adults (Belke, Humphreys, Watson, Meyer & Telling, in press). Belke et al. (in press) assessed performance in search under conditions of high and low working memory load; where participants were presented with a 5-digit (high) or 1-digit (low) string before search and asked to name it after they had made a response. Late measures RTs and viewing times (total fixation durations to the semantically related distractor, target absent trials only) were significantly longer during high rather than low working memory load conditions; whereas early measures (first fixations to the target and semantic distractor) were unaffected by load. This supports the findings of Chapter 3, where patients with frontal lobe damage performed to the same level as older adult controls in their first gazes to the target and distractor, but showed increasing semantic distraction in their first gaze durations to the distractor and error rates, unlike the controls. The functioning of the frontal lobes could be assessed in older versus young adults by including low and working memory load conditions in search amongst semantic distractors. Although both age groups are likely to show deteriorated performance in early measures under high WM load, the older adults could show particular poor biasing towards targets and away from semantic distractors.

A second experiment would utilise fMRI to monitor frontal lobe activity in old versus young adults in conditions where semantically related versus unrelated distractors appear on the search display. Madden (2007) reviewed a number of fMRI studies that report evidence for compensatory recruitment by older adults, including increased frontal and parietal activity compared to young adults in letter search, and this was suggested to compensate for poorer bottom-up processing in the visual pathways. A finding of increased activity in these areas during search for older but not young adults, where RTs and error rates between young and older adults appear equal, would support this compensatory mechanism explanation for the results of Chapter 3.

4.2. The time course of semantic processing in patients with frontal lobe damage

In addition to monitoring eye movements, as carried out in Chapter 3, an ERP study similar to Chapter 2, could be carried out with a group of frontal patients. P1, N1, N2pc and P3 activity could be compared with age-matched controls and used as a measure of early (N1, P1, N2pc) compared to late processing (P3, RTs and accuracy) of semantic information in search. The findings of Experiment 4 of Chapter 3 would predict a similar pattern of neural activity in the early components of the control group and frontal patient group, and a more disrupted pattern in the later measures of neural activity for P3, and behavioural data, compared to age-matched controls.

4.3. Assessing the contribution of the parietal lobes to semantic processing in visual search

Chapter 4 presented evidence for automatic processing of semantic information during search, by recording the behaviour of five patients with damage to posterior parietal cortices, causing them to show visual extinction to one side of space. Despite their attending to one field over another, semantic distractors interfered with their search regardless of the side of space presented to the patients. However, the experiment required the removal of a large number of cases, particularly for eye movements, due to the need to classify trials according to distractor position (trials where the distractor was in the midline, 50%, were removed). Also, the lesions were varied, with two patients suffering from right hemisphere damage, and three with left-hemisphere damage. In addition, one patient showed strategic dominance to his contralesional rather than ipsilesional side. The patients were regular attendants of psychological experiments at the School of Psychology, having an onset of damage to the parietal cortex between seven and twelve years earlier. It is possible that strategic and neuropsychological rehabilitation as a result of their visits to the University of Birmingham may have contributed to their search behaviour.

An alternative to assessing patients with parietal damage in search is to induce the clinical deficit caused by that damage temporarily, in healthy young adults. Repetitive trans-cranial magnetic stimulation (rTMS) is a method that can do this. By applying rTMS to the posterior parietal cortex (PPC), neglect-like behaviour has been induced (e.g., Hilgetag, Theoret & Pascual-Leone, 2001; Muggleton et al., 2006; Pascual-Leone et al., 1994; Rushworth, Ellison & Walsh, 2001). However, such experiments induce changes in behaviour for only short periods of time. Theta burst rTMS, however, has been shown to induce changes for at least 30 minutes, to allow for longer experimental blocks. Nyffeler et al. (2008) applied theta burst rTMS to the right PPC of 12 of healthy adults whilst real-life scenes were presented to them and their eye movements were tracked. The participants made more cumulative fixation durations to the right than left side of the screen over a thirty-minute period, compared to a group of controls that received no rTMS. The finding that equivalent semantic interference is possible in young adults despite rTMS to their right PPC would support the conclusions made in Chapter 4: Semantic activation proceeds preattentively and automatically in search.

4.4. Homophone versus phonologically related distractors

Chapter 2 showed evidence for the semantic properties of the target being used to direct visual search towards it. This experiment could be modified to confirm the homophone but not phonologically related distractor effects reported in Chapters 5 and 6. Chapter 6 discussed possible confounds of the homophone stimuli, including visual quality of the materials (see page 167). If the materials were redesigned and rated to be of the same quality as the standard pictures taken from the Snodgrass and Vandervart (1980), for example, these issues could be ruled out. An experiment could be designed to include homophone and phonologically related conditions. Alternatively, as suggested earlier in Chapter 6, a new set of homophone items could be generated by running the same experiment in a different language (e.g., Biedermann & Nickels, 2008, carried out an experiment using German homophones), so that the effects can be replicated with a new set of items.

5. Closing summary

The results of this thesis will now be summed up using an example from every day life: lost keys. Upon considering that our keys are lost, information is rapidly retrieved from long-term memory about the keys’ visual, semantic and name information and contributed to our template for search. Upon opening the drawer (where we think our keys might be) and prior to making out first fixation to an item inside, early visual processing is being guided towards the object that most fits with our template. In the initial 200 ms of searching, visual, but perhaps also conceptual and name information is activated about the objects in the drawer, which are then compared with our target template to instruct the first eye movement to the most likely target. Although early processing of semantic and name information about objects on the search display cannot be confirmed by the experiments carried out for this thesis, activation of semantic and name information about the target for search to direct top-down attention can be confirmed by these experiments.

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APPENDICES

1. Appendix One

1.1. Materials for Chapters 2 to 4

Target	Related competitor[*]	Related associate
arrow	bullet	bow
bird	fish	feather
cigarette	pipe	ashtray
comb	brush	hair
crown	sceptre	king
hammer	drill	nail
hand	foot	finger
lock	hinge	key
nose	eye	face
organ	church	tuba
plane	ship	propeller
racquet	bat	shuttlecock
saddle	horseshoe	horse
shirt	trousers	tie
screw	hook	screwdriver
thread	rope	needle

Fillers: torch, swan, tie, lollypop, pear, bell, cloud, football, card, mouse, plaster, flower, weight, belt, butterfly, broom.

[*] Chapter 2 only used related competitors

2. Appendix Two

2.1. Materials for Chapter 5

2.1.1. Homophone Set

Target	Related Competitor
bat (animal)	bat (baseball bat)
bow (arrow)	bow (ribbon)
boy	buoy
chest (trunk)	chest (body part)
flower	flour
glasses (spectacles)	glasses (wine glasses)
horn (antler)	horn (hooter)
mouse (rodent)	mouse (computer mouse)
nail (finger nail)	nail (tool)
nut (peanut)	nut (tool)
pipe (drainage pipe)	pipe (smoking)
spade (tool)	spade (card)
table (furniture)	table (chart)
tank (fish tank)	tank (military)

Fillers: anchor, ant, button, candle, chair, clock, face, fence, fish, grapes, guitar, hair, hinge, horseshoe, igloo, king, leaf, mitten, mushroom, necklace, plug, purse, ruler, scissors, ship, snake, thermometer, tree.

2.1.2. Semantic Set

Target	Related Competitor
arrow	bullet
bird	feather
cigarette	ashtray
comb	brush
crown	sceptre
hammer	drill
hand	foot
lock	key
nose	eye
organ	church
plane	propeller
racket	shuttle
saddle	horse
shirt	trousers

Fillers: banana, bell, belt, bone, broom, butterfly, card, cloud, duck, envelope, flag, football, hanger, hat, ladder, lollypop, pear, plaster, rabbit, saw, snowman, swan, tie, toaster, torch, weight, whistle, wheel.

3. Appendix Three

3.1. Materials for Chapter 6

3.1.1. Experiment 7

Target	Related Distractor
bed	bell
camel	candle
bucket	button
pie	pipe
bowl	bow
fox	fork
hand	hat
chair	chain
heart	harp
can	fan
brain	train
letter	lemon
bridge	fridge
cart	dart
mouse	house
snake	cake
car	star
moon	spoon
clown	crown
clock	sock

Fillers: eye straw sheep dress saw drill belt jug corn ankle chicken nose flute rocket racquet piano kite arrow beetle tree shoe igloo tooth mask vase glass sun ball axe king bear skirt bird kettle ladder feather onion brush whale

3.1.2. *Experiment 8*

Target	Distractor 1	Distractor 2	Distractor 3
window	whistle	windmill	whisk
tree	train	trumpet	trousers
steps	strawberry	stool	statue
skirt	screwdriver	scooter	scorpion
sandwich	saddle	saxophone	sack
spider	spray	spade	spoon
plane	plank	plate	pliers
drum	dress	drill	dragon
pencil	peg	pepper	penguin
crown	cracker	crab	crane
clock	clouds	clog	clown
pizza	peeler	peas	peacock
monkey	mummy	mushroom	mug
camera	cactus	camel	candle
box	bomb	boxer	bottle
leg	leopard	lemon	letter
flower	fly	flute	flag
brain	branch	broom	bread