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Focussing selection to the letter level: understanding the letter search task

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Summary

The aim of this PhD thesis was to investigate the interaction between spatial attention mechanisms and English words, when participants are undertaking variations of the letter search (LS) task. In Section 1 the LS task is investigated through manipulating some of the main dimensions upon which LS tasks differ in the published literature. The results reported here add to the current understanding of LS tasks, and extend the knowledge of the effects sometimes subtle manipulations can have. The set of experiments in Section 2 investigates the effect of focussing attention on single letters presented on their own, in letter strings, and in real words. The manipulations of perceptual load and predictability of target location, allow for the testing of the common assumptions about the way items are selected within words. The mechanisms involved in selection are suggested to be interplay between inhibitory and excitatory systems. Finally, in Section 3, the effect of searching for a letter in a word on the semantic priming is examined. The final section concentrates on target letter position effects and positive and negative search. The evidence from the last experiment has implications for the way that prime task effect experiments are constructed, and for models of semantic memory and visual word recognition.

Authors Comment

I began this body of research and my PhD study with the intention of investigating the phenomenon of semantic priming (SP) and in particular the effects associated with searching for a target letter in the prime word of the SP paradigm. As this area was familiar to me, having been involved with many SP experiments as part of a successful research group based at Bangor University, I began with the belief that the investigatory process would be straight forward and the findings simple to elucidate: how wrong I was. My initial experiments were failures, both in design and in the results I had expected to find. As I contemplated why my experiments were failing it became clear to me that I did not know enough about the task I was using to manipulate SP.

To place the SP research in context it is important to note that SP has been offered up as evidence for the automaticity of semantic activation (SA) during visual processing of written words (reading), and that such automaticity has been supposed to result from extensive practice (Posner and Snyder, 1975). While other areas of investigation into the automaticity of SA, such as the Stroop test (1935), and inhibition of return (Houghton, & Tipper; 1994, 1994b) have received extensive amounts of study, one of the fundamental experimental paradigms used to discredit claims of SA in the SP literature is the prime-task (PT) effect. As the majority of PT-effect experiments utilise the letter search task I went in search of articles and publications that could advise me as to what occurs when a word is searched at the letter level for a constituent part. After a dedicated search (and believe me it still continues) I had to conclude that the information I was looking for did not exist, or at least had not been published in any journal available to me.

So in my effort to design better and more successful experiments, that would shed light on the automaticity of SA, I had to explore each dimension of LS that could potentially have an effect on the processing of the lexical information from the words in which the letters were contained. I was able to draw hints and suggestions from a wide range of research areas in cognitive psychology, none of which gave me the definitive answers I required, but many of which lead me to the conclusion that I was heading in the right direction.

I progressed from a simple investigation of word length on reaction times (RTs) during LS tasks, through the effects of target presence (positive or negative search), onto the effects of lexicality, before examining the effects of spatial attention on the processing of target words and letter distractors. Finally, I felt able to design a well controlled and scientifically thorough PT-effect experiment; unfortunately I had also nearly reached the end of my PhD deadline. When I stopped to evaluate all the work I had completed I could not help but be perplexed, while I had assembled the largest (to my knowledge) body of scientific research on LS tasks I had all but failed to investigate the very question that had driven me. One last experiment was all that I had time to complete before deadline pressures forced me to begin writing the thesis that you are now reading.

In summary what I present to you in this thesis is an experiment demonstrating where I began, the extensive research conducted to understand why that initial experiment had failed, and a final experiment that was conducted adhering to the knowledge collected on the way. So while at first glance this thesis would appear to be on the subject of semantic priming it must be remembered that that SP is only the enveloping context, and that the true nature of this work concerns visual search tasks. The experiments recorded here present evidence that has implications for several different fields of psychological research, in particular SP and the automaticity of SA and any visual search task using written words as stimuli. There are also implications for theories of visual attention, the focussing of spatial attention, and at what stage of processing selection occurs.

Doug Cullen

CONTENTS

List of abbreviations (in alphabetical order)

ERP	= event related potential
LS	= Letter search
NP	= negative priming
OUP	= orthographic uniqueness point
OVP	= optimal viewing position
PT	= Prime task
ROM	= right of middle
RT(s)	= reaction time(s)
SA	= semantic activation
SP	= semantic priming
WSE	= word superiority effect

Thesis abstract

In this thesis 12 experiments are reported concerning the letter search task. In the first experiment the normal prime task effect was replicated (no reaction time differences between related and unrelated probe words following a letter search task on the prime word). Experiments 2 to 6 explore searching for letters in words in more detail. The parameters examined are length, target position, written word frequency, presence and absence of the target letter in the display, lexicality, and delay of the cue letter. Experiments 7 to 11 examine the mechanisms of selection involved with attending to the letter level, while identifying single letters on their own, in letter strings, and English words. The results indicate that models of selection must account for the locus (early vs. late), the action of a zoom lens, the inhibition of distractors, and the excitation of targets. Experiment 12 presents evidence that semantic priming can be found following letter search on the prime word, when the target letter is presented at the optimal viewing position (just to the left of the middle). These experiments shed light on what occurs during letter search, and provide a basis for future research using letter search tasks.

Chapter 1: Thesis Introduction

The ability to function within an environment that contains potentially infinite sources of information is common to all living organisms. For humans, everyday conscious experience suggests to us that we select very little information for detailed processing. Indeed, we are unable to process every possible stimulus, and nor are we able to conduct every possible response. We are limited both by our biological and psychological abilities to process incoming stimuli and to formulate appropriate reactions. To take an example, we only have two hands, so, if there are three possible responses, we must select two out of the three (Farah, 2000). Similarly, we cannot select everything that we see for conscious processing. There must be some means for selecting information and responses. *Attention* is the term frequently given to the mechanism of selection that must intuitively exist.

The term *attention* is one recognised by everybody, and one on which most people have an opinion as to its use and potential. In general, researchers agree that it is capacity limited and used in the selection of information (Pashler, 1999). For researchers working in the field of visual cognition the term *selective attention* has been used since the early 20th century, and related concepts have been subject to intensive research from the 1950s through to the present day (Driver, 2001).

Because we have limited response capacities, it is likely we have evolved a brain that processes and selects stimuli (and responses) that are in line with our limitations. Kahneman (1973) described attention as a limited supply of mental processing capacity, which can be increased by mental effort and arousal. The psychological refractory period has been put forward as evidence of a limited capacity processing system (Pashler, 1994). In demonstrations of the psychological refractory period (PRP) when a second stimulus is presented close to a first, responses to the second stimulus are increasingly slowed, as the interval between the two stimuli is decreased (Welford, 1952).

Some of the most common experiments used to investigate PRP effects are the dual task studies, where participants perform two speeded tasks one after the other. The amount of time between the tasks is the main element manipulated. The increase in RTs is attributed to the limited processing resources acting like a bottleneck (Welford, 1952). The second task cannot start until the first has been completed. The use of dual task experiments to explore automaticity utilises the theory that, if the first task is practiced for a long enough period, and becomes automatic, it should not interfere with the second task. Dual task interference has been used as a measure of how automatic a process has become (Pashler, Johnston, & Ruthruff, 2001). The conclusions that Pashler, Johnston, and Ruthruff (2001) reach, in a review of dual task experiments, is that practice merely reduces the durations of the different processing stages, without allowing a bypass of the bottleneck caused by limited attentional resources.

So, to a certain extent, we must expect that the selective mechanisms in our brains must be closely related to our ability to respond. The research of Norman and Bowbrow (1975) demonstrated that there is a relationship between performance and resources, where the resources can be utilised until the addition of more resources has no improvement on performance. This restriction in performance is described as *data-limited* (Styles, 2005) and has been fundamental in the development of cognitive psychology theories. Similarly, a lack of available resources, for the completion of cognitive functions, is described as *resource-limited.*

In this thesis the parameters of visual selection are investigated through using visual search tasks where participants search for letters as individual targets, embedded in either letter strings (non-words) or real English words. The following review begins with traditional and current theories of attention; the evidence for the existence of attention from visual search tasks; and the parameters in which visuo-spatial attention is believed to operate. The next section of this thesis investigates variations of common tasks that require participants to search for a letter. The third section examines what effect searching for a letter, within letter strings and English words, has on selection mechanisms and spatial attention. The letter search task is a good tool for the investigation of selection because it is easy to manipulate the letter target, non-targets and distracter letters. It is also easy to manipulate the lengths of the words, written frequency of words and the lexicality of letter strings (whether a letter string is a word or a non-word). The final section of the thesis uses the results of the previous experiments to design a semantic priming experiment, which uses letter search as a prime task, and demonstrates effects hidden in previous research.

Theories of Attention

Classic Views

Early selection

Selective attention research began with work conducted in the 1950s on the effects of attending to auditory information. Several famous effects were investigated through the presentation of information to one ear while conflicting information was presented to the other ear. It was in these early experiments that the 'cocktail party' effect was revealed. Moray (1959) required participants to shadow the stream of information presented to just one ear. While participants were attending to the designated channel, the participants name was inserted into the stream played to the unattended ear. The result was that, while participants were unable to report the content for the unattended ear, they were able to report that they had heard their name. Similar results were found for information from the unattended ear when the information was semantically similar to the attended channel (Moray, 1959). The discoveries of the differences in what can be attended, and what proceeds to conscious awareness, occurred at a time when the structure of computers was being used as a way to understand the structure of the brain (Driver, 2001).

The idea of using the hierarchical system employed in computers was taken by Donald Broadbent and turned into his 1958 filter theory. This new way of viewing cognitive processes allowed psychological researchers to take a step towards understanding attention, based on the results of observational data, instead of the introspective analysis of previous theorists like William James (Pashler, 1999). Filter theory was the first to model the selection of information, and it stipulated that the selection took place at what was to become known as an early stage of processing. Broadbent suggested that all items are processed in parallel to a basic level (physical descriptions) but that only items matching search criteria would pass through a filtering mechanism he termed the 'selective filter', and be further processed. Essentially, all early selection theories hold that selection occurs before full identification and extraction of meaning is completed. Broadbent's (1958) experiments led him to suggest that stimuli were individually processed at higher cognitive levels, indicating that there must be a filtering mechanism to maintain system stability. The overall structure for Filter theory began with the parallel processing of physical features (Colour, orientation, etc.), and then the serial processing of items at a more complex level (meaning, category, etc.). Stimuli not selected by the filter mechanism would not receive any more processing, and would be lost to conscious awareness, and thus would be unavailable for report (Broadbent, 1958).

Filter theory can be considered to be an extreme model of selective attention, as all unselected stimuli are considered unavailable for response on the part of the participants. Following further experiments it became clear that there were instances when unattended information had received a level of processing greater than that allowed by filter theory (Lewis, 1970; Mackay, 1973). A possible answer to unattended items being processed was proposed in the form of Late selection theories, where all items are processed to determine their meaning. Selection then occurs after this level somewhere before response formulation begins.

Late selection

Typically both early and late selection theories include an early pre-attentive stage where all items are processed in parallel, and then an attentive process that is limited in capacity. The only difference is that in early theories selection takes place before identification (Logan, 1996). Deutsch and Deutsch's (1963) theory suggested that items were processed in parallel without capacity limitations until after identification is complete. This alternative view could explain the unattended stimuli effects that were present in the literature such as the Stroop (1935), and flanker effects (Eriksen & Eriksen, 1974). In the Stroop effect the name of a colour word is written in congruent or incongruent coloured ink. Participants are faster to name the colour of the ink when it is congruent with the semantic information provided by the orthographic information.

In the flanker task participants are asked to direct attention to a central letter flanked by letters. The flanking letters were identical to each other and were selected from either the same response class as the central letter, or a different response class. Differences between the two classes of flankers are reliably found even though the experiment should encourage a highly focussed attention to the central letter (Yantis & Johnston, 1990). The inability to filter the irrelevant semantic information has been used as evidence for a late level of selective attention. However, there are other explanations for the late selection data, which can also incorporate the early selection data.

Feature Integration, Location, Objects, and Spot-lights

Treisman and Gelade (1980) used the results from many visual search experiments to formulate *feature integration theory*. In these experiments participants would search for an item identified through a physical attribute such as colour, location, size, or orientation. In *feature integration theory* (Treisman & Gelade, 1980) focal attention was proposed as the mechanism used to bind the different aspects of an object together so that it can be consciously perceived. The physical features of a stimulus (e.g. colour) are encoded in parallel without the need for visual attention. Each dimension is coded individually onto a feature map. Each dimension then needs to be combined into a whole, in order for further processing to take place. The combining of features takes occurs through three possible routes. First, the features may meet top-down criteria that are being used to guide search which allow for stored knowledge to be accessed. Second, focal attention selects a location to attend which permits the joining of the features, and the progression of the stimulus to higher levels of awareness. The focus of attention at a location allows whatever is at that location to be processed further, whether or not it is the target. The third route is the combination of individual features on their own, which may mean that the features are not combined correctly (resulting in an 'illusionary conjunction'). In the case of the Stroop effect mentioned above, *feature integration theory* accommodates the effect without having to appeal to a late level of selection. The unattended semantic information would still be processed, due to partial activation of the additional information located at the attended focus.

The focussing of attention during visual identification in *feature integration theory* is similar to the attentional spotlight proposed by Eriksen and Eriksen (1974) and Posner (1980). The spotlight was defined as a window, which is circular in shape, and that can be directed around the visual field to items of interest. Cave and Bichot (1999) proposed that the popularity of the spotlight metaphor might be due to its similarity to eye movements, and the fact that eyes select information spatially. It therefore feels natural for attention to follow a spotlight analogy. LaBerge (1983) offered evidence that the spotlight could be adjusted according to the task demands. LaBerge (1983) presented participants with words that were subjected to one of two alternating prime tasks. The first prime task required participants to identify a letter at the centre of the word, while the second prime task required categorisation of the whole word. The probe task was to identify the number '7' in one of the positions previously occupied by letters in the prime task. The results indicated that in the letter categorisation task participants were able to focus their attention finely to the letter level. Focussing to the letter level decreased reaction times (RTs) to letters at the expected position. However, if attention was focussed on the whole word RTs were more equal for all letter positions. This suggested that attention could be focused, or zoomed, and led to the formulation of the zoom-lens model of attention (Eriksen & Murphy, 1987; Eriksen & St. James, 1986).

Eriksen and Murphy (1987) demonstrated that by giving participants a spatial cue attention could be focussed to a finer point. This meant that irrelevant items further from the target would cause less interference. In contrast, when participants did not have a cue, allowing them to change the spatial dimensions of attention, higher interference was elicited. When the zoom lens was unfocussed a larger portion of the visual environment can be attended but with lower resolution (Eriksen & St. James, 1986). The role of location in attention is the most basic in terms of a spotlight model: a spotlight illuminates everything within the region it is focussed on (Cave & Bichot, 1999).

The spotlight models of visual attention are centred on the focussing of attention to locations in the visual environment. If the spotlight metaphor is accurate then location will always be important; and in cases where location is irrelevant to the task (e.g. colour discrimination), the spotlight would have to identify the location first in order to complete the task (Cave & Bichot, 1999). A competing group of theories swap the focus of attention from locations to objects (Driver, 2001), and there is now substantial evidence for object based attention (Duncan, 1984; Driver & Rafal, 1994; Humphreys, Olson, Romani, & Riddoch, 1996). Egly, Driver, and Rafal (1994) presented participants with pairs of rectangles, one of which (on each trial) was cued at one end. Participants had to respond when a rectangle was partially filled in. When the filled in section appeared within the same rectangle as the cue RTs were faster than when it appeared in the other rectangle, even when the distance between the two sections from the cue location was identical. Kahneman, Treisman, and Gibbs (1992) used a matching task where letters were cued by presenting them within objects. The objects then moved around the display and a second letter was presented, to which participants responded whether it was the same letter in the same object, the same letter in a different object, or a new letter. Facilitation in RTs was found for the same letter same object trials, which suggests that even though the object was in a new location attention was selecting information in an object-based manner.

That attention can be object-based provides some problems for spotlight models of attention as it is presumed that location is the dimension to be focussed on. Medin, Ross, and Markman (2005) suggest that a resolution between spotlight models and object-based models would be that selection occurs first for location; which then serves as a basis for object recognition (Egeth & Yantis, 1997; Kramer, Weber, & Watson, 1997). It is likely, that once an object has been selected, location based selective mechanisms are attenuated in favour of the object-based mechanisms. The differences between space-based and object-based attention may be crucial, for understanding the effects of focussing on the individual letters within words. The possibility of words being objects is returned to later in this thesis.

Recent Views on Attention

Early selection with attentional slippage

Lachter, Forster, and Ruthruff (2004) suggested that early processing, in terms of an updated Broadbent model, best describes the majority of data from the selective attention research. In their 2004 paper Lachter et al. describe late selection as resulting from slippage; where attention has accidentally moved to an irrelevant stimulus due to a lack of focussed attention. This is in contrast to leakage; where irrelevant items are selected and processed to a higher level, even though attention was sufficiently focussed. Lachter et al. (2004) take the view that although visual attention may not be very selective, and that for a few degrees around fixation anything will receive some processing, this is in fact due to slippage and not leakage.

Reason (1979) investigated everyday '*slips of action'* (Styles' italics p. 223) through diary studies, and found that in normal everyday life 'neuro-typical' people make action slips, which suggested a loss of intentional control. The lack of control is more noticeable when attention is spread over a wider area, or when location changes. The fact that errors occur frequently suggests that the attentional system is not perfect in its ability to focus. While this effect could be considered detrimental to survival, such an effect has been highlighted in 'inattentional blindness' studies (Simons, 2000). If we were capable of focussing so intently on a task that everything else was ignored, we would be at risk of falling prey to competitors and other animals[1].

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[1] There is an extensive body of literature covering attentional capture by (and in-attentional blindness to) irrelevant stimuli, which while not directly relevant deserves a mention. The research demonstrates the ease (and difficulty) with which focussed attention can be caught by an unexpected novel distractor (see Simons, 2000 for a recent review).

Perceptual Load Theory

The availability of the attentional system to process irrelevant distractors has been investigated by Nilli Lavie (1995, 2005), who presents a theory of perceptual load which offers an explanation for the differences between early and late selection. Perceptual load theory followed suggestions by Kahneman and Treisman (1984) that the results supporting early selection came from experiments using displays containing a high perceptual load (more than five distractors); and those results supporting a late locus of selection came from experiments using displays with a low perceptual load (typically less than five distractors). Lavie's (1995) paper presented researchers with several testable hypotheses that have since become a well-researched theory of selective attention. A key component of the theory is that there are limited resources for perceiving perceptual stimuli. The capacity limitations themselves are what drive the locus of selection. In cases of low perceptual load all display items are processed, up to capacity limits, and cognitive control processes inhibit irrelevant items. In cases of high perceptual load capacity limits are reached; distractors occurring away from the target are not processed; and subsequently do not need to be inhibited (Lavie, 1995; Lavie & Cox, 1997; Lavie & Tsal, 1994). A second component is that as long as capacity is not reached processing occurs automatically. A third component in more recent load theories (Lavie & De Fockert, 2003; Lavie, Hirst, De Fockert, & Viding, 2004; Lavie & De Fockert, 2005; Lavie, 2005) is that high cognitive load (task difficulty) increases the level of interference from distractors, meaning that in cases of low perceptual load distractor interference increases when cognitive load is high (e.g. a hard task or resource use by a concurrent task).

The Flexible-selection Hypothesis

Vogel, Woodman, and Luck (2005) offer further refinements for a load theory of attention, through proposing that the selective locus operates at whatever stage of processing is overloaded by task requirements. The *Flexible-selection Hypothesis* combines the flexible locus ideas of Yantis and Johnston (1990), with some of the capacity limitations suggested in Lavie's perceptual load theory (1995; 2005). However, it must be stated that the *Flexible-selection Hypothesis* does not adhere to all the rules that Yantis and Johnston (1990) highlight. Vogel et al. (2005) conclude from their data that selection occurs at an early level when perception is overloaded: typically by increasing the number of items in a display. Selection occurs at a late level when post perceptual processes are overloaded; in this case by masks that replace target items and thus surpass the capacity of working memory. In this sense there seems to be very little difference between load theory and the *Flexible-selection Hypothesis* as both appeal to selection being flexible depending on perceptual load and task demands.

Competition-based selection

Perceptual load theory is seen as being incomplete for two reasons. The main deficit in the theory is that it fails to give a clear definition of perceptual load, in terms of what constitutes high load, and what constitutes low load. The second reason is that some researchers find it hard to reconcile perceptual load, described as an exhaustion of limited capacity, with mechanisms in the brain (Torralbo & Beck, 2008). Torralbo and Beck (2008) propose a new definition of perceptual load that is 'neurally plausible', and is able to explain perceptual load effects through competitive interactions in the visual cortex. It is the strength of the competition between stimuli representations in the visual cortex, which determines how much the mechanisms underlying selection have to support one representation over another. The amount the mechanisms have to bias themselves towards one item, in order to win the competition, determines how much processing unattended items receive (Torralbo & Beck, 2008). Those tasks that result in greater competition between potential targets, require a strong top-down influence to resolve the competition (and select the target), and are thus classified by Torralbo and Beck (2008) as high perceptual load. The contrasting low perceptual load arises from instances where there is little or no competition between representations in the visual cortex, requiring little top-down influence for the item to be selected.

Based on their new definition of perceptual load, Torralbo and Beck (2008) were able to make predictions on what should happen when they manipulate the density of the display, while keeping set size constant. The results of Torralbo and Becks (2008) first experiment demonstrated an effect of density, where RTs were slower to high-density displays. The distractor effects were also significantly lower for the high-density displays, an effect not explained by Lavie's perceptual load theory. The results of a hemi-field manipulation in Torralbo and Becks (2008) Experiment 2, showed a clear effect of hemi-field. When the distracter was presented in the same visual field as the target competition occurred, however, when the distracter was presented in the other hemi-field there was no competition. This data was taken to support the proposal that perceptual load is determined by local interactions in early to intermediate levels of the visual cortex. In conclusion, Torralbo and Beck (2008) summarise that while the exhaustion of limited resources is a convenient way of explaining perceptual load data, it does not explain what is happening neurally. *Competition-based selection* offers an elegant explanation where 'in order to overcome local competitive interactions, a strong bias is necessary to isolate and improve the representation of the target' (Torralbo & Beck, 2008).

Summary of views on attention

Most theories of attention[2] appeal to limited capacity resources, resulting in the need for an attentional mechanism that selects the relevant information for processing. While both early and late stages of selection have been proposed, recent theories include both stages of selection, and differ only in the manner in which late selection occurs. Load theories (Lavie, 1995, 2005) call on the limited capacity of the visual system to explain early and late differences, with early selection caused by a high perceptual load exhausting processing capabilities. Torralbo and Beck (2008) offer a new definition of perceptual load based upon competition in the visual cortex. The need for top-down influences to resolve the competition results in the 'automatic' selection effects. This theory of competition based perceptual load removes the need to appeal to the exhaustion of limited capacity resources, which have previously never been neurally explained. Slippage theories (Lachter et al., 2004) indicate that late selection only appears to occur through participants not being focussed enough to allow for efficient selection. Any late processing is considered to be due to 'slippage' of attention to irrelevant items.

Attention can act like a spot light or a zoom lens focussing on an area for processing. Whether the information is selected due to excitation or inhibition is under debate. The next section moves on from the traditional and current theories of

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[2] There is a need to clearly define what is meant when referring to attention, as there are differences between the orienting of attention and the orienting eye gaze. Sperling (1960), Grindley and Townsend (1968), and Posner (1980) reported several experiments where participants were able to orient attention without shifting eye gaze. Throughout this paper attention, and the movement of attention, will be taken to mean movement with or without eye movements. In cases of attention only movements it will be made clear that the discussion is of shifts of attention and not eye gaze.

attention, to the mechanisms believed to operate within selective attention tasks: automaticity, facilitation and inhibition.

Mechanisms of Attention

Automatic vs. Non-automatic Processes

The mechanisms of attention have been considered as a dichotomy of automatic (unconscious) and non-automatic (conscious) processes. The idea of automaticity has been around for a long time (James, 1890; Wundt, 1903), and has been invoked in several different areas of the field, such as perception (MacLeod, 1991) and learning (Cleeremans & Jimenz, 2002). To date there is no universally excepted definition for either an automatic or a non-automatic process (Moors & De Hower, 2006). Automatic processes are viewed as those, which were at one stage non-automatic, but have been practiced so heavily that they no longer need any resources or conscious effort for them to proceed (Logan, 1992).

One type of automatic process is the reflex, which occurs automatically in response to specific stimuli. For example, touching something hot with ones fingers causes an automatic retraction of the hand (Pashler, Johnston, & Ruthruff, 2001). Reflexes are an example of an action that occurs without practice, and may be a true automatic behaviour. The biology of the reflex is fairly simple, when compared to behaviours that are thought to be automatic because they have been practiced many times. The understanding of the differences between automatic and non-automatic processes is essential for the teasing apart of human behaviour (Pashler, Johnston, & Ruthruff, 2001).

Posner and Snyder (1975), along with others (e.g. Bargh, 1992, 1994), were influential in outlining the parameters that needed to be met to describe a process as automatic. Five provisions were agreed by most researchers as being important when discussing automaticity, first, the process should be fast acting; second, it should be capacity free; third, it occurs without intention; fourth, it is involuntary and uncontrollable; and fifth, that it occurs without conscious awareness (Neely & Kahan, 2001). The non-automatic process is one which does need limited capacity resources to proceed, cannot occur without conscious awareness, is controllable, and may not be fast acting. From these outlines predictions can be made for the investigation of whether a process is automatic or non-automatic. Neely and Kahan (2001) emphasise that assumptions should not be made about the automaticity of a process based purely on behavioural effects. These effects could be biased by processes other than those involved with the automatic processing of information.

While automaticity has been considered by many researchers as an all or nothing process, some researchers regard automaticity as a continuum where increased practice leads to increased automaticity (Kahneman & Henik, 1981; MacLeod & Dunbar, 1988; Cohen, Dunbar, & McClelland, 1990). If a practiced task does become more automatic one would expect that there would be decreases in RTs for the task, as the neural pathways connecting the inputs and outputs for the task become increasingly efficient. There have been several studies supporting automaticity as a continuum, which demonstrate a continuous increase in processing speed (Logan, 1979; Shiffrin & Schneider, 1977), and a decrease in reaction times, with increased task practice (MacLeod & Dunbar, 1988).

Theories of automaticity have explained the change from non-automatic to automatic behaviour either through the removal of processing steps, as in the direct memory retrieval view (Logan, 1988), or through an algorithm strengthening view (Anderson, 1992). Logan's theory of automaticity focuses on retrieval of information associated with a stimulus becoming easier, as the number of levels between the input level and the memory level decreases with practice. Initially an item will have at least one, if not several, levels of representation between input and representation storage.

The connections between input and storage are controlled by algorithms, which code what is remembered. When a stimulus receives extensive practice the input is directly connected to the memory store and the information can be retrieved immediately without the need for more than one algorithm stage (Logan, 1988, 1996). Anderson's (1992) view on automaticity relies on the strengthening of connections between an item and its representation to produce increased automaticity. In this case, the algorithm that codes the item, is not replaced by a direct connection to memory, rather the original algorithm becomes faster and more efficient.

Tasks that are so well practiced that they proceed automatically should occur without drawing on the limited capacity systems; and should always happen whenever the stimuli are encountered. A task commonly used, due to its well-practiced nature, is reading in adults. If reading is a task that can become increasingly automatic with practice it is possible that other tasks can also become automatic processes. If we are to fully understand cognition, and be able to predict what occurs within the brain, the need to understand those automatic processes becomes essential.

Throughout the rest of this thesis the view taken is that automaticity is a continuum, and that reading is a process that lies on the automatic end of such a continuum. As there is a growing body of evidence that strongly automatic processes are uncommon and that the number of mental operations that are truly automatic are very few (for a review see Pashler, Johnston, & Ruthruff, 2001), reading should be considered one of the most automatic human behaviours (Neely & Kahan, 2001).

Optimising focussed attention

The ability to focus attention during visual search and selection is essential. Some of the apparent discrepancies between early and late debates are due, perhaps, to an inability to focus attention accurately enough, to ensure irrelevant information is not processed beyond the required level. This could be due to the irrelevant information being located in the same spatial location, or sharing too many properties with the target items. Yantis and Johnston (1990) review several papers that demonstrate the difficulty of focusing attention to one spatial location, and suggest seven ways to optimise the focussing of attention. First, the location of the target should be cued 100% of the time. Second, the position of the target should be moved, as attention has been found to habituate when restrained to one location, raising the probability of attentional exploration (possibly due to boredom). Third, a high processing load perceptually should encourage the focussing of attention. Fourth, display geometries of distractors in a circle with a target at the centre should be avoided. Fifth, varied stimulus-response mapping is desirable, as practice with just one response set could reduce the level to which items need to be processed, in order to achieve identification. Sixth, stimuli should not be crowded together, so that efficient attentional focussing can take place. Displays where all items fall within 1deg of central vision should be avoided. Seventh, target items should not appear more than once in displays (Yantis & Johnston, 1990).

By restricting focussed attention, through adhering to the seven rules described above, in visual identification tasks Yantis and Johnston (1990) were able to minimize the interfering effects of irrelevant items. They suggest that in cases where irrelevant items are processed, it is due to attention not being appropriately focussed through experimental procedures, which do not maximise the attentional focus. The findings of Yantis and Johnston (1990) are clearly supportive of accounts where early selection occurs through experiments being adequately controlled. This leads to a rejection of strong forms of late selection, as the processing of to-be-ignored items can be prevented. The strong version "simply has no mechanism to prevent elements appearing in to-be-ignored locations from being fully processed" (Yantis & Johnston, 1990). If their results had shown interference from irrelevant items, it would have been untenable to suggest that theories proposing that selection occurred at a late point in processing were inaccurate.

The evidence from divided task experiments provides data that cannot be accounted for through an early-selection only model. Typically, in a divided attention task participants will view an array of items, and make a response on one or two of the items. In Duncan's (1980) study participants viewed items that appeared in fours, displayed as if they were the corners of a square. Participants had to choose which two targets were present. The key finding from this type of study is that it is hard to detect simultaneous targets while the number of non-targets seems to be unimportant: "non-targets do not compete for limited capacity processes". From his experiments Duncan concluded that all items are processed in parallel to a first level. At this level the items are identified, but not yet available for deciding which response to give (that is they are not available to conscious awareness). A limited capacity mechanism then passes the items for response on to a second level from which a response can be made (Duncan, 1980).

To account for the data from divided attention experiments, like Duncan's (1980), Yantis and Johnston (1990) hypothesise a multiple locus model, where the selection of items is flexible, can occur early in focussed attention and later in divided attention tasks. Where attention acts, depends on the task, and failures to prevent processing of irrelevant items are attributed to unsuccessful attempts to focus attention. In this model, the late processing seen in Duncan's (1980) experiments is attributed to the postponement of selection to the late level due to the nature of the task. In many ways this is similar to the perceptual load account proposed by Nilli Lavie (1995), in that the locus of selection is dependent on the task, whereas in Lavie's account the locus of selection is dependent on the number of items in the display.

Facilitation

There is evidence for both facilitatory and inhibitory mechanisms occurring when attention is fixed at a location. When a location is cued prior to a target being presented there, the target receives processing that is faster and more efficient than if the cue had been absent (Posner, Snyder, & Davidson, 1980). While the effect of cueing does not necessarily indicate that facilitation for neural representations of the target itself has occurred, it seems likely that the location cued receives attention: which improves the processing of the stimulus. As well as location, the effects of attentional facilitation have been demonstrated on several other levels of stimuli including, modality, identity, semantic, and schematic (Johnston & Dark, 1986). These levels are most often measured through priming of some sort, where an initial stimulus is followed by a related stimulus, which is responded to more efficiently and with greater speed. This facilitation has been explained through a theory where items, which share neural pathways with a prime or cueing stimulus, are also activated and subsequently, are easier to respond to when they are displayed (Posner & Snyder, 2004).

Inhibition

In addition to the facilitation of items, that are under the focus of attention, it is important that responses to non-target stimuli are prevented (Kessler & Tipper, 2004). If one considers a search for an item, it is important that previously searched positions are ignored until the search is complete. Posner and Cohen (1984) suggested that it was logical for there to be an inhibitive mechanism that prevented processing of non-target locations, so that search moves to new locations in an efficient manner. In the experiments of Posner and Cohen (1984), when a location is cued, it is followed briefly by facilitation in responses; however after 300ms responses were slowed to the cued location. Initially, inhibition mechanisms were viewed as being space-based, but later theories have emphasised the need for object-based inhibition as a selection mechanism for action (Kessler & Tipper, 2004; Tipper, Driver, & Weaver, 1991).

The theory of inhibition of unattended items is supported by the work of LaBerge and Brown, (1989), Mozer, (1991), Luck and Hillyard, (1994), and Green (1991). Further support for the inhibition of irrelevant information, rather than the excitation of selected information, comes from neurophysiological data where the largest neural responses occur when the distractor and target are within the same neurons receptive field. Tipper (1985), and Houghton and Tipper (1994, 1994b, 1996), have put forward theories that convincingly explain selection through inhibition. The models of selective attention, that they propose, use an inhibitory mechanism to attenuate the neural representations of distractors, allowing the selection of the target based upon a template neural representation.

Moran and Desimone (1985) presented evidence for a neural basis of inhibition by taking single cell recordings from the visual cortex of monkeys. The monkeys had been trained to attend to items at one location and to ignore items that were presented at another location. When the locations were both within one cell's receptive field the firing in response to the unattended item was greatly reduced. The reduced firing for irrelevant information occurred in only one cortical location, and is suggested to underlie identification and recall of an item's properties from a crowded visual array (Moran & Desimone, 1985). This cortical inhibition of irrelevant information has been suggested as the underlying mechanism for inhibition in humans (Tipper, 2001).

Negative Priming

Inhibition

There has been a dominant view that negative priming is the result of an inhibitive mechanism (Houghton & Tipper, 1996; Neill & Westberry, 1987; Tipper 1985; Tipper & Driver, 1988). Tipper and Driver (1988) showed participants overlapping green and red figures and asked them to respond only to the red figure. When the ignored green figure was subsequently presented in red in the next trial, RTs were slower than if a new figure was presented. Inhibition was originally suggested as a means through which selection can be achieved, by suppressing internal representations of competing stimuli. Negative priming is elicited when distracting information is displayed that competes with the information necessary to complete a task. The distracting information needs to be inhibited in order for the correct response to be made. If the distracting information then becomes the target, in a subsequent trial, response times are typically longer (compared to control trials), due to the previously distracting information having been inhibited (Tipper, 1985). For example, a participant has to make a lexical decision on the word TABLE, which is accompanied by the distractor word DOG. If the word DOG were the target for a lexical decision task on the next trial, responses would be slower due to the inhibition from the first trial. In an extension of this theory, if the subsequent word was not the original distractor word DOG, but the semantically related word CAT, responses would still be slower due to a spreading of inhibition from DOG to CAT.

Episodic retrieval

An alternative account for the explanation of negative priming is the episodic retrieval account, where the slower responses are not the result of inhibition, but memory retrieval processes. Neill, Valdes, and Terry (1995) explain negative priming, as resulting from the ignored item (using the previous example: DOG) being given a memory tag that means ‘do not respond’. When the ignored word (DOG) is presented as the target in a subsequent display, the tag causes confusion with new task requirement of attending to DOG. The confusion causes a slowing of participant responses (Neill, Valdes, & Terry, 1995).

A more recent version of the episodic retrieval account (Mayr & Buchner, 2006) explains negative priming through an incompatibility between the response required for the stimulus, the first time it is encountered (ignoring DOG when it is the distractor), and the response required the next time the stimulus is encountered (stating that DOG is a word). Mayr and Buchner (2006) propose that every time an item is encountered the recent response required for that item is also retrieved. The incompatibility between the previous and present responses gives rise to the negative priming.

Episodic and inhibition

In 2001, Tipper proposed a resolution between episodic and inhibitive explanations of negative priming. Tipper (2001) suggested that how a stimulus is viewed at one point, influences subsequent viewings of that stimulus (episodic). Tipper also highlighted that it is necessary to consider the neural processes involved with the completion of any task. The selection processes involved with a task that elicits negative priming must include neural excitation and inhibition. In this case, negative priming would be the result of retrieval of prior processing states, which are created through excitation or inhibition of possible responses. The inhibition system would have inhibited a previous response that was incongruent with the task, to reduce competition between the responses. When the stimulus is encountered again the existing inhibitive response is reactivated (Tipper, 2001).

Mismatching

While the previous theories, proposed for the explanation of negative priming, have focussed on negative priming for words (or objects), the mismatching account focuses mainly on spatial negative priming (Park & Kanwisher, 1994). In the mismatching hypothesis spatial negative priming is the result of a change between the bindings of items and their locations. A neural representation of the relationship between an item and its location is created. When the item is presented again in the same place it is quicker as the binding matches. When the item appears in a different location, negative priming is elicited, due to the mismatch of the previous binding with the current relationship between item and location. A major draw back to the mismatching hypothesis is that it does not explain how the representations are created neurally. Similar to the episodic accounts of negative priming, an explanation of how the mismatch actually causes the slower RTs is needed. If it is due to confusion over the mismatch, which must be competition between previous and current relationship representations, how is the correct representation chosen? Is the competition solved through either excitation, or possibly inhibition as Tipper (1990) suggests.

Other features of attention

Multi-modal attention

Pashler (1999) reviews a wide range of studies on attention and considers if attention should be considered to be either a single resource that all sensory modalities draw upon, or as mechanisms that are multi-modal. Two pieces of evidence are put forward as being the most relevant. First, humans are able to simultaneously select visual stimuli in one part of their environment and auditory stimuli in a completely different part. Second, when capacity limits do affect recognition of items, the effects are more acute when the items are all within one modality, compared to when the items are spread across more than one modality (Pashler, 1999). It is likely that there are separate attention resources for each modality, but that there must also be a central cognitive mechanism that 'manipulates the outputs of perceptual analysis, chooses actions, and does other things as well' (Pashler, 1999). So, while there are separate attention mechanisms for each modality, there is also a central mechanism that allows integration from the different modalities with other cortical functions. This central mechanism is limited in capacity, and is often likened to a bottleneck, through which responses (or actions) can only move if there are available resources (Pashler, 1999).

Split attention

In contrast to the spot light models of visual attention (Posner, Snyder, & Davidson, 1980), where there is one focus that is used to identify a target, Bichot, Cave and Pashler (1999) report a series of experiments that investigated split attention. By presenting two targets at different spatial locations, they were able to elicit correct responses for both targets more frequently than responses to distractor locations. Bichot, Cave and Pashler (1999) believe that the ability to split attention is of advantage when we need to view two parts of an item that is partly occluded. The ability to split attention is not covered by the spotlight model, but as the model was formulated from experimental results where there had been no distractors, Bichot, Cave and Pashler (1999) do not consider this a fundamental flaw in the spotlight model. As Bichot et al.'s (1999) Experiment 6 demonstrates that splitting attention is not an easy thing to do, it may be that in most instances attention acts like a spotlight, which can be split in order to complete a task if necessary.

Jumping attention

The original spotlight theory (Posner, Snyder, & Davidson, 1980) was assumed to predict that attention would move across visual space from one location to another, passing over all the area in between the two locations. If this were true, it would be expected that there would be a gradual decline in processing efficiency at the first location, as the spotlight began to move. Then there would be a gradual increase in processing efficiency at the second location when the spotlight arrived. In addition, RT latencies would increase, as distance increases from the first location to the second. Most of the findings from experiments exploring this aspect of attention have found the opposite: Attention jumps from one location to the next without passing over the area in between (Cave & Bichot, 1999).

The study of the movement of the theorised spotlight was conducted by cueing two locations one after the other. The target could appear at either location, but was more likely to appear after a cue. By varying the interval between cues and target, and measuring the accuracy of target identification, Chastain (1992) was able to identify when attention had reached the target location. If attention had moved like a spotlight, passing over the area in between the two cued locations, there would have been an effect at shorter intervals, where the spotlight had not reached the targets location and identification would have been around baseline. The accuracies remained well above baseline and were unaffected by alterations in the cue-target interval.

The list of researchers who have failed to find evidence of an attentional spotlight moving between positions is growing. Yantis (1988) described a model that showed how attention could jump. Eriksen and Webb (1989) presented participants with eight-letter circular displays, and varied the number of cued locations. There was no effect of increased distance between different cue locations and the target location. A study that used a detection task based on the Posner paradigm and varied the distance between target locations and fixation (Remington & pierce, 1984), also failed to find evidence of a moving spotlight. If the spotlight moves across the intervening space, facilitation from the cue would have been expected at target locations near fixation before being recorded at fixations further away. There was no difference between the target locations, which suggests attention had jumped from cue location to target location, without moving at a steady rate over the space in between (Cave & Bichot, 1999). Sperling and Weichselgartner (1995) placed distracting symbols on the path between cue and target locations and found no interference effects.

In conclusion, it is likely that if attention can be thought of as a spotlight, it moves between locations by jumping, or by being withdrawn from the first location, moved to the new location, and then being focussed on the new location (Cave & Bichot, 1999).

Gradient of processing

Downing (1988) conducted a series of experiments examining how the efficiency of spatial perceptual processing is affected by spatial expectancy. The research revealed that there is a general decrease in perceptual quality, as distances from a targets expected location increases (Downing, 1988). The type of information processed modulates this perceptual gradient, which is also modulated by the way the stimuli are distributed.

He, Cavanagh, and Intrilligator (1997) present evidence from a variety of papers that show attention can only focus to a finite level. They term this level the 'grain of attention', and go on to describe an attention system that has a coarser gradient than the visual system. While humans are able to see that there are several items within a display, we are unable to focus on just one item when the display is crowded. He, Cavanagh and Intrilligator (1997) review evidence from the visual attention field and conclude that spatial attention has a fine grain close to fixation, and that the grain gets larger the further one moves attention from the point of eye gaze fixation. As density increases we are unable to discriminate between items, which subsequently become seen as a texture and less as individual stimuli.

Summary of the properties of attention

First, our cognitive (and physical) resources are capacity limited, which means to respond to the environment there must be a selection mechanism. Second, attention filters information through a selection window, excitation, inhibition, or all three. There is evidence for both excitation and inhibition, but many researchers argue that attention allows processing of the focus while inhibiting the out of focus (Tipper, 1985; Houghton & Tipper, 1994, 1994b, 1996); although there is evidence that the attentional focus receives preferential processing and that there is a gradient of processing away from that central point (Downing, 1988). Third, attention works both early and late: depending on the task demands. Fourth, attention is multi-modal, and different mechanisms work at input selection and response selection (Pashler, 1999). Fifth, attention is space based, object based, or both (recent publications have seen a shift towards a dominance of object-based theories [Egly, Driver, Rafal 1994; Moore, Yantis, Vaughan, 1998]). Sixth, the focus of attention can change in size (LaBerge, 1983; Egeth, 1977; Eriksen & St. James, 1986) and as it changes in size there is a cost of spreading the spotlight (Castiello & Umilta, 1990).

All the evidence points to a mechanism that is incredibly flexible. Attention can quite easily cope with a wide range of tasks adapting to the demands placed upon it. Any theory of attention, or selection, needs to be able to satisfy the range of abilities attributed to attentional mechanisms, as well as provide evidence that there is a neurological basis to the theory. At this point the most valuable model for selection appears to be the zoom lens model, coupled with Torralbo and Becks (2008) competition-based perceptual load theory, as the mechanism for selection within that zoom lens.

The neural basis of attention

Our knowledge about the neural basis of attention is largely based on clinical observations of brain lesions, animal studies (using single cell recordings from monkeys), and neuroscience (EEG, PET, fMRI) (Farah, 2000). Broadly speaking there are 30 or more cortical visual areas (Desimone & Ungerleider, 1989, Felleman & Van Essen, 1991; Desimone & Duncan, 1995) involved with seeing. The study of the neural basis of attention has revealed that there are three areas frequently linked with the movement of attention, and three areas linked with the control of attention. These neural areas give rise to the four component processes believed to be involved in attention: working memory, competitive selection, top-down sensitivity, and filtering for stimuli that are behaviourally important (Knudsen, 2007). This review of the anatomy begins with the basic structure, then discusses the areas involved with selection and attention, and finishes with integration of the component processes.

The structure of the cortex dictates much of what occurs early in the visual processing networks. The organisation of the areas is very hierarchical beginning with the cells in V1 (also know as the primary visual cortex), where very simple processing occurs. V1 is also the start of the two major cortical processing pathways: the ventral and dorsal streams (Kastner & Ungerleider, 2000). The ventral stream goes through the inferior temporal cortex and is involved with the processing of objects (V1, V2, V4, TEO, and TE (in IT). The dorsal stream is used for the processing of spatial representations and travels through the posterior parietal cortex (Desimone & Duncan, 1995). Although the two streams are separate they are highly interconnected. Additionally, the ventral stream does complete some spatial processing, through the V4 and TEO areas having retinotopically organised receptive fields. However, the information is coarsely coded and requires information from the dorsal stream to be efficient in localising the objects.

A critical issue is how selectivity is coordinated across the two streams of processing, so that the right information is selected about location, object, and motor control (Desimone & Duncan, 1995). In terms of selection, the evidence indicates that the location is processed quicker than object features, like colour. Some have taken this to mean that location is identified first and then other attributes are processed, once location processing is complete. Other researchers believe that all the attributes are processed in parallel, and that location just happens to be faster (Desimone & Duncan, 1995).

As information is processed along the ventral stream the complexity of the neural representations increases. In V1 the processing is of small differences in the visual field; in V2 neurons respond to contours in a figure; in IT neurons respond to the shapes or features of objects. This increase in complexity is mirrored in the receptive field size of neurons: in V1 the field size is 0.2°, by area V4 the field size is 3°, by TEO it is 6°, and in the TE area it is 250°. The larger receptive fields allow the processing and recognition of whole objects (Desimone & Duncan, 1995).

Bottom-Up selection

The visual system has some inbuilt selection mechanisms that operate in a bottom-up fashion. They are termed bottom-up because they appear to be largely automatic in nature (Desimone & Duncan, 1995). Stimuli that stand out from the background are processed preferentially by nearly all parts of the visual system. If there are similar stimuli surrounding a target within the same receptive field, the activations of those cells are reduced below their normal activity. The more distractors there are present within the cells receptive field the lower the activation for the target becomes (Desimone et al 1985). When a target is different enough to be salient these mechanisms are the likely cause of the pop-out phenomenon. Pop-out refers to when an item is found with great ease, usually because it differs from the distractors on a level that is being searched (e.g. a green cross surrounded by red crosses). Similarly, if a stimulus was on its own, a long way from other items, it would be more likely to be selected due to having no competing suppression from flanking items (Knudsen, 2007).

There is a bias in the visual system for new, or not recently seen objects. This temporal effect has been localised to the IT cortex of monkeys, where activations decrease in IT, as a monkey becomes more familiar with a target (Fahy et al 1993; Desimone & Duncan, 1995). The numbers of neurons in IT that respond to the stimulus also decreases until only those, which respond to the stimulus most, remain. Novel and rare stimuli have a higher activation in the cortex, which gives them an advantage in gaining control over attention and selection mechanisms (Desimone & Duncan, 1995). There is also an effect for items that are instinctive, or have learned biological importance (Knudsen, 2007). The primary sensory areas of the cortex respond preferentially to stimuli that have acquired learned importance, with very strong activations that spread over larger networks of neurons (Knudsen, 2007).

There is evidence that when competing distractors are presented within V4 and IT cell receptive fields, the cells seem to not only enhance processing of the target, but also resolve the competition from the distractors (Desimone & Duncan, 1995; Moran & Desimone, 1985). Desimone and colleagues attributed this to the cells receptive field shrinking around the target. They suggest that the IT neuron may block responses to more peripheral stimuli in the field over a wide area; while the V4 excites items over a smaller spatial range. In this way, the V4 and IT cells work together in order to enhance processing of target items and reduce competition from distractors.

Top-down selection

Kastner and Ungerleider (2000) believe that competition between items that appear within the same receptive field occurs through mutual suppression. The suppression occurs in V4 and TEO. Attention has been shown to attenuate or abolish the effect of competitor suppression on a target item, when the competitor appears within the same receptive field. Attention may therefore work by counteracting the suppressive force of competing stimuli nearby. The reduction in suppression effectively means that the processing of the target is enhanced. As more attentional resources are given to enhancing the target (through reducing the suppression from competing stimuli) the less processing of irrelevant items occurs.

Kastner and Ungerleider (2000) propose that the top-down bias in attentional processing is through the enhancement of targets at an attended location. As task difficulty increases, activations for the target (if it is inside the receptive field) increase.

Often, following a lesion on one side of the brain there is neglect for objects on the contralateral visual field (Farah, 2000). Neglect is typified by the failure to attend to items in the affected visual field. Patients will, for example, often only shave half of their face, or copy half a picture (Bisiarch & Vallar, 1988; Kastner & Ungerleider, 2000, Rafal, 1994). Lesion studies reveal that the parietal cortex (Yantis, 2008: subregions of the posterior parietal cortex: lateral intraparietal area [LIP], itraparietal sulcus [IPS], superior parietal lobule) is frequently indicated in neglect patients, but that neglect arises from damage to other areas as well: including, the frontal cortex (Yantis, 2008: frontal eye field [FEF], supplementary eye field), the cingulated gyrus, the basal ganglia, the thalamus, the midbrain, the superior colliculus, and the temporal lobe (Desimone & Duncan, 1995).

Desimone and Duncan (1995) suggest that the causes of neglect may be the loss of cortex that facilitates saliency of items, or that supply top-down spatial selection inputs. The idea of competition between items that needs to be resolved is supported by the fact that in cases of bilateral lesions in the areas listed above; cases of neglect are less common. This would suggest neglect is possibly caused by the undamaged hemisphere having an advantage; which disappears when both hemispheres are lesioned (Desimone & Duncan, 1995). The data from lesion research would implicate the posterior parietal cortex as having a role in disengaging attention from its current focus (Desimone & Duncan, 1995). Posner and Peterson (1990) suggest that moving attention is conducted by the superior colliculus, and that focussing (or engaging) attention is controlled by the pulvinar. There is also a suggestion from Farah (2000) that the "parietal cortex is responsible for constructing a stable and perceptually integrated world". The parietal cortex is attributed with combining all of the visual information together, along with sounds and tactile sensations, so that the world around us feels solid and bound together (Farah, 2000).

Other areas implicated in attention are the substantia niagra, the Pdm nucleus (in the pulvinar), the frontal eye fields, and the dorsolateral prefrontal cortex (Desimone & Duncan, 1995). The involvement of the frontal eye fields in attention is in question, as the effect is considered to be specific to saccadic eye movements and not control for processing. Desimone and Duncan (1995) conclude that, from extensive physiological and lesion study evidence, the top-down control of attention most like originates in both the posterior parietal and prefrontal areas. They also believe that these areas are heavily interconnected and work together (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000). The importance of the prefrontal cortex may be that it forms the basis of working memory and that damage to this area removes the interface of working memory with the rest of the cortex (Knudsen, 2007). When a stimulus matches the goals of working memory it receives preferential processing through the selection mechanisms described above (Knudsen, 2007).

Resolving the competition for selection

Just as the organisation of the visual cortex is hierarchical, increasing in complexity with each additional stage, the competition between representations also increases in complexity with each additional stage. Early areas compete over simple lines, or perhaps locations, while later areas compete over object shapes and categories (Knudsen, 2007). The final competition takes place at the interface with working memory, where information from all the domains compete for working memory networks (Knudsen, 2007). Knudsen believes that attention does not identify targets, working memory does: which is not to say that the system cannot be highjacked by salient distractors. Working memory then acts to put the body in the best position (e.g. eye gaze and head orientation) to receive and act on the activations. The representation with the highest activation wins.

Summary of the neural basis of attention

The visual system is highly structured. The neurons in the first stage of visual cortex process simple features and have small receptive fields. The receptive fields increase in size as the information progresses through the system. Similarly, the complexity of competition between stimuli increases from very simple at early stages of processing to complex at later stages. There are two main pathways through the visual system, the object (ventral) and the location (dorsal); which are independent but highly interconnected.

Selection can be driven by bottom-up (automatic) processes, where novel stimuli and stimuli not recently seen are preferentially processed. Stimuli that differ from others or are spatially removed from other stimuli also receive preferential processing. There is evidence that when a distractor is near a target within a single neurons receptive field, the neurons receptive field shrinks around the target. Selection can also occur through top-down or attentional processing, where attention suppresses the inhibition from distractors allowing the targets representation to be enhanced. The selection of stimuli occurs through competition of representations, with the target meeting the top-down goals and so acquiring enhanced activation. The competition for selection is resolved at the interface with working memory

There are three main areas implicated in attention, the pulvinar, the parietal cortex, and the superior colliculus. These areas, disengage, move, and engage attention respectively. The actions of attention are controlled by the posterior and prefrontal areas.

Important for the following chapters of this thesis, is that there is an effect of load, where competition between the stimuli representations is attenuated through the action of attention reducing the suppression from distracters. So, high load conditions result in enhancement of the target and general noise for the non-targets and distracters. In summary the four key points are:

1. Attention can act like a zoom lens.
2. That the search for a target in a high perceptual load display will result in enhanced processing of the target.
3. Non-targets (including distracters) are processed, but only so much as they contribute noise to the cognitive systems. The action of attention is then required to enhance the target. Because there is a high level of noise (and lateral suppression) among the distracters none of them compete with the target, and so do not need to be inhibited.
4. Under conditions of low perceptual load, where there are few non-targets (sometimes just one), the competition between the target and distractor needs to be resolved through suppression of the inhibition coming from the distracter. As the inhibition from the target to the distracter is not suppressed any subsequent presentations of the distracter are subject to the previous suppression.

The Visual Search Task

The visual search task is an effective tool used to investigate selective attention, and to isolate the effect of attention on perception from other cognitive levels where attention plays a role (Palmer, Ames, & Lindsey, 1993). At its most basic, visual search involves a participant searching an array of items for a target, and then making a present/absent judgement. The simplicity of the visual search task means that different parameters (e.g. number of items, target/distractor similarity, and distance between items) can be easily manipulated, while possible confounding parameters can be held reasonably constant. Increasing the size of a display set (the number of items in a display) typically increases search times. The number of fixations required to complete the search can be manipulated through varying exposure times, as well as the spatial separation of stimuli (Palmer et al., 1993). Search tasks also give researchers both reaction time and error data; both of which can be used to shed light on underlying cognitive processes.

Targets producing efficient searches are processed in parallel across space, in that focussed attention is not needed to discriminate targets from distractors. Targets that elicit steep RT slopes require participants to focus attention on each item, for the discrimination to be accurate. If there is a slope, it can be inferred that focussed attention has been used (Treisman & Gormican, 1988). Typically search times vary from efficient (additional distractors do not increase search durations) to inefficient (slope> 30ms per item) (Wolfe, 1998). The similarity of distractors to targets can effectively be used to manipulate the cost of additional items eliciting usually between 20-50ms (Thornton & Gilden, 2007). When a search elicits an efficient slope it is usually because the target pops out from the distractors, on a dimension that is processed early in the visual cortex (colour, motion, orientation, size, luminance)

(Thornton & Gilden, 2007). Thornton and Gilden (2007) point out that it is not easy to differentiate between serial and parallel processes, as parallel processes may be affected by divided attention, which could lead to RT slopes that mirror serial processes. Also, the serial slope could be due to response stage effects and not detection stage limitations.

Parameters Commonly Studied

Search Patterns

The interpretation of RT and error search slopes is difficult, but they can be categorised. A steep slope occurs when items are searched serially and a flat slope is elicited by parallel search. In serial search among similar items, each additional item can add up to 90ms to search times, while, typically, parallel search elicits a slope where additional items do not add to RT. So for parallel search, when the increase in items is plotted a horizontal (or near horizontal) line is evident. When additional items elicit smaller slopes (20-30ms) it can be harder to determine if the search was serial or parallel, as small increases in the slope may be due to decision noise (Pashler, 1999). For many letter search experiments, where the target is embedded in a letter string or real word, the search slopes are indeed around 20-30ms (Atkinson, Holmgren, & Juola, 1969; Cavanagh & Chase, 1971). The increase in slopes for targets embedded in other letters may be due to participants spending longer analysing the display, even though all the items were processed in parallel (Wickelgren, 1977).

When the target letter is present in the display the trial type is commonly called positive-search, and conversely when the target is absent from the display the trial type is called negative-search. Sternberg (1969) predicted that negative-search trials should result in a reaction time that is twice that for Positive search trials.

However, this prediction was in relation to random displays with items dispersed across the whole visual screen. In contrast, when participants were asked to search for a target letter embedded in other letters Atkinson, Holmgren, and Juola (1969) found that negative-search trials on average elicited RTs that were only slightly longer (20-30ms) than positive-search trials. Additionally, Treisman and colleagues, using simple and complex stimuli, found reliable evidence that negative-searches always take on average longer than positive-searches (Treisman and Gelade, 1980; Treisman and Gormican, 1988). That negative-search trials should take longer than positive-search trials is intuitive, as participants will need to search the whole array before responding negatively to a targets presence. If one takes the average of all the positive trials, this will include those trials where the target was found quickly through to those trials where the target was at the only location left after an exhaustive search. This average of positive trials will always be quicker than the average for negative-search trials which (if the participant is responding accurately) will always be exhaustive.

Attentional Set

In Experiment 4 a condition is introduced that manipulates the attentional set that participants have for the letter search task, by introducing trials where the participants view the target letter prior to exposure to the search display. The idea that individuals will perform more efficiently when they have prior knowledge about the intended target has been popular for some time, and is often described as perceptual set effects (Gibson, 1941; Haber, 1966). While set has been used in terms of target location (Posner, Snyder, & Davidson, 1980), or a simple physical property such as spatial frequency (Davis, Kramer, & Graham, 1983), there has been little research on the effect of prior knowledge of a letters identity in LS tasks. Broadly speaking prior knowledge should allow a participant to use top-down influences more effectively, by increasing the activation of channels related to the target, thus reducing the level of interference from irrelevant items (Pashler, 1999). Theories of visual search that describe perception as an interactive process (Hochberg, 1978; Neisser, 1976) suggest that advance target identity information should be beneficial, as participants are better able to discriminate between expected and non-target items.

Summary of visual search

The interpretation of search slopes must be conducted with care, but, put simply, a shallow slope represents parallel processes, while a steep slope represents serial search (Thornton & Gilden, 2007). As searching for letters in words usually elicits fairly shallow slopes, conclusions need to be drawn that avoid assumptions of parallel or serial processing (Wolfe, 1998). Searches for targets made to negative displays should be slower than positive displays, as to decide a target is absent requires exhaustive search of all items or locations. It is expected that each additional letter will each add approximately 30 ms to search times (Atkinson et al., 1969), and that increases in search times may not be due to serial search, but an effect of distractors: the identification of all of the letters may have occurred in parallel (Wickelgren, 1977). The detection of targets should be influenced by the prior knowledge of the to-be-searched for target, resulting in faster RTs and possibly flatter RT slopes (Pashler, 1999).

Visually Processing Words

A skilled reader can identify 30,000 words in less than half a second per word (Risko, Besner & Stolz, 2005). Visual word recognition is often considered to be an example of an automatic process where a lexical item presented in the visual field should activate its semantic representation in long-term memory. Risko et al. (2005) consider that the activation should be independent of spatial attention and independent of the preparedness of the participant.

Previous research has identified that spatial attention operates in a particular manner within an object: spreading across the object from the initial focus point (Richard, Lee, & Vecera, 2008). If words can be considered objects this would allow us to make specific predictions concerning the effect of focussing attention within a word. However, Palmer and Rock (1994) state that words have gestalt grouping principles, and frequency of grouping (the letters appear frequently together), but they should not be treated as objects, as the letters are still individual units and that true objects are bound by stronger effects: which they call uniform connectedness (Kahneman & Henik, 1981), common fate (Driver and Baylis, 1989), and proximity (Banks & Prinzmetal, 1976; Prinzmetal, 1981). Logan (1996) offers an interesting, if somewhat unhelpful, resolution by suggesting that researchers can rely on intuition to define what an object is, therefore: "if I think it is an object it is". In the case of words, Humphreys and Riddoch (2007) believe that the word familiarity enhances processing at all positions and causes the word to be processed as a whole whereas letter strings are not. In the case of words the letters are processed as a whole object, because familiarity with groups of items appearing together makes them a whole object.

The neuroanatomy of reading

A key question concerning the neuroanatomy of reading is if there is a single part of the cortex that is specialized in the processing of written words. Evidence from clinical case studies has examined a syndrome called 'pure alexia'. In pure alexia individuals are impaired at visual word recognition, while retaining the abilities to understand auditory words, producing written language, and understand complex non-word patterns. Farah (2000) makes a note that the understanding of non-word complex patterns is questionable evidence. Whether or not pure alexia is the result of damage to a specialist reading centre is under contention. Following the rule of parsimony, it is more likely that there is a system that recognises faces, objects, animals, *and* words rather than many systems. Farah (2000) highlights the problem that, in terms of word recognition, the category of orthography is decided by the society and is different for different languages. There has not been enough evolutionary time for the brain to develop a specialized system, when there have been so many changes in the languages used.

Typically, while a pure alexic can still read they do so at a very slow rate. Frequently they adopt what is known as *letter-by-letter* reading strategies (Farah, 2000). Pure alexics show two interesting effects when they are reading. First, when they read there is no word superiority effect (WSE) if they are using letter-by-letter strategies. The WSE is typically an improvement in performance of letter identification when the to-be-identified letter appears in a word instead of on its own. Second, when they are encouraged to process the whole word, the word superiority effect returns. This evidence would seem to indicate that, even though they are having problems with reading, they can still process the information. This is indicative that the WSE requires attention to be focussed on the whole of a word. In fact, Johnston and McClelland (1981) found that the WSE was attenuated or abolished when normal readers focussed on letters instead of the whole word. This effect that is similar to the prime task effect discussed previously. Farah (2000) concludes that there may be an area that is specialized for words through practice. However, this area is part of a specialized processing area in the extrastriate cortex that is used in recognising complex shapes (Farah, 2000).

Levels of information associated with visually processed words.

The first level of processing for written words takes the form of the lines and blobs that make up the letters. Once these components have been resolved into letters the abstract identities for each letter need to be accessed. The letter identities are also referred to as graphemes, which when put together in a string form familiar words, unfamiliar words or non-words. If a string of letters is recognised as being familiar, through activation of stored orthographic representations, then the string of graphemes must access the semantic representation. Once the semantic representation has been accessed the phonological representation is accessed. In some cases words without homographs (words spelt the same that are pronounced differently) may access a phonological representation directly (Hillis, 2002). The phonological representation is the basis for subsequent motor controls and articulation. Hillis' (2002) model for the cognitive processes underlying reading also includes a direct orthographic to phonological connection. Some researchers believe that activations spread from the orthographic to the phonological and then proceed to the semantic (Coslett, 1999). Gathercole and Baddeley (1990) offer a cautionary note in the assumption that readers create a phonological code prior to lexical access. The evidence of homographs clearly demonstrates that in order for this class of words to be pronounced phonetically, it is essential that the contextual meaning has been accessed. Understanding the architecture of the cortical mechanisms, underpinning visually processing words, is essential if we are to understand what is occurring within the brain during semantic priming and prime task experiments.

Structure of Semantic Memory

Hierarchical Model

The structure of semantic memory is important, as its organisation has implications for what one can expect from cognitive experiments that directly or indirectly use memory stores. Both interference and priming studies of semantic access make assumptions about the way that information is stored within the cortex, and the way that representations of different items interact. Models of memory have moved through several variations, modern versions based on cognitive experimental results begin with models like the Hierarchical Model (Collins & Quillan, 1969, 1972). In hierarchical models semantic information is arranged by category in a hierarchical manner, for example, cat would be stored under mammal, which itself is stored under animal. Collins and Quillan (1969, 1971) found that sentences composed of items that were closer together within the hierarchy were responded to faster (cat is a mammal) than items, which were farther apart (cat is a living thing). There were problems with the model though, as stimuli, which were atypical for a category, could not be explained by the model, for example, 'a robin is a bird' is responded to faster than 'a penguin is a bird'.

Adaptive control of thought model

A later model of semantic memory, *adaptive control of thought*, was able to explain the atypical results that caused problems for hierarchical models, but was much more complex (Anderson, 1976, 1983, 1991). In *adaptive control of thought* models, memory is based around propositions (the smallest unit of meaning), where the meaning is more important than exact recall. The organisation of memory is through the frequency of items being encountered together: the more frequent the stronger the connections between items. *Adaptive control of thought* models predict, through such strengthening of connections, that activation should spread from one node to other nodes that are frequently encountered at the same time (Anderson, 1976, 1983, 1991). This spreading activation has been an influential idea in modelling memory. Semantic priming effects support spreading activation, for example, where the prime DOCTOR facilitates responses to a target word NURSE, by spreading activation from the node for DOCTOR travelling to the node for NURSE.

Connectionist Models

Connectionist, or parallel distributed processing models, use the same concepts of links and nodes, but with a different emphasis on what is stored where. McClelland and Rumelhart (1986) proposed that instead of each concept being modelled as a node in a system, where new concepts are added by adding nodes, the same nodes are used to represent all possible concepts (Medin, Ross, & Markman, 2005). Each concept is spread out across several nodes, and it is the connections betweens the nodes that is important. The idea that concepts must be spread out across nodes comes from observations of the brain, where neurons are lost constantly. Further, the organisation of the brain and its interconnectivity lead connectionist theorists to the view that it is more likely that concepts are spread across the cortex (Medin, Ross, & Markman, 2005). The connections in these models are important on two accounts. First, they are either excitatory or inhibitory; and second, the strength of the connection determines the level of excitation or inhibition spreading to other nodes. Because the nodes are massively interconnected no one node is crucial to processing. The most important determinant in processing information correctly is the pattern of activations across the network.

Spatial attention and word identification

The role of spatial attention in visual word identification has been seen from either a minimal (Allport, 1977; Carr & Posner, 1995; LaBerge & Samuels, 1974; Sieroff & Posner, 1988) or maximal view point (Chiarello, Maxfield, Richards, & Kahan, 1995; McCann et al., 1992; Ortells, Tudela, Noguera, & Abad, 1998; Treisman, Kahneman, & Burkell, 1983). Auclair and Sieroff (2002) see the two positions as representative of the early late debate. Late selection predicts that words are processed automatically (without capacity limits). Early selection predicts that spatial attention must be allocated to the letters before word identification can be begun. Then there are models that suggest it is familiarity with the stimulus that is involved with whether spatial attention is required (if the word is familiar then spatial attention is not needed to process the letters and make an identification). Through a series of three experiments Auclair and Sieroff (2002) examine the effect of spatial attention on identifying letters in words and conclude that word processing is sensitive to spatial attention (in agreement with early selection theories). However, they suggest that the effect of attention is modulated by familiarity with the stimulus so that a more familiar word will elicit a different effect on spatial attention to an unfamiliar word (Auclair & Sieroff, 2002).

Search Patterns and position effects in words

The Optimal Viewing Position (OVP) is considered to be located between the beginning and the middle of a word (Brysbaert & Nazir, 2005), with some researchers placing it just to the left of the middle letter. In languages that read from left to right, the participants more often fixate first on the OVP than any other position, in isolated written words. This preference has a direct effect on the identification of both letters within the word and of the word itself. The typical identification pattern is a Gaussian curve, where the right hand letters elicit lower probabilities of successful identification. The reasons for eye gaze falling on the OVP are three fold. First, the fovea offers individuals the greatest level of discrimination, and even moving 1 degree away from fovea fixation reduces visual acuity by 40%. Therefore, to maximise written stimuli processing the fovea must be focussed on the part of the word that allows optimal processing. Second, the first part of a word has been shown to contain the most information useful in identifying a word. Third, the first part of a word contains the information, which allows an individual to discriminate between the target word and all other possible words. Many experiments have demonstrated that processing is best when words are fixated between the beginning and middle of words, with large processing costs for fixations to the exterior letters (Brysbaert & Nazir, 2005). Brysbaert and Nazir (2005) suggest four variables that interact in creating the importance of the OVP. The first is the distance between the initial viewing position and the farthest letter; the second, is the fact that the beginning of words are usually more informative than the end of words; the third, is the fact that words are recognised more efficiently after fixation at the OVP, and finally, the fact that stimuli appearing in the right visual field have direct access to the left cerebral hemisphere.

Measuring Levels of Automaticity Using Words

Interference Effects

The measurement of automatic SA is traditionally indirect, as until recently there was no way to determine if the meaning of a word had been accessed, other than through the interference (or priming as discussed below) of the word information with another task. Stroop (1935) presented a set of experiments, that has been incredibly influential ever since, and is possibly the most replicated and studied area of cognitive psychology (MacLeod, 1991). The basic idea of Stroop's test was to present colour words written in different coloured inks. The two conditions most often compared are the congruent, where the ink and the written word information match (e.g. RED), and incongruent, where the ink and written word information are different (e.g. RED). The task is to name the colour of the ink, for which the semantic information contained within the word is irrelevant. Typically the meaning interferes in the incongruent condition eliciting more errors and slower RTs. The results of the Stroop test were used to support automatic SA until experimental designs examined the test in more detail.

Besner, Stoltz, and Boutilier (1997) demonstrated that the Stroop effect can be eliminated through colouring just one letter of the stimulus word. The single letter effect has since been replicated several times (Besner & Stolz, 1999; Manwell, Roberts, & Besner, 2004), but has been criticised for the use of stimuli that are not a perceptually whole, as the use of colour possibly creates at least two perceptually different items (Danziger, Estévez, & Marí-Beffa, 2002). Some of the most interesting research on the single coloured letter Stroop experiments, comes from the investigation of the OVP in Stroop words. Parris, Sharma, and Weekes (2007) demonstrated that although the Stroop effect is eliminated when the coloured letter appeared at most of the letter positions within a word, when it appeared at the OVP the Stroop effect was not extinguished. In fact, it was larger than the interference from all other positions. It can be stated that semantic processing occurred following presentation of the incongruent coloured letter at the OVP, which indicates that words are processed for their meaning automatically.

The Stroop effect has provided cognitive psychology with a seemingly never ending resource for investigating an automatic behaviour (reading), compared with a non-automatic behaviour (colour identification). Catena, Fuentes, and Tudela (2002) believed that priming may be a better indicator of semantic processing than Stroop interference. Following a series of experiments examining not only Stroop interference, but also priming within a Stroop experiment (as first used by Neill, 1977), it was concluded that priming reflects the success of a stimulus to activate its representations in memory. Theoretically, priming effects should suffer from less interference than Stroop effects, which are seen as competition in gaining control of action (which occurs once competing stimuli have been fully processed). Semantic priming studies may, therefore, offer a clearer picture of semantic access.

Semantic Priming

Semantic priming is a more recent phenomenon than the Stroop effect, only being of real interest in cognitive psychology since the seminal experiment by Meyer and Schvaneveldt (1971). Semantic priming is an improvement in speed or accuracy to a stimulus (e.g. the word DOG), when it is preceded by a semantically related stimulus (e.g. the word CAT), as compared to when it is preceded by a semantically unrelated stimulus (e.g. the word FENCE). Semantic priming is found for both words and pictures and typically the initial stimulus is termed the *prime,* and the subsequent stimulus is termed the *target* (McNamara, 2005). The traditional task used for investigating semantic priming is the lexical decision task, where participants have to decide if the target word is a real word, or if it is a string of meaningless letters. Typically, lexical decisions to target words, that follow a related prime word, are faster and more accurate than lexical decisions to target words that follow unrelated prime words (McNamara, 2005). The more semantic representations the words share, or the closer related the words are, the more facilitation the probe word should receive (Neely & Kahan, 2001).

McNamara (2005) provides an excellent summary of semantic priming and lists three reasons why it has been so influential. First, semantic priming occurs in many cognitive tasks, which allows for converging evidence of what would appear to be a fundamental mechanism in the brain. If it is seen in so many different experimental paradigms then it is likely that the mechanisms that drive it are of potentially universal nature. Second, semantic priming can be utilised in other areas of research as a tool for understanding diverse areas of cognition, including, sentence comprehension, word recognition, and automaticity of processing. Third, when people participate in semantic priming experiments they are often unaware that there are related items within the experiment. Meaning that it is likely the experiments are measuring a true RT representation of cognitive functions, in the absence of participant performance effects (McNamara, 2005). The models that try to explain semantic priming are discussed below.

Spreading activation model

The spreading activation model was first suggested as part of Quillian's model of memory (1967), and later extended by Collins and Loftus (1975). It was also included in the models of Anderson (1976, 1983a) and Posner and Snyder (1980). The models that incorporate spreading activation are different in many aspects, but they all share some key elements. First, when an item is retrieved from memory its cortical representation is activated. Second, this activation spreads from the initial item to all related item representations. Third, the spreading activation builds up in the related concept representations, which then subsequently aids retrieval of the related representation (McNamara, 2005). In these models the representations are nodes in a network and the spreading activation passes through links between the nodes. The strength of the link between nodes alters the strength of the spreading activation, as does the semantic distance between concepts nodes.

Accounts of spreading activation do not try to explain their results in terms of the cortical structures within the brain. In order for a model of semantic priming to be really satisfactory it should fit with what is known about the structure of the visual system, such as the increasing complexity of representations and the hierarchical structure. There are several problems with spreading activation models of semantic priming, in that these models can not explain priming occurring at very short SOAs, or that semantic distance has little effect on the size of the priming effect, or that the decay of priming, in may cases, is very rapid (McNamara, 2005).

Verification model

Whereas the spreading activation account of semantic priming requires the activation at one node to spread to related nodes, the verification model of semantic priming does not require spreading activation (Becker, 1976, 1979). In this model a prime word enters visual sensory memory and its basic features are extracted. These features activate detectors in the word lexicon for those features. All words in the lexicon that share the features will be activated. The most active word from the lexicon is chosen and then compared to the visual sensory memory. If there is a match then the stimulus word is identified as the lexicon word. After the word is identified in the lexicon semantic information becomes available. All semantic representations that are related to the lexicon word are activated and become a semantic set (McNamara, 2005). The most active semantic representation is matched to the lexicon word, and if there is a match the semantic information is identified as being the lexicon word and also the stimulus word. Semantic priming occurs because the semantic set for the related prime has already been activated. This means that the stimulus word can be identified from the semantic set, bypassing the feature analysis stage in visual sensory memory and speeding up responses (McNamara, 2005).

The verification model takes a step in an interesting direction through the inclusion of several stages of processing, and there being communication between these levels of processing. While the bypassing of the visual feature processing stage explains the priming data, it seems unlikely that a whole stage is bypassed so easily, when normal considerable practice is thought to be required for the removal (or reduction) in a processing stage to occur.

Distributed network models

The distributed network models do not require any sort of spreading activation to explain semantic priming. There are some differences in these models in terms of the structure of semantic memory, compared with the models previously described. The most important difference is that the nodes used in the previous models were for a whole concept, such as 'table', whereas in the distributed networks models, 'table' would be a pattern spread across several nodes. It is the pattern in these models that is important and not the nodes themselves (McNamara, 2005).

Semantic priming can be explained through each concept being a pattern spread out over a network. Related items would have similar patterns and would activate the nodes in similar ways. In this instance the prime 'table' would activate the semantic network pattern for 'table'. It would also activate some of the nodes used for the word 'chair', through them sharing similar patterns of semantic representation. In contrast 'table' would not share a very similar pattern to the semantic representation of 'sausage'. The closer the pattern of representation in semantic memory, the more likely there will be semantic priming.

Multistage activation models

All multistage activation models share three components. First, all contain multiple levels of lexical and semantic representation, for example, visual features, whole letters, words, and meanings. Second, there is communication between the levels that is both feed forward and feed back. Third, each level within the model represents a stage of processing that can be likened to the hierarchy seen in the neurons of the cortex (McNamara, 2005). Morton (1969) described a model where words are represented by feature counters that were termed *logogens*. When a word is visually perceived information about the features build up in the logogens for every word that share visual features with that word. The word is recognized when the build up of information in the logogens exceeds the recognition threshold for one logogen. Similar to the spreading activation accounts of semantic priming the multistage model includes a spread of activity from the semantic features of the recognized logogen to other related logogens. When the related probe is subsequently presented, the logogen requires fewer stimulus features to be activated by the visual stimulus, because some of the semantic features have already been recognized, and information has fed back to the orthographic and lexical levels (McNamara, 2005).

Besner and colleagues have proposed an extension to Mortons' (1969) original multistage model, in which there are two main stages that are important for explaining the semantic priming effect. These two stages are the orthographic input lexicon and the semantic system. A word activates the orthographic lexicon, which passes the activation onto the semantic system. The semantic system then passes this activation on to related concepts, which then pass the activation to their related inputs in the orthographic lexicon. In this model, related words are processed faster because their representations in the orthographic input lexicon and in the semantic system are partially active after the prime word (McNamara, 2005).

The multistage model also relies on the spread of activation from one concept to another in the semantic stage of visual word processing. The other levels rely on inhibition within the level in order to resolve competition between items. It seems strange that the inhibition from the previous levels is absent in the semantic level.

Otherwise it could be expected that related items would be inhibited to prevent an incorrect choice being made. Perhaps the inhibition is only active when competing items pass a certain activity threshold, which is not reached during the spread of activation through the semantic stage. It would be simpler if related items were activated through shared neurons as in the distributed and verification models.

Summary of semantic priming models

There are several models of visual word recognition that have been used to explain semantic priming effects. The few that have been reviewed here have been chosen for their contributions to, or impact on, semantic priming research. The idea of spreading activation between concepts or nodes has been pervasive since it was first introduced by Quillian (1967). There does not seem to be any evidence for spreading activation, other than effects like semantic priming. As, semantic priming can be explained by the distributed networks models, in a way that is more parsimonious than requiring the spread of attention, perhaps distributed networks are a better choice for future investigation.

The original spreading activation model does not offer more than a simplified explanation of the semantic priming results. It is also unable to explain certain results like the prime-task effect (discussed later in this thesis). It also fails on the explanation of a lack of distance effects between primes in the literature.

The multistage models also rely on spreading activation to explain how activation of the prime representations activates related concepts. While the distributed network models and verification models are unable to explain the prime task effect, the multistage model has an elegant explanation that can explain the prime-task effect, and the occurrence of morphological priming.

Perhaps a model of visual word processing that incorporates the structure of the multistage processing, with the distribution across nodes of the connectionist model, would offer a fuller explanation of the semantic priming data.

Negative Semantic Priming

In addition to positive semantic priming, where related items receive facilitation through shared neural networks underpinning representations, there has been some evidence of negative semantic priming (Fox, 1994, 1996; Tipper & Driver, 1988). The negative priming is typified through slower RTs when an item is presented in the previous display as a distractor (Tipper, 1985; Tipper & Canston, 1985; Tipper & Driver, 1988), when a subsequent item is related to a previous distractor (Fox, 1994, 1996), and only occurs in those dimensions relevant to the task (Tipper et al., 1994; Frings, 2006; Frings & Wentura, 2006). The inhibition network is thought to be directed by the current task the participant is undertaking (Tipper, et al., 1994). Negative semantic priming offers another way of measuring the selection and depth of processing a stimulus undergoes within a particular task (Fox, 1995b).

While negative priming from distractors is questioned by some researchers (Duscherer & Holender, 2002), there is growing evidence that negative semantic priming occurs following the presentation of words that are task irrelevant (Fox, 1994, 1995, 1995b; Frings & Wentura, 2006; Marí-Beffa, Fuentes, Catena, & Houghton, 2000).

Word length effects

An area often overlooked in letter search experiments is the length of the words the target letter is embedded in. This is possibly due to the common belief that there are no word length effects found in reading. However, word length has been shown to have a small effect, with increased length eliciting increased RTs. The RTs of individuals less well practiced at reading show that longer words are responded to slower than shorter words, and that this difference between lengths disappears with practice (Bijeljac-Babic, Millogo, Farioli, Grainger, 2004). Recent research from neuroscience, using scalp electrical amplitude recordings, has shown clear EEG data modulations of peak amplitudes and latencies, in response to words of different lengths (Hauk & Pulvermüller, 2004). The differences found in ERP data, as well as in the RTs of individuals less practiced at reading, suggest that there may be an effect of length that is extinguished through practice for behavioural data. When given normal reading development, the RT effect of length is found to decrease with age and is practically non-existent in adults (Bijeljac-Babic et. Al., 2004). Experiments that use words should consider the impact the lengths of the words may be having on cognitive processes, as these may not always be directly visible in the participants RTs.

Searching for Letters in letter strings.

The previous research on searching for letters in words comes from a variety of areas, in particular the visual search literature, and the optimal viewing position/orthographic uniqueness point research. What is clear from the research is that in terms of target detection the exterior letter positions are responded to differently from the internal positions. Humphreys and Riddoch (2007) report on several experiments where the processing of the outside letters is more efficient than the central letters due to a lack of flanking neighbours. This lateral masking effect has several possibilities for affecting the way that spatial attention is used in the identification of target letters.

As well as the external positions having particular importance there are two related findings that suggest a position effect should be expected in any letter search task: the orthographic uniqueness point (OUP) and the optimal viewing position (OVP). Kwantes and Mewhort (1999) investigated the point in a word where it becomes distinguishable from all other words, the OUP. Participants were presented with words that had either an early (left of middle) or late (right of middle) OUP. The data showed that the letters in words are processed serially from left to right.

The identification of letters in non-words has shown serial processing from left to right (Carr et al., 1976). In the case of words, Humphreys and Riddoch (2007) believe that the word familiarity enhances processing at all positions, and causes the word to be processed as a whole, whereas the non-words are not. So, familiarity of items appearing together makes them a whole. If letters within a word become part of an object it is possible that there should be equal efficiency of processing across all letter positions.

The word superiority effect

A classic paradigm often used as the basis for research, using alphabetic stimuli, is the Reicher-Wheeler task. In experiments using the Reicher-Wheeler task letters in words are reported more accurately than the same letters presented in isolation (Reicher, 1969; Jordan & Bevan, 1996; Wheeler, 1970). The benefit of presenting letters within words has been termed the word superiority effect (WSE).

Two early studies that contradicted the WSE are those of Mezrich (1973) and Johnston and McClelland (1973). Mezrich (1973) obtained a reversal of the word superiority effect by requiring participants to articulate the word and letter stimuli before responding. Johnston and McClelland (1973) found that if you remove the mask from the Reicher paradigm the WSE disappears.

The work of Krueger (Krueger & Shapiro, 1979; Krueger & Stadtlander, 1991) can be summarized as, letters are not seen any more clearly or rapidly in words, but are simply filled in or inferred more accurately from the familiar context. However, the words non-visual (phonological and/or semantic) code may have detracted attention from the visually perceived information. In agreement with Hawkins et al. (1976) Krueger and Stadtlander (1991) believe that the word information is almost entirely non-visual, is processed as a whole, and that letters may be detected more efficiently in words, purely due to a top down flow of information to the letter level.

The prime task effect

In lexical decision experiments, where participants have to state whether a stimulus is a word or a non-word, responses are typically fairly fast (McNamara, 2005). A common effect investigated using lexical decision tasks is semantic priming, where an initial word (the prime) is followed by a second word (the probe) that is either semantically related (e.g. nurse followed by doctor) or unrelated (e.g. nurse followed by house). When the probe word is semantically related to the prime word RTs are faster and fewer errors are made. However, when letter search is conducted on the first word there is no difference in the RTs elicited between related and unrelated subsequent words (Smith, 1979; Henik, Friedrich, & Kellogg, 1983; Stolz & Besner, 1999; Brown, Roberts, & Besner, 2001; Smith & Besner, 2001; Hohlfeld & Sommer, 2005; Otsuka & Kawaguchi, 2007). The lack of differences between related and unrelated probe words following letter search on the prime word is termed the prime-task (PT) effect. This PT-effect is frequently presented as evidence that when a participant's attention is directed to a low level of information, when viewing written words (i.e. the individual letters in a word) the processing of information contained within the word does not activate the semantic level.

In terms of visual word recognition and letter search tasks the model often cited in the semantic priming literature used is that presented by Stolz and Besner (1999). The model explains how recognition, and higher level processing, occurs after presentation with a visual written word. A simplified form would be a three level model with: a Letter level, a Word/Morphologic level, and a Semantic level. Information flows upwards from the letter level to the word/morphologic level and then onto the semantic level. A backward flow of information flows from the semantic level to the word/morphologic level and then the letter level. The flow of information from different levels can be interrupted depending on the current task. Stolz and Besner (1999) present evidence from several studies that support an interruption of word recognition (following a LS task) before access to the semantic level has occurred (Henik, Friedrich, & Kellogg, 1983; Smith, Theodore, & Franklin, 1983; Besner, Smith, & MacLeod, 1990; Stolz & Besner, 1996; Maxfield, 1997). Stolz and Besner (1998) demonstrated that access to the morphological level was still intact following LS prime tasks, through morphological priming of the probe word. The differences between morphological and semantic priming led Stolz and Besner (1999) to infer that LS tasks interrupt the progression of processing between the morphological level and the semantic level.

Stolz and Besner (1999) made the claim that "automatic semantic activation is a myth" based on their LS prime task experiments. While, there is some evidence that the interruption of activation progressing to the semantic level is not an all or nothing process, there are several experiments that have shown automatic semantic access following LS in prime words (for example, Marí-Beffa, et al., 2005). Therefore, it seems that under certain conditions LS tasks do not prevent semantic activation. Which conditions these may be is very unclear, as little research has been undertaken to elucidate the letter search task itself.

Prime task effect: Evidence from neuroscience

The use of event related potentials (ERPs) to explore brain function and cognitive processes is growing in popularity. A well established electroencephalogram component is the N400, a negative peak occurring approximately 400ms after stimulus presentation. It has been used to index the effect of working memory on semantics (D'Arcy, Service, Connelly, & Hawco, 2005), word length (Hauk & Pulvermuller, 2004), and bilingualism (Phillips, Segalowitz, O'Brien, & Yamasaki, 2003).

The N400 was first observed by Kutas and Hillyard (1980) as a component sensitive to the semantic congruity of sentences. The N400 has been shown to be sensitive to semantic processing during listening and reading, and is typified by increased amplitude when the semantic context is violated (Hill, Strube, Roesch-Ely, & Weisbrod, 2002). There is still much debate over what processes the N400 represents (for a review see Hill, Strube, Roesch-Ely & Weisbrod, 2002), but for several research groups the N400 is believed to be modulated by automatic spreading activation, expectancy, and semantic matching (Chwilla et al., 1998; Hill, Strube, Roesch-Ely, & Weisbrod, 2002; Kutas & Hillyard, 1989; Kutas et al., 1984). The nature of the N400 is beyond the scope of this thesis; however, it is likely that the evidence from the neuroscience research may not exclusively supportive automatic-spreading-activation models of semantic priming. The key evidence, that applies for all models, is that there is increasing evidence of the N400, which responds to semantic context, showing a difference between related and unrelated trials, following letter search on a prime.

Mari-Beffa and colleagues (2005) compared a categorization task and a two choice letter-identification task, instead of the traditional PT-effect experiment. The RTs to probes showed the normal lack of semantic relatedness effects. However, category effects were found in the prime RT data, which would suggest that category information had been processed during letter search. There were also ERP differences between related and unrelated probes around the 400ms time scale. These differences were not the typical N400. Dombrowski and Heil (2006) suggest that the lack of normal N400 effects is due to the use of the CZ electrode as a reference. As the CZ is in the middle of the centroparietal region, where effects for N400 are usually found, any N400 effects would have been attenuated.

Heil, Rolke, and Pecchinenda (2004) used simultaneous letter search and included a related, unrelated and a repetition condition. They did away with the lexical decision comparison condition, as they were comparing related, unrelated and repetition trials. The RT data showed priming for repetition trials as compared to both semantically related and unrelated trials. There was no RT difference between the related and unrelated trials (671 and 672ms respectively). The ERP data showed differences that were reliable over the parietal positions, where the N400 is maximal. The repetition trials elicited the smallest N400 with related trials eliciting the next smallest.

The data were taken as evidence that semantic activation does occur during letter search tasks. The authors reject the case against automatic SA. What is not clear is whether semantic access was occurring for every trial, or whether there were certain trials that were contributing the differences that appeared in the averaged data. It may be that there were large effects for some of the trials that were then averaged into the trials where automatic semantic access did not occur. Heil, Rolke, and Pecchinenda (2004) admit that this is a possibility, and that the data may result from attention moving away from the letter level on a certain number of trials.

Broadly speaking automatic semantic access would be supportive of late theories of selection, where items are processed for meaning before selection. However as LS tasks introduce a high perceptual competition load, which should interfere with successful processing of word level information, we should see early selection filtering out the word information.

Heil, Rolke and Pecchinenda (2004) conclude that it is important not to question why SA is blocked (Chiappe et al., 1996; Stolz & Besner, 1996), because SA is in fact present. The critical question is why RT-effects are blocked in the standard letter-search paradigm.

Dombrowski and Heil (2006) used an exact replication of the standard LS task, which Heil et al (2004) did not do as they had included a repetition condition. This experiment found N400 effects for the related vs. unrelated trials. The authors state that they are unable to make any claims as to what sort of processing results in the N400, but that it does seem to reflect a difference in semantic processing.

The papers of Marí-Beffa et al., (2005,), Heil et al., (2004) and Dombrowski and Heil (2006) all provide evidence that there are differences in the ERP components for the N400 between related and unrelated probes, following letter search on prime words. The N400 PT-effect differences typically take the form of reduced peak amplitude for the related condition, which occurs even when there are no differences detected in the RT data. The replicable nature of the N400, following letter search on prime words, indicates that just because you can not see it does not mean it is not there (Pashler, 1999). Heil, Rolke and Pecchinenda (2004) suggest that there seems to have been a lack of care when interpreting the RT data in the previous research, leading to premature conclusions being made concerning the blocking of semantic access during letter search.

Summary of visually processing words

The visual processing of words utilises spatial attention and may occur in a similar manner to that of objects. There is no conclusive evidence that words are objects, but there are indications that common words will have been viewed so many times that the grouping of the letters becomes object-like (Logan, 1996). Words are processed at several different levels, parts of letters, letters, words, and meaning. When searching for letters in words it is possible that there will be a WSE with faster RTs and better accuracy (Reicher, 1969), but that the search may also elicit slower RTs and worse accuracy effect (Krueger & Shapiro, 1979).

The search for letters should also show greater efficiency for exterior letter positions due to a lack of lateral masking, and similarly, there should also be an effect of position where letters at the OVP will be detected more efficiently (Parris et al., 2007). Processing words visually has effects on the presentation of subsequently presented semantically related items. This effect is most often a facilitation, which has helped formulate models of semantic memory, where related items are interconnected and activation can spread from one item to related items. Connectionist models of semantic priming do not rely on spreading activation between representation nodes, instead related items are represented by similar activations across a network. Searching for a letter within a word results in attenuation of the semantic priming effect. However, evidence from neuroscience indicates that semantic processing occurs following letter search, but that these differences are not apparent in RTs. Finally, previous research indicates that there should be an interaction between spatial attention and written word frequency which may be detectable using a LS task (Auclair & Sieroff, 2002).

Initial research: Experiment 1

The first experiment in this thesis replicates the standard practices in stimuli control (including word choices), display durations, and data analyses typically found in the published literature on the PT-effect, semantic priming, and lexical decision tasks. Of particular interest in this experiment was the LS task. Previous research has demonstrated that there is an effect of task proportion on participant responses. As the effects of searching for a letter in prime task experiments has been of little concern (the effect on probe RTs is almost exclusively examined), typically prime task LS experiments often use a proportion of 25% LS trials and 75% lexical decision trials. However, recent research (Cullen, unpublished) has indicated that the LS task is heavily affected by such a weighting, and that a 50/50 task proportion is a better weighting in order to best measure the effects from both tasks. In order to make this possible and still have an experiment that could comfortably be completed by participants (while also using the least number of repetitions of stimuli words), an experiment with LS as the only prime task was used. In order to ensure that the stimulus list produced normal priming a pilot study was conducted using lexical decisions for the prime and probe trials. The results of the pilot study are reported in the stimuli section.

This first experiment was conducted as a baseline for subsequent manipulations of the letter search task. It is expected that the results of this experiment will replicate the results of previous prime task effect experiments where RTs to probe words show no difference between related and unrelated trials.

Method

Participants: 22 participants from Bangor University, School of Psychology voluntary participation panel, undertook this experiment in return for course credit and printer credit (worth £5 for each hour). All the participants met selection criteria of normal, or corrected to normal vision, non-dyslexic, and English first language: data collected from students not meeting these requirements were excluded from the analysis.

Apparatus and Stimuli: An IBM compatible computer and a 17-inch flat screen monitor were used to present the stimuli in this experiment. The 48 prime words for Experiment One were taken from the Kucera and Francis's (1967) word database. The words were controlled for concreteness and written frequency; and contained between three and eight characters (see Appendix A). The word pairs were created by selecting 48 semantically related probe words (one for each prime) from the Edinburgh word association thesaurus database. The probe words were matched for written frequency and word length, using data from the MRC psycholinguistic database. The unrelated word pairs were created by swapping the semantically related probes amongst the prime words. As the experiment would be using only an LS task for the prime trials the word pairs were presented to a pilot-experiment group of six participants not involved with the main study. This pilot experiment used a lexical decision task for both the primes and probes with participant RTs recorded and analysed. The RTs for related word pairs were on average 25ms faster (514msec) than RTs to unrelated word pairs (539msec) $t(5)=8.36$, $p=.001$.

Each prime word appeared in the two search-types of target display (positive and negative) giving 96 different prime trials. The primes could then be associated with a related or unrelated probe display resulting in a total of 192 experimental trials.

As the lexical decision task on the probe required trials with non-words, a further 192 trials with non-words in the probes were created using filler words with similar written frequencies and concreteness values.

Then the stimuli lists were compared across conditions to ensure that the standard scores for each stimuli list were equivalent, using a one-way analysis of variance (ANOVA). There were no significant differences found for written frequency of use or concreteness.

Non-word stimuli were created by rearranging letters in the probe words to form non-words. The target words were always presented in upper case and the letter cues were always presented in lower case. The visual angles subtended by the lower case letters were 0.41° in height and 0.31° in width with spaces of 0.21° between each letter. The upper case letters subtended a visual angle of 0.62° in height and 0.31° in width. The stimuli were presented in silver on a black background and the participants completed the experiments in a darkened room.

Design: The experiment was a 2X2 design with factors of Search Type (Positive, Negative) and Relatedness (Related, Unrelated). There were two experimental blocks each containing the same word pairs. Each block contained 192 trials made up of 96 word/word pairs and 96 word/non-word pairs. The stimuli pairs for each block were counterbalanced by hand prior to the experiment so that each participant had a different combination of stimuli pairs in each block. An algorithm in E-prime was used to randomly assign the order of the stimuli in the experimental blocks.

Procedure: Participant instructions were displayed at the beginning of the experiment. Following the instructions, participants completed a block of 24 practice trials, which was not subsequently analysed. The stimuli used in the practice trials were completely unrelated to the experimental stimuli. The prime task was to identify whether the target letter (presented above each letter position) was present in the prime word (positive search) or absent form the prime word (negative search). Responses to the primes were made using the left hand by pressing the 'C' key if the search was positive and the 'D' key if the search was negative. The probe task was to make a lexical decision: half of the probe displays contained non-words and half contained English words. The responses to the probe trials were made using the right hand to press the 'M' key if the probe was a word and the 'K' key if the probe was a non-word. Each trial began with a fixation cross at the centre of the monitor followed by an inter stimulus interval (ISI) for 250ms. The probe and target letter appeared for up to 2000ms and was replaced by another ISI lasting 500ms, then the probe stimulus was displayed for up to 2000ms before being followed with the inter trial interval (ITI) lasting 500ms. Incorrect responses were followed by a 250ms buzzer that sounded during the ISI. Please see Figure 1 for a graphic depiction of a complete trial.

Data Analysis and Error Rates: The RT data was trimmed to include only those trials slower than 200 ms and those faster than 1500 ms. The data from those participants achieving an average of less than 70% correct responses (after trimming) were excluded from further analyses resulting in the loss of data from two participants.

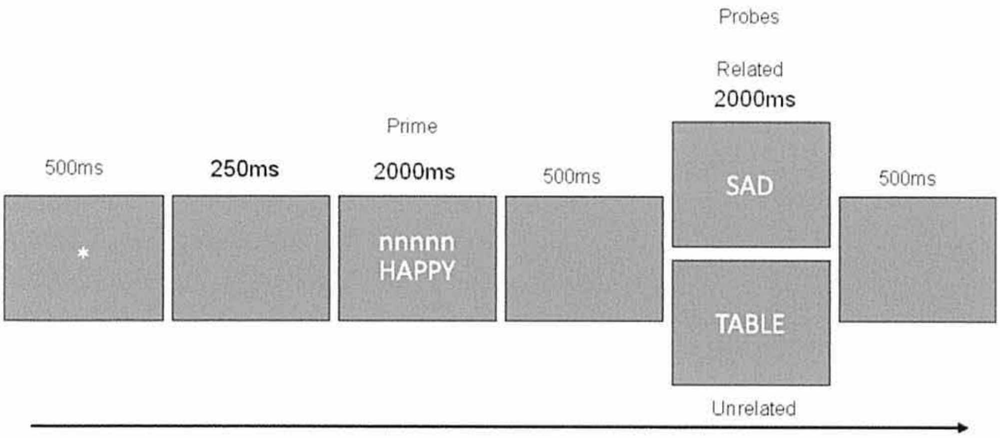

Figure 1: A depiction of the sequence of events in each trial. The auditory feedback lasted for only 250ms of the intervals following both prime and probe displays.

Results & Discussion

Analyses of Primes: The data from the primes were analysed in a repeated measures ANOVA with a condition of Search-type (Positive, Negative). Mean RTs for Positive searches (837 ms, SD=92.88) were significantly faster than mean RTs for Negative searches (893 ms, SD= 92.97) $F(1,21)=28.22$, $p=.00001$, $\eta_p^2=.57$ (see Figure 2). The analysis of the errors to prime displays was not significant $F=1.37$, $p=.26$.

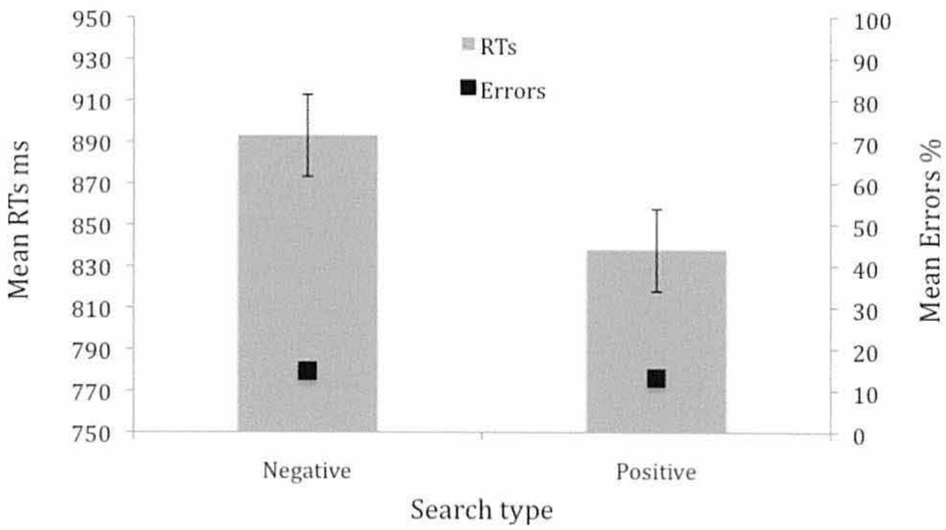

Figure 2: Mean RTs in ms (columns) and mean error rates in % (black squares) to prime displays in Experiment 1.The bars represent the standard error.

Analysis of Probes: The RTs to probe displays were analysed through a repeated measures ANOVA with a condition of Relatedness (Related, Unrelated), which revealed that there were no significant differences between Related (727 ms, SD=66.91) and Unrelated (724 ms, SD=77.76) probe displays F=.14, p=.71 (see Figure 3). The analysis of the error rates to probe displays was also non-significant F=.047, p=.83.

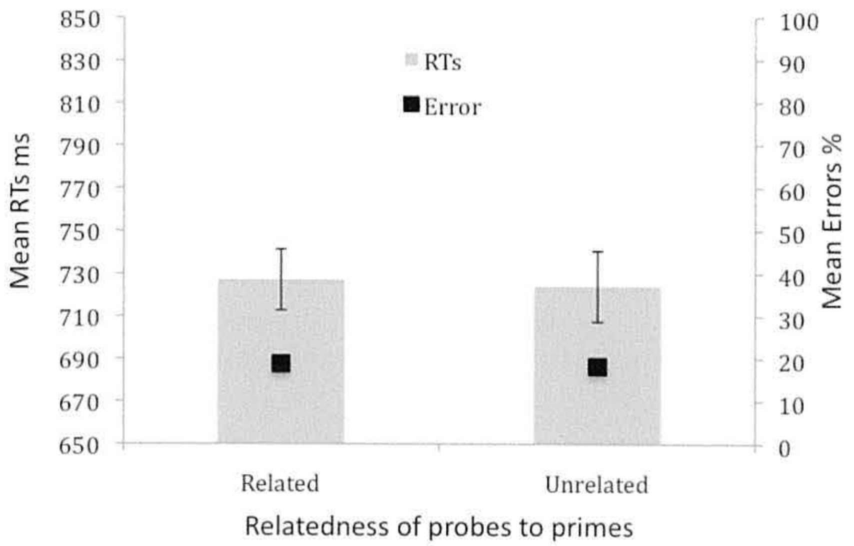

Figure 3: Mean RTs in ms (columns) and mean error rates in % (black squares) to probe displays in Experiment 1.The bars represent the standard error.

In light of the pilot study demonstrating normal semantic priming when the task was a lexical decision, the lack of a difference between related and unrelated word pairs to probe displays is a replication of the standard PT-effect. This type of result is used as evidence of the lack of semantic activation following LS tasks (Smith, 1979), and that semantic activation is affected while morphological activation is not (Stolz & Besner, 1998). Leading some researchers to the conclusion that directing search to the letter level somehow interferes with the processing of semantic information, as measured by semantic priming.

Traditionally a 'levels of processing' (Craik & Lockhart, 1972) explanation has been offered, where the direction of a task goal to a level (i.e. the letter level) that is not congruent with coincidental information (the word level) prevents the processing of the additional information (semantic). A shallow level of processing would be a feature such as colour, while a deep level of processing would be for meaning. The deeper the level of processing the better an item is encoded and subsequently remembered. Chiappe, Smith, and Besner (1996) demonstrated that it is not directing attention to a low level that results in the prime-task effect, as when the participants' task was to identify the colour of the words letters, a low level task, normal semantic priming was elicited. This indicates that it is something about the direction of attention to the letter level in particular, which is congruent with the evidence from pure alexics and letter-by-letter reading.

One could expect there to be an effect of search as there is a theoretical difference between positive and negative trials. Positive trials end with the identification of a letter, in some cases this identification will take place immediately as the participant's eye gaze will happen to fall on that letter. In some cases the letter target may be an exterior letter and not have any flankers making identification easier. In other cases still, the target letter may be in a position that is among the last to be searched. Each of these possibilities may affect the visual system in different ways, for example, if visual attention is like a spot light there may be a difference between finding a letter in the first position gaze falls on, and the last position to be searched. Following this logic, negative displays must be fully searched for a target, with the possibility that participants re-search some positions in order to make sure that their response is correct. On this basis, it can be suggested that there should be a difference between positive and negative displays but that this difference may be hidden by position effects. This possibility is returned to at the end of this thesis.

The analysis of the prime data revealed significant differences between the Positive and Negative trials. There is very little RT evidence, from previous prime task effect research, to compare with the growing evidence of differences in the neuroscience research. Couple this with the established practice of treating positive and negative trials as different conditions in the visual search literature, and an investigation of the differences positive and negative search have on subsequent priming is sensible. In order to discount an effect of Search-type an exploratory post-hoc analysis of Search-type on probe displays was conducted. A repeated measures ANOVA on the probe RTs, for conditions of Search-type (Positive, Negative) and Relatedness (Related, Unrelated) was conducted. This analysis did not reveal any significant differences for the main effects ($F<.15$, $p>.71$) or the interaction ($F=.73$, $p=.4$). The error analysis was also non-significant ($F(1,21)=3.30$, $p=.08$, $\eta_p^2=.14$) (see Figure 4).

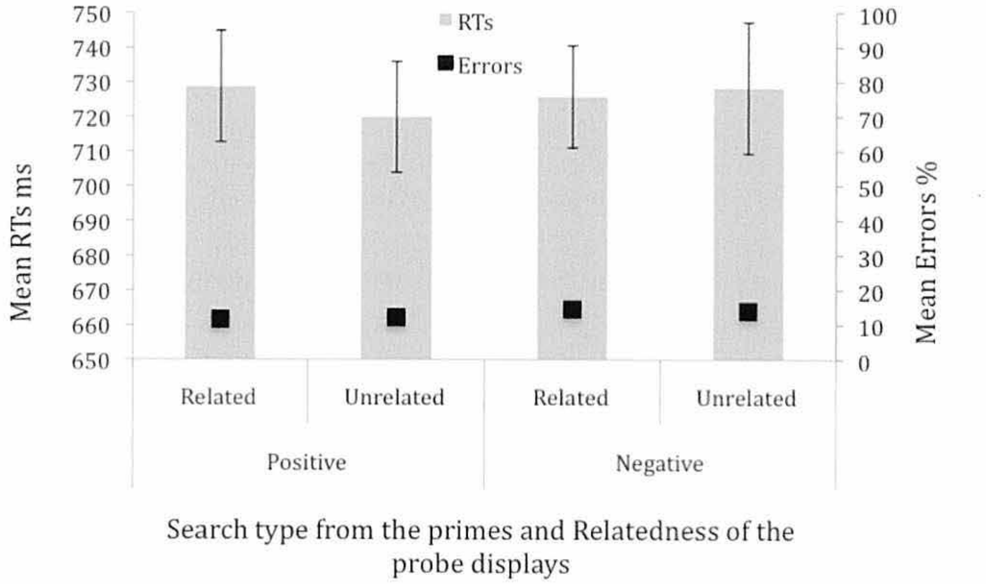

Figure 4: Mean RTs in ms (columns) and mean error rates in % (black squares) for Search-type vs. Relatedness in probe displays in Experiment 1.The bars represent the standard error.

The effects that are appearing with increasing frequency in the neuroscience data (Marí-Beffa et al, 2005; Heil et al., 2004; Dombrowski & Heil 2006) should have some visible effect on the RT data, but they were not found in Experiment 1. The models of visual word recognition, and the explanation of the PT-effect put forward by Besner and Colleagues, may be the best explanation of the data obtained in this first experiment. However, the difference between positive and negative displays in the prime RTs indicates that there may still be a difference that has an effect on the probes, but is being hidden by other as yet uncontrolled parameters. In order that some control be placed upon prime task effect research a thorough investigation of tasks that involve searching for a letter within a word must be conducted.

The literature highlights several research questions that are poorly answered in terms of semantic priming LS tasks these include: the length of the prime word, search-type (positive or negative), written word frequency, focus of attention, task load, and style of presentation. In the subsequent sections of this thesis evidence from several experiments is presented to begin the process of fully understanding the behavioural effects of searching for a letter in a word.

The following experiments were run for three reasons. First, to better understand what happens during LS tasks, and what effects the parameters of length, lexicality, written word frequency, and target position have on participant RTs. Second, to be able to predict why there is no RT effect to probe displays in semantic priming experiments, where the task for prime displays is to search for a letter. Third, to identify those parameters that are essential to control, in order to make predictions about searching for a letter target in a word, the subsequent semantic access, and activation of related concepts.

Section 1: the letter search task

Chapter 2: Introduction and General Method for Experiments 2-6

The research examining reading often considers the process from a basic level of single word reading. The lack of length effects for well practiced readers has lead to the suggestion that words are encoded without the need for cognitive resources, and that words are processed for meaning automatically. Paradigms such as length effects in reading, and the Stroop effect (MacLeod, 1991), led to the belief that reading was an automatic process, which could be easily used in order to understand how a process could become automatic, and what the limitations of that process would be.

Since the paper of Smith (1979), letter search tasks have been used extensively in support of the PT-effect, and the results taken as proof that the processing of written words to the semantic level is a process that does not become automatic after extensive practice. However, the recent literature has neglected to fully explore the LS task itself. The original intention of this work had been to investigate the parameters of the PT-effect. However, it became clear that not enough was understood about the LS task, on which so many claims were being made. This first experimental series is exploratory, as understanding is sought of what occurs during the LS task, and the responses elicited from participants. While there has been extensive visual search research conducted, the application of that research to LS tasks within words, has received little attention. Experiments 2-6 examine the different styles of LS: simultaneous and pre-stimulus, the search type (Positive or Negative), the length of words, the written frequency, the position of the target in the word, and the difference between real words and pseudo-words.

General Method for Experiments 2-6

Participants: All the participants reported in the experiments in this section were recruited from Bangor University, School of Psychology participation panel. The participants were all undergraduate students and received course credit and printer credit (worth £5 for each hour) in compensation. All the participants met selection criteria of normal or corrected to normal vision, non-dyslexic, and English first language. Data collected from students not meeting these requirements were excluded from the analysis.

Apparatus and Stimuli: An IBM compatible computer was used to present the data on a 17inch flat panel monitor (refresh rate 12ms) 60cm from the participants viewing position. The same computer was used to record participant responses on a QWERTY keyboard. *E*-prime 1.1(*Psy*net) was used to create, present, and record the experiment data.

The words used in Experiments 2-6 were selected from the Kucera and Francis's (1967) word database and were controlled for concreteness, frequency, and length. Each stimuli list for each condition within individual experiments was statistically compared to ensure equivalence and control possible confounds (see Appendices B-F). The specific stimuli differences are explained in the method section for each experiment. The target words were always presented in upper case and the letter cues were always presented in lower case. The visual angles and distances were the same for each experiment. The lower case letters subtended a visual angle of 0.30° in height and 0.20° in width, the visual angle between letters was 0.2°. The upper case letters subtended a visual angle twice that of the lower case letters in height and 0.3° in width. The stimuli were presented in light grey on a black background and the participants completed the experiments in a darkened room.

Data Analysis and Error Rates: The RT data from each experiment was trimmed to include only those trials slower than 250ms and faster than 1500ms. The data from those participants achieving an average of less than 70% correct responses, after trimming, were excluded from further analyses.

Chapter 3: Experiments 2-6

Experiment 2

In this experiment the effect of word length and the presence of the target letter during LS, are examined. The priming literature (although not the visual search literature) often mixes words of different lengths, as the numbers of possible word pairs can be constrained through the selection criteria it is necessary to apply to stimuli (e.g. written frequency and concreteness). While there is no difference between reading words of different lengths, there should be a difference in the durations of responses when conducting LS. The effect of length on RTs will be examined so that the serial or more parallel nature of such a visual search can be determined.

In the visual search literature it is normal to analyse the positive and negative trials separately (Logan, 1978; Treisman & Gelade, 1980; Treisman & Souther, 1985; Chun & Wolfe, 1996; Wolfe, 2001; Beck, Peterson, & Vomela, 2006). Only one paper reviewed seems to not explicitly state that they had been separated. However, from what is written, it can be inferred that they did separate the positive and negative trials (Castel, Pratt Drummond, 2005). Conversely, in the priming literature it has been traditional to analyse the effects of positive and negative displays, when the data from both are averaged together (Henik, Freidrich, & Kellogg, 1983; Kaye & Brown, 1985; Freidrich, Henik, & Tzelgov, 1991; Henik, Freidrich, Tzelgov, & Tramer, 1994; Chiappe, Smith, & Besner, 1996; Stolz, & Besner, 1996; Stolz & Besner, 1998; Stolz & Besner, 1999; Marí-Beffa, Fuentes, Catena, Houghton, 2000; Marí-Beffa, Houghton, Estevez, Fuentes, 2000; Smith, Bentin, & Spalek, 2001; Heil, Rolke, & Pecchinenda, 2004; Dombrowski & Heil, 2007). Most of the papers averaging positive and negative trials have one thing in common: a lack of semantic priming following LS tasks. There are a few that do find evidence that is non-significant

(Smith, 1979; Marí-Beffa, Fuentes et al., 2000; Tse, & Neely, 2007) or under other LS related conditions, such as, segregated displays (Marí-Beffa, Houghton et al. 2000); delayed probe display (Stolz & Besner, 1996); ERP differences (Dombrowski, & Heil, 2007; Heil, Rolke, & Pecchinenda, 2004); a high proportion of related word pairs (Henik et al., 1994); and in children (Kaye, & Brown, 1985). The few times when researchers have examined the differences between positive and negative searches there has always been some effect of presence elicited. Valdes, Catena, and Marí-Beffa (2005) found differences in priming related and unrelated probe words when they analysed the presence of the target as did Ziegler, Van Orden, and Jacobs (1997). Brown, Roberts, and Besner (2001) in one of the few experiments that they report presence differences find small effects when the LS task was conducted with digits as distractors. Finally, Hutchinson and Bosco (2007) report large significant effects for positive and negative search when the probe word is semantically congruent with the presence of the target letter (e.g. the word 'absent' when the target search was negative).

Throughout the literature LS studies can be classified into two main styles. First, there are those experiments with a positive/negative condition (termed here 'letter search') and, second, there are those that have only positive trials (termed here 'letter identification'. Fundamentally there is a difference between these two styles of experiment; while attention is still being directed to the letter level, it should not be assumed that they are exactly the same in terms of cognitive and response demands, as the lack of a negative response condition may change the response set and/or the attentional set. Whether there is any importance in identifying a difference between positive and negative trials is an open question. At this point no one has considered it (Maxfield, 1997; Neely, 1977; Neely & Kahan, 2001; Stolz, Besner, & Carr, 2005). In terms of the word recognition models mention previously it is hard to see why a negative trial would have an effect on any subsequent priming. It would be wise, however, to examine the processes involved with not finding a target, compared with when a target is found. Future studies may wish to alter the proportion of Positive and Negative trials to compare differences between the two trial types.

In the next five experiments instead of examining the effect of LS on subsequent priming, an effort is made to understand more about the LS task itself. In Experiment 2 the parameters of length and target presence are manipulated. Based on the previous research, it is predicted that there will be an effect of length, and that it will be a serial increase of reaction times, in the magnitude of an additional 20-60ms per letter. The longer RTs should produce a linear RT slope with approximately equal increases for each letter added to the target words length. The negative searches should also average RTs that are consistently slower for every word length, due to participants searching every possible position before responding that the search is negative. While this knowledge can be indirectly inferred from previous research, in an attempt to understand LS fully it is considered a precautionary step to test these parameters directly.

Method

Participants: 32 undergraduate students (21 females and 11 males) with an age range of 18-32 (*M*= 20.7) took part in this experiment.

Stimuli: 200 English nouns were selected from the Medical Research Council database comprised of an equal number of five different word lengths (5, 6, 7, 8, and 9 letters). Analysis of the written frequencies and concreteness did not reveal any significant differences between each word length (see Appendix B for word list).

Design: A repeated measures design was used with conditions of length-in-letters (5, 6, 7, 8, and 9 letters) and target Presence (Positive, Negative). The conditions were evenly mixed across two experimental blocks. The order of trials was randomised by the presentation software.

Procedure: Experiment 2 began with a block of 20 practice trials, which were not included in the analyses. Each trial began with a letter presented at fixation for 500ms. The target letter display was followed by an inter stimulus interval of 250ms which was followed by the Probe word display. The probe word displays remained on the screen for a maximum duration of 2000ms or until the participant's response. The participants had to make a positive or negative response to the presence of the target letter in the probe word. If the search for the target letter was positive the 'C' key was pressed and if the search for the target letter was negative the 'M' key was pressed. For half of the participants the response keys were swapped and 'M' indicated a positive search and 'C' a negative search. If an incorrect response was given a feedback buzzer lasting 250ms was played in the interval immediately following the Probe word display. At the end of each experimental trial a blank screen lasting 500ms was presented. Figure 5 shows a graphic depiction of a complete trial. When the search was positive the target letter could appear in any position in the probe words, for example if the search were to be positive and the word was HOUSE the target letter could have been *h*, *o*, *u*, *s*, or *e*.

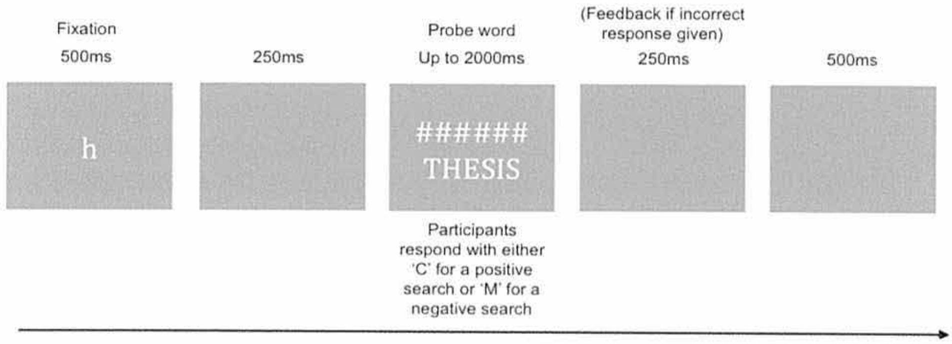

Figure 5: a graphic depiction of a complete trial in Experiment 2

Results

A repeated measures ANOVA for Presence (Positive, Negative) and Length (5, 6, 7, 8, 9) was conducted. As can be seen in Figure 6 there was a linear effect of word length. Each additional letter added on average 30ms to search times $\underline{F}(4, 124) = 252.52$; $\underline{p} < .0001$; $\eta_p^2 = .89$. There was also a main effect of Presence with Negative searches eliciting RTs that were on average 48ms slower than Positive displays $\underline{F}(1, 31) = 86.45$, $\underline{p} < .0001$; $\eta_p^2 = .74$. The interaction between Presence and length was not significant ($\underline{F} = 2.01$, $\underline{p} = .1$). This strongly suggests that during letter search the search occurs serially and not in parallel as some researchers suggest (Wickelgren, 1977). If the words are being searched for the target letter in a serial fashion one might assume that, as in the interruptions of the WSE by directing attention to the letter level (Johnston & McClelland, 1973), doing so will interfere with the processing of word level information. The five letter words were, on average, the fastest (652ms), then the six letter words (688ms), seven letter words (709ms), eight letter words (735ms), and finally the nine letter words (772ms). See Appendix C for all Means and Standard deviations in Experiment 2. Paired t-tests for each word length comparing positive and negative trials were conducted, revealing significant differences for each comparison (5 letters, $t(31)=10.35, p=.0001$; 6 letters, $t(31)=5.82, p=.0001$; 7 letters, $t(31)=6.71, p=.0001$; 8 letters, $t(31)=8.02, p=.0001$; 9 letters, $t(31)=7.02, p=.0001$).

On average more mistakes were made in the Positive condition $F(1, 31) = 8.66, p < .006, \eta_p^2=.22$; there was a significant main effect of Length $F(4, 124) = 11.29; p < .0001; \eta_p^2=.27$; and a significant interaction $F(4, 124) = 4.04; p < .004; \eta_p^2=.11$.

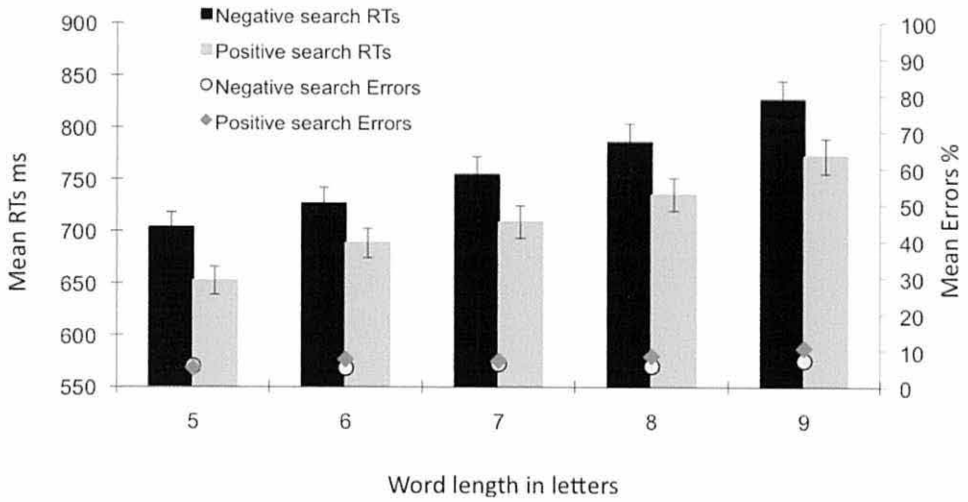

Figure 6: Mean RTs in ms (columns) and mean error rates in % (circles and diamonds) for Search-type and Word length in prime displays in Experiment 2.The bars represent the standard error.

Discussion

The findings are commensurate with the visual search literature, where search for a target is slowed through the addition of more distractors. In this case the additional distractors are extra letters in the words within which the target letter is contained. Similar to previous studies examining the effect of word length, each additional letter adds approximately 30ms to search times (Atkinson, Holmgren, & Juola, 1969; Treisman & Gormican, 1988). The increase in response durations may be due to either a search for the target that is essential serial in nature, or a search that occurs in parallel, but takes longer because adding more letters increases the difficulty of the task. Experiment 3 examines the effect of position in order to determine if the search is of a serial nature, which would explain the increase in RTs with the addition of letters. If participants are adopting a serial search technique to identify the presence of a target letter, this may be similar to the letter-by-letter reading that extinguished the WSE in Johnston & McClelland's (1973) research. The increase in RTs for longer words is incongruent with the finding that, for adults at least, reading longer words does not elicit slower RTs (Bijeljac-Babic et al., 2004), however, LS is very different from reading for meaning.

The slower RTs for negative searches were reliable for every word length, where negative searches took an average 48ms longer than positive searches. This negative search cost is smaller than that predicted by Sternberg (1969), but is similar to the costs found by Atkinson, Holmgren, and Juola (1969). The smaller negative search costs are likely due to the fact that Stenberg (1969) was working with stimuli spread across a display, and unlike the letters in a word not concentrated in one area. The effect of the negative trials being slower than the positive trials is consistent with visual search theories of target location. The lack of an interaction between length and search-type means that in theory the RTs can be collapsed together. At this point it should not be assumed that just because there is no interaction between search-type and word length, that positive and negative search probe RTs in prime-task experiments can be treated as the same. There may be other factors that interact with search-type.

The error rates indicate that participants on average made more mistakes in the positive trials than in the negative trials for every word length (6, 7, 8, and 9 letters) except the shortest (5 letters). As the proportions of positive and negative trials were equal, it was expected that there would be no difference between the search-type conditions. However, from the results reported here, it is more likely that a participant will declare a target absent when it was present, than declare a target present when it was absent. The reason for this bias is not clear and analyses of the subsequent experiments may reveal if this is a replicable finding.

Experiment 3

The third consideration, after the length and presence effects examined in experiment 2, is the position of the target letter in the probe word. The OVP (O'Regan, Levy-Schoen, Pynte, & Brugaillere, 1984; O'Regan & Levy-Schoen, 1987) literature shows us that there should be effects of position. In a related set of experiments, using the Stroop paradigm, Parris, Sharma and Weekes (2007) demonstrated that when a single coloured letter was presented at the OVP, the effects that are usually extinguished are replaced with a larger than normal Stroop effect. In this experiment the effects of the position of the target letter is examined for the beginning, middle and end of words.

As a counterpoint to the OVP, which falls between the start and the middle of words, the position to the right of the middle (ROM) is useful as comparison as it shares the same number of flankers. It is possible that letter targets in the ROM position will suffer from the high number of flanking letters, and a lack of initial foveal processing. This should be typified by increased errors and slower RTs to targets appearing at the ROM position.

If there is an effect of position, it may help identify the manner in which participants are searching for the target letter within the word. If the search is of a serial nature, then responses would be expected to be faster to positions at the start of the word, and slower as target positions move rightwards.

In addition to examining letter position, Experiment 3 also examines the effects of search-type and length. If there is an interaction between position and length in this experiment, it would indicate that any position effect is not reliable, as differences between word lengths for position would indicate that participants adopt different search strategies for different lengths. It is expected that similar results to Experiment 2 will be elicited for both the search-type and word length conditions. In terms of search-type and position the results may shed light on the differences between the positive and negative searches.

Method

Participants: 32 participants (20 female and 12 male) with a mean age 20.7 years took part in Experiment 3.

Stimuli: The stimulus list contained 80 words of which 40 contained six letters and 40 contained eight letters. The stimuli were the same words as those used in the six and eight letter lengths of Experiment 2 (see Appendix B).

Design: A repeated measures design with conditions of Length (Six, Eight letters), Position (OVP, Middle, ROM), and Search-type (Positive, Negative). The OVP target position was the 2nd letter in the words for both the 6-letter and 8-letter words. The middle position could be the 3rd or 4th letters in the 6-letter words; and the 4th or 5th letters in the 8-letter words. The ROM position was the 5th letter in 6-letter words, and the 7th letter in 8-letter words. The different lengths, positions, and search-types were mixed and presented randomly across two blocks. The first and last positions were not used as they have less lateral masking due to the lack of flanking letters.

Procedure: The task in this experiment was the same as that used in Experiment 2. Participants had to search for letter target presented at fixation in a subsequent probe word. If the search was positive participants pressed the 'C' key and if the search was negative they pressed the 'M' key. Please see Figure 7 for a depiction of a complete trial. A buzzer lasting 250ms followed incorrect responses during the interval after the probe word displays. The experimental program randomly selected the order of the stimuli. The experiment began with twenty practice trials, which were discarded before the analyses. The target letter could appear in the 2nd, 3rd, 4th, and 5th positions in a six-letter word so in the word '*avenue*' the target could be the *v*, *e*, *n*, or *u*. In an eight-letter word the target letter could appear in the 2nd, 4th, 5th and 7th positions for example in the word '*educator*' the target letter could be the *d*, *c*, *a*, or *o*.

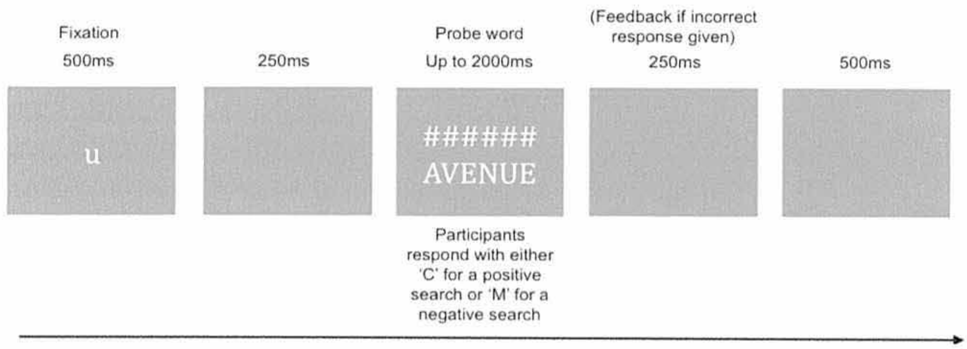

Figure 7: A graphic depiction of a complete trial in Experiment 3

Results

A repeated measures ANOVA was conducted with variables of position (Absent, Left, Middle, Right) and length (six, eight). There was a significant effect of position $F(3,93) = 24.72, p<.0001, \eta_p^2 = .44$, and of length $F(1,31) = 108.36, p<.0001, \eta_p^2 = .78$, and a significant interaction $F(3,93)=5.89, p<.002, \eta_p^2=.16$. Paired t-tests revealed significant differences between six and eight letter words at all positions, including absent trials (all positions significant with a *t*-value of at least $t(31)>2.9$, $p<.007$, using the Holm adjustment). There were also significant differences between the Absent vs. Left and Absent vs. Middle conditions for both six and eight letter words (both tests significant to at least $t(31)>4.27, p<.0002$). The was no difference between the Absent and Right position conditions for both word lengths ($t<.78, p>.44$). See Appendix D for the Means and Standard deviations of Experiment 3.

A repeated measures ANOVA was conducted on the error data which revealed a significant main effect of position (Absent, Left, Middle, Right) $F(3,93)=9.71$, $p<.001, \eta_p^2=.24$.

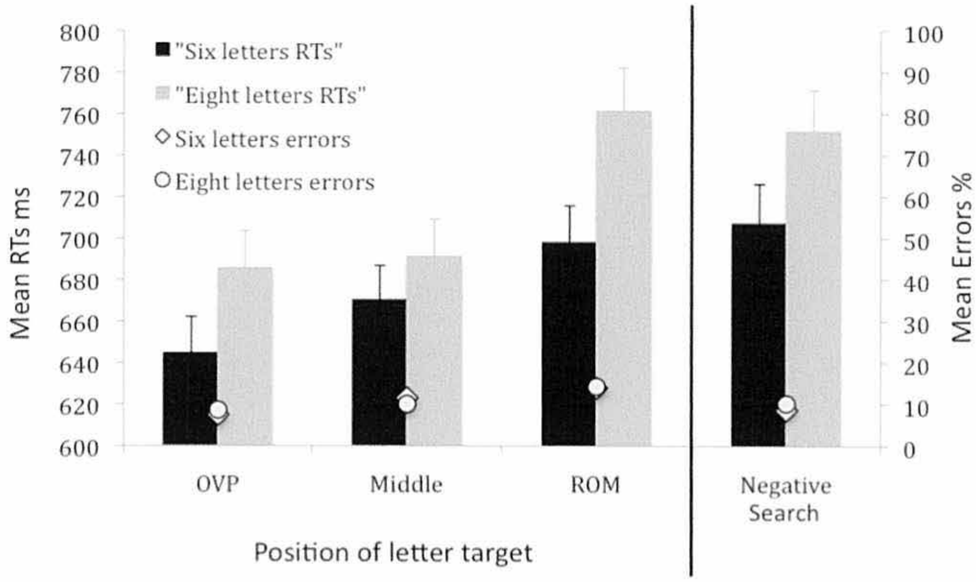

Figure 8: Mean RTs in ms (columns) and mean error rates in % (diamonds and circles) for Search-type, Length, and Position in Experiment 3. The bars represent the standard error.

Discussion

In order to draw conclusions about the effect of search-type, the RTs for all positions with positive displays were collapsed to give a mean RT for positive search. These were then analysed using a repeated measures ANOVA, with the mean RTs for the Negative search displays for both 6 and 8 letter words. A significant difference was found for Search-type $F(1,31)=12.93$, $p=.001$, $\eta_p^2=.29$, and Length $F(1,31)=120.79$, $p=.0001$, $\eta_p^2=.80$. The interaction between search-type and Length was not significant (F=.19, p=.67). The increase in RT with the increase in word length replicates the results of Experiment 2 as does the slower RT to Negative search trials. The fact that the data replicates the previous experiment with a completely new stimuli list emphasises the effects of presence and length for LS tasks in real words.

The pattern of the data is interesting, as there appears to be a linear increase in RTs from the left to the right of the words. Additionally, there was no difference between the RTs to the negative condition and the RTs to target letters located in the right side of the words. This similarity for negative and right side words was found in both word lengths. Negative trials are traditionally thought to be slower than positive trials. However, the slower RTs in the case of searching for letters in words may reflect the point at which the search is exhausted. In this case as the RT data indicates that the search for a letter in words seems to proceed serially from the left to the right the last position to be focused on is the right position. It may be that negative trial durations reflect the termination of search at the final point and not a slower response for a negative search.

Experiment 3 offers further support for the separation of positive and negative trials prior to analysis. What effect the negative trials would have on priming and whether this effect would be similar to right hand target positions remains to be seen, and will be investigated later in this thesis. The increased errors to the right hand of words are an effect that can be explained through lower efficiency of processing, due to initial foveal fixation at the OVP. As participants search the word letter-by-letter, the statistical likelihood of making a mistake increases the further to the right they have to search for the target.

Experiment 4

The vast majority of research has been conducted using a simultaneous style of presentation, where the target letter is presented at the same time as the word in which participants have to search for the target letter. The results from this research are varied and need careful consideration when designing a new experiment. Researchers finding some sort of semantic priming following LS as a prime task have found negative priming (Besner, Smith, & Macleod, 1990; Marí-Beffa, Houghton, Estevez, & Fuentes, 2000), semantic priming using a cross-modal technique (Friedrich, Henik, & Tzelgov, 1991), ERP differences (Heil, Rolke, & Pecchinenda, 2004; Dombrowski, & Heil, 2007), priming for low written frequency probes (Tse & Neely, 2007), priming using a high proportion of related word pairs (Henik, Friedrich, Tzelgov, & Tramer, 1994), and priming from distractor words (Marí-Beffa, Fuentes, Catena, & Houghton, 2000). Interestingly, two papers have used both the simultaneous style of presentation, and a 'delayed' presentation, where the prime word appeared after the target letter (Stolz & Besner, 1996; Valdes, Catena, & Marí-Beffa, et al. 2005). In both papers priming was elicited when using the delayed presentation, although it is worth noting that Stolz and Besner (1996) report positive priming and Valdes et al. (2005) report negative priming.

Approaching the topic from a visual search direction the use of simultaneous presentation increases the perceptual load, as well as increasing the spatial area that participants need to attend to. Yantis and Johnston (1990) suggest several ways to optimise the focussing of attention. While some of these are not possible to implement within a traditional LS task, the suggestion to avoid displays where target items are present in multiple locations can be included in the delayed style of LS (Yantis & Johnston, 1990). By using the delayed LS task participants identify the target prior to the word display. Prior information about the target letter allows the selection mechanisms in the visual system to prepare for the target letter before the prime display, containing the to-be-searched word, appears. It is expected that prior information about the target will facilitate faster RTs and indicate that delayed-style, or *pre-stimulus,* LS tasks are easier to complete. As lexical decision tasks are generally considered to be an easy task that can be completed quickly it is desirable to identify LS tasks which have a similar level of difficulty for comparison. The difficulty of the LS task may be directly affecting the subsequent priming and cause the prime-task effect instead of the direction of attention to the letter level.

The position effects examined in Experiment 3 are further investigated for the effects of flanking letters and the OVP. The first and last positions, which do not suffer from lateral masking, will be used, as will the OVP and ROM. The data is expected to show slower RTs (and more errors) to both the OVP and ROM position compared to the exterior positions. Additionally, it is predicted that the OVP will elicit faster RTs and fewer errors than the ROM due to the benefit of foveal processing and being the natural location for eye gaze to fall on. The OVP literature, and the evidence from the single letter Stroop tests (Parris et al, 2007), indicate that as the eye gaze falls on the OVP the subsequent processing should be more efficient and faster.

Method

Participants: 33 participants (23 female and 16 male), with an average age of 22.4 years, were selected to take part in this experiment.

Stimuli: A similar list to the 40 seven letter English words used in Experiment 2 was created for use with both styles of presentation. Those words with duplicated letters appearing in search positions were replaced with words matched on concreteness and frequency from the Medical Research Council database (see Appendix E).

Design: A repeated measures design was used with conditions of Presentation-type (Pre-stimulus, Simultaneous) and Position (First, OVP, ROM, Last). There was also a secondary condition of Search type (Positive, Negative). The Presentation-types were presented in separate blocks, while the positions were randomly mixed within (and across) each block, using *E*-prime.

Procedure: There were two different styles of target letter presentation in Experiment 4: Pre-stimulus and Simultaneous. Each style was used in a block of trials. The order of blocks was counterbalanced across participants so that half of the participants completed the Pre-stimulus letter search block first. In the Pre-stimulus block each trial began with the target letter presented at fixation for 500ms. This was followed by an interval of a blank screen lasting 250ms. The probe word was then displayed for up to 2000ms or until the participants response whichever was shorter. On the probe word displays, '#' symbols were displayed above each letter position to make sure that there were an equal number of items on probe displays for both Pre-stimulus and Simultaneous trials. If the response was incorrect a feedback buzzer, played over an interval screen, which lasted 250ms, followed the probe display. At the end of each trial was a 500ms interval before the next trial began. The simultaneous trials were exactly the same as the Pre-stimulus except that the letter at fixation at the start of each trial was replaced with a'*' symbol. Instead the target letter was presented simultaneously with the probe word on the probe displays. The target letter was displayed above every letter position, see Figure 9 for a graphic example.

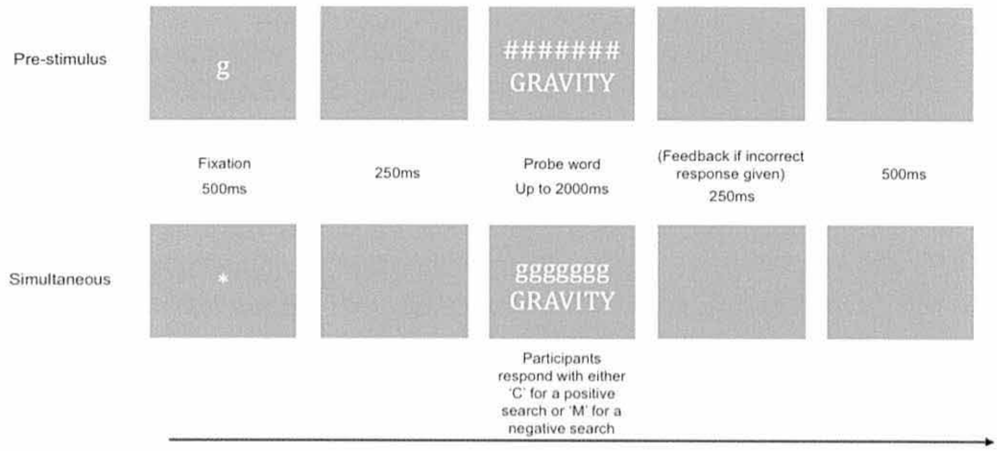

Figure 9: A depiction of complete trials for each of the presentation styles.

Results

The data were first analysed using a repeated measures ANOVA, with conditions of Style (Pre-stimulus, Simultaneous) and Search (Positive, Negative). There was a main effect of Style $F(1,32)=196.94$, $p<.0001$, $\eta_p^2=.86$, and a main effect of Search $F(1,32)=24.61$, $p<.0001$, $\eta_p^2=.44$; the interaction was not significant $F=2.01$, $p=.16$. A second ANOVA was run with conditions of Style (Pre-stimulus, Simultaneous) and Position (First, OVP, ROM, Last) see Figure 10. Significant main effects were found for Style $F(1,32)=171.85$, $p<.0001$, $\eta_p^2=.84$, and Position $F(3,96)=12.61$, $p<.001$, $\eta_p^2=.28$, and a significant interaction between Style and Position $F(3,96)=6.37$, $p<.001$, $\eta_p^2=.16$. Paired t-tests revealed significant differences between the two presentation styles at every position (all t values larger than $t(32)>8.23$, and all p values less than $p<.0001$). There were also significant differences in the Pre-stimulus target positions and the Negative search displays (all values larger than $t(32)>3.80$, and all values less than $p<.001$) except for the ROM position which reached marginal significance from the Negative search displays ($t(32)=1.95$, $p=.06$). For the simultaneous displays there were significant differences between the First ($t(32)=4.47$, $p=.0001$) and Last ($t(32)=2.82$, $p=.009$) target positions and the Negative search displays. The difference between the simultaneous ROM target position and the Negative search displays was not significant ($t=.06$, $p=.95$). There was no difference between the simultaneous OVP position and the Negative search displays ($t=.45$, $p=.66$).

Analysis of the error rates revealed a non-significant effect of Style $F=1.61$, $p=.2$, a significant main effect of Position $F(4, 156)=5.90$; $p<.0003$; $\eta_p^2=.13$, and a significant interaction $F(4, 156)=4.52$; $p<.002$, $\eta_p^2=.10$. Paired t-test revealed that the errors for the ROM position to Simultaneous displays was significantly different from the First ($t(32)=4.77$, $p=.001$), OVP ($t(32)=2.70$, $p=.02$), and Last positions ($t(32)=2.30$, $p=.03$). The errors to the ROM position were not significantly different to the errors to Negative displays. A paired samples t-test was conducted for the differences between the errors at the ROM position between the simultaneous and delayed displays, $t(32)=-2.84$, $p=.008$.

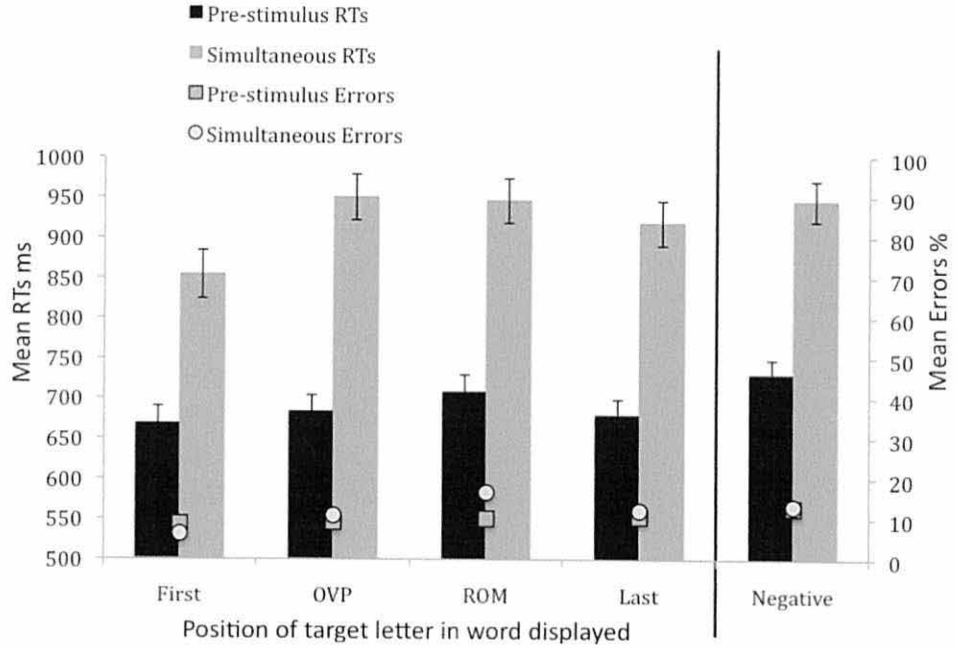

Figure 10: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for Presentation-type, Search-type and Position to probe displays in Experiment 4.The bars represent the standard error.

Discussion

As predicted the results were supportive of both Stolz and Besner (1996) and Valdes et al. (2005). RTs following simultaneous presentation were slower than RTs to delayed-search presentation. The slower RTs for the simultaneous displays could be due to the need to complete more steps than the pre-stimulus displays, as in the delayed-search displays the letter to be found has already been identified. Alternatively, the simultaneous displays may take longer because they contain more perceptual information, which increases the competition in the visual system. However, this alternative explanation seems less likely as all of the letters above the to-be-searched word are identical. This should mean that they can be easily filtered and produce less competition.

It could be argued that the faster RTs, and the lack of difference between the target positions, reflect a tighter controlled attentional system, which was better able to focus on the relevant information. If this is the case, certain predictions can be made over subsequent semantic priming following delayed letter search. First, there would be no effect for related words, as the focused attention would have prevented processing to a word level: this could be examined using repetition priming. Second, the letter positions were processed in parallel. Additionally, the lack of needing to move attention spatially between the prime letter and prime word meant that the word could be processed as a whole: this should result in priming of some sort. If the word information was interfering with the search, then negative priming should be found. However, if word information was of benefit to the search then positive priming should be found. It is possible that the two instances of delayed priming reported in the literature are the result of one of these processes. In the Stolz and Besner (1996) study the word information was beneficial, aiding search, and as such did not require inhibiting. The Valdes et al. (2005) paper reported on a design where the word information was of no benefit to participants, and resulted in negative priming.

The error rates to the different positions and styles in Experiment 4 were fairly even, except for the simultaneous displays when the target letter was in the ROM position. The error rates to the ROM position were significantly higher for the simultaneous displays. This is attributed to the simultaneous displays being more crowded. The ROM position is also the one that is furthest from the initial point of eye gaze with the maximum level of flanking letters. So, even though the RT results did not reveal differences between the OVP and ROM positions for the simultaneous displays, the error rates indicate that there is a cost of the target being positioned at the ROM.

In terms of searching for a letter within a word there is a definite benefit of prior knowledge of the target letter. Experiment 4 provides a starting point for future research to compare the different styles of letter search.

Experiment 5

In Experiment 5 the difference between high and low written frequency words is examined. Previous claims have been made as to the priming ability of low versus high frequency words, following LS tasks (Tse & Neely, 2007). If priming can be found in low written frequency probe words, following LS, then it is likely that there are some measurable effects in the prime words. If the letters in high written frequency words are grouped together as a whole object it is expected that all letter positions will elicit similar RTs, as attention should spread automatically across the letters, as it does across an object (Auclair & Sieroff, 2002; Humphreys & Riddoch, 2007). This effect may shed light on why low frequency words are able to proceed to semantic levels in LS tasks, while high frequency words do not.

The presence of the target and target position, in relation to the written frequency of the stimuli, are investigated. There are two possible outcomes of LS on words of different frequencies. First, high frequency words may aid letter identification when compared with low frequency words (as in the Reicher-Wheeler paradigm). Second, high frequency words may cause Stroop like interference, and result in slower letter detection than displays containing low frequency words.

Method

Participants: 14 participants (9 female and 5 male), with an average age of 28.2 years, took part in this experiment.

Stimuli: 50 high frequency five letter English words with an average written frequency score of 42.74 were selected from the Medical Research Council word database. 50 low frequency five letter English words, with an average written frequency 4.12, were also selected. The written frequencies are determined by measuring the number of times each of the words appeared in a list of documents. The word lists were controlled for concreteness (see Appendix F).

Design: A repeated measures design with conditions of written frequency (High, Low) and position (Absent, First, Second, Middle, Penultimate, Last) was used. The frequencies and positions were randomly mixed between two experimental blocks.

Procedure: The procedure for Experiment 5 is identical to that used in Experiments 2 and 3. The task participants had to complete was the same letter search task and the response keys were the same. The same counterbalancing of responses was used. The experiment began with 25 practice trials, which were not included in the analyses. See Figure 11 for a depiction of a complete trial.

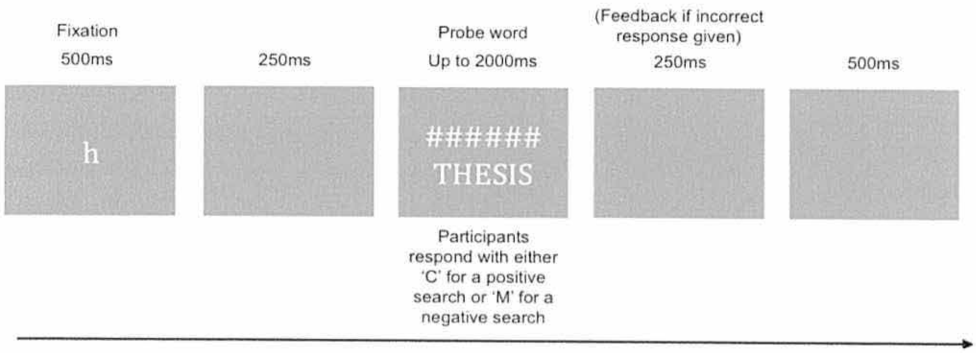

Figure 11: a graphic depiction of a complete trial in Experiment 5.

Results

A repeated-measures 2 (Frequency: High, Low) by 5 (Position: First, Second, Middle, Penultimate, Last) ANOVA was conducted. There was a main effect of Frequency $F(1,13)=10.32, p<.008, \eta_p^2=.44$, and a main effect of Position $F(4,52)=19.65$, $p<.0001, \eta_p^2=.60$, and a significant interaction $F(4,52)=6.76, p<.001, \eta_p^2=.34$. Paired t-tests revealed significant differences between, high and low frequencies at the second ($t(13)=3.23, p=.007$ and penultimate positions ($t(13)>-6.09, p<.0001$ (see Figure 12).

A second repeated-measures 2 (Search type: Positive, Negative) and 2X(Frequency: High, Low) ANOVA was run on the data collapsing across the letter positions for the Positive displays. There was a main effect of Presence ($F(1,13)=54.21, p=.0001, \eta_p^2=.81$), and a significant effect of Frequency ($F(1,13)=30.38, p=.0001, \eta_p^2=.70$). The interaction was not significant (F=.41, p=.53).

The error rates displayed a similar pattern but were not significant.

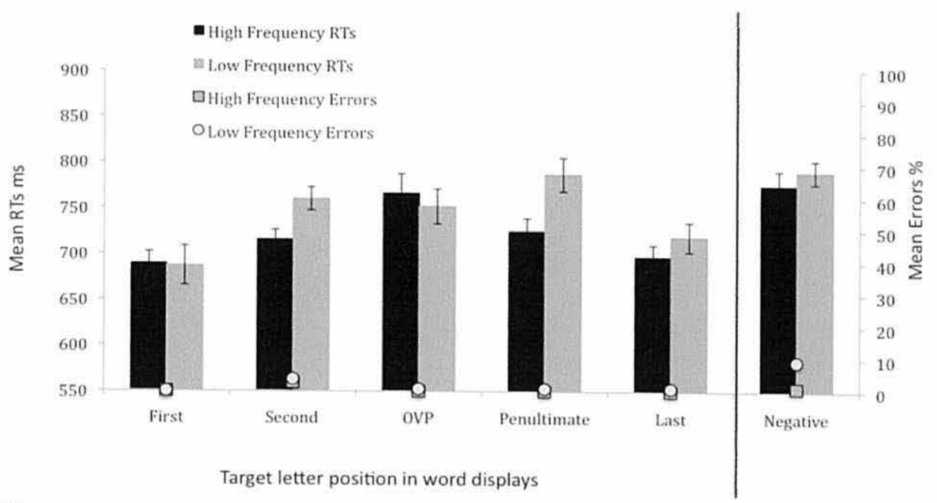

Figure 12: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for Search-type, Position, and Written word frequency for Experiment 5.The bars represent the standard error.

Discussion

As expected, the now standard difference for presence and position was apparent. Interestingly, the effect of written frequency was that the low frequency words showed an increased effect of flankers except for the middle position, which benefited from being close to the fixation point. It could be that the slower RTs to low frequency words in some way aids access to semantic information. This would contribute to the priming described by Tse and Neely (2007) who, unfortunately, do not report the RTs to the low and high frequency letter searches. If the view is taken that words are objects composed of letters, the flatter RT pattern for the high frequency words could be interpreted as suggesting that the word information aided the LS and resulted in overall faster RTs.

The facilitatory effect has been described by McClelland and Rogers (2003) as a feedback loop that helps to identify the target at the letter level, a view in agreement with Krueger and Stadtlander (1991), who believed that information flowed back from the word level in a top down way.

The similarity between the ROM letters and the negative search displays was only found for the low written frequency words. This suggests that the ROM effect reported in Experiment 4 may be biased towards low written frequency words. When the pattern of RTs for the high frequency words is examined, it appears that there is an effect of flankers only. The ROM position for the high written frequency words is very similar, although slightly slower, to the OVP. The pattern is an upside down V shape, with the central positions eliciting the slowest RTs and the external positions eliciting the fastest RTs.

The increased number of errors for the low written frequency words suggests that they did not provide as much feedback information from the word level to the letter level. High frequency words provided a beneficial effect, for both error rates and RTs. This is most likely due to high frequency words being encountered more often than the low written frequency words. However, as these differences did not reach significance future research should examine these differences in greater detail. Future research should also examine, in more detail, the differences written word frequency has on semantic priming following LS as a prime task.

Experiment 6

So far all of the Experiments have focused on LS in words; Experiment 6 compares presence and length for both words and pseudo-words. The previous results from Experiments 2-5 have shown that searching for a letter in words is affected by the word length, target position, delay of target letter, target presence and written frequency. In Experiment 6 the effect of lexicality (whether the target is in a real word or a letter string), length of stimuli and presence of the target are investigated. If results like the WSE are correct it is expected that there should be a benefit of searching for a letter in real words as compared to searching for a letter in non-words. The search for letters in low frequency words elicited slower RTs in Experiment 5, so it is expected that non-words will elicit even slower RTs. However, it may be that there could be a reverse WSE effect where letters in non-words elicit faster RTs (Krueger & Shapiro, 1979. Based on the visual search literature (Wolfe, 1998) and the previous Experiments 2-5 it is expected that there will be a linear increase of RTs, as the lengths of both letter strings and words increases (similar to the pattern found in Experiment 2).

Method

Participants: 14 participants (9 female and 5 male), with an average age of 31.4 years, participated in Experiment 6.

Stimuli: 85 words of 5, 6, 7, 8, and 9 letters were selected from the MRC Psycholinguistic Database (Wilson, 1988). An equal number of pseudo words were selected from the English Lexicon Project database (Balota et al., 2002). The mean frequency of the words was 20.9 on the Kucera and Francis database score of written frequency.

Design: A repeated measures design with Search-type (Negative, Positive), String type (Pseudo-word, Word), and Length (5, 6, 7, 8, and 9 letters) as factors was used. All three factors were randomly mixed across two blocks of trials.

Procedure: This sixth Experiment uses the same procedure used in Experiments 2, 3, and 5. Participants responded to the presence of the letter presented at fixation at the beginning of each trial in the subsequent probe word. Please see Figure 13 for a graphic depiction of a complete trial and the durations of each screen in a complete trial. The experiment began with 30 practice trials, which were not further analysed.

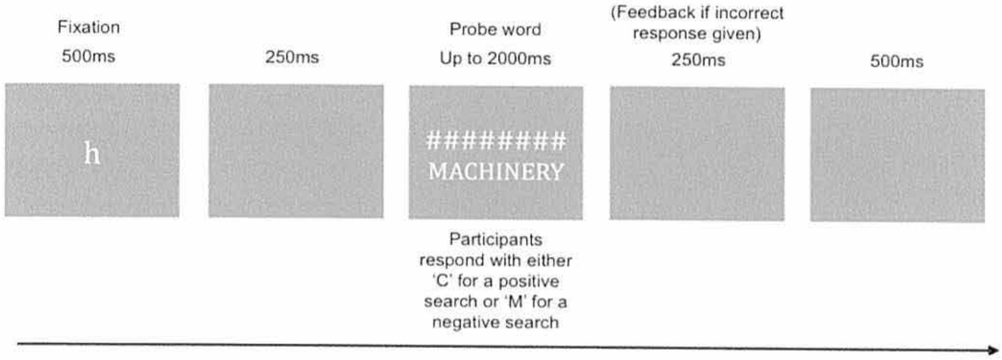

Figure 13: a graphic depiction of a complete trial in Experiment 6

Results

A repeated measures ANOVA 2X (Search-type: Negative, Positive) 2X (Type: Pseudo-word, Word) 5X (Length: 5, 6, 7, 8, and 9 letters) was conducted. There was a main effect of Presence $F(1,13)=104.34$, $p<.0001$, $\eta_p^2=.89$, a main effect of Type $F(1,13)=55.07$, $p<.0001$, $\eta_p^2=.81$, a main effect of Length $F(4,52)=60.05$, $p<.0001$ where additional letters on average increased RTs by 25ms, $\eta_p^2=.82$, a significant interaction between Presence and Type $F(1,13)=6.03$, $p<.03$, $\eta_p^2=.32$, a significant interaction between Presence and Length $F(4,52)=4.11$, $p<.006$, $\eta_p^2=.24$, and a significant interaction between Type and Length $F(4,52)=3.25$, $p<.02$, $\eta_p^2=.20$ (See Appendix H for all the means and standard deviations from Experiment 6). The global interaction between Presence, Type, and Length was not significant $F=.36$, $p=.83$. Two follow up ANOVAS were run showing significant effects between the word and pseudo-words in the negative and positive conditions although only the positive condition elicited a significant interaction between stimuli type and word length.

Post hoc analyses of the positions found no significant differences between the words and letter strings, although the 'n' shape tended to be pronounced for the letter strings which were also on average slower.

Analysis of the error rates revealed a similar pattern to the RT data with a non-significant trend. There was a trend for the negative searches in words to be responded to less accurately than the positive searches. These differences are in contrast to the differences found in Experiment 3, where participants were more likely to say that a target was absent from a Positive display. The differences between Positive and Negative search displays are rarely significant and do not have a reliable pattern between experiments. These differences indicate that the use of error rates to draw conclusions from LS data should be approached with caution, especially when generalising across different experimental designs.

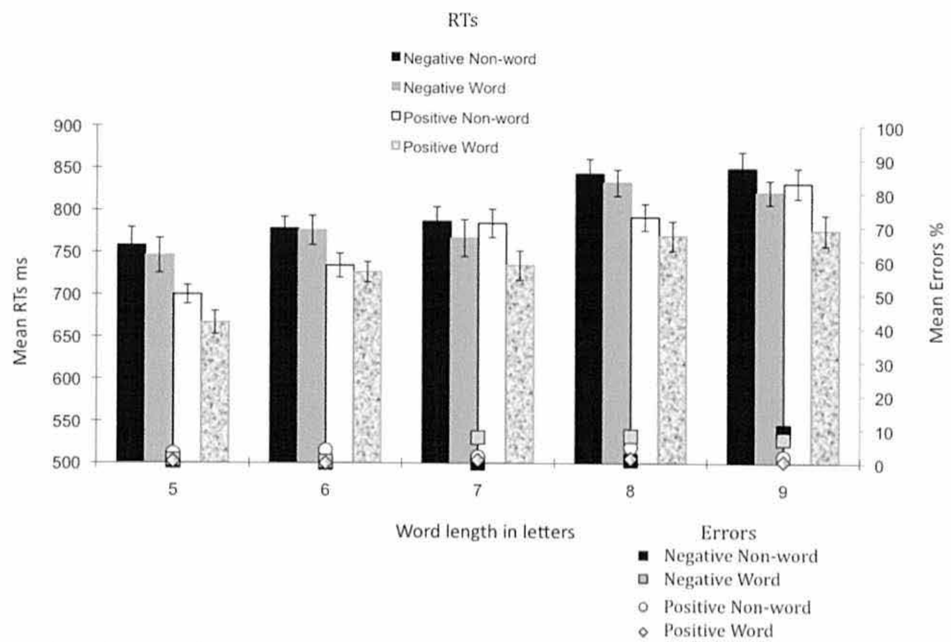

Figure 14: Mean RTs in ms (columns) and mean error rates in % (squares, circles and diamonds) for Search-type, Lexicality and Length in Experiment 6.The bars represent the standard error.

Discussion

Overall searching for letters in letter strings, and in words, can be considered to be equal tasks in terms of search-type (positive or negative), length in letters, and even target position. This is reassuring, as although there may well be information feeding back from the semantic/ word levels to the letter level, these processes do not result in RTs that are of a different pattern from search in letter strings. This would suggest that exactly the same processes underlie search for letters in words and strings. Indeed, it may be that it is frequency or experience that results in the WSE: something that was proposed by Krueger & Shapiro (1979). It could be suggested that Experiment six does not examine LS in words, as the inclusion of pseudo-words may have introduced a demand characteristic, where participants were encouraged to engage in letter-by-letter search. Comparing the pattern of RTs from Experiment 6 to Experiments 2 through 4, presents the conclusion that when the task is letter search participants engage in letter-by letter search in all cases. If participants had engaged in whole word processing, it would have been expected that the RT patterns would not have shown effects of position (left to right) or length.

It is entirely possible therefore, that the results of Experiment 6 are due to the familiarity of participants with the words. Then, if it is frequency, it must be considered that search for letters in words, with frequencies higher than those used in Experiment 6, would differ even more from search in letter strings. The further investigation of word frequency is beyond the scope of this thesis. It can be predicted that very high frequency words should elicit: faster RTs, with flatter search patterns, smaller differences between positions, and smaller additions in time for extra letters. Whether the processing of very high frequency words would progress to semantic levels more robustly is also a matter for future research. Research from pilot studies run on different frequencies of words suggests that high frequency words should elicit greater SP in subsequent related words. In contrast, Tse and Neely (2007) found semantic priming for low frequency words; however, their data examined the frequency of the probe displays, and not the primes. This leaves open the possibility that word frequency may have an effect on both prime and probe RTs.

General Discussion: Experiments 2-6

The previous five experiments have examined what happens when searching for letters in words, more comprehensively than the previous research. The results can be summarised with five points. First, during LS length has a consistent affect with additional letters eliciting RTs 25-30ms each, for both positive and negative trials. Second, negative searches are slower than positive searches (in all five experiments) by about 30ms. The differences are consistent across every manipulation included, and as such, indicate that they can be considered identical and collapsible. Third, Simultaneous search is slower than delayed search, and the patterns of RTs to letter positions would suggest that delayed search is more efficient and less demanding (possibly in terms of the movement of attention through space/location). Fourth, higher frequency words elicit flatter search patterns reflecting a more efficient search, which suggests that very high frequency words may be processed in parallel to LS tasks. Fifth, the search pattern for words is faster and parallel to that for letter strings, which, when the error rates are considered, seems to be due to a feedback from the word level.

The replication of WSEs, similar to those found by Krueger and Stadtlander (1991) and Besner, Smith, & Macleod (1990), would support that at least word level information is available when searching for a letter in words. Spotlight theories of attention would predict that information outside of the attentional window is either not processed (Theewues & Kramer, 2001) or inhibited (LaBerge & Brown, 1989). As the word information is in the attentional window it should be processed, and the WSEs found here support processing of the stimuli as words.

The next Section of this thesis examines the effects of focussing attention to the letter level during a letter identification task. Neely and Kahan (2000) highlighted the importance of understanding the visual spatial aspect of letter search tasks. In light of the findings discussed in the literature review, in particular the models of visual selection and visual word processing, it is essential that a better understanding of visual spatial selection for letters in words is made.

Of interest are the mechanisms behind such selection, and if there is any way to understand what occurs during letter search tasks, that could result in the prime-task effect. As mentioned previously, the *letter identification task* is similar to LS tasks except that there is no negative search condition. Instead, participants have to identify one of a small group of pre-identified letters. In this sense attention is still directed to the letter level.

The next section starts with an overview from perceptual load experiments. The paradigm has been chosen because it can be used to examine the selection mechanisms involved with spatial attention. In particular the positive priming of repeated items and the inhibition of distractors can be measured within the same experimental design. It is expected that a better understanding of what happens when attention is focussed to the letter level will be gained.

Section 2: Perceptual load

Chapter 4: Introduction and General Method for Experiments 7-11

Priming From Single Letters.

Perceptual Load

The fate of attended and unattended letters during letter search is now examined, in the context of the perceptual load priming paradigm (Lavie, 1995, 2005; Lavie & Cox, 1997). This experimental design allows experimenters to determine the consequences of attending and ignoring target and distractor items.

In summary from Chapter One, perceptual load models assume that attention has a limited capacity and that when this capacity is reached selection takes place. These models also assume that if the limited capacity has not been reached then any stimuli present will be processed. When high load conditions are present early selection takes place, as the capacity of attention is exhausted. Conversely, late selection occurs when low load conditions are present. Therefore, Lavie's model can predict the level of processing that stimuli presented should elicit. Lavie (1995, 1997, & 2005) has been heavily involved with the proposal that perceptual load is the factor which determines whether attentional mechanisms work early or later in the perceptual networks.

Lavie and Fox (2000) examined the effect of perceptual load, and the similarity of load between prime and probe displays, in a series of four experiments. Prime displays consisted of either a low load (single letter) or high load (six letters in a horizontal string) presented across a horizontal midline. Their probe displays were either of a single letter (Experiment 1) or a six letter string (Experiments 2, 3, and 4). Negative priming (NP) was elicited from all experiments for low load prime displays, when the distractor in the prime was the target in the probe, as compared to a control condition where the probe target was not present in the prime display. Importantly, when the prime display contained a high perceptual load, the negative priming found in low load displays was absent. For all 4 experiments positive priming was elicited when the prime target was identical to the probe target, compared to the control condition.

Lavie and Fox (2000) concluded that the role of load is essential for the understanding of selective attention. In terms of the role of perceptual load in distractor inhibition, Lavie and Fox (2000) suggest that in the low load conditions attentional capacity has not been exhausted, meaning the distractor receives attentional processing and then suppression. In high load conditions there are no resources left over to process the distractor, leaving the distractor unprocessed instead of inhibited. Lavie and Fox (2000) go on to propose that there are at least two selective attentional modes. The first is a passive selection mode, where the attentional system has been used to capacity, and the processing that occurs is driven by this limitation. The second is an active selection mode where stimuli that are irrelevant are processed by the resources available and then inhibited (Lavie & Fox, 2000).

Using a design similar to that of Lavie and Cox (1997), and Yantis and Johnston (1990), Johnson et al. (2002) found that a 100% valid cue allowed selective attention to occur, even under low loads. In Johnson and colleagues experiments the 100% valid cue always predicted the location of the target, when the target could appear in one of several positions in the display. Johnson et al. (2002) raise the possibility that the inclusion of the cue could have raised the perceptual load of the low load condition, and so be a possible confound in their experiment. The task that

Johnson et al. (2002) used required participants to identify which one of two targets was present in a circular display of six letters. The circle of six letters was always accompanied by a flanking letter, which could be compatible, incompatible, or neutral. In the compatible condition, the target letter was identical to a flanking distractor. In the incompatible condition, the flanking letter was the other target letter. In the neutral condition, the flanking letter was not from the target set. Looking at the NP elicited between Johnson et al.'s (2002) neutral and incompatible flanker conditions, it can be seen that the only significant NP elicited was in the no-cue low load condition (-67ms). This means that when there is a low perceptual load, with a valid cue, processing of all items in the display (including irrelevant items) does not necessarily occur.

Torralbo and Beck (2008) present a modification of perceptual load theory, where the early selection resulting from the 'high perceptual load', is due to crowding in the display. The crowding results in competition between items, which prevents stimuli, other than the target, from being processed beyond basic feature levels. When there is no crowding, either through a low number of perceptual items or a display where items are widely dispersed, all of the items are processed to a higher level. The irrelevant items then require inhibitive mechanisms to prevent them from competing with the target. This inhibition produces negative priming when an irrelevant item becomes the target in the successive trial.

Words and Perceptual Load

Brand-D'Abrescia and Lavie (2007) present one of the first studies to examine the modulation of perceptual load when searching for letters in words. Using a design similar to the Lavie and Fox (2000) paper, and to that used in this thesis, they found that words had a lower perceptual load than letter strings. The results showed increased RTs when the distractor letters were incompatible with the correct response. Similar patterns were elicited in the error rates, which is congruent with the WSE literature, where word information facilitates letter identification. This finding also suggests a reduced perceptual load for words compared to letter strings. Brand-D'Abrescia and Lavie (2007) do not explain why the words elicit low load. It may be that words are processed as whole objects, and as such do not create competition in the visual system. Letter strings which are not perceived as whole objects do elicit competition in the visual system and so show less compatibility effects.

The study by Brand-D'Abrescia and Lavie (2007) begins to shed light on the attentional mechanisms involved with processing visually presented words, but there is still much that is unclear. The conclusions drawn that words draw a reduced attentional load need to be supported with further evidence. It remains unclear what the effects of focussing attention to the letter level means in terms of processing resource availability. Further, a WSE may not always be present, or be shown, in the same way as found by Brand-D'Abrescia and Lavie.

Spatial Attention and Perceptual Load

The action of perceptual load on selection is moderated by spatial attention (Johnson, McGrath, & McNeil, 2002), and Johnson, McGrath and McNeil (2002) suggest that the focussing of attention contributes to what is selected. Theeuwes, Kramer, and Beloposky (2004) presented high and low load displays within the same block, in an attempt to encourage the participants to adopt a mental set for the data and a spatial focus that needed to be set to different sizes. Theeuwes, Kramer, and Beloposky (2004) found that when a high load display was preceded by a high load display, the typical perceptual load effect of no distractor interference was elicited. Interestingly, when a high load display was preceded by a low load display distractor interference was significant. This result was interpreted through the low load displays not needing focussed selection, which was then carried onto the following high load display. The normal distractor effect was found when a high load display preceded a low load display[3].

The following experiments were designed to explore the effects of perceptual load, while searching for a letter, in letter strings and English words. In some of the experiments the target will always appear in the same location in the display. The same location is used in order to facilitate participants' focussing. If perceptual load theory (Lavie 1995) is correct visual systems should reach attentional capacity limits, whenever the displays contain a high visual load. Yantis and Johnston (1990) suggest that using a high perceptual load should increase selectivity, due to the information processing systems having to concentrate on the target in order to maximise efficiency of identification

Analysis of the prime target positions is planned in order to understand whether there is a difference in the shape of RT responses elicited. It is expected that the search patterns between high load displays containing non-word letter strings and real words will differ, as the letters in words will be grouped together. The level of priming for irrelevant distractors and attended targets should be modulated by the level of semantic content. Finally, when target position is 100% predictable it is suggested that there will be an effect of priming for words, but not letter strings, as

[3] The fact that the high load focused display did not have a carry over effect onto the low load display, which one would have expected to be indicated through reduced distractor processing due to a focused selection, indicates that the spatial window resizing effects need to be examined in closer detail in future studies. Otherwise it must be claimed that low load displays reset the selective window while high load displays do not.

attention will be focussed more accurately in letter strings (as they are less likely to be processed as whole objects).

Summary of Priming from Single Letters

The control of what individuals visually perceive has been debated to occur both early and late in the visual system; and some theories, for example perceptual load theory (Lavie, 1995) have included both stages of selection as a function of a limited capacity system. Through five experiments, the extent to which spatial attention is essential for such selection theories is explored. It is suggested that perceptual load theory on its own cannot account for when selection takes place. In Experiments 7-10 the slower RTs to ignored distracters are investigated as a measure of the inhibitive mechanisms involved with visual selection. In addition the duration of RTs to repeated targets following high load and word prime displays is investigated. It is expected that light will be shed on the role of attention on resolving competition in the visual system and ultimately may indicate a need to rethink perceptual load theories. In Experiment 11, word stimuli are presented in a visual orientation, which should enable participants to focus almost completely away from word level information.

General Method for Experiments 7-11

Participants: 92 undergraduate students from Bangor University participated in the four experiments (23 in each). The students were reimbursed with £5 for their time: a 60 minute session. Selection criteria of normal or corrected to normal vision and English as first language were used.

Apparatus and Stimuli: All the stimuli were presented on a flat panel 17-in monitor and produced using an IBM compatible PC upon which participant reaction times were also recorded. The stimuli were created and presented using *E*-prime software from Psychology Software Tools, Inc. A distance of approximately 56cm was kept between the participants' eyes and the monitor screen.

Three sets of stimuli were used in the primes, a low load condition, a high load condition and an English word condition. In the low load condition one of three lower case targets ("d", "r", or, "n") was presented randomly in one of six horizontal positions spanning the centre of the screen. In the high load condition one of the same three targets as in the low condition was presented randomly in any of the six positions with five non-target letters ("v", "u", "s", "k", and "t") filling in the vacant spaces (see Figure 8). In the word condition the target was presented embedded in a real English word (see Figures 9B & 9D). An upper case distractor appeared randomly in equal amounts above and below the targets. The distractors were an upper case version of one of the lower case target letters in the primes (although the same letter never appeared simultaneously as a distractor and as non-target in the letter/word string). The probe task consisted of a similar array to the low load task where one of the lower case target letters was presented horizontally across the centre of the screen, with an upper case probe distractor ("X", "Q", or "Z") that never appeared as targets or distractors in the primes. The lower case letters each subtended a visual angle of 0.61° in height and 0.51° in width with spaces between each letter of 1.02°. The distractor letters subtended a visual angle of 1.02° in height and 0.51° in width and were presented with their nearest edge 1.73° from fixation.

Design and Procedure: Three types of trial were used: Attended, Ignored, and Control. In the Attended trials the lower case target was identical in both the prime and probe while in the ignored trials the upper case distractor in the prime was the lower case target in the subsequent probe. In the control condition the target and distractors in the prime and probe were not identical and were not repeated.

Each trial began with a star symbol presented at fixation for 1000ms; this was followed by the prime for a duration of 100ms. The prime and probe task was to identify which of the three lower case target letters (d, r, n) was present in the display. Each letter had a corresponding key on the keyboard. Responses were made with the participant's right hand using the number pad. For example, the presence of the letter 'd' would be reported by pressing the number '1' key; the presence of the letter 'r' would be reported by pressing the number '2' key; and the presence of the letter 'n' would be reported with the number '3' key. The relationships between target letters and response keys were counterbalanced across participants. Participants had up to 2000ms to respond to each prime and each probe. Following incorrect responses an automatic feedback buzzer, lasting 150ms, was played by the recording PC during the 850ms inter-stimulus-interval following the prime, and also during the 1500ms inter-trial-interval following the probe. The first 30 trials from each block of 270 trials were discarded as practice trials and not analysed. The trial order within each block was randomly assigned by the *E*-prime program.

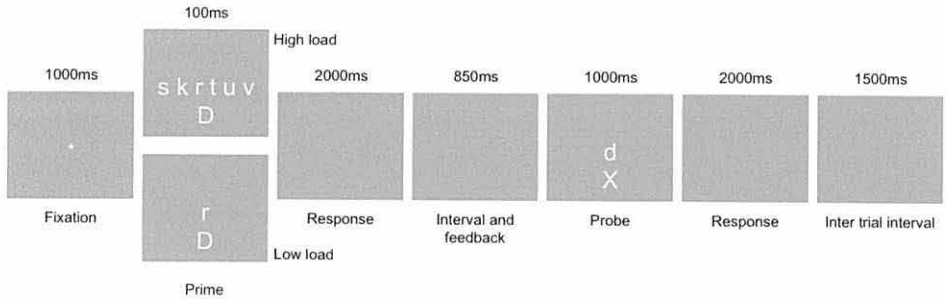

Figure 15: A graphic depiction of a complete trial. The high perceptual load and low load displays were presented in separate blocks. The example here is of a complete ignored trial, where the upper case distractor 'D' in the prime display is the lower case target in the probe display. The response in the prime is for the letter 'r' and the response in the probe is the letter 'd'.

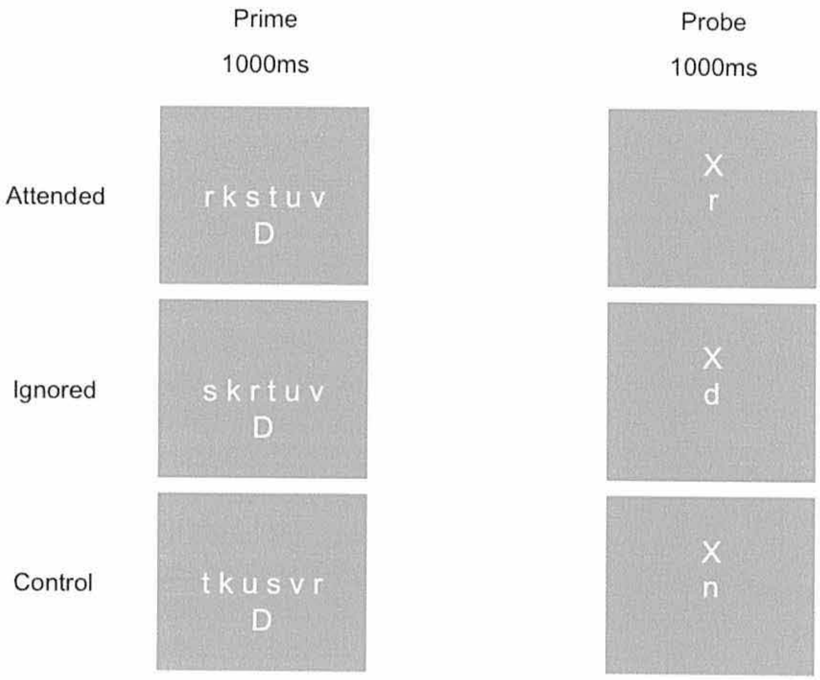

Figure 16: The three high load displays for a perceptual load experiment. Experiments 7-11 each have conditions of Attended, Ignored, and Control. In this example the Attended condition has a lower case 'r' in the prime display, and a lower case 'r' in the probe display. The ignored condition has a lower case 'r' and an upper case distractor 'D' in the prime display, but has a lower case 'd' in the probe display. In the control condition the prime display lower case 'r' and distractor 'D' are not present in the probe display. The upper case distractors appeared, in equal proportions, above and below the letter targets.

General Trimming of data: Those trials in all experiments with RTs slower than 100 ms and faster than 1500 ms were included in the analyses. Participants achieving accuracy scores lower than 75% were excluded from the analyses, except in those cases where the very nature of the experiment precluded a high accuracy score (Experiment 8).

Data Analysis: All global analyses were repeated measures ANOVAs unless otherwise stated. Where necessary Bonferoni adjustments were conducted on the alpha levels, these are indicated by the use of p_B<.05, and where Greenhouse-Geisser adjustments were made their use is indicated by $F_{G\text{-}G.}$

Section 2 Chapter 5: Experiments 7-11

Experiment 7

This experiment was a direct replication of Lavie and Fox's (2000) study, except that attention has been paid to the effect of position on target search in the Primes. The positions were of interest because it is hypothesised that subsequent experiments, using English words, will show a different RT pattern for position. It is expected that even though short display durations will be used for the prime and probe displays, participants will conduct search in their visual sensory stores. In Experiment 7 the letter strings should elicit a pattern of RTs that is similar to that found in the OVP literature. The general pattern for the prime displays should be a 'u' shape.

Similar to the letter search studies previously reported, the letter identification design used in Experiment 7 should shed light on the way that vision interacts with selection. It is important to validate the three new letters with this methodology, which will be used in a similar experiment where the high load string primes are replaced with real English words (see Experiment 8). It was important to replicate as closely as possible the results obtained by Lavie and Fox, as this would provide a sound basis for the next experiment.

Method

Stimuli and Procedure: The stimuli used were as described in the General Method section. The letter strings were presented in six fixed positions across the centre of the screen. The middle letters were presented either side of the central fixation point. In Figure 17, the *r* is in position 1; *k* is in position 2; and so on, finishing with the *v* in position 6.

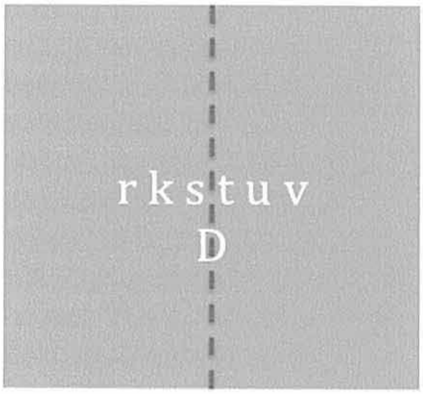

Figure 17: A graphic depiction of a high load prime display. The central letter positions can be seen either side of the dashed black line. The dashed line represents the theoretical vertical mid-line, and was not present in the experimental displays.

Results

Prime Displays: Mean reaction times per participants and per condition were analysed through a 2 (Load: High, Low) x 6 (Position) repeated measures ANOVA. As expected, responses to high load strings were slower (847ms) than those to low load displays (680 ms), $F(1,22)=100.17, p<0.001, \eta_p^2=0.82$ (see Appendix I for all means and standard deviations). Also, reaction times were different depending on the position of the target letter, $F(5,110)=34.61, p<0.001, \eta_p^2=0.61$. However, this effect of position was different depending on the load, $F(5,110)=6.52, p<0.001, \eta_p^2=0.23$. As shown in Figure 3, the V-shape of the position curves for high and low load conditions are similar. Indeed, in both cases there is a reduction in reaction times for the central positions (3 and 4) as compared to the external ones (1 and 6). This pattern is confirmed by a significant global quadratic trend of position, $F(1,22)=109.47$, $p<0.001$, $\eta_p^2=0.83$. However, the difference between centred and external positions is more acute with high load strings, being this observation supported by a reliable interaction of the quadratic trend with load ($F(1,22)=5.79$, $p<0.03$, $\eta_p^2=0.21$). This position pattern suggests a strategy where attention has been successfully located at fixation. Indeed an ANOVA exploring averaged positions (central, exterior) found that for the central positions, the presence of additional non-target letters in the high load string does not seem to produce as much lateral inhibition as for the external positions ($F(1,22)=149.27$, $p<0.001$, $\eta_p^2=0.87$).

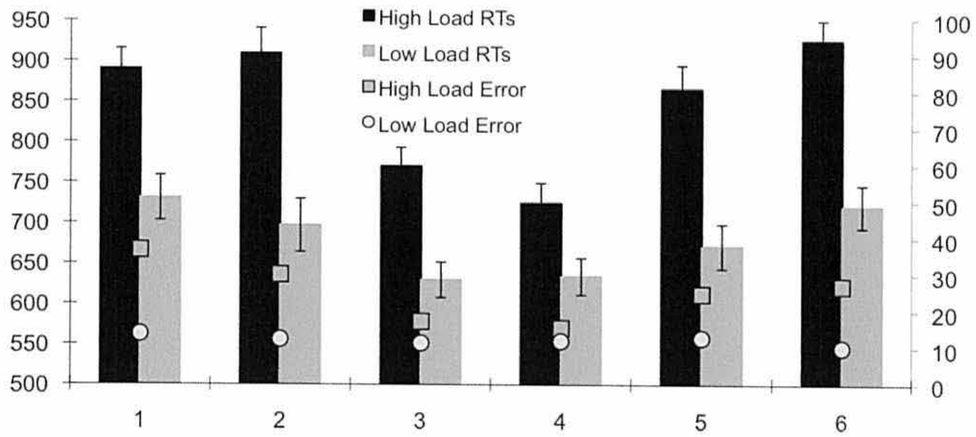

Figure 18: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for Perceptual load vs. Target position in prime displays in Experiment 7.The bars represent the standard error.

Analysis of errors in the Prime displays: Mean error rates were calculated per participant and per condition and were analysed through a 2(Load: High, Low) x 6(Position) repeated measured ANOVA. The error rates reflected the pattern of results revealed in the RT analysis (As can be seen in Figure 4). Mean error rates were greater for the high load condition $F(1,22)=32.46$, $p<0.001$, $\eta_p^2=0.6$, and error rates were different for position $F_{G\text{-}G}(5,110)=11.99$, $p<0.001$, $\eta_p^2=0.35$. These main effects of load and position interacted to a significant level $F(5,110)=7.48$, $p<0.001$, $\eta_p^2=0.25$.

Probe Displays: An initial analysis that explored the effect of target position in the prime on the priming in the probe did not reveal any significant effects. As a result the positions were collapsed and the subsequent analysis conducted. The mean reaction times per participant and per condition were analysed for Control vs. Ignored and Control vs. Attended separately. A repeated measures ANOVA 2 (Load: High, Low) x 2 (Distractor condition: Control, Ignored) revealed a significant main effect of distractor condition $F(1,22)=12.05$, $p< .003$, $\eta^2=.36$, and a marginally significant interaction between display load and distractor condition $F(1,22)=3.79$, $p< .065$, $\eta^2=.15$. The repeated measures ANOVA for 2 (Load: High, Low) x 2 (Distractor condition: Control, Attended) revealed as expected a significant effect of Distractor condition $F(1,22)=58.98$, $p<.001$, $\eta^2=.73$ and a significant interaction between Distractor condition and Display Load $F(1,22)=5.13$, $p<.04$, $\eta^2=.19$. Our data provided a good replication of Lavie and Fox (2000) (see Table 1). For the low load displays the ignored condition was significantly different from the control condition (-24ms) ($t(22)=-3.04$, $p<0.007$). There was an increase of positive priming for the attended condition following high load prime strings (123 ms, $t(22)=8.29$, $p<0.001$) compared to those responses following low load strings (91 ms, $t(22)=5.61$, $p<0.001$).

Table 1: Mean RTs, standard deviations (Sd) and percentage of errors (%E) to probes displays in Experiment 7. Priming for the different types of stimuli is also shown C: Control, I: Ignored, A: Attended. The'*' indicate an effect that was significant beyond the $p<.05$ level.

	Ignored	C-I	Control	C-A	Attended
Low	**622**	-24*	**598**	91*	**507**
Sd	124		119		88
%E	14		15		11
High	**620**	-5	**615**	123*	**492**
Sd	124		126		73
%E	27		26		25

Analysis of errors in the Probe displays: The error rates for the probes displays were analysed using a repeated measures ANOVA 2(Load: High, Low) x 2(Distractor condition: Ignored, Control). The error rates did not reveal a significant difference between the distractor conditions but it did reveal a significant main effect of load with the high load displays eliciting more errors $F(1,22)=35.28$, $p<.001$, $\eta_p^2=.62$. There was no significant effect of priming $F<1$.

Discussion

The position effects in the RTs to high load prime displays suggests that identifying targets in the central positions is easier, even though they are flanked by letters on both sides. The central positions should have suffered the most from lateral inhibition, but any lateral effects seem to have been hidden by fixation effects: where the target appears at fixation. In contrast RTs to exterior positions in the prime displays elicited much slower RTs (and higher error levels).

The gentle gradient v-shape observed following low load displays, possibly reflects the amount of time taken to shift attention from the middle position, to more distant points in visual short term memory. This is supported through a roughly linear increase of RTs, for both left and right directions from the centre, and equal increases in RT for each progressively distant letter position. However, as the display durations were so short (100ms), the slower reaction times to letters further from fixation may reflect the processing gradient. Processing efficiency decreases the further from the fovea stimuli are presented. If a processing gradient was responsible for the slower RTs to external positions, there should have been increases in the number of errors. In contrast, the errors to low load displays stay constant for each letter position. This suggests that the slower RTs are due to the shifting of attention either to the stimuli on the screen, or to the retinotopically organised representations of the stimuli in early visual stores (Desimone & Duncan, 1995).

The probe RTs for the load and priming conditions replicated those found by Lavie and Fox (2000), demonstrating that the new stimuli set used in this experiment are comparative to those used by Lavie and Fox (2000), and that they can be used as the basis for the subsequent series of experiments reported here.

The results also show that when attention is directed to perceptually loaded visual displays ignored distractor information does not receive the same kind of processing (i.e. inhibition) as less loaded displays. Additionally the increase in positive priming from attended letters in the high load condition supports the idea that when the system is loaded, attentional resources are devoted mainly to relevant target processing. This may indicate excitation is being implemented in the attentional window, and inhibition outside of the attentional window.

Yantis and Johnston (1990) suggested that harder tasks should require attention to be focussed more intently which is shown through the lower negative priming to distractors and the increased facilitation of attended items during high load conditions.

Future research may wish to examine if attention moves more slowly when it is focussed more tightly, which would have applications in both attention and reading research. Additionally it would shed light on neurological disorders of attention and reading. Future research could make use of masking following the prime displays, in order to remove the influence of the visual memory stores. This would help to identify the level at which selection is occurring.

As attentional load is modulated under high load conditions, the introduction of word level information may modulate the focus of attention. As words can be considered objects (Auclair & Sieroff, 2002; Humphreys & Riddoch, 2007), will they encourage the spread of attention across all letter positions? If words are objects and the letters perceived as part of a whole object, will searching for letters in a word represent a lower perceptual load than searching for letters in a non-word? Alternatively, the word information, which is irrelevant to the task, could add an extra load for limited resources. In Experiment 8, the effect of identifying a target letter in an English word on perceptual load is investigated.

Experiment 8

In Experiment 8 the same design as Experiment 7 is used, except for replacing the letter string high load condition with 6-letter real English words. This would have one of two effects: either, as the word superiority effect suggests, the targets letters should be easier to identify due to the word level information being able to help give participants top down feedback (Reicher, 1969); or the word level information will interfere with the letter identification.

Experiments using the PT-effect, to examine semantic processing (Smith, 1979, Besner et al., 1990), show results where letter search in a word is a harder task than just reading the word. It is expected that the short stimuli durations (100ms), and the level of focussed attention required to discriminate between the three target letters, will result in the word information making the letter identification task harder: thus requiring a greater focus of attention. If attention needs to be more focussed within a word it is expected that trials where the target letter is repeated will receive increased priming, as compared to Experiment 7. This is due to more excitation (or inhibition of distractors) being needed to resolve the competition between the visual representations of the different letters.

Method

Stimuli and Presentation: As can be seen in Figure 19 the presentation was identical to Experiment 7, however the letter strings were replaced with real English words chosen from the Kucera and Francis word database. The English words were selected initially on the basis that they contained only one of the three target letters (d, r, and n). For each target letter, four words were chosen that contained the target letter, in each of the six positions: giving 72 words (see Appendix J).

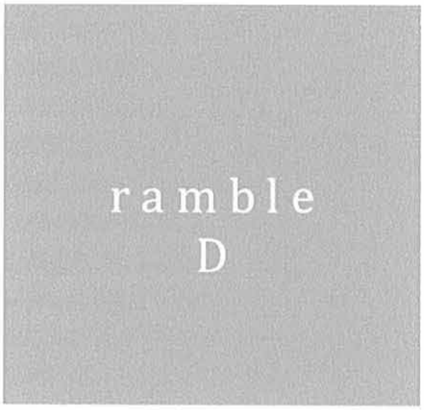

Figure 19: an example of a high load display where the target letter 'r' is embedded in the English word 'ramble'.

Results

Prime Displays: Mean reaction times per participants and per condition were analysed through a 2 (Load: Word, Low) x 6 (Position) repeated measures ANOVA. As expected, responses to word strings were slower (967ms) than those to low load displays (729 ms), $F(1,22)=140.85, p<0.001, \eta_p^2=0.87$. Also, reaction times were different depending on the position of the target letter, $F(5,110)=10.10, p<0.001, \eta_p^2=0.32$ (see Appendix K). However, this effect of position was different depending on the load, $F_{G\text{-}G}(5,110)=4.69, p<0.005, \eta_p^2=0.18$. As in Experiment 7, responses to central positions were faster than to the extreme ones (see Figure 10), showing a significant quadratic trend $F(1,24)=32.66, p<0.001, \eta_p^2=0.60$.

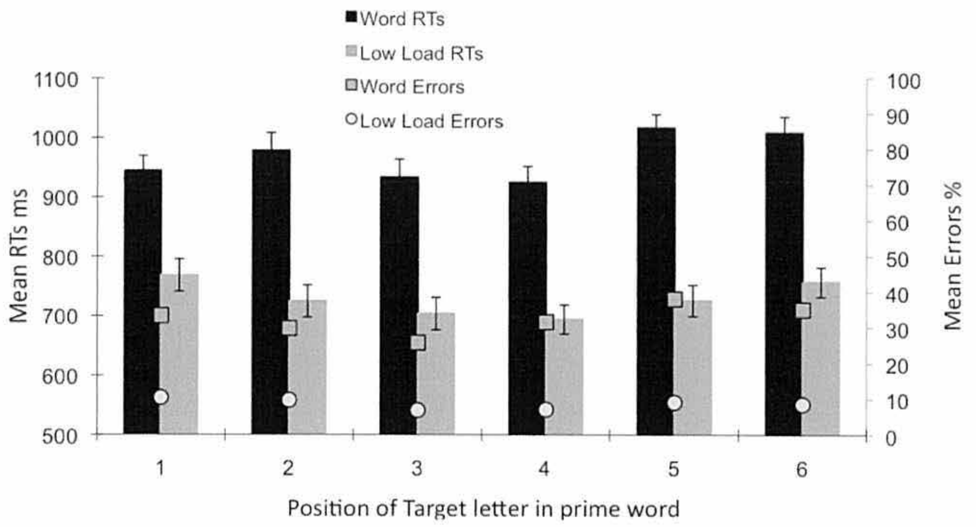

Figure 20: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for Perceptual load vs. Target position for prime displays in Experiment 8.The bars represent the standard error.

Analysis of errors in the Prime displays: Analyses for the error rates in the primes revealed a similar pattern of results to the RTs. Similarly, there was a significant effect of Position $F(5,110)=2.98, p<0.015, \eta_p^2=0.19$, where central letters were responded to more accurately than external ones $F(1,22)=4.93, p<0.04, \eta_p^2=0.18$, and a significant effect of Load, since more errors were committed in the word condition than in the Low-load condition, $F(1,22)=43.46, p<0.001, \eta_p^2=0.66$.

Probe Displays: There were no position effects in the probe RTs. The data was first analysed in a repeated measures ANOVA with conditions of Load (Word, Non-word) and Priming (Control, Ignored, and Attended) which revealed significant main effects of Load $F(1,22)=15.62, p=.001, \eta_p^2 =.42$ and Priming $F(2,44)=116.78, p=.0001, \eta_p^2 = .84$, and a significant interaction between Load and Priming $F(2,44)=15.36, p=.001, \eta_p^2 =.41$. The data was then analysed in two separate repeated measures ANOVAs: 2 (Load: Word, Non-word) x 2 (Distractor condition: Ignored, Control), and 2(Load: Word, Non-word) x 2 (Attended condition: Attended, Control).

For the Ignored Control ANOVA there was a significant effect of load $F(1,22)=26.35$, $p<.001$, $\eta_p^2=0.55$. For the Attended Control ANOVA significant main effects were found Distractor condition $F(1,22)=115.28$, $p<.001$, $\eta_p^2=0.84$, and the Load condition $F(1,22)=10.68$, $p<.005$, $\eta_p^2=0.33$, and a significant interaction between Distractor condition and Load $F(1,22)=23.98$, $p<.001$, $\eta_p^2=0.52$. There was significant negative priming in the ignored condition only for the low load displays ($t(22)=-2.13$, $p<0.05$) and significant positive priming in the attended conditions for both the Low-load ($t(22)=9.40$, $p<0.001$) and the Word displays ($t(22)=9.50$, $p<.001$.

Table 2: Mean Rts and priming for each condition in Experiment 8. The bold text represents the Mean. RTs.

		Ignored	C-I	Control	C-A	Attended
Non-word		**673**	-15*	**658**	91*	**567**
	Sd	131		120		101
	%E	14		14		10
Word		**723**	1	**724**	165*	**559**
	Sd	129		134		94
	%E	35		35		33

Analysis of errors in the Probe displays: The pattern of error rates for the probes is similar to the pattern elicited in the RTs although only the error rate differences for the load condition reached significance $F(1,22)=43.70$, $p<0.0001$, $\eta_p^2=0.67$.

Comparisons between prime displays for Experiments 7 and 8: A Position (1,2,3,4,5,6) x Load (Word, Low) mixed ANOVA with the Experiment (7,8) as a between groups factor was run. Significant main effects of Position $F(5,220)=7.44$,

$p<0.001$, $\eta_p^2=0.14$ and Load $F(1,44)=7.53$, $p<0.009$, $\eta_p^2=0.15$ were revealed. The interaction between Position and Load was significant $F_{G\text{-}G}(5,220)=3.19$, $p<.02$, $\eta_p^2=.068$. The between groups analysis revealed a significant difference between Experiment 7 and 8 $F(1,44)=7.51$, $p<0.009$, $\eta_p^2=0.15$.

A between groups ANOVA was conducted on the RTs to low load displays for Experiments 7 and 8, showing that there was no significant difference between the low load conditions $F=1.55$, $p=.18$, nor was there a between groups effect $F=1.94$, $p=.17$. A mixed ANOVA testing Position and Experiment (7, 8) for the high load displays gave a significant effect for position $F_{G\text{-}G}(5,220)=7.07$, $p<0.001$, $\eta_p^2=0.14$. The Between groups test was significant $F(1,44)=14.30$, $p<0.001$, $\eta_p^2=0.25$. The low load displays in Experiment 8 elicited a smaller level of negative priming (9ms smaller). The difference was not significant, but may still reflect a change caused by the inclusion of words in the experiment. Theoretically the inclusion of words may have encouraged participants to focus their attention more finely during the word displays. This effect may have carried over to the low load displays.

Discussion

The slower RTs to word primes in Experiment 8, as compared to Experiment 7, suggests that the inclusion of word level information increased the difficulty of the letter identification task: which is also supported by the error data. This cost of identifying letters in a word is incongruent with the WSE literature; however, there have been examples of a cost previously reported (Krueger & Shapiro, 1979). It is possible that the short stimuli durations encouraged participants to use short term memory, in which case the word information can be used in a top-down manner to facilitate recall. If this is the case, there should have been fewer errors. In contrast, there were more errors in the Experiment 8 word displays, compared to the Experiment 7 high load displays.

The pattern of RTs to the prime displays shows a small range between the different letter positions. This may reflect the letters receiving processing as part of a whole object. If the letters are perceived as part of a whole object, the letters themselves will be harder to discriminate, and there should be smaller position effects, as each position gains from its lexical membership. The predictions of no priming for distractors and increased priming for repeated targets were supported. It is concluded that these results reflect the need for a higher level of focussed attention to discriminate letters when searching within a word.

In contrast to the paper by Brand-D'Abrescia and Lavie (2007), there was no negative priming following ignored displays when the target was embedded in a word. Indicating that words do not elicit similar demands of resources compared to low load displays. This can be accounted for through Brand-D'Abrescia and Lavie's (2007) study using longer stimuli durations, and a two letter identification task.

Experiment 8 used a three letters identification task, which would have led to a higher cognitive load and a harder identification task.

The results of Experiment 5 (searching for letters in high frequency words is more efficient than low frequency words) and Experiment 6 (Searching for letters in words is faster and more efficient than searching for letters in non-words), would have led me to propose that the identification of letters in a word should be easier than the identification of letters in a non-word. However, the Experiment 8 word displays elicited slower RTs than the letter strings of Experiment 7.

In terms of perceptual load theory the lack of negative priming for word displays means that the displays are high load. This is in contrast to Brand-D'Abrescia and Lavie who found that words are low load. This experiment used a three choice letter identification which is much harder than a two choice. The letters may also be harder to discriminate as 'r' and 'n' share several components.

It is possible that the experiment design introduced an undesired confound in that there is a difference in the lexicality of the load conditions. The low load condition contained a single letter, which means that any results may be due to lexicality and not load. Future work could repeat this experiment using short words for the low load displays. The main difficulty in running such an experiment would be the word frequencies of the short words. Shorter words in English usually have a much higher written frequency than longer words. When this is taken into account, while considering the difficulty of constructing a word list that contains words with only one of the three target letters, such a word list will be incredibly hard to construct.

So, when attention is focussed within a word or letter string there are increases in the facilitation of attended letters, and attenuation of the inhibition on ignored letters. An aspect of Experiments 7 and 8 is the need to move attention spatially. The next two experiments investigate the effect of removing the need to orient attention across displays. This should allow participants to focus more effectively.

Experiment 9

Yantis and Jonides (1990) and Johnson et al. (2002) suggest that a cue of 100% predictability should allow participants to focus attention to the maximal level. In Experiment 9 the targets were presented at fixation 100% of the time. So, in the High Load condition participants were still presented with the same perceptual load as in Experiment 7. This means that, in Experiment 9, there is no need to spatially search for the target letter, instead participants only had to identify which of the letter targets was present in the display.

As there has been such a pronounced search pattern in both letter strings (Experiment 7) and words (Experiment 8), it seems likely that perceptual load modulates the way spatial attention works in the selection processes. It is predicted that the typical search pattern associated with letter strings will be interrupted. The RTs should show a pattern that is flatter than that seen in Experiment 7, as the lateral inhibition from distracting letters will have been reduced. The priming from the ignored distractors will be affected as a result of task demands focussing attention to fixation.

If perceptual load theories are correct then the high load condition should still elicit minimal priming from the distractors, and the low load condition, which is not exhausting the limited capacity of attention, should elicit negative priming from the distractors. However, if Yantis and Jonides' (1990) theories are correct, highly focussed attention should have an early locus of selection, resulting in minimal priming from both perceptual load conditions. It may be intuitive that a fixed target location will reduce the perceptual load. However, as there is no published experimental evidence demonstrating this, Experiment 9 directly manipulates this variable. If there is a reduction in perceptual load due to a fixed target location this must be through some sort of focussing to the target location. If no focussing takes place, one could expect the same perceptual load effects as found in Experiment 7.

Method

Stimuli and Procedure: Experiment 9 used exactly the same stimuli as Experiment 7, however instead of the letter strings being presented in the fixed locations across the centre point, the string was shifted to the left or right so that the target letter was always presented at the centre (see Figure 20).

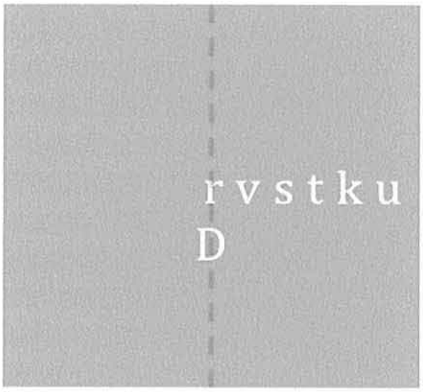

Figure 20: an example of a high load prime display in Experiment 9. The lower case letter target are always presented at the centre of the screen, in the example, the letter 'r' is placed on the invisible vertical-central line represented by the dashes.

Results

Prime Displays: 6 paired sample t-tests were conducted on the data comparing each high load position with the central low load position. As can be seen from the data there was a tendency for central fixation positions to be responded to slower than external positions, although this trend did not reach significance.

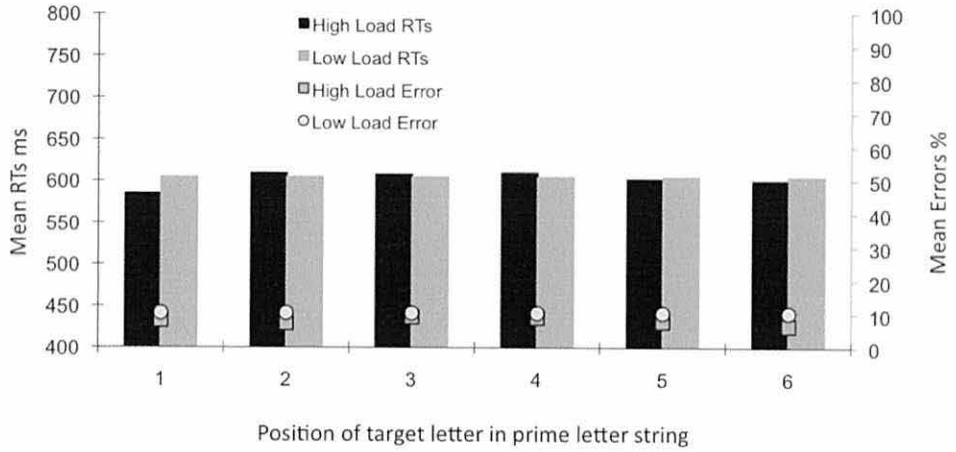

Figure 21: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for perceptual load vs. target position in prime displays in Experiment 9.

Error rates to Prime Displays: 6 paired sample t-tests were conducted on the data comparing each high load position with the central low load position: no significant differences were found.

Probe Displays: There were no position effects in the probe RTs. A grand repeated measures ANOVA for all conditions was conducted and a significant effect of priming was found $F_{G-G}(2,66)=102.933$, $p<.001$, $\eta_p^2=.76$. A second set of analyses was conducted comparing control and ignored and control and attended conditions. A repeated measures ANOVA 2(Load: High, Low) x 2(Priming: Ignored, Control) and a significant effect was found for priming $F(1,33)= 8.28$, $p<0.007$, $\eta_p^2=0.20$. Load and the interaction between Load and Priming did not produce a significant effect. A repeated measures ANOVA 2(Load: High, Low) x 2 (Priming: Control, Attended) found a significant effect for priming $F(1,33)=109.25$, $p<.001$, $\eta_p^2=.77$. The effect for Load was not significant ($p=.22$), but the interaction between Load and Priming was marginally significant ($p=.065$), showing a trend of an increased priming effect for high load conditions, although this positive priming was significant for both load conditions ($t(33)=9.04$,$p<.001$, for low load, and $t(33)=9.79$,$p<.001$ for high load).

Table 3: Mean Rts and priming for Experiment 9 with standard deviation and percentage error. The asterisks signify a significant difference in the *t*-test.

	Ignored	C-I	Control	C-A	Attended
Low	**583**	-10	**573**	81*	**492**
Sd	101		96		90
%E	15		15		12
High	**584**	-13	**571**	97*	**474**
Sd	109		96		72
%E	11		12		9

Error rates to probe displays: A repeated measures ANOVA found a significant effect of Priming $F(2,66)= 12.36$, $p<0.001$, $\eta_p^2=0.27$, and a significant Load $F(1,33)=5.51$, $p<.025$, $\eta_p^2=.14$. There was not a significant interaction between Load and Priming ($p=.8$).

Discussion

The most obvious difference in the RTs to the primes in Experiment 9 is that there were no position differences. The lack of differences was true for both high and low load displays. The fact that the position effects disappeared, suggests that the rest of the letters did not interfere with the identification of the target letter. This suggests that it is not the number of letters per se, that increases the load in these experiments, but the need to actively search amongst non-target items. Because there were no flanker effects in the prime data, attention can be focussed effectively, when participants do not need to move attention (as suggested by Yantis and Johnston, 1990). Alternatively, the difference between RTs to prime displays in Experiments 7 and 9, may be due to the differences in visual resolution the targets received. In Experiment 7, the targets further from fixation would not have benefited from the efficient visual resolution targets near fixation received. In Experiment 9, all the targets benefited from the excellent visual resolution at fixation. If it were, purely, a case of visual resolution, it is expected that the RTs to the central target positions in Experiment 7, would have been very close to the RTs in Experiment 9. However, the RTs in Experiment 7, to the low load central position targets, are 20ms slower, and the RTs to the high load central position targets are slower again (140ms). This would suggest that the faster RTs in Experiment 9 are due to more than visual resolution. The simplest explanation is that attention has been focussed effectively thus reducing the interference of flankers.

That there was a trend to negative priming elicited in the high load condition, is possibly due to spatial attention expanding to envelop all the letters presented on the screen. However, as there was a reduction in the NP from the low load displays it is likely that the effects are due to the focussing of attention and an increase in slippage occurring in the high load conditions. If the RT patterns to high load displays are the result of a reduction in load (caused by the fixed target location), it would be expected that the low load displays in Experiment 9 would have elicited a similar pattern to the low load displays in Experiment 7.

It must be considered that the predictability of the target location allowed for the better focussing of attention and so a reduction in the amount of slippage occurring. In the case of high load, the focussed attention produced a low load display with flankers that encouraged a perceptual focus. Experiment 10 examines the predictable location presentation with English words.

Experiment 10

In this experiment the same word stimuli as Experiment 8, are presented in a manner where the target letter always appears at the fixation point. This was achieved by moving the word left or right horizontally, so that the target letter was positioned at the centre of the screen. It is expected that the priming effects found in Experiment 10 will be different to those found in Experiment 9. It is predicted that there will be a position effect in the primes, due to participants being unable to stop seeing word: even though there is no benefit from doing so. The benefits of word items in Experiments 5 and 6, and the costs associated with words in Experiment 8 indicate that, even though the word information should be easily ignored, the effects of words may still be seen on participant RTs.

Method

Stimuli and Procedure: Experiment 10 used exactly the same stimuli as Experiment 8, however instead of the words being presented in the fixed locations across the fixation point the words were shifted to the left or right so that the target letter always appeared at fixation (see Figure 21).

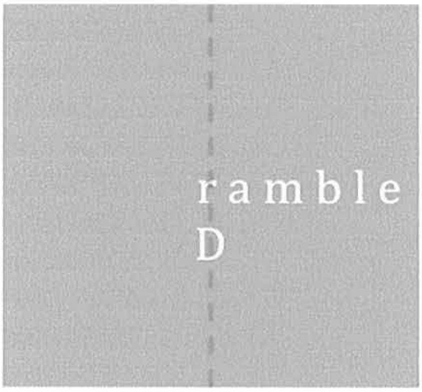

Figure 21: an example of a Word load prime display in Experiment 10. The lower case letter targets are always presented at the centre of the screen. In the example the vertical dashed line represents the mid-point on which the target letter 'r' is placed.

Results

Prime Displays: After trimming the average for the low load displays was compared against the Word display positions through 6 paired t-tests. Significant effects were found for the 2^{nd} $t(22)= 3.60$, $p<.002$, 3^{rd} $t(22)= 3.65$, $p<.002$, 4^{th} $t(22)= 3.17$, $p<.005$, and 5^{th} positions $t(22)= 2.73$, $p<.02$. The analysis was conducted with 6 paired t-tests as there was only one low load target position (central), to compare with the Word load target positions.

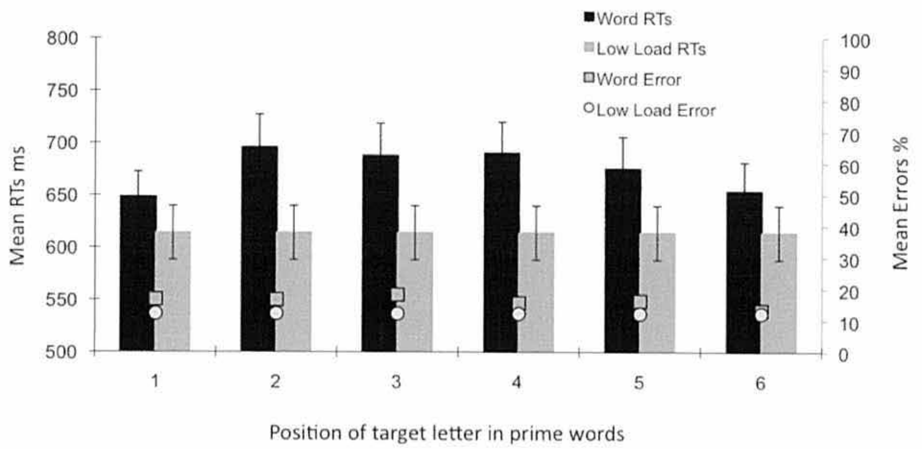

Figure 22: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for Perceptual load vs. target position to prime displays in Experiment 10.The bars represent the standard error.

Analysis of error rates in the primes: 6 Paired t tests were run for each position comparing the Non-word load displays and Word displays. Significant differences were found at the 1st ($t(22)=2.13$, $p<.05$), 3rd ($t(22)=2.32$, $p<.03$) and 5th ($t(22)=2.16$, $p<.05$) positions.

Probe Displays: There were no position effects in the probe RTs. A grand repeated measures ANOVA was run on all the conditions which revealed a significant main effect for Priming $F(2,44)=86.25$, $p=.0001$, $\eta_p^2=.80$, the main effect for load was not significant ($p=.36$), and the interaction between load and priming was significant $F(2,44)=9.49$, $p=.001$, $\eta_p^2= .30$. A repeated measures ANOVA for Load (Word, Non-word) and Priming (Control, Ignored) was run which did not reveal any significant effects after adjustments had been made. The repeated measures ANOVA for Load (Word, Non-word) and Priming (Control, Attended) found a significant effect of priming $F(1,22)=91.52$, $p<.001$, $\eta_p^2=.81$, but not load and a significant interaction between load and priming $F(1,22)=17.18$, $p<.001$, $\eta_p^2=.44$. Paired t-tests revealed significant differences between the attended and control conditions low displays $t(22)=6.41$, $p<0.001$, and high displays $t(22)= 10.93$, $p< 0.001$ only.

Table 4: Mean Rts Standard deviations (Sd) and percentage errors (%) to the probe displays in Experiment 10.

	Ignored	C-I	Control	C-A	Attended
Non-word	**604**	-10	**594**	95*	**498**
Sd	141		136		88
%E	15		13		12
Word	**635**	-7	**627**	148*	**479**
Sd	130		123		72
%E	19		21		15

Analyses of probe display errors: A repeated measures ANOVA was run on the error rates to the probe displays 2(Load: Word, Non-word) X 3(Priming: Control, Ignored, Attended). A significant effect was found for priming $F(2,44)= 7.4$, $p<0.002$, $\eta_p^2=0.26$ and a significant effect for load $F(1,22)= 5.25$, $p=0.04$, $\eta_p^2=0.19$. The interaction between priming and load was not significant ($p=.19$). The Control and Ignored analysis revealed a significant main effect of load only $F(1,22)=6.39$, $p<.02$, $\eta_p^2=.23$ (Priming, $p=.9$, Priming x Load, $p=.2$) The Control and Attended analysis revealed a marginally significant effect of Load $F(1,22)=5.32$, $p<.03$, $\eta_p^2=.19$, and a significant effect of Priming $F(1,22)=8.47$, $p<.009$, $\eta_p^2=.28$, and a marginally significant interaction $F(1,22)=4.51$, $p<.05$, $\eta_p^2=.17$. The paired samples t-tests comparing priming for each load level revealed a significant effect for the Word displays between the Control and Attended conditions only $t(22)=3.20$, $p<.005$.

Discussion

Although the presentation style was the same as Experiment 9, there was a trend for the word displays to elicit slower RTs than the low load displays. So, whereas in Experiment 9 there were no differences between high and low load displays, the word information in Experiment 10 still had an effect.

The shape of the RT pattern curve is inverted compared to Experiment 8. This reflects the same shape as found in OVP experiments where the trend for faster RTs to exterior letter positions is evident. The shape also suggests that the u-shape found in experiment six is very likely due to fixation effects and that if the fixation position was varied away from the word the u-shape would be replaced with an n-shape curve.

This pattern of RTs must be an effect of the word information, which is problematic for slippage theories. There are several possibilities that can be considered, first, is that the RT pattern is the result of slippage from the fixation point. It may be that in using just one location, in violation of Yantis and Jonides (1990) movement rule, slippage has been encouraged. The second possibility is that attention was efficiently focussed and that the word information has affected the RTs through leakage. If this is the case then slippage theories of selection are wrong, although they can appeal to the violation of the movement rule mentioned above. The final possibility offered is that the letters in a word form an object and attention spreads across the letters as they would in an object. The fact that words altered the pattern of RTs, while the non-words in Experiment 9 did not, is supportive of the theory that words should be viewed as objects, or at least have some of the properties of objects.

The loss of priming for the ignored condition indicates that there is less processing of the irrelevant letters in both the word and low load conditions. Compared to Experiment 9, this is indicative that attention is better focussed when the letters form a real word, and that slippage is less likely to occur. This reduced NP is accompanied by significant positive priming for attended letter targets. Indeed it could be considered that the word information provides extra excitation for detected attended targets that is noticeably less following low load displays. Experiment 11 seeks to present the stimuli in such a way as to make the processing of word information less likely.

Experiment 11

In this Experiment an attempt is made to prevent any processing of the word information, by presenting the stimuli vertically. The word information is still available, but the vertical orientation should make focussing easier, as the word information takes longer to process. This is due to a change in the amount of information that can be attended to. The visual span is the region around fixation that useful information is perceived (Laarni, Simola, Kojo, & Risto, 2004). The vertical directions have smaller visual spans, which are produced by the visual acuity falling faster in vertical directions than the horizontal direction (Curcio & Allen, 1990). Because English readers have had no need to develop their vertical para-foveal vision (vision in the region just outside the fovea) it is possible that this results in a poorer ability with vertically presented words (Laarni, Simola, Kojo, & Risto, 2004).

Yu, Gerold, Park, and Legge (2008) found that visual span is smaller for vertically orientated words (as compared to horizontal) resulting in slower reading speeds. Yu et al. (2008) presented words horizontally, rotated 90° clockwise to a vertical position, and presented as upright letters arranged in a vertical orientation (marquee). The fastest reading speeds were recorded for the horizontal words, then the rotated words and finally the marquee words.

By arranging the letters in the words in a vertical orientation similar to the marquee displays used by Yu et al. (2008) the likelihood of processing the word information should be reduced. It is expected that there will be no difference, between words and single letters, in the RT patters to prime. It is also expected that there will be no effect of load (words or single letters) on the probe displays, as participants will be able to focus efficiently and the word information will not be available quickly enough to interfere with the task.

Method

Participants: 14 undergraduate students from Bangor University, selected for English first language and normal or corrected to normal vision, took part in this experiment that lasted approximately 1 and a half hours. The participants received course and printer credits for their time.

Stimuli: The stimuli list is identical to that used in Experiment 10. However, instead of the letters forming words horizontally across the screen, in this experiment they form words vertically down the screen.

Design: Experiment 11 is a repeated measures 2 (Load: Non-word, Word) X 3(Priming: Control, Ignored, Attended) experiment. The conditions were randomly mixed within two blocks using the *E*-prime program.

Procedure: The durations were exactly the same as the experiments 7-10, the only difference was the presentation of the stimuli vertically down the midline (see Figure 23).

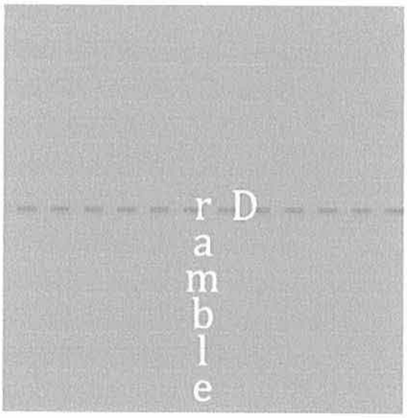

Figure 23: A graphic depiction of the stimuli orientation used in Experiment 11. The target letter (in this example 'r') always appears at the centre of the display. The other letters in the word are presented on the vertical midline, with the first letter of the word at the top.

Results

Prime Displays: After trimming, the average for the Non-word displays was compared against the Word display positions through 6 paired t-tests. No significant effects were found ($t<.38$, $p>.70$).

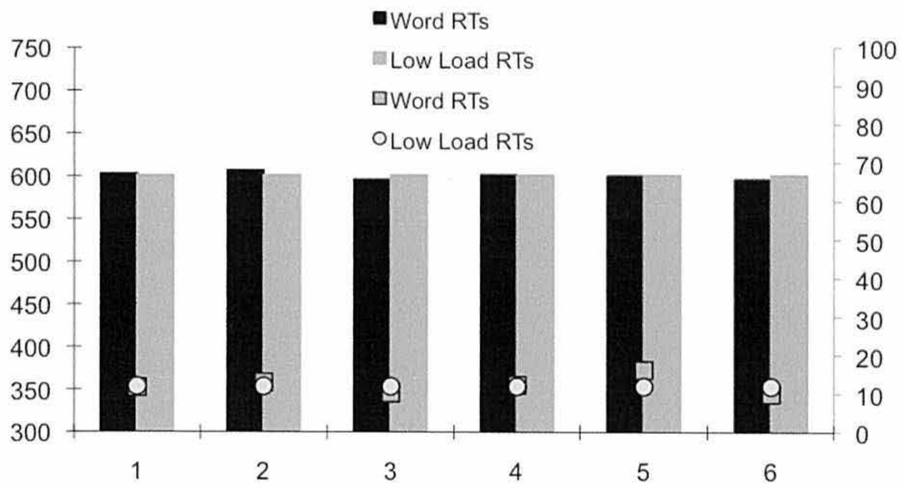

Figure 24: Mean RTs in ms (columns) and mean error rates in % (Squares and circles) for Perceptual load vs. target position in prime displays for Experiment 11.

Analysis of error rates in the primes: 6 Paired t tests were run for each position comparing the Non-word displays and Word displays. No significant differences were found ($t<1.1$, $p>.25$).

Probe Displays: There were no position effects in the probe RTs. A grand repeated measures ANOVA was run on all the conditions which revealed a significant main effect for Priming $F(2,26)=53.91$, $\underline{p}=.0001$, $\eta_p^2=.81$, the main effect for load was marginally significant ($F(1,13)=3.79$, $p=.073$, $\eta_p^2=.23$), and the interaction between load and priming was not significant $F=1.04$, $p=.37$. A repeated measures ANOVA for Load (Word, Non-word) and Priming (Control, Ignored) was run which did not reveal any significant effects. The repeated measures ANOVA for Load (Word, Non-word) and Priming (Control, Attended) found a significant effect of priming $F(1,13)=45.69$, $p<.001$, $\eta_p^2=.78$, and a marginal effect for load $F(1,13)=4.18$, $p=.06$. $\eta_p^2=.24$. The interaction between priming and load was not significant ($F=1.45$, $p=.25$). Paired t-tests revealed significant differences between the attended and control conditions for Non-word displays $t(13)=4.61$, $p<0.006$, and Word displays $t(13)= 7.99$, $p< 0.001$ only.

Table 5: Mean RTs (ms) and SDs and error rates (%) for probe displays in Experiment 11.

	Ignored	C-I	Control	C-A	Attended
Non-word	**616**	-2	**614**	103*	**512**
Sd	137		134		118
%E	14		13		9
Word	**591**	2	**593**	125*	**468**
Sd	106		116		85
%E	15		13		9

Analyses of probe display errors: A repeated measures ANOVA was run on the error rates to the probe displays 2(Load: Word, Non-word) X 3(Priming: Control, Ignored, Attended). A significant effect was found for priming $F(2,26)= 13.9$, $p<0.0001$, $\eta_p^2=.52$, there was no effect of load ($F=.02$, $p=090$). The interaction between priming and load was not significant ($F=.007$, $p=.99$). The Control and Ignored analysis revealed no significant effects. The Control and Attended analysis revealed a significant effect of Priming $F(1,13)=15.16$, $p<.002$, $\eta_p^2=.41$ The effect of load ($F=.04$, $p=.85$) and the interaction ($F=.0003$, $p=.99$) were not significant. The paired samples t-tests comparing priming for each load level revealed a significant effect for the Word ($t(13)=2.47$, $p<.03$) and Non-word ($t(13)=2.93$, $p<.02$) displays between the Control and Attended conditions.

Discussion

The lack of any effect in the RTs to prime displays between word and Non-word conditions suggests that, when orienting the letters vertically, the word information is no longer of benefit to letter identification.

The complete lack of NP for the ignored condition, following both word and Non-word displays, suggests that the distractor letters were not processed. The faster RTs in the probes following search for letters in words possible reflects the WSE. If this is the case the word information had an effect on the probes, while there was no observable effect in the primes.

The now standard greater facilitation to attended letters in the high load/word displays was present, however a comparison of the differences between the attended and control conditions for low and word displays did not reveal a significant difference (t=1.2, p=.25) which suggests that the greater facilitation was not due to the word information. This is supported through the analysis of the priming differences for low and high load displays in experiments 7 to 10. Experiments 7 and 9 ($t(22)$=2.26, p=.03; and $t(22)$=1.91, p=.07 respectively) that did not contain word information elicited smaller effects than experiments 8 and 10 ($t(22)$=4.9, p=.00007; and $t(22)$=4.15, p=.0004 respectively) which did contain word information.

General Discussion experiments 7-11

The goal of this section of the thesis was to determine the priming effects of searching for single letters within words. The second goal was to determine if there were target position effects that could affect levels of priming for single letters. The third goal was to examine the role of spatial attention during LS, when the target letter appears on its own, in letter strings and in English words. Finally, the effect of presenting targets in words on perceptual capacity resources in the hope of shedding light on the effect of perceptual load on stimuli selection.

Priming effects in terms of perceptual load

The initial replication, of the standard perceptual load priming in Experiments 7 and 8, supports Load theories. An increase in the number of items presented visually left no capacity for distractor items to be processed. However, the results from Experiments 8 and 9, which contain an identical number of display items to Experiments 6 and 7, show that merely presenting items in a display is not enough. There was a decrease in the level of NP elicited from distractors when participants did not need to search for the target letter spatially. The results reported here suggest that there is either some interplay between the movement of spatial attention and perceptual load effects, or that there is another answer to the early/late debate than that suggested by Lavie (2005); for example slippage theories (Lachter et al., 2007), or competition-based selection (Toralbo & Beck, 2008).

The lack of NP in Experiment 9, and the increase of positive priming for attended targets, suggests that attention was more sharply focussed within a word than within a letter string. As there was also an increase in the positive priming elicited from attended targets in Experiment 8, as compared to Experiment 7, it is concluded that attention was more sharply focussed within the words. Although non-significant, the ignored distractors flanking words in Experiment 8 also elicited less NP than the ignored distractors flanking letter strings in Experiment 7.

There are marked differences between the results reported here and those reported by Brand-D'Abrescia and Lavie (2007). They concluded that words are processed more easily and leave spare capacity for the processing of distractors. There are differences between their experiments and those reported in this thesis. The facilitation measured by Brand-D'Abrescia and Lavie was simultaneous, where the distractor presented could be identical to the target letter. The experiments reported here presented the primed letters in a subsequent display. The differences between Experiments 7-11 and those reported by Brand-D'Abrescia and Lavie (2007) mean that comparisons are hard to make. Further experiments are needed to shed light on why there are differences in priming between simultaneous and delayed presentations. However, as there are differences between simultaneous and delayed priming designs for the LS experiments, it is not surprising that differences have been found in letter identification experiments.

In this series of experiments the inclusion of word information failed at any point to elicit RT or error patterns that could be used as evidence of lower resource demands when LS occurs in words. It should be considered that the results reported by Brand-D'Abrescia and Lavie (2007) are the result of a failure to focus attention, effectively resulting in word information being of benefit in a top-down manner. Such effects should not be used in support of theories suggesting that word information exacts a lower resource load than letter strings, without first showing that attention has been efficiently focussed.

Positive Priming.

The type of priming that is increased following LS in words is the faster responses to previously attended letters in the probe displays. While this effect is present for non-words in Experiment 7, it disappears in Experiment 9, while it is present at higher levels in Experiments 8 and 10. The increased attended priming following LS in words could be either WSE, or an increased focus of attention required during LS when the letters form a word. If the results of Brand-D'Abrescia and Lavie (2007) can be assumed to have utilised attentional mechanisms, in the same way as the Experiments reported here, the effect can be attributed to a WSE. Further investigation is needed to determine if the focus of attention is efficiently focussed in their experiments. If the similar results were found with a 100% predictable target location then the priming reported here can be attributed to WSE only, and not to excitation occurring within the attentional window. However, should the priming be due to excitation this would be incompatible with current perceptual load theories of selection.

Searching for letters in words

The ability for the word information to distract is demonstrated through its existence in Experiment 10. The fact that it takes the manipulations in Experiment 11 (Vertical orientation and spatial predictability) to extinguish the distractor effects in the primes, is a testament to the automaticity of a practised task such as reading.

Position effects

None of the experiments revealed a position effect on the subsequent probe RTs and error rates. It was expected that there would be effects from either the exterior target positions (due to a lack of lateral masking) or the OVP (as previous research using the Stroop effect has demonstrated effects from this position). The lack of letter priming effects from different positions suggests that the OVP effect found by Parris, Sharma, and Weekes (2007) is a semantic or word level effect that does not affect the letter level. That the meaning was irrelevant in these experiments is possibly why there are no position effects to report. It remains to be seen if semantic information is relevant whether there will be an effect of position on the priming of subsequent words.

Attentional focus: letters, strings and words

The results of Experiments 6 to 10 do not support the WSE and, in fact, offer evidence of a reversal to the WSE, where letters are identified slower and less accurately in words than on their own, and in letter non-words. These findings are congruent with a growing body of research that disputes the WSE (Mezrich, 1975; Johnston & McClelland, 1980; Krueger & Shapiro, 1979; Krueger & Stadtlander, 1991) and suggest that letter information is simply inferred from the familiar context. Two results require highlighting: first, that word information is resilient and can only be extinguished (in the context of these experiments), by presenting the stimuli in an unfamiliar orientation, with short durations, and a highly focussed letter level task (Experiment 11); second, that word information encourages equal processing of all letter positions when that word information is in a familiar context (Experiment 8).

Conversely, focussing attention within letter strings results in RT patterns that are less equal over target positions (Experiment 7), unless attention is focussed at a predictable location (Experiment 9). The difference between identifying a letter on its own and identifying a letter in a string, is subject to the predictability of target location and whether that letter forms part of a larger object. When participants identify letters in letter strings, under conditions of 100% target location predictability, there are no significant differences between low load and high load displays.

Experiment 11 revealed some unexpected results for letter identification at word and single letter levels. First, lexicality had no effect on RTs in the primes or the probes, although there was a non-significant trend for probes, following words, to be faster for the first time in this series of experiments. Second, there was absolutely no NP from the low load displays, when it had been expected that there would have been an increase compared to horizontally presented displays. It was assumed that letters would have greater inhibition for items above and below, as while reading information above and below the place of fixation is irrelevant. So, by presenting the distractors to the left and right of the target it was expected that there would be an increase of processing, and subsequent inhibition, due to items on the same line receiving more processing (as they were potentially relevant to the context). Prime RTs were identical between Experiments 9 and 11, as were the error rates, which suggest that the task difficulty was equivalent, but that attention is focussed differently to items above and below, than it is to items appearing to the left and right of target position (when position is predictable).

Slippage vs Load

The results from these load experiments suggest that when attention can be efficiently focussed, the NP associated with low perceptual load conditions (e.g. Lavie & Fox, 2000) is completely extinguished. As the level of perceptual load in Experiment 11 is identical to that used by Lavie and Fox (2000), for both the low and high load displays (with the addition of word level information) *load theory* is unable to account for this data. According to Load theory any item in the visual display that is within the processing capacity should be processed, and irrelevant items actively inhibited. Load theory does not at any point include a focussing mechanism or attentional window that prevents the processing of unattended items. The data of Experiment 10, and to a lesser extent Experiments 8 and 9, fit better with models of selection that utilise an attentional window to filter items on display, such as the spot light (Posner, Snyder, & Davidson, 1980) and zoom lens models (Eriksen & Murphy, 1987; Eriksen & St. James, 1986).

The results of these experiments also show an increase in subsequent activation, through greater repetition priming for high load conditions. The repetition priming is larger when the letters form real words (but only when the word information is presented in a familiar orientation). Yantis and Johnston (1990) suggest that higher processing loads should encourage better focussing of attention, which may result in excitation at the focus point. Of the seven suggestions for focussing attention, the current research meets the suggestions for, predictable location; the level of processing load; the avoidance of circular displays with the target in the centre; lack of crowding of stimuli; and that targets should not appear more than once in a display. The experiments reported here fail to move the target position and to change the stimulus-response mapping. In terms of moving the position of the target Johnston et al. (2002) raised the possibility that the use of a cue to predict target location added to the load of the task, and possibly interfered with their results. The lack of varied stimulus response mapping may have had a consequence for the results, but the use of three possible targets occurring randomly throughout the experiment should have prevented the creation of just one response map set.

In brief, there is excitation of items within the focus of attention and inhibition of items that are processed but are irrelevant to the task, but only when attention has not been efficiently focussed (even in cases of low perceptual load).

Summary experiments 7-11

Lavie and Fox's (2000) study was successfully replicated, and in addition large amounts of priming for attended targets was revealed. The inclusion of word information in Experiment 8 did not reduce the resources required by high load displays. In fact RTs to the primes were slower for words than they had been for letter strings in Experiment 7: a reverse WSE effect.

Interestingly, identifying a letter in a word results in greater priming for the attended target when it is subsequently repeated. The priming was 40ms greater than that for letter strings, which is interpreted as meaning that attention is more focussed under high load, and that the greater the load the more excitation there is.

The effect of non-word flanking letters in high load displays can be removed using a 100% predictable target location. The RT data from Experiment 9 supports the notion that participants were able to efficiently focus their attention, which made the task easier. This had two effects, first a reduction in negative priming following low load ignored displays, with an approximately equal increase in negative priming from high load displays. Second, the facilitation for attended targets in the high load condition is attenuated. It can be concluded that in this instance high load displays were identical to low load displays an effect that is incongruent with perceptual load theory.

Presenting word information in the same way as Experiment 9 reveals that it is not as easily filtered. There are effects in both the primes and probes and the attended facilitation is relatively unaffected.

Section 3

Chapter 6: Experiment 12

Stolz, Besner, and Carr (2005) stated "harnessing semantic memory is like herding cats- without considerable constraint associations tend to come and go their own way in independent fashion". It would be difficult not to agree that understanding semantic priming is difficult, especially in terms of the PT-effect. However, it is perhaps not yet time to give up on what is potentially still a useful tool. The twelfth experiment reported in this thesis puts into practice some of the knowledge gained from the previous experiments.

This experiment focuses on the effects of the effects of presenting targets at different positions on the subsequent priming of related probe words. The work of Parris et al. (2007) demonstrated that targets presented at the OVP , during a single coloured letter Stroop experiment, elicited a larger than normal Stroop effect. It is expected that by presenting targets at the OVP, in the prime words of a prime-task experiment, a significant difference between related and unrelated probe words will be found.

This experiment also includes a repeated condition, where the same word appears in the prime and probe displays. The inclusion of repeat trials is made, so that Besner and colleagues' model of semantic priming can be tested. If their model is correct there should be priming for the repeat condition only.

Method

Participants: 15 participants from Bangor University, School of Psychology voluntary participation panel undertook this experiment in return for course credit and printer credit (worth £5 for each hour) in compensation. All the participants met selection criteria of normal or corrected to normal vision, non-dyslexic, and English first language.

Apparatus and Stimuli: The stimuli for Experiment 12 were taken from the Kucera and Francis's (1967) word database and were controlled for concreteness, frequency, length, and letter position (see Appendix L). The stimuli lists were compared across conditions to ensure that the standard scores for each stimuli list were equivalent. Non-word stimuli were selected from the English Lexicon Project (Balota et al., 2002). The target words were always presented in upper case and the letter cues were always presented in lower case. The visual angles were 0.31° for letter heights and 0.24° widths with distances of 0.18° between stimuli. The stimuli were presented in silver on a black background and the participants completed the experiments in a darkened room.

Design: A repeated measures design was used with conditions of Relatedness (Related, Unrelated, and Repeated), and Position (First, OVP, ROM, Last). In addition a third condition of Search-type (Positive, Negative) was coded at the start of the experiment and analysed as both part of position and as a separate condition.

Procedure: The procedure was close to that used in Experiment 1 please see Figure 16 for a graphic depiction of a complete trial. The order of stimuli presentation was randomly assigned by *E*-prime.

Data Analysis and Error Rates: The RT data was trimmed to include only those trials slower than 2.5 SDs below the mean and faster than 2.5 SDs above the mean. The data from those participants achieving an average of less than 70% correct responses, after trimming, were excluded from further analyses, resulting in the loss of data from one participant.

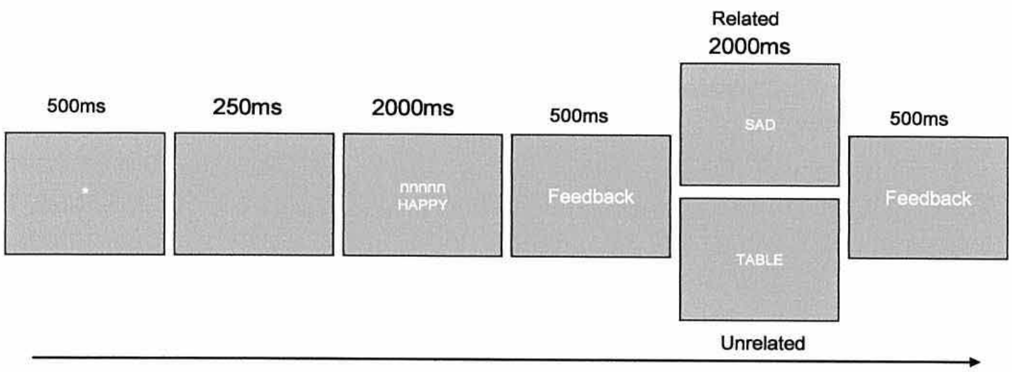

Figure 25: Graphic depiction of a complete trial in Experiment 12.

Results

Analysis of Prime RTs: A repeated measures ANOVA was conducted on the average RTs to the different positions and the negative search trials (Negative, First, OVP, ROM, and Last). Negative searches were on average slower (600 ms) than all Positive search positions (First: 551 ms, OVP: 567 ms, ROM: 576, Last: 568 ms). A significant main effect of position was found $F_{G\text{-}G}(4,52)=13.44$, $p=.00001$ $\eta_p^2=.51$(see figure 17). The RT pattern was significantly Linear $F(1,14)=8.80$, $p=.02$, $\eta_p^2=.40$.

Analysis of Prime Error %: A repeated measures ANOVA was conducted on the error data for the same conditions as the RT data which did not reveal a significant effect.

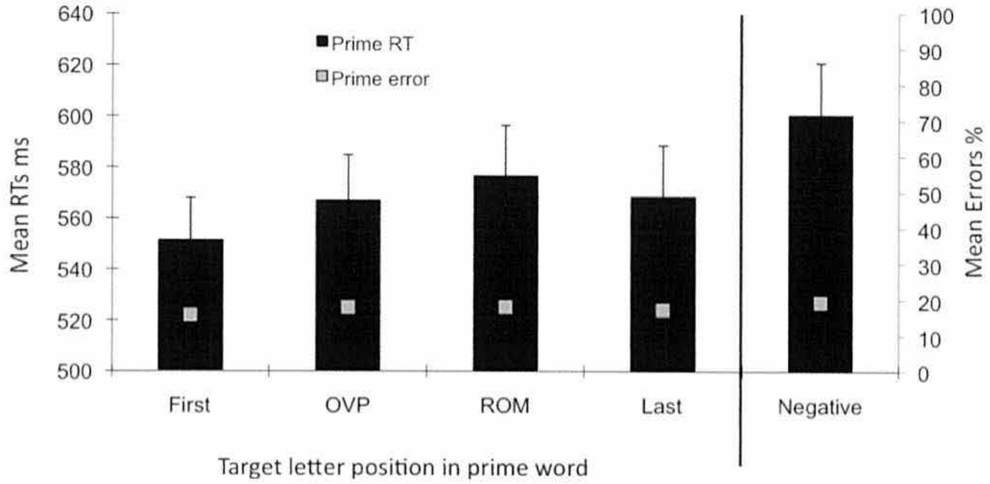

Figure 26: Mean RTs in ms (columns) and mean error rates in % (grey squares) for Search-type and Position in prime displays in Experiment 12.The error bars represent the standard error.

Analyses of Probe RTs: The mean RTs were analysed through a repeated measures ANOVA with the conditions of Relatedness (Related, Repeated, Unrelated), and Position (First, OVP, ROM, and Last). A significant main effect of Relatedness, with Unrelated probes eliciting the slowest RTs (566 ms), Related probes eliciting faster mean RTs (548 ms) and Repeated probes producing the fastest mean RTs (508 ms) $F(2,28)=22.38$, $p=.00001$, $\eta_p^2=.62$. There was no effect of Position $F=1.38$, $p=.26$ (First: 542 ms, OVP: 536 ms, ROM: 538 ms, Last: 548 ms). The interaction between Relatedness and Position was significant $F(6,84)=2.22$, $p=.048$, $\eta_p^2=.14$. The analysis of differences at the OVP between related and unrelated probes revealed a priming effect of 53 ms $F(1,14)=13.58$, $p=.003$, $\eta_p^2=.50$ (see figure 18).

Analyses of Probe Errors: The error rates to probe displays were analysed in the same way as the initial probe RTs analysis (Relatedness X Position). A significant main effect for Relatedness $F(2,26)=8.16$, $p=.002$, and Position $F(3,39)=3.40$, $p=.027$, and a significant interaction between Relatedness and Position $F(6,78)=3.24$, $p=.007$.

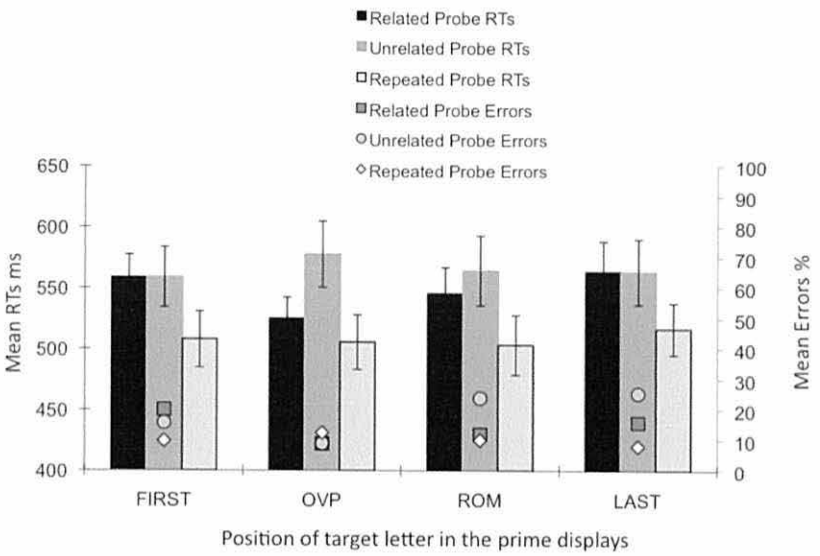

Figure 27: Mean RTs in ms (columns) and mean error rates in % (squares, circles and diamonds) for Relatedness and Position in probe displays in Experiment 12.The error bars represent the standard error.

A second round of analyses was conducted on the probe RT data examining the interaction between Search-type (Positive, Negative) and Relatedness (Related, Unrelated, and Repeated). There was a marginally significant effect of Search-type (Positive = 535 ms, Negative = 550 ms) $F(1,14)=4.28$, $p=.058$, $\eta_p^2=.23$ and a significant effect of Relatedness (Related = 545 ms, Unrelated = 561 ms, Repeated = 522 ms) $F(2,28)=23.82$, $p=.00001$, $\eta_p^2=.63$ (see figure 19). The interaction between Search-type and Relatedness was marginally significant $F(2,28)=3.16$, $p=.058$, $\eta_p^2=.18$. Follow up tests revealed that, when the Positive and Negative were averaged together, significant differences were shown between the Related and Unrelated trials $t(14)=3.75$, $p=.002$. The analysis of the probe errors revealed a significant interaction only $F(2,28)=17.45$, $p=.00001$.

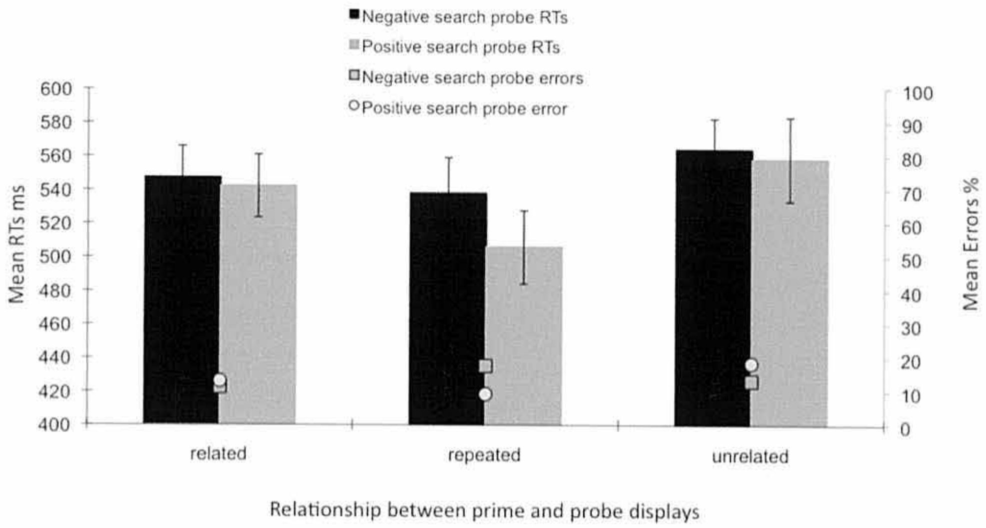

Figure 28: Mean RTs in ms (columns) and mean error rates in % (squares and circles) for Search-type and Relatedness in probe displays in Experiment 12.The error bars represent the standard error.

Discussion

The key finding is that when a PT-effect experiment is properly controlled, an effect is found between related and unrelated probes that reaches significance. Further, by constructing the experiment to allow for the analysis of position effects a large OVP difference between related and unrelated probes is revealed. As the OVP effect is absent from the prime RT data it can be concluded that the subsequent priming elicited in the probe data is an effect of spreading activation that has no effect on letter identification RTs in the primes. This evidence demonstrates that the support for theories where semantic access is prevented during LS needs to be reconsidered, especially as the large amount of priming at the OVP position was shown by 14 out of the 15 participants. Similar to the work of Parris, Sharma, and Weekes (2007) the OVP has elicited semantic effects when much of the previous research had not looked for effects there. Since the initial paper of Smith (1979) evidence has built up against the automaticity of semantic access (Henik, Friedrich, & Kellogg, 1983; Brown, Roberts, & Besner, 2001; Smith & Besner, 2001; Hohlfeld & Sommer, 2005; Otsuka & Kawaguchi, 2007) such that it has been called a myth (Stolz & Besner, 1999), without investigating the LS task adequately first. Following the research reviewed and presented here there is an opportunity to really understand what drives selection during LS tasks and how this selection affects subsequent processing.

The model of visual word recognition put forward by Stolz and Besner (1999) can not explain the results presented in Experiment 12. There would need to be substantial changes made to the model which currently does not take into account target position or the effects of attention (even though Stolz and Besner recognise the importance of spatial attention in word reading).

Chapter 7: Thesis Discussion

The initial experiment of this thesis replicated the traditional PT-effect, but did not reveal the RT priming differences that are expected when one considers the visual search, language processing and neuroscience literature. The inability of researchers to find priming effects, following LS in a word, highlighted how little is known about LS tasks compared to other measures of SA, like the Stroop effect.

The following section begins with a summary of all the results from this thesis and their implications for the relevant theories and previous research. From Chapter One the two key findings are that there is a consistent difference between positive and negative search, and that there is an effect of position where OVP targets are responded to faster than ROM targets (even though the number of flanking letters are equivalent). In addition there is a linear effect on RTs for each additional letter added to displays which is evident for both words and non-words. Searching for letters within words is faster than searching for letters within non-words as shown previously in the WSE. Searching for letters in high frequency words results in a different pattern of RTs than searching for letters in low frequency words. The different positions in high frequency words elicit RTs that are more similar than low frequency words. This would seem to indicate that high frequency words are treated much more like whole objects, which attract attention equally across the whole object, than low frequency words which are processed more as individual letters. A prediction can be made that letter strings should elicit a pattern of RTs that indicates less of an object grouping effect. It can be hypothesised from this result that attention should react differently for words and non-words and that there should be a difference in the amount of semantic information selected for further processing during LS. Finally, the timing of the presentation of the to-be-searched for letter changes the elicited RT pattern.

Experiment Seven replicated the findings of Lavie and Fox's (2000) Experiment One with new stimuli. The results support a theory where the number of items in a visual display can drive the selection of items for further processing. In terms of the prime displays the search pattern for the low load (single letter with one distractor) displays were characterised by a v shape with a gentle gradient. The further the target position was from fixation the greater the amount of time needed to identify the letter. The increases in RTs were identical for each direction from fixation and for the distance between inner positions and exterior positions. This finding is contrary to research which demonstrates that attention jumps from one location to another not processing the space in between (Cave & Bichot, 1999). However, the distances involved here are fairly small (although larger than what is considered normal for the fovea), which may be why there does not appear to be a jumping of attention effect.

The priming effects for ignored primes, under high and low load, were almost identical to Lavie and Fox's (2000) Experiment 1. The attended condition elicited priming that was larger for the high load, compared to low load displays. This could indicate that under high load attention is focussed and that whatever is in the focus of attention receives facilitation. The increase in the attended priming for high loads is caused both by a slowing of RTs to control displays and a speeding up for the attended displays, which suggests that the task of searching for a letter is harder when there are more items in the display, and that targets that appear in a high load display receive increased processing. The increased processing for targets in high load displays is suggested to be the result of competition resolution in the visual system.

In Experiment 8 the replacement of the high load displays with English words had a clear effect on the patterns elicited in prime displays, and slowed the subsequent RTs to the probe displays. The most striking observation is that the RT patterns for words is much flatter than for letter strings, which is similar to the result found in Experiment 5 for high frequency words eliciting RTs that are more grouped together. The error rates for high load displays were lowest for the OVP position which may indicate an effect for position that was absent in the RT patterns or priming.

The probe display priming in Experiment 8 is the same as Experiment 7. The words could have been viewed as drawing less attentional load than letter strings as they are a perceptual object. However there was no NP in the ignored word condition. It is believed that the word information encouraged a smaller focus of attention, which elicited greater facilitation for items within focus due to competition between the letter representation itself and the letter as part of an object (the word). The comparative priming for the attended condition is much greater for words. However, as the control condition is much slower than the low load the priming may possibly be a result of the slowing of RTs to control displays. The attended condition is still slightly faster for word displays than the low load displays (8 ms) which indicates that for the attended condition in word load displays the focus of attention is very focussed.

The application of several of the control parameters suggested by Yantis and Johnston (1990) dramatically changed the RTs to both prime and probe displays for both letter strings and English words. For letter strings (Experiment 9) there was no difference between the RTs or error rates for high and low load prime displays. Importantly there was no difference in the negative priming to probe displays following ignored distractors between high and low load conditions. This indicates that the perceptual load hypothesis itself must incorporate a spatial dimension where selection is not purely driven by capacity, but also through focussing of a selection spot light. The processing of the distracters occurs either because there is no zoom lens selective window and all items have the potential to be processed, or because the selective mechanism was not efficiently focussed. The lack of focussing could either occur in a few trials and have a large effect, or occur at some level in every trial. The priming from the attended conditions was faster for the high load displays by 16 ms while the control displays were the same for low and high load displays.

In Experiment 10 the word information still had an effect on the prime displays which is attributed to the letters within words forming an object that makes selecting a single letter and not-selecting the other letters more difficult. The fact that when searching for a letter within a word, it is harder to ignore the non-target letters in the word means that there is likely to be greater levels of interference from the other letters. Considering the results from Experiment 5 it can be predicted that high frequency words should increase the difficulty of selecting the target letter from the perceived object. The attended priming reaches a high level for the word condition which indicates that the need to focus within words has a facilitative effect on subsequent processing. Future research may wish to replicate the current experiment with different frequencies of words to check on subsequent facilitation in priming and increasingly dispersed RTs to prime displays.

Word information survived the effects of focussing selection to the fixation point in Experiment 10. In Experiment 11 it was shown that by changing the orientation of the words from horizontal to vertical the usual effects of words were removed. This finding indicates that it takes a lot to remove word information from visual processing. The level to which the word information is processed can not be determined beyond at least the word form level as there are clear differences between words and non-words. However, the differences between words and non-words for vertically presented information can not be determined as the experiment has yet to be run. It is predicted that there would be no difference between words and letter strings when the stimuli are presented in an unfamiliar way (vertical) and with focussed attention.

In the final experiment the information learnt through the previous experiments is implemented in an improved PT-effect study. The results can not be used to support a strong version of the automaticity of SA. It is clear from the RT data that if automatic SA exists it is only to the OVP position. The cause of the OVP advantage is that when participants find the target letter at the OVP they do not need to initiate letter-by-letter search. This means that the whole word is more likely to be processed when the target is the OVP as compared to other positions such as the ROM. The data supports all those studies that have demonstrated semantic priming following letter search.

The large effects found at the OVP are likely to be present, to some extent, in all studies of PT-effects. It may also be that those studies that have found smaller levels of priming following LS, but have not reported the positions of targets, may have averaged out the priming from the OVP. Similarly, those experiments reporting no SP that have not reported position, may have failed to use the OVP as a target position, or may have used all the positions. For example, in an eight letter word if all the positions were used the OVP priming would be averaged down to an eighth of its size. The OVP priming in Experiment 12 was 53ms, which, if averaged across eight positions, would show approximately 6.5ms priming. It is likely that the large effect at the OVP attenuates towards each end of the word and that experiments that do not include equal proportions of targets at the OVP position averaged over as few other positions as possible would not have found significant results. While the OVP effects would appear to indicate that the automaticity of SA is still a relevant topic of research, the constraints that need to be placed upon the experimental design would indicate that the strong form of automaticity needs to be rejected in favour of a weaker gradient.

Linking the current findings with previous research

Theories of visual search

In summary from the first set of experiments the evidence presented here supports the previous visual search discussed in the introduction. The number of distractors increases RTs (Wolfe, 1998; Thornton & Gilden, 2007) at a rate of approximately 30ms per item (Atkinson, Holmgren, & Juola, 1969; Cavanagh & Chase, 1971). The RT patterns for single letters presented horizontally across the fixation point in different positions are a v-shape (Parris et al., 2007) with a fixation effect that is either facilitatory (Lavie, 2005) or costly, as in the n-shape lateral masking effects in Experiments 5 and 10 (Humphreys & Riddoch, 2007). The evidence from Experiments 2 to 6 also supports that in addition to the fixation effects words are searched for letters serially from left to right (Carr et al., 1976).

There is also an effect of attentional set (Gibson,1941; Haber, 1966; Pashler, 1999) that changes the way LS is conducted with an apparent speeding of search (in agreement with theories that say that prior knowledge is beneficial in visual search, Hochberg, 1978; Neisser, 1976) and a more grouped RT position pattern (Experiment 4). This indicates that the word is treated as a whole and does not suffer the potential degradation caused by the movement of attention to the line above to identify the target letter.

The data concerning positive and negative search (Logan, 1978; Treisman & Gelade, 1980; Treisman & Souther, 1985; Chun & Wolfe, 1996) is as yet inconclusive. Experiments 2 to 6 and Experiment 12 are suggestive of a difference between the two conditions. At this time very little is known about the fate of targets that result in negative search. Future research may wish to examine this issue. If there is a long lasting memory tag for a negative search target there may be an effect on subsequent processing, as in long term inhibition effects found by Tipper, Grison, and Kessler (2008). In addition, Experiment 12 has the same effect for positive and negative searches but this may not always be so. It cannot be emphasise enough that each change in the stimuli set, or task parameters, can change the cognitive load, selective window, and mental set; each of which may have an effect on subsequent priming. It would be wise to always analyse the trials of positive and negative searches separately until more is known about LS tasks and negative search items. In light of the semantic congruency effects for positive and negative searches reported by Hutchinson and Bosco (2007) this seems doubly wise.

The locus of selection

The first general observation about the locus of selection is that there is extensive support for a limited capacity theory where cognitive resources determine the point of selection for further processing (Lavie, 1995, 2005; Lavie & Cox, 1997; Lavie & Fox, 2000; Pashler, 1999; Farah, 2000). The second general observation is that the selection occurs early when either perceptual load is high (Lavie, 1995, 2005) or when the focussing of the selection window is optimal (Yantis & Johnston, 1990). The processing of ignored items is likely due to low perceptual load and an unfocussed selection window which allows for slippage to occur (Lachter, Forster, & Ruthruff, 2004). The selection window is theorised to change in size like the zoom lens model (LaBerge, 1983; Eriksen & Murphy, 1987; Eriksen & St. James, 1986) with a need for focussed attention to process items (Treisman & Gelade, 1980). Eriksen and St. James (1986) suggested that a higher focussed zoom lens would lead to facilitated focussing which is apparent in Experiments 7 to 10. In summary, late selection occurs when the task demands allow it otherwise the locus of selection is at an early stage (Auclair & Sieroff, 2002; Mozer, 1991).

This view of early selection with slippage is contrary to explanations appealing to late selection with inhibition (Tipper, 1985; Houghton & Tipper, 1994, 1994b, 1996) of irrelevant items (LaBerge & Brown, 1989; Mozer, 1991; Luck & Hillyard, 1994; Green, 1991; Moran & Desimone, 1985). Based on the data reported here models of inhibition that do not consider a spatial selection mechanism need a revision to explain the aspects of LS that seem to modulate a spatial window (Posner & Cohen, 1984; Kessler & Tipper, 2004).

Words as Objects

The evidence from the experiments reported in this thesis support the view that words are objects, across which attention will spread when searching for a letter. The spread of attention across the word also increases the difficulty of focussing on a single part to identify the letter (Humphreys & Riddoch, 2007). The WSE only applies under certain circumstances which to date are not clearly understood. Future research should look to examine the parameters of this phenomenon in more detail. Commensurate with Auclair & Sieroff (2002) higher frequency words are more like objects than lower frequency words as embodied through RT search patterns that are flatter and in shape and less differences between the different letter positions. It can be hypothesised that it is not just perceptual grouping but also familiarity driving the grouping of individual letters into a whole object. In the case of words Humphreys and Riddoch (2007) believe that the word familiarity enhances processing at all positions and causes the word to be processed as a whole, whereas the letter strings are not. So in the case of words the letters are processed as an object where the familiarity of items appearing together makes them whole.

The research reported here does not use words with written frequencies on average higher than 50 (Kucera & Francis). Future work should examine the possibility that flatter RT patterns would be elicited from higher frequency words. As well as frequency and item familiarity the orientation of word stimuli can be used to encourage attention away from the word level information. If one assumes that the neural networks of recognition are based on familiarity and frequency of presentation then presenting a stimulus in an unfamiliar way will result in less efficient processing as the items need to be recombined or reoriented. The work presented here suggests that the view of Palmer & Rock (1994) that words are not objects as the letters are still individual items and that true objects are bound by stronger effects that they call uniform connectedness, is only true of lower frequency words and that familiarity is enough to make high frequency words objects. This leaves as a possibility that very high frequency words will be processed automatically to the semantic level and that the use of low frequency words to test automaticity is not a fair measure of reading as a well practiced activity.

Conclusions

In conclusion the work contained in the thesis has covered several aspects of the LS task and its permutations (letter search and letter identification). The work described here adds to the understanding of visual cognitive processes and semantic organisation. The findings can be summarised into three main areas, searching for letters, priming of letters (and the mechanisms of selection), and the priming of words.

Searching for letters within words and letter strings follows some basic rules that are found across cognitive psychology, in particular the visual search paradigms. The addition of a letter to the length of a word will add approximately 30ms to search times. Negative searches, where the target letter is absent, are on average slower than positive search. The data reported here suggests that, for negative search displays, the termination of LS in words occurs at the right side of the stimuli just before the last letter. This finding indicates that when searching for a letter participants engage in a serial letter-by-letter strategy. All of the RT data indicated that LS is conducted serially, except in cases where target location was 100% predictable (i.e. participants did not have to actively search for the letter). Searching for a letter in high frequency words should be quicker than search in low frequency words, but only when the task demands are not too high (such as the short display durations used in Experiments 7-11). The search for letters in non-words will usually be slower than in words, due to a lack of feedback from the word level facilitating letter identification.

The priming of letters contained within words and the priming of ignored distractors is subject to the action of spatial attention. Experiments 7-11 reveal a selective mechanism that can be focussed like a zoom lens. The selective mechanism works most efficiently when the target location is predictable, which suggests that every time the location is changed it takes time to focus the selection window. Items that are presented outside of the window will not be processed for more than the lowest level features (e.g. location). Processing of distractors outside of the selection window occurs because they have accidentally been attended to.

Items that are included within the selection window will be responded to differently by the selection mechanisms depending on the level of competition in the visual system. Displays that include few items are unable to produce enough visual crowding to result in a high level of competition. Stimuli in low crowding displays are all processed to a late level, prior to selection. The items which are not the target then have to be inhibited to prevent them from competing with the target for response mechanisms. When there are several items close together in the visual display (typically 6 or more items), the competition between the items in early stages of visual processing requires the target to be facilitated before it can be processed further. Distractors are not processed further as the noise generated by the competing items prevents a clear signal from progressing to the next stage of processing.

The priming of words following LS tasks should not be measured on traditional LS paradigms alone, as the work presented here in Experiment 12 highlights that semantic activation and the spread of the activation to related items still occurs following targets appearing at the OVP. This result, in addition to the already published ERP N400 effects, provides converging evidence of semantic activation following letter search. However, the results reported in this thesis provide strong evidence that when participants are searching for a letter in a word they engage in letter-by-letter search. When a letter-by-letter approach is adopted, the semantic level of processing is not reached unless the target letter is at the OVP position. The lack of semantic processing from other positions is due to the letter-by-letter approach

inducing a focussed selection window, which, by focussing to the letter level, induces competition in the visual system from the other letters in the word. If the target is at the OVP position, detection and identification occurs before search has to be conducted. In this case the selection window does not have time to focus down to the letter level, and the visual system is not overloaded with competing items, which means that the word can be processed as a whole.

A letter search task will therefore interrupt semantic processing when the target letter appears in a position other than the OVP. Other factors will also effect the processing of a word searched for a letter, such as, word length (which should affect the level of competition in the visual system) and written word frequency. The most influential results, supporting semantic processing after searching for a letter, come from neuroscience. The N400 modulations show that following LS some semantic processing occurs, however, as the positions of letter targets have not been examined, the effect may be due to OVP processing alone. Future research should examine the effect of target position on N400 modulations, as well as word length, and written word frequency. Any modulation that affects the way spatial attention is applied to written words may alter the way the information is processed and additionally alter the level to which processing proceeds.

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APPENDICES

Appendix A

Table I: Word list for Experiment 1.

HUSBAND	WIFE	FATHER	MOTHER
BOY	GIRL	LAMP	LIGHT
LAUGH	CRY	PINE	TREE
AUNT	UNCLE	KNIFE	FORK
ENVELOPE	LETTER	SUGAR	SWEET
WATER	LAKE	SALT	PEPPER
TRUE	FALSE	MEAL	FOOD
DOG	CAT	SMILE	LAUGH
MINUTE	SECOND	SPOKE	WHEEL
HAPPY	SAD	LOSS	GAIN
TABLE	CHAIR	ARM	LEG
PIPE	SMOKE	NOVEL	BOOK
BOTTOM	TOP	SINGER	SONG
FLAME	FIRE	GIFT	PRESENT
SOUND	NOISE	SKETCH	DRAW
EMOTION	LOVE	BOOTS	SHOES
PONY	HORSE	RAIL	TRAIN
PLATFORM	STATION	SLIDE	PUSH
ARMY	NAVY	SMOKE	FIRE
NECK	HEAD	PAINT	BRUSH
BEACH	SAND	BAT	BALL
SHOWER	BATH	EAR	NOSE
VERSE	POEM	MAIL	POST
BACON	EGG	ROOF	TOP

Appendix B

Table II: Word list for Experiment 2 and Experiment 3.

Length in letters				
9	8	7	6	5
POLICEMAN	CEREMONY	BARGAIN	AVENUE	PAUSE
PREJUDICE	CONCRETE	BELOVED	BANKER	SPARE
REDUCTION	CREATURE	BOULDER	BREAST	ANGER
SOCIALIST	CUSTOMER	CAPSULE	BURDEN	TREND
SUBSTANCE	DISASTER	CHARITY	CLOVER	FLAIR
TESTIMONY	EDUCATOR	CONTEXT	COMEDY	COUNT
UNIVERSAL	EXPOSURE	COSTUME	DEFEAT	PRIME
VIOLATION	FAREWELL	CRYSTAL	EXCUSE	CRUEL
VOLUNTARY	FLOURISH	DEPOSIT	FABRIC	GHOST
HURRICANE	FRICTION	DISPLAY	FASTER	ANGEL
INFECTION	GRADUATE	DISPUTE	GENIUS	THROW
INSTITUTE	INCIDENT	EMBRACE	HEAVEN	CRAWL
INSURANCE	IGNITION	EPISODE	HEIGHT	SPLIT
INTERVIEW	INSTINCT	EXPANSE	IMPORT	MAKER
INVENTION	JUNCTION	FISHING	INFANT	WASTE
LIGHTNING	KEROSENE	FORTUNE	JACKET	FLUSH
MAGNITUDE	LAUGHTER	GLIMPSE	JOCKEY	BUNCH
MESSENGER	LECTURER	HARVEST	MANURE	ROUGH
PHYSICIAN	MAGAZINE	HOLIDAY	MISTER	SHEAR
CRITICISM	MAHOGANY	INQUIRY	PENCIL	SAINT
CURIOSITY	PARADISE	LIBERTY	PHRASE	PLUMB
DEDUCTION	MERCHANT	LIGHTER	PRAISE	SHOUT
DIFFUSION	MIDNIGHT	MIXTURE	PRIEST	FLOCK
DISCOVERY	MISCHIEF	MUSTARD	PRINCE	FLASH
DISMISSAL	MOISTURE	PAINTER	REMARK	ADULT
EMERGENCY	MOLECULE	PHYSICS	ROCKET	SLIDE
ENCOUNTER	MONUMENT	POVERTY	SAFETY	WRECK
ENTERTAIN	RIDICULE	PRELUDE	SILVER	TRAIL
EVOLUTION	MUSICIAN	PROTEST	SINGER	SLOPE
EXPANSION	PRISONER	ROMANCE	STABLE	GIANT
FORMATION	QUANTITY	SOLDIER	STUPID	POUND
FRANCHISE	REGISTER	STADIUM	THREAT	GUEST
FURNITURE	REPUBLIC	THINKER	VIOLET	THIEF
GEOGRAPHY	SERGEANT	THUNDER	WALNUT	WITCH
HIERARCHY	SHORTAGE	TRIBUTE	WEALTH	STORM
BRUTALITY	SPECIMEN	TRIUMPH	HUNGER	GRAVE
CANDIDATE	STRANGER	WHISPER	PARISH	STAIN
CATHEDRAL	TRANSFER	YOUNGER	DEPUTY	LODGE
CHEMISTRY	VELOCITY	COMPACT	SHADOW	SLAVE
CHOCOLATE	VERTICAL	RECITAL	MARGIN	STAKE

Appendix C

Table III: Means and Sds for Experiment 2

	Length				
	5	**6**	**7**	**8**	**9**
Negative	703.79	726.53	754.39	785.52	826.38
Sd	81.06	86.56	97.65	100.26	101.90
Positive	652.12	688.34	708.63	735.05	772.00
Sd	81.06	86.56	97.65	100.26	101.90

Appendix D

Table IV: Means and Sds for Experiment 3.

		Position		
Length	**Absent**	**Left**	**Middle**	**Right**
Six	707.09	644.58	670.35	697.96
Sd	108.19	99.77	93.70	100.02
Eight	751.45	685.79	691.11	761.29
Sd	112.33	100.75	101.78	117.99

Appendix E

Table V: Word list for Experiment 4

GRAVITY	LIBERTY	DISPUTE	SOLDIER
BELOVED	LIGHTER	TRAGEDY	STADIUM
BOULDER	MIXTURE	REMOVAL	THINKER
CAPSULE	MUSTARD	SLAVERY	THUNDER
CHARITY	PAINTER	ALBUMIN	TRIBUTE
OBSCURE	SCHOLAR	FORTUNE	TRIUMPH
COSTUME	POVERTY	GLIMPSE	WHISPER
CRYSTAL	EXHAUST	HARVEST	YOUNGER
DEPOSIT	RECITAL	HOLIDAY	ANTIQUE
DISPLAY	ROMANCE	FATIGUE	RECITAL

Appendix F

Table VI: Word list for Experiment 5

High		Low	
FRUIT	BRAIN	CHALK	FAIRY
BENCH	NOVEL	ROBIN	RHYME
STONE	GRAVE	THUMB	SALVE
PIANO	MATCH	STEAK	SPASM
SUGAR	GUARD	SPICY	BATON
SNAKE	GUEST	FEAST	SPURT
BREAD	SMILE	WRECK	SPIKE
PHONE	ANGLE	GROIN	CORAL
STICK	GUIDE	RUSTY	CRYPT
BRUSH	OWNER	STING	WHARF
OCEAN	SCALE	AISLE	PERCH
CHAIN	MAYOR	SHADY	SPIRE
TRUCK	TRAIL	GRAZE	SWORD
PORCH	ROUGH	MURAL	LATCH
FENCE	SHEAR	HAREM	SNAIL
FLESH	TOUGH	THIEF	CIGAR
PAINT	RAPID	STAIR	NAVEL
CHEST	SPLIT	ULCER	HOUND
CLOTH	URBAN	PASTE	SPEAR
UNCLE	PLAIN	BADGE	THORN
SLAVE	WASTE	CLASH	FLUTE
SMOKE	ROUTE	MINCE	SHRUB
CROWD	BLIND	GIVER	TRASH
TRACK	CURVE	GROAN	SPICE
LUNCH	THROW	GRATE	PLANK

Appendix G

Table VII: Word list for Experiment 6

Length				
5	6	7	8	9
CHAIR	SPONGE	ARTICLE	CHLORIDE	CHEMISTRY
GLOVE	CLOSET	THIMBLE	GRAPHITE	LABYRINTH
FROST	GARDEN	CAPSULE	MORPHINE	LUBRICANT
LEMON	BASKET	COSTUME	CHLORINE	CARTILAGE
BEACH	THREAD	PASTURE	LEMONADE	LANDSCAPE
KNIFE	FOREST	JOURNAL	CLARINET	MACHINERY
SKIRT	MARBLE	STADIUM	NUTRIENT	TELEGRAPH
BENCH	PENCIL	THICKET	SEDATIVE	MONASTERY
STONE	BRIDGE	LAUNDRY	GAUNTLET	AMPLIFIER
PIANO	LIQUOR	WHISTLE	PLATFORM	HURRICANE
SHIRT	JACKET	CRYSTAL	BUNGALOW	ABDUCTION
SUGAR	GARLIC	GLACIER	KERCHIEF	BEHAVIOUR
CANOE	BLOUSE	CABINET	BASEMENT	LUBRICANT
PHONE	MANURE	MUSTARD	BRACELET	VOLUNTARY
CHALK	ROCKET	BOULDER	PAINTING	UNIVERSAL
PSALM	BANDIT	BAYONET	CHAMPION	SOLEMNITY
SLAVE	NATIVE	BRISTLE	JEOPARDY	MAGNITUDE

Table VIIB: Pseudowords for Experiment 6

Length				
5	6	7	8	9
CRIPS	RASHED	PAINTLY	HUMORISN	SPLANGLED
SCURE	FALONS	SENITAL	UMDERLAY	REPTILIAS
DOWSY	SICKED	TWINDLE	TIGHTERS	TRADESMAK
SPINK	THIFTS	FIREDOP	SCULPTAR	SNOWINGLY
RENOW	RITALS	DUCKERS	UMDERCUT	HAZERDOUS
MOSTY	BOYING	FIGHTEN	BACKLISH	UNREALISY
LAMED	SLYING	FURNICE	GANISHED	GESTALION
GADET	HAYING	SLUNDER	UNLOVEDY	QUADRUTIC
SLEAD	MOLDLY	CRUNDLE	ABHESIVE	PHONAMICS
HUSTY	DIVELY	TRACKLE	CASTEFUL	BASTERFUL
CHULK	SALDLE	PATIONS	ESULSION	WINDBREAH
CRASP	PURING	PERTIAN	ADERSIVE	DESOLVING
TAKED	BURING	UNWARDS	PERMINAL	SCRUMBLED
CHAVE	NUMBLE	SLURTED	SECTURED	RESTIBULE
LATED	HEALTY	CRUMPED	BRASHING	RECORTING

Appendix H

Table VIII: Means and Standard deviations for Experiment 6.

		Length in Letters				
		5	**6**	**7**	**8**	**9**
Word	**Negative**	745.92	775.90	766.75	832.45	820.75
	sd	77.59	64.87	81.72	58.09	52.78
	Positive	666.61	726.53	734.45	769.41	775.99
	sd	51.22	44.49	64.90	64.78	67.77
Non-word	**Negative**	757.71	777.91	786.55	843.33	849.43
	sd	81.27	52.25	64.80	64.69	72.98
	Positive	699.82	734.20	784.27	791.66	831.64
	sd	41.38	53.16	62.85	59.23	66.82

Appendix I

Table IX: Means and standard deviations for prime displays in Experiment 7

	Position					
	1	**2**	**3**	**4**	**5**	**6**
Low	730.33	696.47	629.16	633.37	670.52	719.75
Sd	133.74	157.69	105.02	108.47	131.29	125.82
High	889.64	908.64	769.43	723.92	864.66	924.30
Sd	121.43	149.84	110.38	118.35	139.53	118.69

Appendix J

Table X: Word list for Experiments 8, 10, and 11.

ABSENT	EDIBLE	NOTICE	CHARGE	INVOKE	PSEUDO
ADJUST	ENOUGH	NOVICE	CHOSEN	LOUNGE	RAMBLE
ADVISE	FABRIC	OBTAIN	CHROME	MAGNET	RELISH
AMIDST	FATHER	ODIOUS	CINEMA	MARBLE	RHYTHM
ASPIRE	FIGURE	PASTRY	CLIENT	MEADOW	ROCKET
AUTHOR	FLOWER	PATROL	CLOSED	MEDIUM	SEARCH
BEACON	FOREST	PENCIL	CLOUDY	MELODY	SELDOM
BRACES	FRIGHT	PICKED	CLOVER	METHOD	SOFTEN
BREATH	GENIUS	PLANET	DEBATE	MODIFY	STEADY
BUDGET	HONEST	PODIUM	DEPUTY	MUTINY	STUDIO
CARPET	INCOME	POETRY	DIGEST	NAMELY	UPHELD
CHANGE	INSECT	PREACH	DOUBLE	NICKEL	WAKING

Appendix K

Table XI: Means and standard deviations for the prime conditions in Experiment 8

	Position					
	1	**2**	**3**	**4**	**5**	**6**
Low	768.12	724.68	703.79	694.25	725.79	756.97
Sd	130.86	129.99	130.86	117.66	125.46	119.33
High	943.98	977.91	933.22	924.65	1016.46	1008.27
Sd	122.05	144.03	144.95	127.92	108.43	127.38

Appendix L

Table XII: Word list for Experiment 12

Prime	Probe	Prime	Probe
LANTERN	LIGHT	ICICLE	COLD
LODGE	HOUSE	PADLOCK	KEY
LIFT	UP	CROW	BIRD
BATH	WATER	TACK	NAIL
STABLE	HORSE	TOWEL	DRY
CREW	SHIP	HOUND	DOG
AVENUE	TREES	HOSE	PIPE
TILL	MONEY	HEROIN	DRUG
MARKET	PLACE	VEST	JACKET
SHAME	GUILT	CRYPT	TOMB
BISHOP	CHURCH	CANAL	WATER
MATE	FRIEND	MOLE	HILL
DRILL	HOLE	SPEAR	ARROW
MAYOR	TOWN	MEDAL	GOLD
NATIVE	COUNTRY	OVEN	HOT
SHORE	BEACH	EARL	LORD
OFFICE	WORK	LIAR	CHEAT
COAL	FUEL	ANXIETY	NERVOUS