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"Object Based Attention in Visual Word Processing"

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“Object Based Attention in Visual Word Processing”

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Submitted for the degree of Doctor of Philosophy

School of Psychology

University of Dundee

January 2015

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This thesis is dedicated to my wife and children, whose love and support made completion of this work possible.

Gavin Revie

January 2015

Declaration

I confirm that I am the sole author of this thesis and that all references cited (unless otherwise stated) have been consulted by me. This thesis is a record of the work done by me in pursuit of the degree of PhD in Psychology. This work has not been previously submitted for any other higher degree.

Gavin Revie

14th January 2015

Summary

This thesis focusses on whether words are treated like visual objects by the human attentional system. Previous research has shown an attentional phenomenon that is associated specifically with objects: this is known as "object based attention" (e.g. Egly, Driver & Rafal, 1994). This is where drawing a participant's attention (cuing) to any part of a visual object facilitates target detection at non-cued locations within that object. That is, the cue elevates visual attention across the whole object. The primary objective of this thesis was to demonstrate this effect using words instead of objects. The main finding of this thesis is that this effect can indeed be found within English words – but only when they are presented in their canonical horizontal orientation. The effect is also highly sensitive to the type of cue and target used. Cues which draw attention to the "wholeness" of the word appear to amplify the object based effect. A secondary finding of this thesis is that under certain circumstances participants apply some form of attentional mapping to words which respects the direction of reading. Participants are faster (or experience less cost) when prompted to move their attention in accord with reading direction than against. This effect only occurs when the word stimuli are used repeatedly during the course of the experiment. The final finding of this thesis is that both the object based attentional effect and the reading direction effect described above can be found using either real words or a non-lexical stimulus: specifically symbol strings. This strongly implies that these phenomena are not exclusively associated with word stimuli, but are instead associated with lower level visual processing. Nonetheless, it is considered highly likely that these processes are involved in the day to day process of reading.

1. Literature Review - "Attention to words and to objects"

Section 1 - Attention to Objects

When you look at each of the words which compose this sentence, what is your brain actually doing? How do you get from seeing each individual contour on the page, to recognising what you see as being a collection of words? In many models of reading this mysterious transition is subsumed under the simple headings of "identification" or "familiarity check", and the exact workings of this mechanism are left unexplained (e.g. Engbert, Longtin, & Kliegl, 2002, Reingold & Rayner, 2006). Specifically, how the brain assembles the diverse contours of grouped letters into "words" which can then be subjected to further processing is unknown. This question serves as the starting point for this thesis. However, "How do we visually process words?" is an enormous question which has been the subject matter of over 100 years of research, and is far too large a topic for a PhD thesis. A smaller question is needed. The hypothesis that will drive the work in this thesis is that words are a type of "visual object" and accordingly they will be processed in a way consistent with other "visual objects". The reasoning behind this hypothesis will be discussed in detail in the forthcoming chapter. Derived from this hypothesis is the question this thesis will aim to address: "Are words processed like visual objects?".

Before the above question can be addressed, some background on both reading and visual processing generally will need to be provided. Writing is a relatively recent cultural invention of mankind, going back only around 5400 years (Dehaene, 2004), and it is only in the last two centuries that the ability to read and write has become widespread amongst the human population. It is highly unlikely that these very constrained evolutionary timescales and circumstances could have given rise to a dedicated "reading centre" of the brain. Consequently, humans must be utilising resources originally intended for other purposes in order to accomplish the novel task of reading. Reading, unlike other forms of language processing (e.g. listening to speech) requires the processing of visual stimuli. The human visual system is optimised for identifying the location of other animals who we may wish to eat, mate with or run away from, and to provide us with information regarding the location of pertinent objects e.g. fruits, vegetables and raw materials for tools (Wade & Swanston, 2001). Since a "reading centre" of the brain has been ruled out, these evolutionarily older visual resources must be a major component of the mechanism humans use to read. As a result, the mechanisms crucial for reading will have a lot of similarities with the mechanisms used to process other kinds of visual stimuli. One of the most important areas in the study of visual processing is the study of *attention*. Attention is one of the principle ways by which human beings make sense of our world. It allows us to filter the massive amount of information flooding in through our five senses. The research upon *visual attention* (and in particular how it relates to objects) will be the focus of this section.

Dating back to the work of Helmholtz in the 19th century it has been understood that human beings can concentrate their attention on one particular location in their visual field in preference over other areas at a given time. Since that time this concept has come to be known as "spatial attention", and much of the debate over the last 150 years has been concerned with the nature of this attentional focal point (Wright & Ward, 2008). Many of the recent developments have been driven by the work of Michael Posner. The "Posner Paradigm" is the most well-known method of studying attention allocation in use today. Posner and Cohen (1984) described the methodology. They found that the speed at which participants are able to detect a visual object varies depending on the information the participants are given beforehand. This phenomenon was not related to eye movements (known as overt attention), which were controlled for by removing trials in which participants moved their eyes. The information given to the participant beforehand was named a "cue" (in this case it was a "brightening"), and the visual object they had to detect was named a "target" (in this case a small black box). The two types of relationship between cue and target are illustrated in figure 1-1.

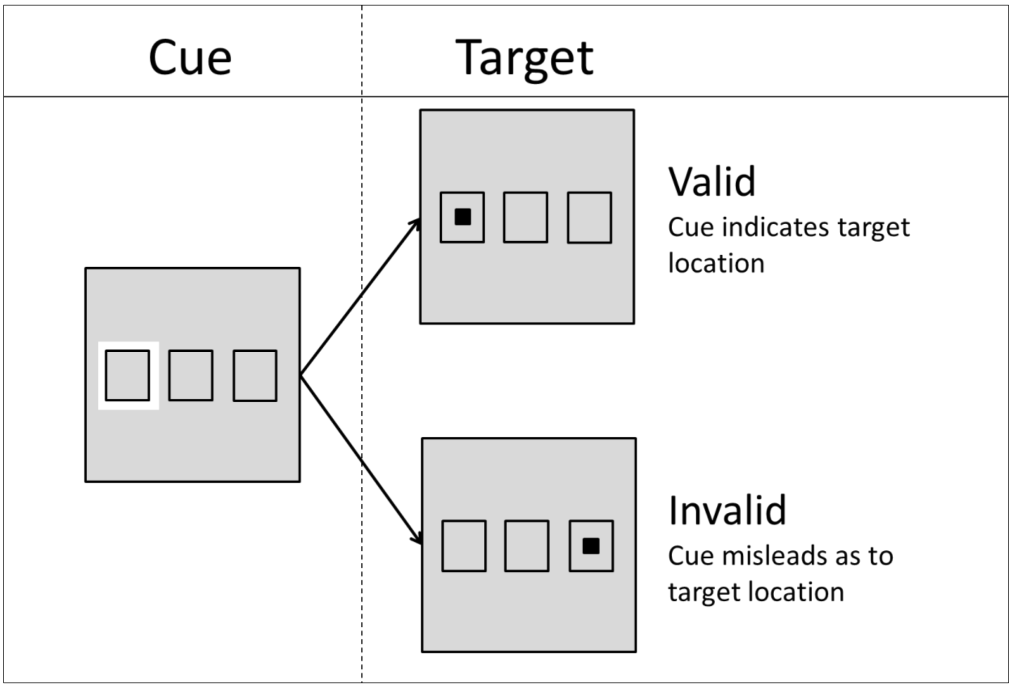


FIGURE 1-1 - THE 2 TYPES OF CUE-TARGET RELATIONSHIP DESCRIBED IN POSNER AND COHEN (1984). FIGURE ADAPTED FROM CITED PAPER. NOT TO SCALE.

When the cue provided accurate information regarding the location of the target, it was described as "valid". What was found with a cue of this type is that it noticeably enhances reaction time to the target. When the cue misleads the participant as to the location of the target, it is described as "invalid". Posner and Cohen observed a reaction time penalty in this case; that is, the use of an invalid cue slowed the participants down when detecting the target. This was true as long as the gap between cue offset and target onset was relatively short (around 100ms). When the interval was increased to 650ms, the effects ran in the opposite direction. Valid cues now conferred no reaction time advantage. 80% of the cues were valid. This is necessary because if a cue is not found to be trustworthy, it will affect how participants use it (see for example Waechter, Besner, & Stolz, 2011 for a recent discussion). The explanation given for the valid trial reaction time benefit was to do with how participants were focussing and moving the focal point of their visual attention. It was hypothesised that when the cue was valid, it encouraged participants to begin shifting their covert attention (i.e. they moved their attention but not their eyes) to the location the target would appear in before the target had actually appeared. This enabled them to detect it quickly and efficiently. Conversely, when the cue was invalid participants shifted their attention to the incorrect target location. This meant that in order to detect the target, they had to programme and execute a further shift of covert attention to the actual target location before they were able to detect it. These additional attention shifting processes are what created the slower reaction times. When the interval between the cue and target was made very long, valid cues ceased to provide a boost to reaction times. Now they caused a penalty. This effect is known as "Inhibition of Return". When the cue appeared, participants directed their attention to the region the cue had indicated the target would appear in. They thoroughly searched this region and found nothing so they mentally marked that region as "searched". As a result they were less likely to make attention shifts back into that region and found it difficult to detect the late appearance of targets there.

The Posner paradigm findings on spatial attention have come to be described using something called the "spotlight metaphor" (Wright & Ward, 2008). Spatial attention is characterised as being like the beam of a torch illuminating a darkened room. The items that the torch is being pointed at can be seen, processed and understood. The items outside the beam of the torch can only be processed very minimally since they are in the "shadows". The "room" in the spotlight metaphor is usually considered to be the surface of the human retina (or as it is known a retinotopic frame of reference) and this introduces complications: most notably that human visual acuity is not uniform but rather falls away the further you get from the fovea. For the purposes of the discussion here that is not a crucial point. Other characteristics of this spotlight are that it takes time to programme and execute a shift of the attentional spotlight, so there are systems in place to try and ensure the spotlight is used efficiently. This includes the aforementioned "Inhibition of Return" effect, which under normal circumstances results in a more efficient search strategy since you will not search the same region twice. However, as illustrated this sometimes backfires and makes target detection *harder*. Another strategy humans use to efficiently allocate their attention is the use of prior knowledge (Tatler, 2009). If you ask someone to search their environment for a rug, they will immediately begin examining the floor. Again, this is normally a very effective strategy and only occasionally causes problems, for example if the experimenter in this scenario was very mischievous and had nailed the rug to the ceiling. In that case the approach of searching the floor area first would result in very slow reaction times to the presence of the rug. The key point to be taken from the classic description of attention is that attentional resources are finite, they need to be "aimed" at something in order to fully process it, they take time to move, they must be used efficiently and when a stimulus falls outside of the region "illuminated" by the spotlight it will receive only very minimal processing.

The spotlight metaphor above is elegant, simple, and brilliant. And unfortunately, like all seductively simple ideas, rather fails to capture the nuances of how human beings use their visual attention. While visual attention does have many characteristics in common with a spotlight, it also has many which are harder to fit into the spotlight metaphor. For example, a number of researchers have claimed that the attentional spotlight can be divided (e.g. Müller, Malinowski, Gruber & Hillyard, 2003). While attempts can be made to incorporate such findings into it, this is where the spotlight metaphor begins to become rather tortured. Some authors now suggest that visual attention is more like a surface on which attention is heaped. In some areas you pile large amounts of attention, and in others very little, although the entire surface gets *some* attention (Wright & Ward, 2008). While probably closer to the truth these ways of describing visual attention have gained little traction and for day to day purposes, psychologists will still often describe attention in terms of Posner's spotlight metaphor.

A further area in which the classic attentional spotlight metaphor falls down is the allocation of attention to objects. Given that this thesis hopes to address the question of whether written words are like objects, this is a key point. The classic Posner paradigm dealt exclusively with whole objects. That is, participants were cued either to one object, or another, in their entirety. More recently however researchers began to question what would happen if participants were cued to *part* of an object. A recent example of this research is Jan Theeuwes, Mathôt and Grainger (2013). They presented participants with rotating objects in which cues and targets could appear. Using this method it was possible to dissociate spatial and object-based aspects of attention. Cues and targets could be within the same object as one another, but in an entirely different spatial location. Conversely, they could be in the same spatial location but not within the same object. Using this method they confirmed the classic Posner findings: that cues and targets which occur in the same location (defined by Theeuwes et al as retinotopic space) have very fast reaction times. But they also identified a second process whereby cues and targets in different locations, but still inside the same object experienced a reaction time benefit compared to cues and targets that did not fall inside the same object. A reaction time benefit that is incurred simply because a cue and target were inside the same object is impossible to explain using the classic description of spatial attention. To account for this this unexplained effect Jan Theeuwes, Mathôt and Grainger (2014) (and others, to be discussed shortly) have proposed a second type of visual attention: *object-based attention*. This is a second system that is quite distinct from the spatial attention discussed thus far. Instead of allowing attention to focus on particular points in retinotopic space, object-based attention elevates attention to particular *objects* within the visual field regardless of where they are located. The object-based and the spatial attentional systems operate in tandem and under normal circumstances their relative contribution to any single attentional effect would be difficult to discern. However, given that object-based attention deals exclusively with how human beings attend to visual objects, it is of critical importance in answering the question of whether words are like visual objects.

At this point it is worth pausing to consider whether the a priori assumption that words are like visual objects has some merit. The remainder of this chapter is going to provide a variety of justifications for this point from neuropsychological and behavioural data – but before considering any of this is the starting point that words are like objects *reasonable*? It is commonly believed that there are two (not necessarily mutually exclusive) means by which we come to define something as an object. In the first instance there is past experience (Wade & Swanston, 2001). Learning networks come to associate certain visual features with the properties of certain objects. This could be construed as a "top-down" definition of an object since this is contingent on prior knowledge. A second way in which objects can be defined is on the basis of much lower level visual characteristics which allows our visual system to "group" the different elements of an object together. This process could be construed as "bottom-up" as it is almost entirely based on the visual characteristics of the objects themselves. Marr (1983) provided a now classic description of how objects are defined in visual space. At the time of his death the model had not been fully elaborated, but what Marr was confident about is that the human visual system takes the visual stimuli coming in through our eyes, and forms it into groups of stimuli during the construction of something Marr termed the 2½D sketch. The characteristics that were used to group the visual stimuli together were (amongst others) features such as similarity, spatial continuity (i.e. features that are near one another) and continuity of discontinuities (e.g. closure by illusion). These characteristics bear striking similarity to the much older Gestalt method of segmenting the visual scene outlined in Wade and Swanston (2001). In this system terms such as “similarity”, “proximity” and “good continuation” are used to describe much the same ideas as Marr’s much later system. Given that our every-day experience involves seeing letters and “grouping” them into words, it is certainly reasonable that words could be considered objects by the “top-down” definition provided above. Words are objects because we habitually group those specific letters together into a single “thing”. However it could also be argued that words are objects by the much lower level “bottom-up” definition provided by Marr and the Gestalt Psychologists. Both systems use “similarity” as their starting point. Letters are dissimilar to one another in terms of primary contours, but they are similar to one another in as much as they are all letters. The letter “A” has a lot more in common with the letter “D” than it does with a natural image of a can of coke for example. Both “A” and “D” are stylised primitives of contours and they serve the same function. In terms of spatial proximity/continuity, in English the letters which form words are placed immediately next to one another and are separated from the letters of other words by a space. If you consider cursive writing you could even argue that words meet the definition of continuity of discontinuities/good continuation. The letters within one word can be joined together physically, but not the letters from different words. The extent to which these top-down and bottom-up processes are independent of one another is unknown, although it is reasonable to conclude that the low level bottom-up processes form a crucial component of the higher-level top-down process. That is, it is likely that to meet the top-down definition of an object a stimuli would also have to meet at least some of the bottom-up definitions. The reverse is not necessarily true, however. Something may appear like an object on the basis of its lower level visual characteristics, but through the application of top-down knowledge we may decide that it is in fact not (i.e. a visual illusion). In any case, it appears as though there are several criteria under which words can be considered “objects”. On the basis of this very preliminary discussion it can be concluded that the hypothesis that words are a type of visual object is a reasonable starting point for this thesis.

If words are indeed like visual objects, then it would be expected that the study of object-based attention as it relates to words should yield findings similar to what has been observed with objects that are not words. In order to design experiments which will look for these effects, it is first going to be necessary to precisely define what attentional effects have been found to be "object based". What follows will be a discussion of the experimental findings of studies into object-based attentional effects. At the most basic sensory level, Theeuwes, Mathôt and Kingstone (2010) found that their participants had a statistically reliable preference for keeping their eye movements within single objects, even though the constraints of the task did not force them to use this strategy. In addition Lamy and Egeth (2002) have found that "object" represents a level of representation that is used by the human attention system. Greater reaction time costs are incurred when moving attention between objects than within objects. The spatial separation of the cue and target locations was controlled for, so spatial attention alone cannot explain these findings. The magnitude of the object-likeness of a particular stimulus appears to be modulated by various factors, most notably the number of visual elements the object is composed of. It is difficult to see how such findings can be accounted for using a purely spatial account, so this can be taken as evidence for the validity of the concept of object-based attention.

Some of the strongest evidence for object based attention comes from the classic study conducted by Egly, Driver and Rafal (1994). In this study they presented participants with two rectangular "objects" in the middle of the screen. These could be oriented either both horizontally or both vertically. The spatial attention of the participants was drawn to one end of one of the rectangles through the use of a cue (a brightening). The participants then had to detect the appearance of a target (a grey square inside one of the rectangle ends). The measure of interest in this study was reaction time. As might be expected on the basis of spatial attention alone, participants responded fastest when the cue and the target were in the same location (a valid target).

There were 3 types of cue target relationship, which are illustrated in figure 1-2.

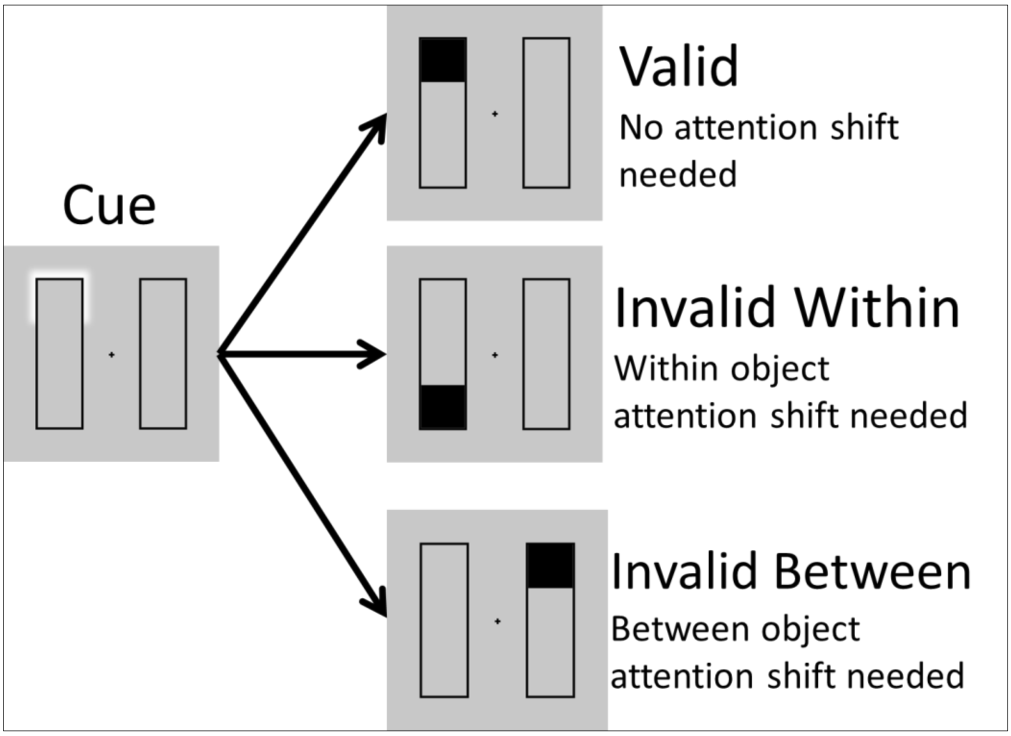


FIGURE 1-2 - SCHEMATIC REPRESENTATIONS OF THE 3 CUE/TARGET RELATIONSHIP TYPES FOUND IN EGLY ET AL. (1994). FIGURE ADAPTED FROM CITED PAPER. FOR ILLUSTRATIVE PURPOSES TRIALS WITH VERTICALLY ORIENTED RECTANGES SHOWN. NOT DRAWN TO SCALE.

Egly et al found something else which is not easy to explain using spatial attention alone. There were two classes of "invalid" trial: within object trials where the cue and target were inside the same object, and between object trials where the cue and the target were in different objects. These two types of cue/target relationship had exactly the same degree of spatial separation and will have required an attention shift of equal magnitude from the cue location, so going by the spatial attention account alone they should have had similar reaction times. Nonetheless, there was a significant reaction time benefit for the within object invalid trials compared to the between object invalid trials. This effect has been attributed to an elevation of attention to the whole object whenever part of that object is cued. This is what is meant by "object based attention".

Luo, Lupiáñez, Funes and Fu (2011) found what could now be described as the "classic" object based effect while using an Egly type paradigm, where same location responses were fastest, same object responses were next fastest and different object responses were slowest. Their findings matched those of Egly et al. (1994). In an extension of Egly et al's method, they also studied Spatial Stroop effects and Simon effects within the same experiment. The Spatial Stroop (Funes, Lupiáñez & Milliken, 2007) is a reaction time benefit incurred in a target detection task. When a participant is cued to a target location and the target they have to detect is an arrow which is compatible with the side of the screen on which it is presented, responses are faster (e.g. leftward pointing arrow on the left of the screen). Conversely when the arrow is incompatible with the location in which is presented, there will be a reaction time penalty. This is in spite of the participants being specifically instructed that the location of the target is irrelevant. Due the use of central fixation points, this effect may be being driven either by the location of the target, or the direction of attention shift required to detect it: the arrow will be compatible or incompatible with both at the same time. The Simon Effect (Simon, 1969) is the well replicated observation that participants are faster at responding to targets which share a spatial mapping with the response keys (i.e. you will respond faster to a target on the right of the screen faster if the correct response button is to the right of the response box). In Luo et al's (2011) experiment, they found the Simon Effect to be always present, but in the case of the Spatial Stroop, something more interesting was going on. A normal, large incompatibility effect was observed for different object targets, but when the target occurred inside the cued object, the spatial incompatibility was greatly reduced. Indeed, the size of the spatial incompatibility effect for same location and same object targets was indistinguishable from one another. They were only able to display this effect at a short cue-target onset asynchrony of 100ms. The authors concluded that while the Simon Effect was an outcome of response production, and was accordingly unaffected by the constraints of the task, the Spatial Stroop effect was a product of early visual processing and was modulated by the allocation of object based attention. When a region was tagged as an object, spatial compatibility effects within that region were greatly reduced. While it may be arguable that perception and response production can so easily be teased apart, the fact that effects were modulated by being within an object supports both the idea that objects are indeed processed as discrete entities by the attentional system, and that this is an early perceptual process that has implications for all later processing.

It should be mentioned that there are limits to object based attention. Object based effects are not always found even in Egly type paradigms, nor do the effects always go in the expected directions. Instead, the manner in which object based attention presents itself will vary according the demands of the task. For example Jordan and Tipper (1999) demonstrated an object based reaction time penalty rather than a benefit. They did this by lengthening the time from the cue to the target and in so doing induced inhibition of return (IOR). The idea being that in their study, just as in Egly et al's, a cue landing inside an object elevated attention to that whole object. However, because of the extended time between the cue and the target the attentional system "gave up" looking within that object for a target and inhibited attention deployment to that region so as to mark it as thoroughly searched. Lamy and Egeth (2002) found that the intensity of object based effects can be modulated by the visual characteristics of the objects used. The more elements the object is made of (for example having a differently coloured “handle”) the more the object based effects will be diluted. Additionally, sometimes no object based effects will be found at all. For example, Davis and Holmes (2005) used an Egly type paradigm that successfully eradicated any object based effects, depending on what type of stimuli they used. When they used standard canonical forms like rectangles as their objects, a standard object based attention effect was observed. But when they changed their stimuli to novel, irregular, non-canonical shapes the object based effects disappeared. Accordingly we can conclude that there is more to the perceptual definition of an object than simply being a contiguous shape.

Indeed, some object based effects have been found with canonical objects which only meet the criteria of being contiguous through visual illusion i.e. the “objects” used were not contiguous shapes (Heather Jordan & Tipper, 1998). So canonicity seems to be rather more important for the brain's definition of an object than it simply being a contiguous shape. Past experience plays an important role in whether something is going to be perceived as an object or not.

The key role of past experience in defining what is an “object” does not undermine the case for object based attention. It could be argued that the lack of a generalizable effect to novel objects suggests that it is not an “object” based effect at all, since entirely novel objects are certainly something we may encounter. However, there is evidence that our internal criteria for defining an object may indeed depend on prior experience. A great deal of research (for example Kriegeskorte et al., 2008, Haxby et al., 2001) has focussed on the nature of object based representations in the brain. It is generally agreed that primates (including humans) have groups of cells in the inferior temporal cortex that, through exposure, become specialised to the detection of particular things in the environment. Claims have been made for cells which become specialised to all manner of environmental features or household objects, the most dramatic claim being neurons for specific people (Connor, 2005). Whether or not object detectors can ever really be that specialised, what is not in question is that these neural representations are formed through exposure. As such, it is not surprising that object based effects would be easy to demonstrate with familiar, canonical shapes like rectangles, and hard to demonstrate with novel, irregular shapes we have never seen before. If this explanation is true, we would of course expect a stronger object based effect for the non-canonical shapes the more we are exposed to them.

Section 2 - Neuroanatomy of Reading

The specific neuroanatomical features that are utilised in visual word recognition are a subject of considerable debate. It is agreed that in most participants reading is more strongly associated with the left hemisphere of the brain than the right (e.g. Fiez & Petersen, 1998, Seghier & Price, 2011). This is reflected in a processing advantage for words in the right visual field (which projects to the left hemisphere of the brain). This has effects for how words are processed. For example, Lindell, Arend, Ward and Norton (2007) found a greater number of feature conjunction errors in the left visual field than in the right visual field. This is indicative of more efficient processing for words in the right visual field. Superior word processing in the right visual field is not an isolated finding and has been found by numerous researchers (Dehaene, 2009, Lindell et al., 2007, Calvo, 2009). However, moving beyond the observation that for most people the left hemisphere is important for language generally and reading in particular has proved to be problematic. There is extensive debate about the specific structures involved in the processing of written words.

Of importance to this thesis is the neuropsychological account of how written words are decoded provided by Caramazza and Hillis (1990). They used studies of patients with various kinds of neglect to build a model of how words are visually decoded. This paper has since become very influential. It argues that words have different levels of representation in the brain. The lowest level of representation they propose is that of a "Retino-Centric Feature Map". Here all information is judged with regard to its position on the retina. Damage to processing at this stage will produce hemianopia where the one side of absolute retinal space is not attended. Neglect of this sort would typically be caused by damage to the very "early" regions of the primary visual cortex, or even to the connections of the optic nerve as it travels from the eye. The second level of representation they propose is that of a "Stimulus Centred Letter Shape Map". Here information is processed with regard to the stimuli itself regardless of its retinal position or size. Damage to processing at this stage will produce neglect where one side of a shape or object is not attended, even if that object is wholly in one side of the visual field. In Subbiah and Caramazza (2000) it was speculated that this level of representation was shared between both object and word processing, indicating a common evolutionary heritage. They provided an example of a patient who neglected the left side of both words and objects. That this neglect was not centred on word level processing was indicated by their extremely poor performance at reading vertically written words: they were neglecting the left hand side of every single letter in this case. This patient had damage to the right inferior mesial temporal lobe and some damage to the lateral and inferior thalamus. The final level of representation they propose is a "Word Centred Grapheme Description". This is specific to words and is not shared with object processing. Here information is coalesced into a "word" and all processing is in reference to a canonical representation of that word (even though it has not yet been identified). The relative proportions of the letters and their spacing do not matter at this stage, as we are attending to our internal representation of the word rather than the external one with which we have been provided, so top down knowledge can compensate for irregularity or degradation of the actual stimulus. That is, we can use what we know about a word to compensate for inadequacies in the actual visual information we are provided with. Damage to processing at this stage will mean that patients are unable to attend to either the beginning or the end of a word, regardless of the spatial orientation in which it is presented. For example, if a word is printed vertically top to bottom, and the patient has a problem with word endings, they will neglect the bottom of the stimulus. This effect holds even if the word is written right-to-left (i.e. backwards). Patients who neglect word endings will neglect the left side of the stimulus in this case, even though in normal reading they neglect the right. Caramazza and Hillis (1990) provide a case study as further evidence of the reality of this level of representation. Patient NG displayed the symptoms described above following damage to her brain which was primarily concentrated in the left parietal region. Note that this model says nothing about how lexical access is completed. It simply takes us from a word being a series of incoherent squiggles on a page, to it being something we could reasonably describe having been recognised as a word. In most modern models of reading (e.g. EZ-Reader, SWIFT) this process would fit in either during or before the "familiarity check" stage. Lexical access occurs after the process described by Caramazza and Hillis. Given that the first two levels of this model posit a common system for both words and objects, it can be speculated as to how exactly the human perceptual system is tackling the problem of recognising words using the available resources. The different stages of Caramazza and Hillis's levels of representation model and how they affect perception of example scenes are illustrated in figure 1-3.

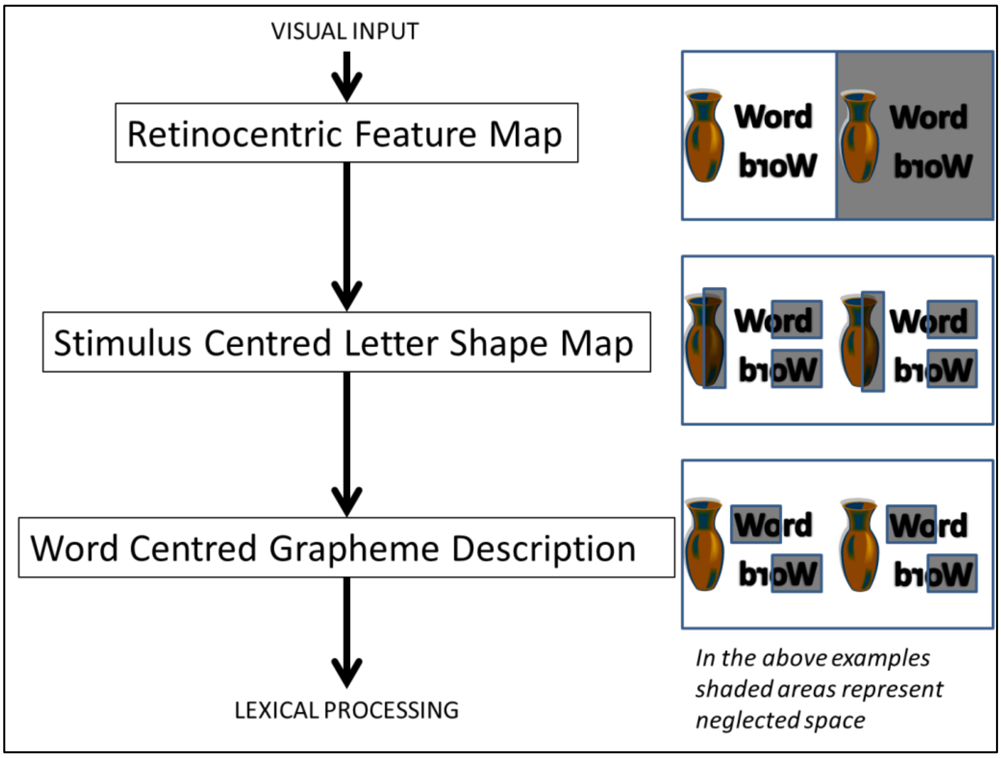


FIGURE 1-3 - THE 3 STAGES OF CARAMAZZA & HILLIS, (1990) AND HOW DAMAGE AT EACH LEVEL RELATES TO THE NEGLECT OF EXAMPLE SCENES.

On the basis of the pattern of deficits displayed by Caramazza and Hillis (1990) patient NG, it is reasonable to conclude that the left parietal region of the brain is important for the processing of written words. This is at odds with several theories which posit that the left *temporal* region is important for reading. However, what is not in doubt is that the left side of the brain appears to be crucial for reading. The way in which this brain hemisphere is important for reading is a point of considerable debate. Some of the competing claims for the importance of the left side of the brain in visually processing written words will now be discussed. To begin with, what has become one of the most influential and hotly debated theories relating to the low level visual properties of words will be discussed. This is the theoretical reading mechanism referred variously to as Neuronal Recycling, Neural Reuse, the Visual Word Form Area (VWFA) (Dehaene & Cohen, 2007), the "Letterbox" area (Dehaene, 2009) and the Local Combination Detector (LCD) (Dehaene & Cohen, 2011). Within the domain of reading research all of these terms are referring to the same idea - that through neural plasticity and an evolutionary process called exaptation parts of the brain that originally evolved for one purpose can become specialised for a new purpose - in this case reading. This neatly allows researchers to sidestep the issue of evolutionary timescales making a dedicated "reading centre" of the brain unlikely - it can "evolve" anew with each new reader. The lead researcher behind much of this work is Stanislas Dehaene.

The specifics of this theory are laid out in great detail in Dehaene (2009). In the first instance he claims that written languages have been specifically developed to be easily processed by the human brain. Since the brain has not had a sufficient evolutionary timescale in which to become well attuned to reading, humans through the creation of "culture" have instead deliberately crafted the written form to be well suited to human neural architecture. He cites evidence from Tanaka (2003) which shows a primitive "alphabet" of feature detectors in the early visual areas of the monkey brain (areas V1, V2 and V4). Dehaene claims that the individual letters of the Latin alphabet bear a striking similarity to the individual contour detectors which have been identified within the monkey brain. So for example, in looking at a simple cube with a horizon line in the distance behind it, contours which resemble the letters T, F and Y can be identified. Consequently, when it comes to identifying letters which resemble real world contours, the brain already has much of the necessary architecture in place because it has evolved to recognize objects. By a gradual process of refinement scribes over the centuries have been tweaking written languages to find ways of making them more easily readable. The Latin alphabet is one of the most sophisticated languages, where many (but not all) of its letters closely resemble natural contours for which we will already have a dedicated feature detector. Thus it should be possible to identify most of the letters of the Latin alphabet without needing to use more than the most low-level visual processing areas in the brain. Leading on from this, the central (and most contentious) claim of Dehaene's theory is that there is a region of the brain located in the left occipito-temporal sulcus (named variously the Letterbox Area, VWFA and LCD) that in most healthy readers becomes specialised for the processing of both letter and word stimuli. Through training this region overcomes the usual insensitivity of the human visual system to mirror flipping, and becomes able to discriminate “d” from “b” (Pegado, Nakamura, Cohen & Dehaene, 2011). Dehaene argues that the VWFA comprises part of the “what” pathway (Dehaene, Cohen, Sigman & Vinckier, 2005) described by Goodale & Milner (2004). This is a visual pathway specialised for identifying visual stimuli. It is sensitive to object identity, colour and texture. Near the VWFA are regions of the brain which become specialised for detecting physical objects (Tamura & Tanaka, 2001) or even, as previously mentioned, people (Connor, 2005). Primitive contours, when encountered in a particular pattern, come to be associated with a face or an object and are accordingly recognised. It is not such a stretch to conclude that the same process could be responsible for the processing of words. Dehaene believes that the VWFA has become attuned to the detection of words, or at the very least large parts of them, such as bigrams. He hypothesizes an intermediate stage between primitive contours and whole word processing involving what he calls "Bigram detectors". These would look for frequent pairings of letters, and would be concentrated in cells located toward the rear of the VWFA. He claims that the VWFA shows heightened activation during reading and is specifically responsive to word-like stimuli, showing more activation for legal non-words than for illegal non-words. He cites some neurological evidence where brain damage can produce alexia, and argues that this is because it is disrupting signals to the VWFA.

There is some independent evidence for the claims coming from Dehaene and colleagues. For example Turkeltaub, Eden, Jones, and Zeffiro (2002), in an extensive review on the neuroimaging data from reading participants, did find some evidence that there was a VWFA. However, of the papers reviewed which believed there was a VWFA, there was not agreement on its location. Turkeltaub et al's (2002) meta-analysis of 11 different papers (totalling 117 participants) studying single word processing using neuroimaging concluded that there are 11 key areas that are unambiguously involved in the processes of human reading. These were located in the bilateral primary motor cortex, the middle superior frontal gyrus, the bilateral temporal sulci, the left fusiform gyrus and the bilateral cerebellum. Dehaene's location for the VWFA is included under the left fusiform gyrus, so clearly this region is important for reading. The other areas cited all have additional functions so could be explained by activations in motor planning and visual perception. Only the VWFA seems to be involved in reading exclusively. The approximate locations of the areas of the brain that Turkeltaub et al (2002) considered crucial for reading are illustrated in figure 1-4.

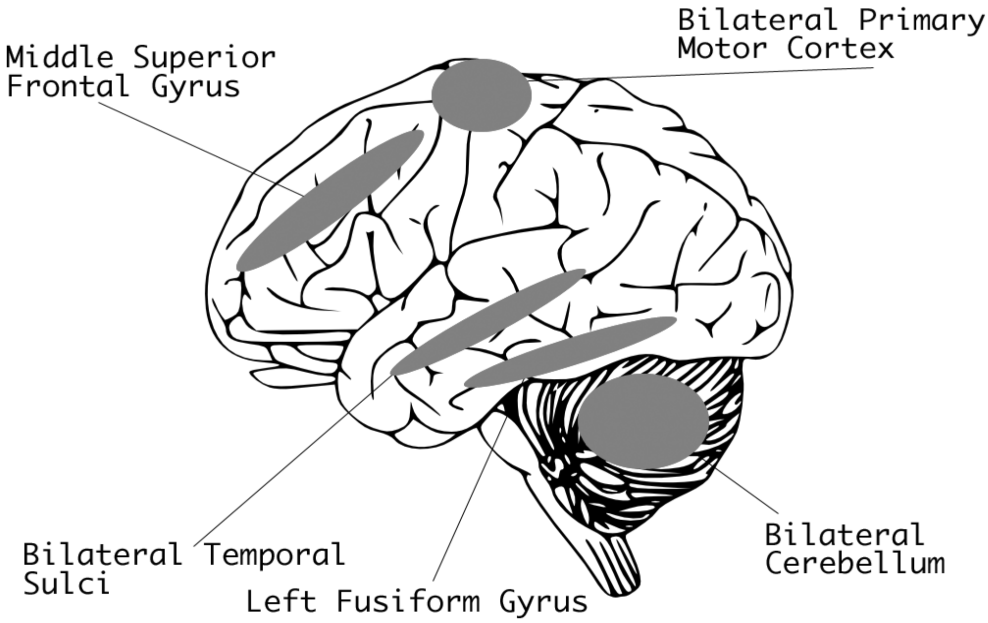


FIGURE 1-4 - THE KEY REGIONS OF THE BRAIN INVOLVED IN READING IDENTIFIED BY TURKELTAUB ET AL. (2002). POSITIONS ARE APPROXIMATE. SOURCE IMAGE FROM ROYALTY FREE WEBSITE WWW.CLKER.COM

Proverbio and Adorni (2009) found much more unambiguous evidence for a VWFA. Looking at Dehaene's location for the VWFA they found that activation was higher in this region when participants were performing a lexical decision task compared with when they were detecting a target letter. Whole-word stimuli were used for both tasks, indicating that this region had some specialisation for processing words as words, as opposed to hunting for targets embedded inside them. As predicted by Dehaene they also found that activation when visually processing words was highly left lateralised and this was found to have an effect on manual responses, with the lexical decision task producing a greater right-hand bias than the target detection task.

While it undoubtedly poses some very interesting questions and presents some fascinating data, a number of researchers have suggested that the VWFA theory overreaches. James, James, Jobard, Wong and Gauthier (2005), for example, confirmed that the VWFA does respond more to pronounceable letter strings versus non-pronounceable letter strings. They also found that non-pronounceable letter strings still produced a qualitatively different pattern of activation than the observation of single letters. This suggests that there is a process which deals specifically with visual groups of letters, regardless of whether they form a familiar or pronounceable word or not. Furthermore, they found the anterior regions in front of the VWFA were sensitive to single letters. The VWFA theory stipulates that the more posterior regions should deal with more primitive forms of words and complexity should increase as you move forwards. These findings are difficult to reconcile fully with the VWFA theory.

Flowers et al. (2004) agreed that there is a region of the extrastriate cortex which is sensitive to words. However this region was not where Dehaene said it should be, but was instead located more than a centimetre away in Brodmann's area 37. The authors did point out that the "object areas" of the brain (of which the VWFA is meant to be a sub-type) do tend to have large regions that are shared with other stimuli, and only very small regions of specialisation. This could account for some of the ambiguity regarding the location of this word region. In Dehaene (2009) it is claimed that variations in the location of the VWFA can be attributed to differences in individual anatomy and the location of specific features on an individual subject's brain. The VWFA is however always in the Occipito-temporal sulcus, of which part is located in Brodmann's area 37. Flowers et al. may have been being too literal regarding the location of the VWFA.

More problematically for the VWFA is the paper by Seghier and Price (2011), who denied there was a VWFA at all. They did not find an increase in left ventral occipito-temporal processing in response to words. What they did find was a corresponding drop in right ventral occipito-temporal processing when subjects were viewing words. Thus the reason word processing appears to be left lateralised is because normally present right hemisphere activations reduce when processing words. They hypothesise that this reduction is because words require less visual processing than other stimuli due to top down influences. They deny that the so-called VWFA has any special significance for the processing of words, or more specifically they deny that the VWFA is only for processing written words. It appears to be active in many tasks. Instead they posit words as a special class of stimuli that require less attention deployment (explaining the right hemisphere reduction in activity) due to top down factors. They do not specify what these top down factors are, but presumably they are referring to words originating from a relatively constrained set of stimuli, having relatively consistent features and adhering to very specific rules. Thus when looking at words, much more than when looking at other things, we may already have a pretty good idea of what word we are looking at before we have processed it. This foreknowledge facilitates the task of identification and reduces the processing load the brain has to bear.

Offering a picture of what they perceive an alternative to the VWFA, Thierry and Price (2006) describe a system of modal and amodal networks in the brain which contribute to the processing of all visual stimuli, not just words. There are resources in the left hemisphere which activate for both verbal and non-verbal stimuli. This has been attributed to an amodal conceptual system which utilises the posterior/superior middle temporal gyri, the inferior frontal gyrus and the right cerebellum. However there were also networks that differed for verbal and non-verbal stimuli. The left anterior and posterior superior temporal areas were involved in word comprehension (either visual or auditory). This is the region where the VWFA would be located. The right midfusiform and posterior middle temporal cortices were involved in processing the non-verbal sounds and images (cows mooing, pictures of a cow etc.). This produces a reasonably appealing picture of overlapping cortical networks with both shared resources and dissociated pathways that seems biologically plausible, however it is not nearly as “neat” as a model which proposes a single location for word processing. It is also worth noting that the VWFA theory proposes that dealing with words is all the eponymous region does, whereas in Thierry and Price’s model, their reading network does more than one thing.

Price et al. (2006) looked at the difference between reading aloud and object naming. In the first instance, they did not find greater activation in the VWFA for reading than for object naming. When they introduced a baseline task of saying “OK” over and over again to meaningless scrambled images to identify the areas involved in speech production, it was found that these were the only areas that differed between reading aloud and object naming. Greater activation in the speech production areas was found for reading compared to object naming. It is hypothesised that written words feed back into this region and amplify activation in a way not found with object naming, for example the word MONKEY will also partially activate the word MONK. While Price et al. would clearly disagree with Dehaene that words acquire a neural representation in the same way as other visual objects, it is nonetheless interesting to note that Price et al. found object naming and reading aloud to be very similar in terms of the activation patterns they produce. They may indicate that words are processed similarly to objects, even if the mechanism is not the one Dehaene specifies.

Finally for Price’s rebuttal of the VWFA, Price and Devlin (2003) found that, contrary to Dehaene’s claim, the VWFA is active for lots of tasks other than reading. These included naming, recognition and visual form processing. Amazingly activation during Braille reading by blind participants has also been observed. Price suggests that there is no direct neuroanatomical representation of word forms but rather that words are an emergent process brought about by particular interactions between the language centres and the visual cortex. Price and Devlin claim that calling that a particular area the VWFA makes about as much sense as calling V1 the "Vertical Bar Area", since that region is sensitive to vertical bars (amongst many, many other things). However it should be noted that to eliminate the possibility of true specialisation of the VWFA at the level of cortical columns is currently beyond the capabilities of medical imaging. The possibility that a very small region of the brain becomes specialised for word processing accordingly cannot be ruled out. Price and Devlin seem to lean toward the position that one population of cells can have multiple functions and that these cells overlap with other populations which also have multiple functions - making regionalising the brain very difficult. Indeed such an amorphous structure may make highly compartmentalised models of the brain nonsensical.

On the basis of the preceding review it is clear that there is a great deal of debate regarding how and where in the brain the human visual and attentional system decodes written words. Caramazza and Hillis's (1990) lesion evidence suggests the left parietal area is important for reading, although caution always needs to be used when using lesion studies to localise processing centres in the brain. Dehaene’s various publications suggest the left temporal region is important. Price claims that there is no single reading centre and that processing of words is more diffuse. These claims compete directly. If one proves to be true, the others really cannot be. This is a debate which continues to rage in the literature. However what all of these different approaches incorporate is a belief that at some level visual word processing must be similar to object processing. In principle this should allow us to look for effects in written words that would normally be associated with visual objects. However, it is not clear how (or even if) this element of overlap with object processing will affect attention deployment to words. That is, although plausible it is by no means certain that any similarity between reading and object processing at the neurological level will be observable in effects at the behavioural level. An examination of the findings related to attention deployment to words is needed.

Section 3 – Attention to Words

The study of what human beings actually do with their attention during reading is an area of research with a long heritage. One of the seminal works in the field is the study by Reicher (1969). He demonstrated what has now become known as the “Word Superiority Effect”. Put simply, humans are much more accurate at identifying specific target letters when they are embedded inside real words than when they are embedded inside nonsense strings. Participants were presented with a two-alternative forced choice (2AFC) regarding whether a particular target letter was inside the previously presented stimulus array. In one condition those targets were embedded inside real words, in the other the targets were embedded inside nonsense strings. The participants were informed where in the nonsense string the target would appear, but they were still more accurate at identifying the targets when they were embedded inside real words. This has been attributed to so called “top down effects”, where the successful identification of a word feeds back into an activation of all the information associated with that word, including that word’s constituent letters. If we know what word we have just seen, we will have a very good idea of what letters we have just seen as well even if we did not notice one letter specifically. However, in the case of the nonsense strings, if we didn’t notice the target letter we have no way of deducing its presence after the fact. This paper was considered ground-breaking because it was the first instance where providing more information did not improve performance. When provided with advance notice of what the target location would be, performance on the nonsense strings still did not rise above the level of the targets embedded inside words with no advance notice of the target.

Following on from this paper Johnston and McClelland (1974) also asked participants to detect targets inside words and nonsense letter strings. In a further manipulation they asked participants to either attend to a specific letter position, or to try and attend to the whole string. In the case of nonsense letter strings, focusing only on the location where the target would occur enhanced performance, whereas in the case of words trying to attend to the whole string brought the best performance. Performance at target detection inside holistically processed words was better than the performance at target detection inside any kind of letter string. Of key importance in this study was the finding that participants can selectively process words in different ways, and that this has an impact on how they allocate attention to words. This is considered a further demonstration of the word superiority effect.

Mapelli, Umilta, Nicoletti, Fanini and Capezzani (1996) also found a word superiority effect. However in their study words could be presented horizontally or vertically, as could the response buttons. Word superiority effects were still present in both orientations. It was also found that there was a Simon effect when the response mode matched the word orientation (i.e. participants responded faster with a right button to right targets, a top button to top targets and so on). Amazingly when the words were presented at fixation by Rapid Serial Visual Presentation (RSVP), a Simon effect in the horizontal dimension was found. That is, participants responded faster with the right button to targets present at locations that would have been on the right side of the word had it been printed normally. This was hypothesised to be the result of the canonical orientation information present in the internal word representation. The authors agreed with Caramazza and Hillis (1990) that internal word representations include spatial information, but they attached the proviso that if the response mode participants must use carries its own spatial information it can override the internal representations and produce a Simon effect consistent with the visual configuration of the stimulus, rather than the internal representation. In the case of the RSVP task the spatial effects of the internal representation show through, whereas in the horizontal and vertical tasks the local task parameters induced a Simon effect that matched the presentation orientation. The key point to take away from this study is that some key attentional effects associated with words map onto a novel (vertical) orientation but not all. The word superiority effect was present in the vertical dimension, but the canonical left/right Simon effect was overridden by local task-contingent factors.

In further evidence of top-down processing influencing the decoding of words Inhoff, Pollatsek, Posner and Rayner (1989) had participants read text presented in different orientations. The text could be written left-to-right, right-to-left and it could either be mirror flipped or not. The participants were remarkably good at reading in non-standard orientations, although mirror flipping made things somewhat harder. It was hypothesised that mirror flipping forced participants to adopt a more constrained attentional spotlight. Processing for right-to-left but non-flipped text appeared to be very similar to normal reading, albeit slower in terms of how participants' attention was distributed. This can be taken as further evidence for internal representations at the word level which can aid in decoding text even when it is visually distorted.

While it does appear that humans have a largely invariant internal representation of words which are used to make sense of the visual input during reading, not all of the visual features of words are of equal importance when it comes to successfully activating this representation. Treccani, Cubelli, Sala and Umilta (2008) found that the first few letters of any given word were the most important for identifying that word. They did this by having the participants perform a lexical decision task, while manipulating the written orientation of the words (left-to-right or right-to-left). When participants had to make a response they were faster at doing so with the button that was on the same side as the word beginning. The authors interpreted this as indicating a spatial preference for word beginnings. This may suggest a further commonality with object processing. In object processing, certain features of an object are more important for its identification than others (Biederman, 1987). It may be that for words, word-beginnings are those crucial features for successfully identifying a word. However, it is worth noting that the authors did not control for fixation location. In normal reading participants prefer to fixate slightly nearer the start of a word than the end. This may be true when forcing participants to read right-to-left as well, so their results may simply reflect a preference for issuing responses on the side you are fixating.

At the most basic level these preceding papers could be considered evidence for object-like processing of words. When we identify words, we gain access to lots of information related to that word including the letters it is composed of. Objects, like words, come packaged with a whole swathe of information which we have access to once we have successfully identified the object in question. On identifying a teapot for example we also gain access to information relating to its function; it would be surprising to find that it contained something other than tea for example. However, all this really tells us so far is that in terms of their informational content words are indeed discrete “things” which are filed in such a way as to give us access to the information associated with that word whenever it is identified. This may or may not suggest broader similarities with objects. The mechanism by which words are identified could still be very different from the way objects are identified, even if the later information retrieval processes appear to be similar. If we are to claim that words are like objects in any meaningful way, we need to find a way of more directly measuring attention distribution across words.

Tydgat and Grainger(2009) measured participants’ ability to identify target letters at different locations inside 5 character letter, digit and symbol strings. So for example in the letter string EBYTS they might be asked to say whether that string contained a Y. They found that in a graph plotting accuracy across all 5 positions, the functions for letter and digit strings tend to be approximately “W” shaped (participants were most accurate at the ends and the middle), whereas the function for symbol strings tends to be the shape of an inverted “V” (that is, participants were most accurate in the middle). Tydgat and Grainger suggest that this is due to a fundamental difference in how we process letters and digits when compared with how we process symbols. They argue (like Dehaene) that there are feature detectors in the human visual system that become specialised for the perception of letters and digits. Due to high levels of exposure in daily life, the receptive fields of both the brain’s letter and digit detectors become very small, providing less uncertainty of their identify when other letters and digits are close by. The symbols on the other hand are much less frequently observed, so their detectors do not have such small receptive fields and there will be more potential for confusion when presented alongside other symbols. Accordingly they experience different effects of “crowding”, where close proximity to other characters interferes with processing. This gives rise to the differently shaped accuracy functions. Tydgat and Grainger did not show participants legal words in this experiment, so it is important to be careful about drawing too large inferences. Nonetheless, what is clear from this study is that digits and letters appear to be a special class of stimuli that are processed differently from other visually similar materials like symbols.

Although most models of reading make no attempt to incorporate early visual processing, some authors have created models that try to do so: Whitney's (2001), SERIOL model suggests that the position of letters in a word is encoded using a serial mechanism. Many models have proposed serial word encoding within text (e.g. Reichle, Pollatsek & Rayner, 2006, Just & Carpenter, 1980), but Whitney proposes applying this to the sub-word level as well. SERIOL posits a number of levels in word decoding. The first is the Retinal Level. This model suggests that we take advantage of the different levels of acuity in the human retina to encode letter positions. Our visual acuity drops off the further from fixation something is. Once an acuity map of the visual stimulus is created, the model moves into the Feature level, where sub-letter features are encoded. The acuity map can be used to create a positional gradient, where lower acuity is used to indicate that something is further away from fixation. This model posits that the positional map generated in the left visual field will partly inhibit the map generated in the right visual field, resulting in a descending left-to-right positional gradient of activation with the strongest signal being generated by the first letter of the word. Once letter positions have been encoded the model then moves from encoding letters, to bigrams, to whole words. This model is in many respects similar to that proposed by Caramazza and Hillis (1990).

Competing with the SERIOL model is the LTRS model (Adelman, 2011). This model suggests that somewhat differently from the SERIOL model different features of words will become available to us at different stages during their recognition. As evidence for this he shows that, if presented rapidly enough, the word “LTRS” can be misread as “LETTERS”. The reason for this is that we encode words as a series of relations. We know that if what we are looking at is the word “LETTERS”, L should come before T, which comes before R, and so on, before we have complete information about that word (such as where the “E”s go). If we are denied more complete analysis of a word due to rapid presentation, the stimuli “LTRS” may well fulfil enough spatial relationship criteria in terms of its letter order to be mistakenly identified as being the word “LETTERS”. Furthermore, unlike SERIOL, the authors posit that this information extraction process happens across the whole word in parallel, with information about each letter position being gathered at an equal pace. This hypothesis was supported by Adelman, Marquis and Sabatos-DeVito (2010) who measured the speed at which we extract information from letter locations within a word. Using the most rapid presentation rates possible with an ultra-high refresh rate monitor they presented 4 letter words for either 18 or 24ms. The participants had to identify whether probe letters were present using a 2AFC. At 18ms performance at all letter locations was at chance level. At 24ms presentation performance at all 4 letter locations was significantly above chance. The authors concluded that this was indicative of information being extracted from all four letter locations at an equal rate. It seems unlikely that the short 6ms window between the two time intervals could have concealed some sort of serial processing of the letter locations, although it cannot of course be entirely ruled out. However, it is problematic to separate the early visual processing of words from the response preparation and top down processing that will necessarily occur while participants perform an experiment. It is possible that the visual processing of the letter locations might well use some sort of serial process, but that it occurs rapidly and the word only becomes available for further analysis once all letter locations have been extracted. At 18ms presumably this process was not yet complete. In any case, even if Adelman is correct and early visual processing of words is a parallel process, this does not imply that any later processing stages will be.

While these two models disagree on the specifics, they both claim that low level visual features of the words will be available before complete information about the word is. So we may well know something about the relative position of letters before we know exactly what word it is. Furthermore, they both suggest that identifying the letters in a word is a precursor to identifying the bigrams and finally the full word. However, there are a number of studies that suggest not all letters are encoded in the same way. Some form part of a group which can distort how they are processed. Human perception of the spatial properties of words is often distorted in consistent ways, and these “errors” can be informative about how we are representing these words cognitively.

In Fischer (1996) it was found that, unlike simple lines (which were bisected very slightly to the right),words are consistently bisected toward the left side when participants are asked to place a mark at their mid-point. The author hypothesised that this was to do with word beginnings being over-represented attentionally since they are so important for lexical access. Several studies (including Treccani et al., 2008, above) have observed that the word beginning is the most important part of the word in terms of how it is processed. Because we devote more attention to the word beginnings, Fischer claims that this causes it to be perceived as bigger than it really is, causing a leftward bias in bisection. Fischer (2000) also observed this leftward bias with character strings, but only when they were mixed in with pseudowords. This effect disappears when the words were printed vertically, suggesting this non-canonical form of printing uses quite different types of processing than is encountered in normal reading. When participants were English-Hebrew bilinguals (being tested in English), they displayed an even bigger leftward bias which would be predicted by this theory if we expect bilinguals to have higher attentional load during reading (Wickens, 2007). This was also the case for pronounceable non-words, presumably because they also will induce higher attentional load. The basic idea is that the more attention we allocate to a part of a word, the bigger it will appear to be. The author calls this the "Attentional Scaling Hypothesis".

In an extension of this hypothesis, Fischer (2004) also observed distortions in how we represent the spatial characteristics of words. Again using a bisection task, he found that German words which contained the trigram SCH (such trigrams are much more common in German than in English) had accompanying distortions to how they were bisected by participants. These distortions were consistent with the participants perceiving the trigrams to occupy less space than their actual 3 character spaces. Within the terms of the Attentional Scaling Hypothesis the trigrams are sufficiently frequently co-occurring that they come to be treated as a single unit. As a result less attention per-letter needs to be allocated to the trigram for its effective processing. This results in the illusion of them occupying less physical space than they really do.

So far a lot about the properties of the word themselves has been discussed: what parts of them are important, what parts induce distortions, and ultimately whether the processing of words could be said to be similar to the processing of objects. But what exactly are humans doing with their spatial attention during reading? It is commonly assumed that humans need to direct their attention toward a word in order for it to be processed. It seems like a simple claim, yet it is one that has not been without controversy. Besner, Risko and Sklair (2005) explored the role of directed spatial attention in reading. They did this by manipulating the reliability of a spatial cue. They sought to test the hypothesis that cue validities below 100% induce more distributed visual attention. Accordingly in their study the cues could either be 100% or 50% valid. In the 100% condition, the cue would always direct participants to the correct location for observing the target word. In the 50% condition the cue would take participants to the wrong location on half of all trials. In addition to a target word, each array would also contain a distractor word. The distractor word would sometimes be the same word as the target. The same distractors would be expected to produce relatedness priming. In both cases it was assumed that a more distributed attention should increase the effect of the distractor. This is what they found. When 100% cue validity was used there was no effect of priming. When 50% cue validity was found there was an effect of priming. They concluded that without directed spatial attention words are not normally processed, indicating that it is important for reading. Waechter, Besner and Stolz (2011) replicated these results, but they also conducted a variation on the Stroop task, printing a non-colour word in a coloured font which had to be named. The distractor was a black colour word. Even at 100% cue validity there was Stroop interference from the distractor. The authors concluded that colour naming tasks are a special case that forces participants to adopt a wider attentional spotlight. If this is true the much vaunted "automaticity of reading" demonstrated by the Stroop task may be nothing more than an artefact of the task parameters. Of relevance to the experiments in this thesis is the observation that in cases of less than 100% cue validity, a broader distribution of visual attention is employed than otherwise would have been. Accordingly findings should be interpreted in the knowledge that the type of attention deployment used is highly sensitive to how trustworthy the cue was in indicating where the target would be.

The preceding section has dealt with much of what is known about how people allocate attention to single words and groups of letters. From this is can be concluded that attention to words is indeed very similar to how we allocate attention to other things. We move our attention to the correct location and then process what we see there. This deals with how humans are using their spatial attention. But a key question of this project is the role of object based attention in reading. Accordingly it is necessary to look for object-based effects in word reading to be able to say with any authority that words are like visual objects when it comes to their processing.

Section 4 – Words as Objects

In the preceding sections it has been repeatedly noted that words appear to have a lot in common with visual objects in terms of how they are processed. Johnston and McClelland (1974) made the observation that participants can electively decide to process words in different ways. If an argument is to be made that words are indeed like objects, this requires that words are like objects when they are being processed as words (and not for example as letters inside words). LaBerge (1983) asked participants to detect a probe which was embedded inside a 5 letter word. The probe could appear at any of the 5 letter locations. The results he obtained depended on the task participants had to complete immediately beforehand. When asked to categorise only the middle letter of the 5 words, participants showed a “V” shaped reaction time curve, where they were fastest to detect targets in the middle location only, and slow at either end of the word. Conversely, when they were asked to categorise the whole word beforehand, reaction times across the 5 letter spaces were both fast and similar from location to location. LaBerge hypothesised that depending on the task they have to perform, participants will either adopt a wide or a narrow attentional spotlight. From the point of view of the object-based effects discussed in section 1, this could be interpreted as an object-like finding for words. When asked to categorise the whole word, they may treat that word as an object and consequently their attention will be elevated across the whole word simultaneously, producing flat reaction times. When asked to categorise only the middle letter, this object based representation of the word is not activated and variable reaction times across the whole word are found. Certainly it seems that allocating attention to the word (when the word is itself being processed) elevates attention and facilitates target detection at all 5 letter locations. This is consistent with what would be expected if words are treated as visual objects.

Taking this further, Prinzmetal and Millis-Wright (1984) found that certain types of word-like stimuli were treated as “perceptual units”. Words, pseudowords and non-pronounceable but familiar acronyms appeared to be grouped by the human perceptual system. When participants had to identify the colour of a target letter, feature conjunction errors were more common within these “perceptual units” than they were within unrelated letter strings. That is, they were more likely to mistakenly assign the attributes of another letter in the word to the target letter if that word was one of the aforementioned “perceptual units”. Prinzmetal, Treiman and Rho (1986) found that these perceptual units were not necessarily whole words. Feature conjunction errors were more common among letters which formed part of the same syllable. The authors concluded this attentional segmenting of words was not a purely phonological effect (although they believed that was a component) but that it was mainly driven by participants’ awareness of legal and illegal bigrams.

Sieroff and Posner (1988) used a paradigm where participants were cued to a location within a word and had to report the letters from within the word. It was observed that in all cases participants were better at reporting words from the left i.e. the start of words. However cuing did have an effect, in particular in terms of enhancing the left side preference. This effect was greatest in the least word-like stimuli. In the case of illegal non-words there was a strong effect of cuing on participants’ performance at reporting letters, whereas in the case of real words the effect was greatly reduced. The authors attributed this finding to real words being processed as a single unit, so they were proportionately less affected by cues to move their spatial attention to particular locations. Attention was already allocated to the whole, so cues to attend to part of the whole had less impact. At the very least this is indicative of strong top-down influences where the pre-stored properties of known words has a significant impact on how we allocate attention to them, and can override the influence of visual cues that are present alongside those words. More optimistically, this may again be evidence for object-like processing, where words are treated as indivisible units attentionally and drawing attention to one part of the word elevates attention to the whole thing. The findings of Sieroff and Posner were replicated by Auclair and Sieroff (2002).

They attempted to weigh two possible explanations for the above findings, the "replacement" theory and the "redistribution" theory. The replacement theory states that when identifying the word, top-down influences overwrite the visual input to a certain extent; participants complete the word with what they already know rather than what they see. The redistribution theory states that real words and pseudowords are a special case of stimuli which are processed by a differently shaped attentional distribution. They specify that there is also a temporal limit to how quickly the shape of an attentional distribution can be changed. On the basis of their analysis they concluded the redistribution theory to be the most plausible. In any case, what is clear is that words do not appear to be processed as multi-part entities to the degree that would be implied by their alphabetic structure. Some concept of "wholeness" is regulating how attention is allocated to words.

When discussing how people process words, it is worth noting that the task itself may not always compel participants to do it the same way. While the preceding experiments had instructed participants to process words in a particular way, Besner and Stolz (1999) were able to manipulate how participants processed words by either cuing them to attend to a specific letter location, or by only cuing them to the whole word. Using a modification of the Stroop paradigm, they found that identifying the target letter colour was only interfered with by the identity of the whole word when the participants were cued to attend the whole word. When they knew the location of the target letter beforehand, no Stroop interference was observed. These effects were highly sensitive to blocking context. When both classes of trials were mixed together, both types displayed Stroop interference. When they were blocked, only the "whole word" cued trials displayed Stroop interference. The experimental manipulation was drastically altering how the words were processed. When cued to the whole word, participants seem to have processed it as a whole. When only cued to parts of the word, participants seem to have been ignoring the "wholeness" of the word and were not processing its lexical identity. Accordingly it should not be assumed that word processing is always automatic or that attention is always allocated to word stimuli in the same way.

At this point it is worth drawing attention to the fact that visually processing words and “reading” are not necessarily the same thing. It is common for reading researchers to be highly critical of studies which involve presenting single words as “not proper reading” (Marmolejo-Ramos, 2009). Certainly these experimental paradigms are highly divorced from the context in which humans would usually encounter reading. Nonetheless they may still be highly informative. “Reading” as a cognitive process may not be the indivisible monolith it is commonly assumed to be: it may be possible to look at parts of the reading process in isolation. For example Grainger, Dufau, Montant, Ziegler and Fagot (2012) explored “reading” in Baboons. Baboons were trained to make discriminations between 4-letter real words and 4-letter non-words until proficiency. Once this was done the Baboons were shown novel stimuli and in a display of apparently insightful learning, they showed the ability to make inferences about stimuli they had never been exposed to before. The precise mechanisms by which they were doing this is a source of contention. Grainger et al. (2012) assert that the Baboons were displaying statistical learning using bigram frequencies as their guide. The Baboons appeared to select words containing low frequency bigrams as non-words more often. Bains (2012) suggested that the Baboons had no awareness of bigrams and were using a statistical learning technique based on the frequency of individual letters in individual slots. For example if position 2 in word is occupied by an “E” it is quite likely to be a real word, whereas if it is a “Q” then it is significantly less likely. For the purposes of this thesis it does not matter how the Baboons were accomplishing the task. These animals were performing a very convincing analogue of real word reading whilst being completely devoid of the lexical, grammatical and semantic knowledge we usually think of underpinning language. Thus it seems that at some level, “reading” as a process is reducible to a low level perceptual task. Of course it is entirely possible that given their lack of background knowledge, the

Baboons were approaching the task of reading in a novel way. It seems more parsimonious to assume that the Baboons were using the same low level visual and attentional processes as humans to accomplish this task, and that the difference between Baboon and Human readers is that the Baboons are incapable of subjecting the words to any more advanced process. This initial low level processing of words, before all of the mechanisms of lexical access and semantics are activated, is the domain which this thesis focusses upon.

Li and Logan (2008) took the research on object perception and developed an elegant, simple paradigm to look for object based attention in words. Using a modification of Egly et al.'s (1994) paradigm, they presented participants with two 2-character Chinese words in a 2x2 array. The words could be written either horizontally or vertically. Either the first or the last character of one of the words would be cued. This was followed by a target which had to be detected using a speeded button response. To prevent anticipatory responses there were some trials with no target (a catch trial). When both appeared, the cue and the target could have one of three relationships: they could be in the same location (valid); they could be in different locations but still within the same word (invalid within); or they could be in different locations and in different words (invalid between). This study successfully replicated Egly et al's results. Participants detected the targets fastest when they were in the same location as the cue. Nonetheless, there was a clearly detectable benefit found for invalid targets that were still inside the same word as the cue. This indicates that a cue landing anywhere inside a word to some degree elevates attentional allocation to the whole word. This is an effect which would normally be termed object-based attention and is indicative that this form of attention is involved in the processing of Chinese characters. In this respect words are processed like objects. The reason why this is so remarkable is that the visual contiguity of the shapes in the Egly study were effectively simulated by an abstract, top-down contiguity imposed by the stimuli's status as a word. The conditions in the original Li and Logan (2008) study are described in figure 1-5.

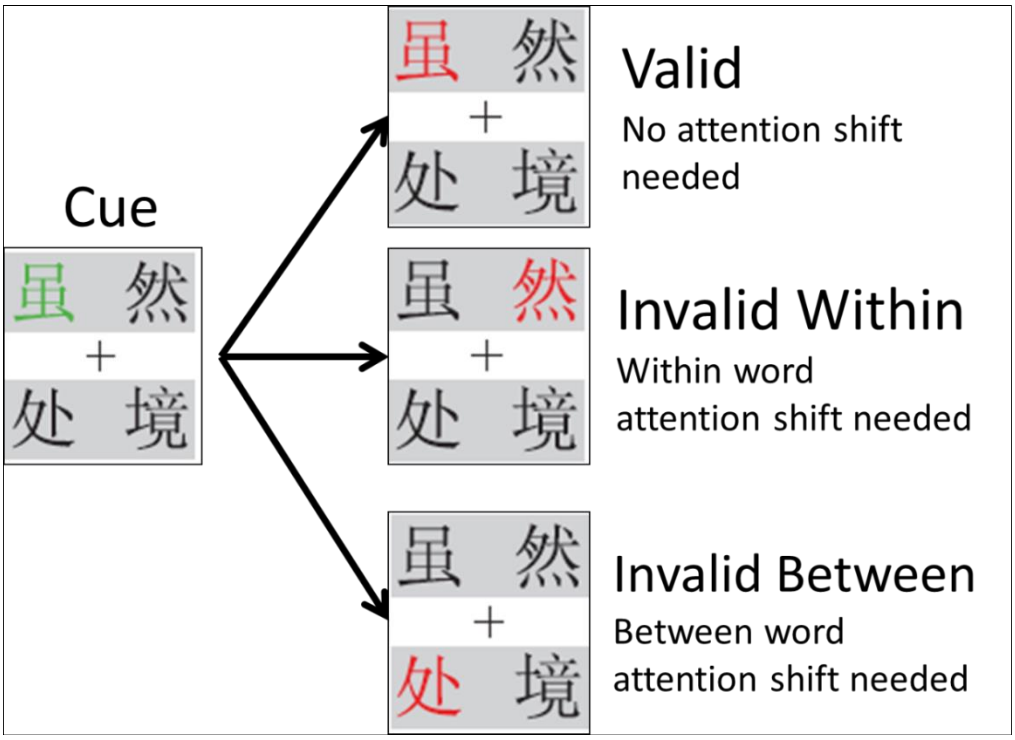


FIGURE 1-5 - DESCRIPTION OF THE TRIAL TYPES FOUND IN LI AND LOGAN'S (2008) PAPER. FIGURE ADAPTED FROM CITED PAPER. NOT TO SCALE. NOTE THAT THE GREY SHADED AREA REPRESENTS WHICH TWO CHARACTERS FORMED A WORD, AND THIS WAS NOT VISIBLE TO PARTICIPANTS.

The same effect was also observed by Liu, Wang and Zhou (2011). They replicated the "object based" finding with the additional finding that there appear to be qualitative differences between the top-down attentional groupings formed by processed words, and the bottom-up attentional groupings of visual stimuli formed by gestalt processes. They observed that the lower level Gestalt processes were vulnerable to changes in experimental design and would sometimes disappear depending on the blocking context employed. This means that any effect contingent on these lower level processes will be harder to demonstrate experimentally than an effect that is contingent on more top-down attentional groupings. This has implications when making comparisons between studies in English and Chinese. Chinese characters, unlike English, can only be grouped into words *after* they have been processed since Chinese writing does not use spaces. As a result the relative importance of low level Gestalt grouping processes in segmenting text into words is lower than in English. Conversely, in English the text can be segmented into words long before the words themselves have been processed. Accordingly the top-down and bottom-up processes described by Liu et al. (2011) will be employed quite differently in English compared to Chinese. Notice also the similarities between Liu et al's distinction between top-down/bottom-up word identification processes and the earlier discussion of the top-down/bottom-up processes involved in object identification. Given that they involve near identical processes (the application of prior knowledge vs. low level visual characteristics) is seems reasonable to conclude that they are in fact the same two processes. What we can infer when examining Liu et al is that Chinese readers make proportionately less use of the low-level Gestalt grouping process than English readers do. Given Liu et al's observation that the low-level Gestalt processes are very sensitive to the design of the experimental task, this indicates that any attempt to replicate their findings in English may find rather different results. The relatively heightened importance of the "vulnerable" Gestalt grouping processes in English studies will need to be attended to carefully as a potential pitfall for this thesis. It may result in object based effects being considerably harder to demonstrate in English due to high sensitivity to the design of the experiments used. A discussion of the impact of this phenomenon on the experiments in this thesis can be found in Chapter 6.

Li and Logan (2008) (and the subsequent Liu et al., 2011, replication) raise a number of questions. For one, how generalizable are these findings to English? Do these findings tell us something about reading generally, or are they specific to the written form of Chinese? Two character Chinese words are usually compound words, akin to English words like "Cow-boy" – will the effects generalise to stimuli that are not compound words? How consistent is this object-based effect for reading? How is the effect affected by the constraints of the experiment? And if object based attention really can be demonstrated to be critical to the process of understanding words what does this actually tell us about how humans read? The paradigm offered by Li and Logan (2008) appears to be ideal for answering the core question of this thesis: what is the role of object based attention in reading? As a result, a replication of Li and Logan's experiment in English was planned.

Section 5 – Organisation of this Thesis

This thesis attempts to explore the role of object based attention in English word reading. To do this it primarily uses various adaptations of the Li and Logan (2008) paradigm. The preceding chapter is chapter 1 and it consists of a literature review. In the experimental chapters 10 experiments are carried out. Experiments 1 and 2 were the first attempt at directly replicating Li and Logan (2008). Experiment 1 dealt with English words in the horizontal orientation and experiment 2 dealt with words in the vertical orientation. These experiments found some interesting findings (notably an effect of reading direction on attention shifts), but there were some criticisms of the design utilised. Experiments 1-2 comprise chapter 2 of this thesis.

Accordingly experiment 3 was created to try and address these criticisms. It utilised an improved design which prevented stimuli words from being shown more than once, and also controlled for the size of the cues and targets. Experiment 4 was run in parallel with experiment 3 and used non-lexical placeholder stimuli. Both experiments 3 and 4 were unsuccessful in finding any main effect of cuing. It was concluded that the stimuli were now too small to elicit an effect.

Experiment 5 and 6 were direct replications of experiment 3 and 4 using much larger stimuli. Experiment 5 found a very interesting "object based effect" when words were presented horizontally, but not vertically. Experiment 6 did not find anything, suggesting that the use of non-lexical stimuli somehow reduced attention to the array. The remainder of the thesis is concerned with explaining why experiment 5 found an object based effect and no reading direction effect, whereas experiments 1 and 2 found a reading direction effect but no object based effect.

Experiment 7 sought to test the hypothesis that the differences between experiments 1/2 and 5 were to do with blocking context. It replicated experiment 5, but used a blocked presentation of stimuli. It was concluded that blocking context cannot account for the results. Experiments 3-7 comprise chapter 3 of this thesis.

Experiment 8 sought to test the hypothesis that the differences between experiments 1/2 and 5 were to do with the types of cues and targets employed. In a departure from the rest of the thesis this experiment utilised a modified version of LaBerge's (1983) single word presentation paradigm. Detection speed for targets was measured across a single word. On the basis of this experiment it was concluded that the types of cue and target employed could not account for the differences between experiments 1/2 and 5. However there were some questions over whether this radically different paradigm was well suited to ascertaining whether this was the case. Experiment 8 comprises chapter 4 of this thesis.

Experiments 9 and 10 sought to test two hypotheses. First it would revisit whether the type of cue and target used could explain the differences between experiments 1/2 and 5, second it would ascertain whether the effects observed so far were reproducible using stimuli other than words. Experiment 9 presented participants with an almost direct replication of experiment 1, except using symbol strings instead of words. Experiment 10 replicated experiment 2 in the same way. It was concluded that the differences in the results found could be explained in terms of the types of cue and target employed, whether stimuli words were shown more than once, and whether the stimuli were actual words or not. Experiments 9-10 comprise chapter 5 of this thesis.

Finally these results are discussed in the concluding chapter (6). A summary of the structure of this thesis is provided below.

TABLE 1-1- ADVANCE SUMMARY OF THESIS STRUCTURE

Chapter	Title	Experiments	Description
1	"Attention to Words and Objects"		Literature Review
2	"Words as Objects"	1	Initial replication of Li and Logan 2008
		2	
3	"Refining the Design"	3	Attempt to create a more robust paradigm
		4	
		5	
		6	
		7	
4	"Attentional Gradients Across Words"	8	Trying to measure the effect of cue/target type on attention across single words
5	"The Role of Low Level Visual Features"	9	Replication of experiments 1 and 2 using symbol strings and also manipulated cue/target type
		10	
6	"Are Words Like Objects?"		Discussion

2. Experiments 1 (Horizontal) and 2 (Vertical) - "Words as Objects"

Experiments 1 and 2 Introduction

On the basis of the literature discussed in Chapter 1, a study was designed to explore the role of Object-based attention during the reading of English words. Li and Logan (2008) have demonstrated that the visual contiguity of shapes can be "simulated" by the abstract lexical contiguity of words. There were no physical connections between the characters in their array, and yet the participants clearly treated them as in some way connected. One way of explaining this is that the participants were treating the 2-character words as if they were a single object. However, this study does not necessarily tell us about English reading. The properties of Chinese may lend themselves well to an object based reading strategy. Chinese characters are both more visually dense than English, and more spatially plastic in that the Chinese characters are not always arranged in a left-to-right fashion. Traditionally, it could also be written legally both left-to-right and top-to-bottom, although the latter has become much rarer. Given that Chinese is approached differently by its readers, it may be that effects found in Chinese would not be found in another language. The fact that orientation seems less important in Chinese may cause readers to favour an object-based decoding strategy where words are treated as wholes to be decoded in blocks, whereas in English the strict left-to-right writing and reading may force a more letter-by-letter decoding than is found in Chinese, or perhaps some kind of attentional distribution that reflects the reading direction. Would the within-word benefit carry over to English? Two experiments were devised to try and answer that question. In this study, the method employed by Li and Logan was adhered to as closely as possible. There is no English equivalent to the many 2-character words available in Chinese, so in this experiment transitioned to using 4-character English words. Each cell of the 2x2 array would contain 2 characters. In the first experiment, the words were written in the traditional horizontal mode. In the second experiment the words were written in more novel vertical orientation. It will be interesting to see what effect the more linear and less dense script of English has on the effects found in comparison with Chinese. Can an object based account explain reading single words generally, or is it only a special-case phenomenon?

Experiment 1 Method

Participants

Participants were 8 females and 6 male members of the University of Dundee community who received course credit. Their ages ranged from 18 to 26. All participants were self-described as fluent speakers and readers of English.

Apparatus

Stimuli were presented through an 18” monitor running at 60 Hz and target detection responses were recorded on a gamepad, with the response button pressed by the dominant hand. An SR Research Eyelink-1000 desk-based eye tracker running SR Research Experiment Builder software version 1.5.201 recorded monocular eye position at 1000 Hz. This was used to control for fixation location. A desk-mounted chinrest kept participants’ eyes 60cm from the screen and both their peripheral vision and vision in their non-dominant eye were eliminated through blinkered spectacles.

Stimuli

Twenty 4-character upper case words with a written frequency of at least 6.39 (mean:43.33, SD: 101.73) and an overall average spoken and written frequency of 41.17 were selected using the CELEX word frequency database (Baayen, Piepenbrock & Gulikers, 1995). (see Appendix I). The twenty stimulus words were paired off to create 10 word pairs. These were selected to ensure that each word of the pair shared no letters, and each word could appear in either the primary or secondary position within the array. Each word within a pair appeared equally often in the primary or secondary position. Letters were printed in 60 point Monaco monospaced font and measured 0.95º by 1.66º of visual angle. Each array covered approximately 4.75º x 3.50º and the fixation cross measured 0.76º by 0.76º. Screen background was white (RGB values: 255/255/255; luminance: 82.8 cd/m2) and letters were either black (0/0/0, 8.415 cd/m2) or red (255/0/0, 36cd/m2) or green (0/255/0, 50.76 cd/m2). Stimulus files were all 500x500 pixel bitmaps. All word arrays appeared in all conditions of the experiment (see below).

Design

The experiment consisted of an individually randomized sequence of 560 trials: 320 valid trials (cue and target were the same two letters), 80 invalid-within trials (cue and target were different letter pairs in the same word), 80 invalid-between trials (cue and target were in different words but never in diagonally opposed letter pairs, to maintain equidistance between cue and target across all invalid trials; see Figure 1), and 80 catch trials (no target appeared). All of the 10 word-pair stimulus arrays appeared in all conditions. Each stimulus array appeared in the valid condition 32 times, the invalid in condition 8 times, the invalid between condition 8 times and was a catch trial 8 times. All participants saw the same stimuli/condition pairings. The order of presentation was fully randomised between subjects. The arrays were configured in the traditional left-to-right writing mode of English. The different trial types are illustrated in figure 2-1.

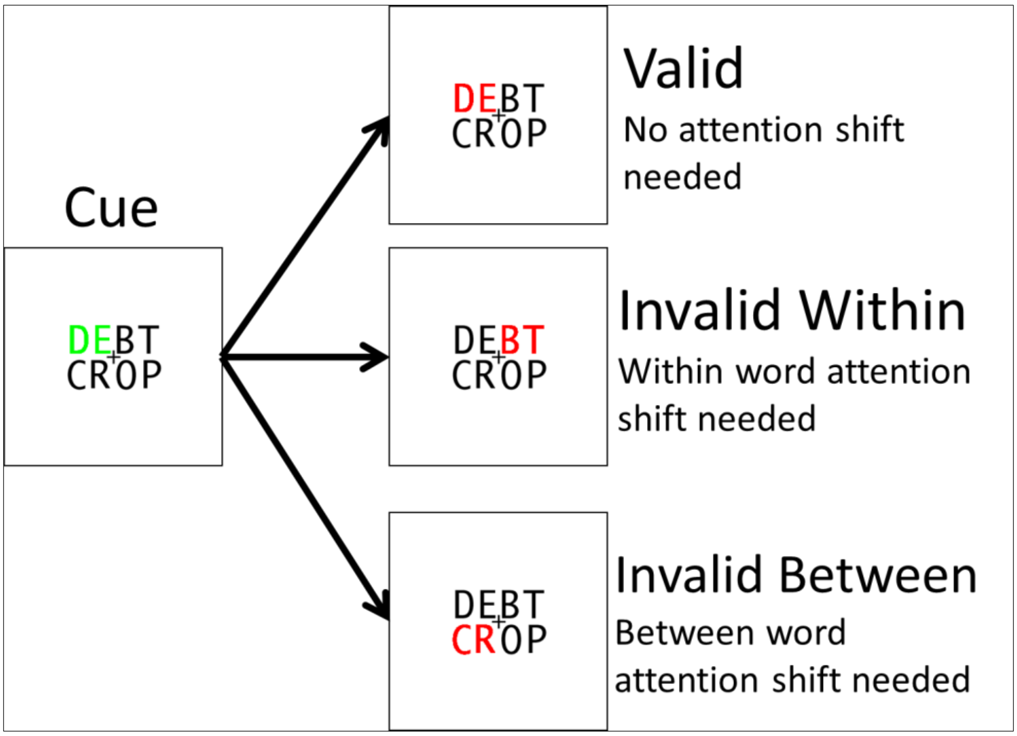


FIGURE 2-1 - THE THREE CONDITIONS OF CUE-TARGET RELATIONSHIP FOUND IN EXPERIMENT 1. NOT DRAWN TO SCALE.

Procedure

After giving informed consent the eye tracker was calibrated on the participant’s dominant eye, determined via majority result from the Miles, Porta, and Camera tests (Roth, Lora & Heilman, 1992). Peripheral vision and the non-dominant eye were occluded with blinkered spectacles. Participants were informed that they would be periodically asked about the last array they had seen in order to highlight the importance of actually reading the words onscreen.

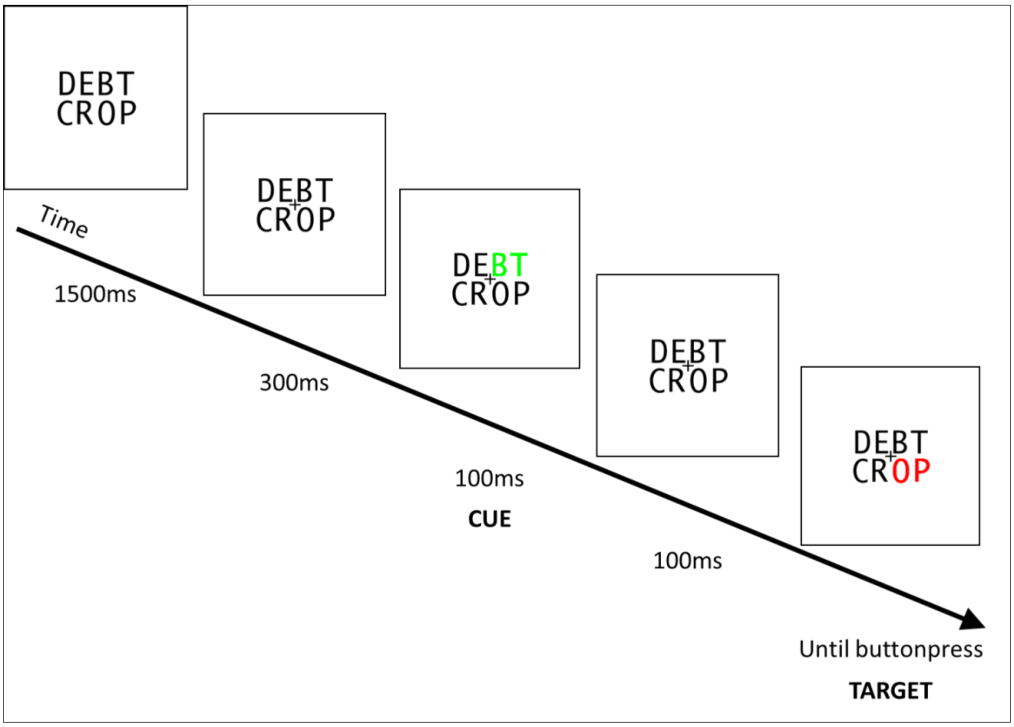


FIGURE 2-2- EXPERIMENT 1 TRIAL SEQUENCE, ILLUSTRATING AN INVALID-WITHIN WORD. NOT DRAWN TO SCALE. THE TASK WAS TO PRESS THE BUTTON AS SOON AS RED LETTERS WERE DETECTED.

Figure 2-2 gives a schematic representation of trial events. Eye position was recorded throughout a trial. The start array for each trial contained two words. These were presented for 1500 ms, followed by an additional fixation cross for 300 ms. Participants were told to read the words and then fixate the cross. The first or last two characters of one of the words were coloured green for 100 ms to cue attention to this location. Following a further 100 ms of displaying the monochrome array with neither cue nor target, the first or last two characters of the top or bottom word were coloured red (the target). The trial proceeded only if fixation was within 1.6 degrees around the fixation cross during this cue-target onset asynchrony, or else an error message appeared and the trial was discarded. The time from the target onset to the button press was the reaction time (RT). Participants were instructed to press the button as soon as they detected letters in red and to refrain from responding in catch trials. Responses were issued via a gamepad held in front of the participant, as close to their midline as possible. The response button was pressed with the dominant hand. If no response was issued a new trial started after 3000 ms.

Experiment 1 Results

Performance and Filtering Information

An analysis of error rates amongst the 15 participants was conducted. Overall the retained participants issued the correct response on 96% of all trials. On trials where a response was required, the correct response was issued on 98% of trials. On catch trials the error rates were slightly higher with 88% of all responses being the correct one. A filter was created on the basis of what would effectively remove the most extreme outliers. Extreme was approximately defined the 2-3% most extreme scores. A 100-700ms filter was used to remove reaction times which were considered unlikely to be the product of the rapid target detection processes of interest in this study. Scores falling outside this range were removed. 98% of the correct responses remained after the application of this filter. In total, 95% of all responses issued by participants were retained after the application of error and reaction time filters.

Nine additional participants were tested but not included in this dataset due to very high error rates. In the case of 3 of them this was the result of poor eye tracker calibration. In one case the participant arrived wearing varifocal glasses which interfered with the functioning of the eye tracker, and they lacked sufficient visual acuity to complete the experiment without them. The remaining 5 were removed due to poor performance on Catch (68%, 66%, 73%, 70% and 71% correct respectively). Catch trial errors tended to be the highest, so they were considered the most diagnostic for removing underperforming subjects. Since the cue-target interval was constant, catch trials were crucial in detecting participants who were not detecting the onset of the target, but were merely pressing the response button after they saw the cue. To distinguishing between “responders” and “anticipators”, an arbitrary threshold was set at 75% correct responses on catch trials. Participants who did more poorly than this were removed from the data.

Reaction Times - Validity

Non-erroneous reaction times were analysed using a one-way repeated measures ANOVA, with 3 levels (Valid, Invalid In and Invalid Between) There was a significant effect of validity, ($F(1.272, 16.536)=8.617$, $p=.006$, Greenhouse-Geisser Corrected). Simple planned comparisons found that Invalid In and Invalid Between both differed significantly from Valid RTs, ($F(1, 13)=8.712$, $p=.011$) and ($F(1,13)=10.802$, $p=.006$), respectively. Posthoc Bonferoni analysis found that Invalid In and Invalid Between did not differ significantly from one another, ($p=1$). These results are described in figure 2-3.

Broadly speaking these results seem to indicate that responses were fast when cues and targets were in the same location, but slow in all other situations. That is, responses were fast to valid trials and equally slow to both classes of invalid trial. This is not in accord with the predicted “within object benefit” which would require the Invalid In responses to have a detectible reaction time benefit. These results do however indicate that attention was being successfully drawn to the cued location.

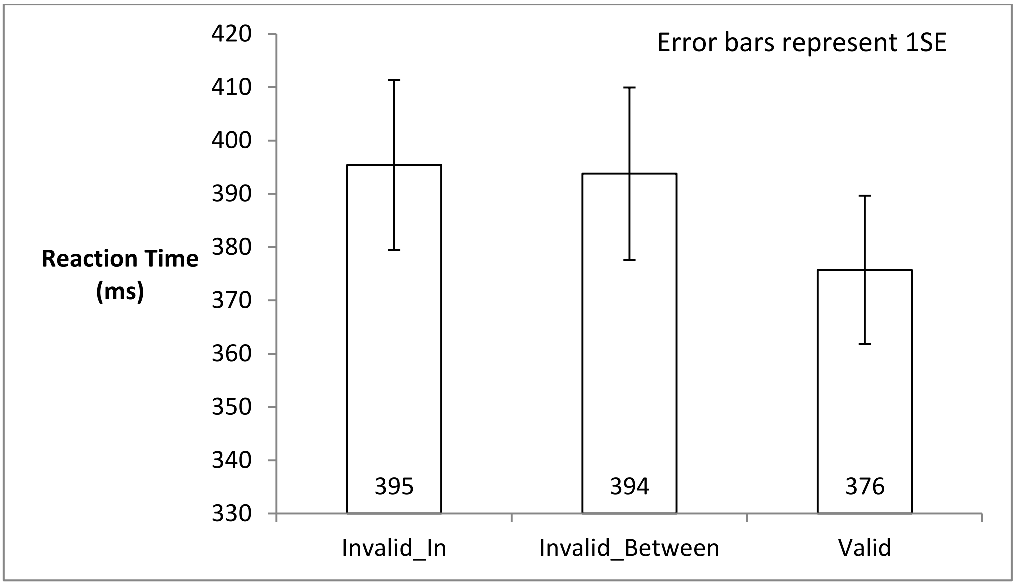


FIGURE 2-3- EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 1)

Reaction times – Target Location

An analysis was conducted to see whether participants had a preference for responding to targets in particular locations. A one-way repeated measures ANOVA with 4 levels (Bottom Left (BL), Bottom Right (BR), Top Left (TL), Top Right (TR)) was carried out (see Figure 2-4). There was a significant effect of target location, ($F(3,39)=6.269$, $p=.001$). Post-hoc Bonferoni analysis found that the only significant differences between quadrant reaction times was BR vs TL ($p=.012$). BL vs BR was marginally significant ($p=.052$). Broadly speaking reaction times in the bottom right location were fastest.

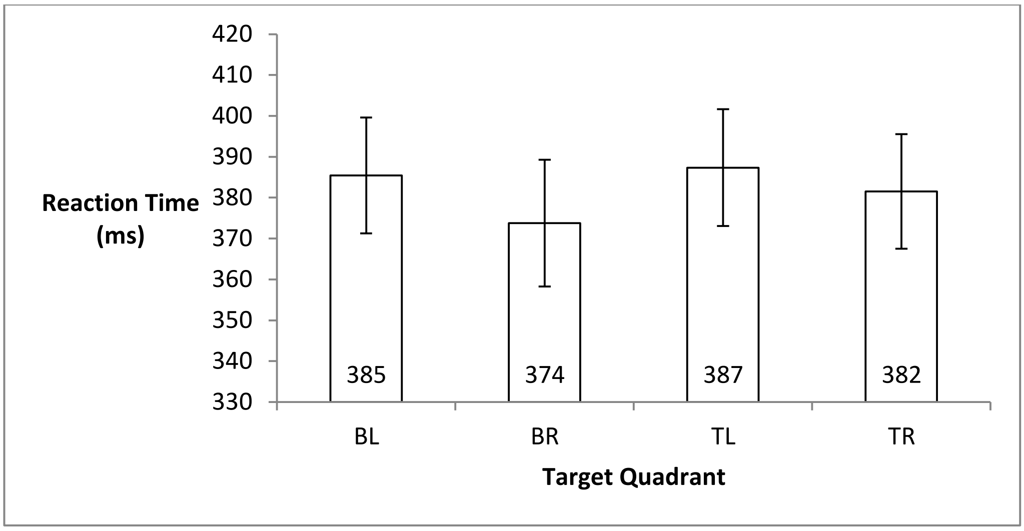


FIGURE 2-4 - EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 1)

Reaction Times - Direction of Attention Shift

An analysis was conducted to see if reaction times differed in the invalid trials as a function of the direction of attention shift mandated by the cue/target relationship (see Figure 2-6). Trials where attention shifts were within word were analysed separately from trials where the attention shifts were between words since it seemed likely that these reflected different processes. Left to right attention shifts were labelled "In Reading Direction", whereas right to left attention shifts were labelled "Against Reading Direction". For the between word attention shifts, top to bottom movements were classed as "Canonical" (since they reflect the typical method of moving down a page of text), whereas bottom to top movements were classed as "Non-Canonical". The naming conventions for these directional relationships are illustrated in figure 2-5.

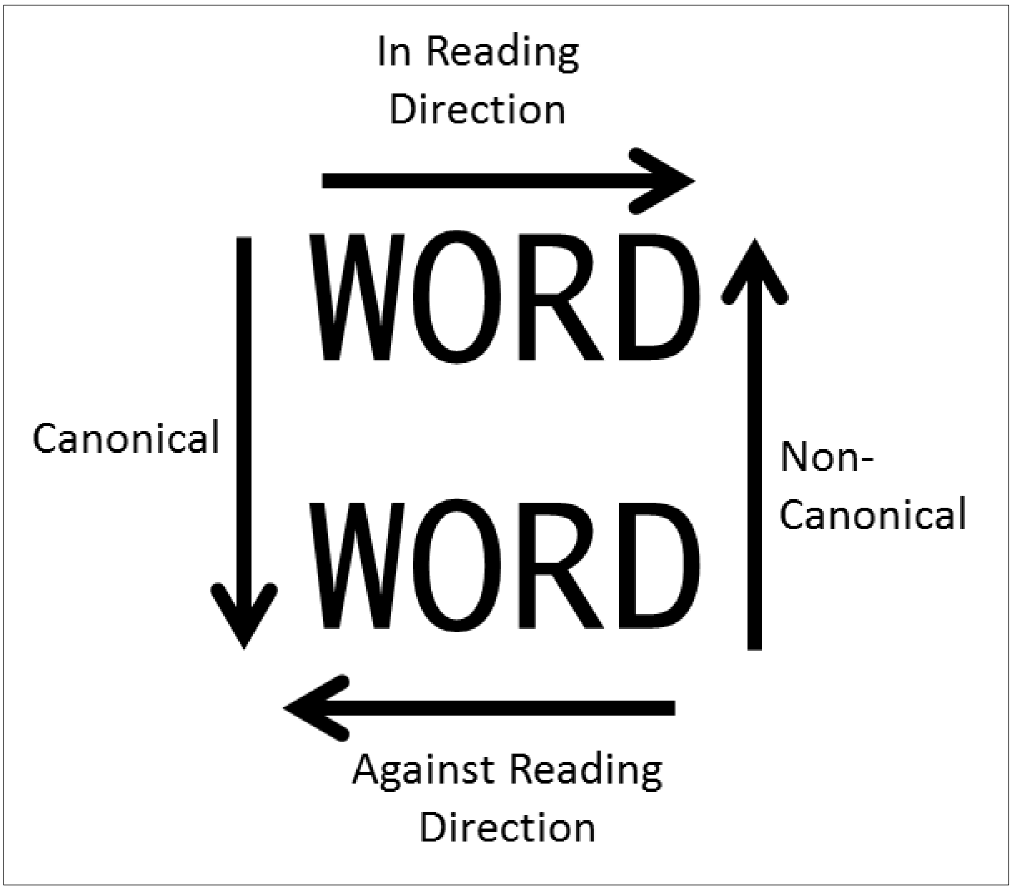


FIGURE 2-5 - NAMING CONVENTIONS FOR THE ATTENTION SHIFTS MANDATED IN INVALID TRIALS. (HORIZONTAL ARRAYS)

Within Word Shifts

A paired sample t-test was carried out on the within word attention shift data, comparing reaction times from in reading direction shifts with reaction times from against reading direction shifts. There was no significant effect of reading direction, ($t(13)=1.053$, $p=.311$, 2-tailed). When analysing filtered but untransformed reaction times participants showed no preference for one direction of attention shift over the other.

Between Word Shifts

A paired sample t-test was carried out on the between word attention shift data, comparing reaction times from canonical shifts with RTs from non-canonical shifts. There was no significant effect of canonicity, ($t(13)=0.812$, p=.432, 2-tailed). As before, participants seemed to show no preference for one direction of attention shift over another.

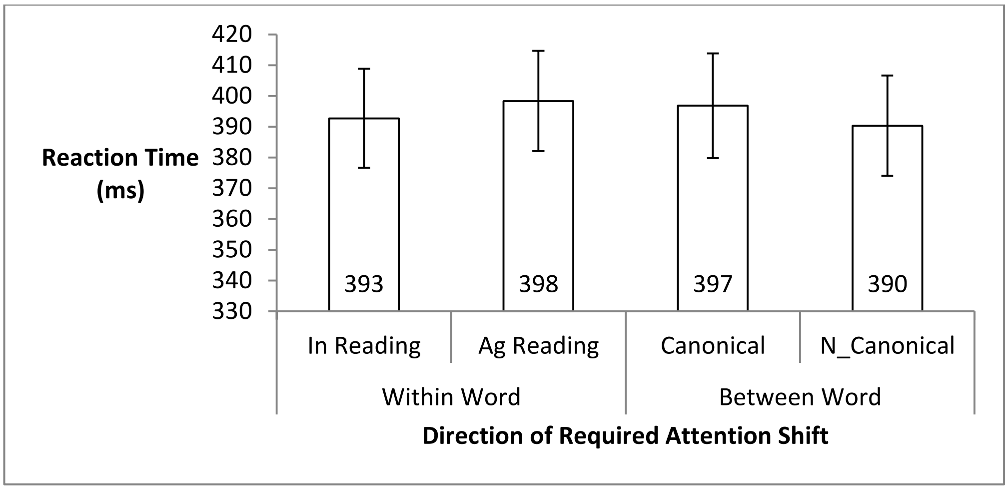


FIGURE 2-6 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME (EXPERIMENT 1)

Calculating Costs

The quadrant response data clearly indicated that the 2x2 array in which the stimuli were presented was not as influence-free on reaction times as was hoped. Targets appearing in certain locations were experiencing reaction time benefits regardless of the condition of the experiment. This may have been obscuring the sorts of effects this study was designed to detect. Accordingly, a transformation was looked for which would counteract the inherent effects of target location. A new measure, which shall hereafter be referred to as "Reaction Time Costs" was created to look at the data from both classes of invalid trial. In this measure the reaction time for detecting a valid target with the same cue was subtracted from the reaction time of an invalid trial where the target was in a different location. If this value was positive it would indicate that the valid trial that used the same cue was detected faster. This measure very effectively gave us the cost (in ms) of having to make an attention shift, since up until the appearance of the target, the trials were identical. The reaction times derived from this measure were all calculated from multiple locations, so the effects of target location should be reduced. These cost scores were calculated on a participant-by-participant basis, so for any given participant their reaction time cost indicated how much slower they were at responding to an invalid trial when compared with their own performance on a valid trial.

Reaction Time Costs – Within vs. Between Word Attention Shifts

A paired samples t-test was carried out comparing the costs for Invalid In Trials vs. the costs for Invalid Between trials. (see Figure 2-7) There was no significant difference between Invalid In costs and Invalid Between costs, $t(13)=0.676$, $p=.511$.

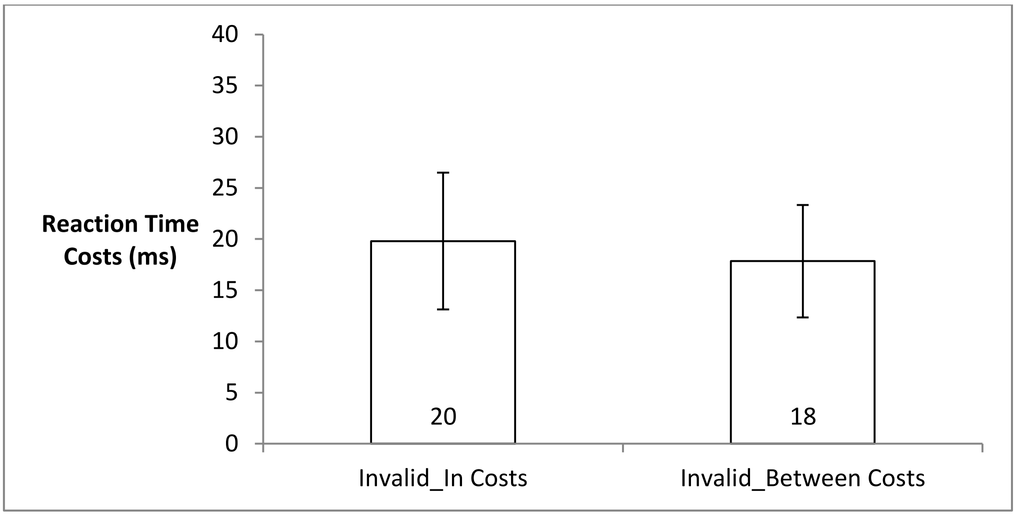


FIGURE 2-7- WITHIN VS. BETWEEN WORD ATTENTION SHIFTS: EFFECTS ON REACTION TIME COSTS (EXPERIMENT 1)

Reaction Time Costs – Direction of Attention Shift

The RT costs transformation was then applied to the directional analysis (see Figure 2-8).

Within Word Shifts

A paired sample t-test was carried out on the within-word attention shift costs data. There was a significant difference between attention shifts in reading direction, and shifts against reading direction, (t(13)=3.125, p=.008, 2-tailed). Participants were encountering less RT cost relative to valid trials when they were moving their attention in accordance with reading direction than when they moved against it.

Between Word Shifts

A paired samples t-test was carried out on the between-word attention shifts costs data. There was no significant difference between canonical and non-canonical between word shifts, (t(13)=0.098, p=.923, 2-tailed). Participants' costs data showed no preference for canonical or non-canonical attention shifts.

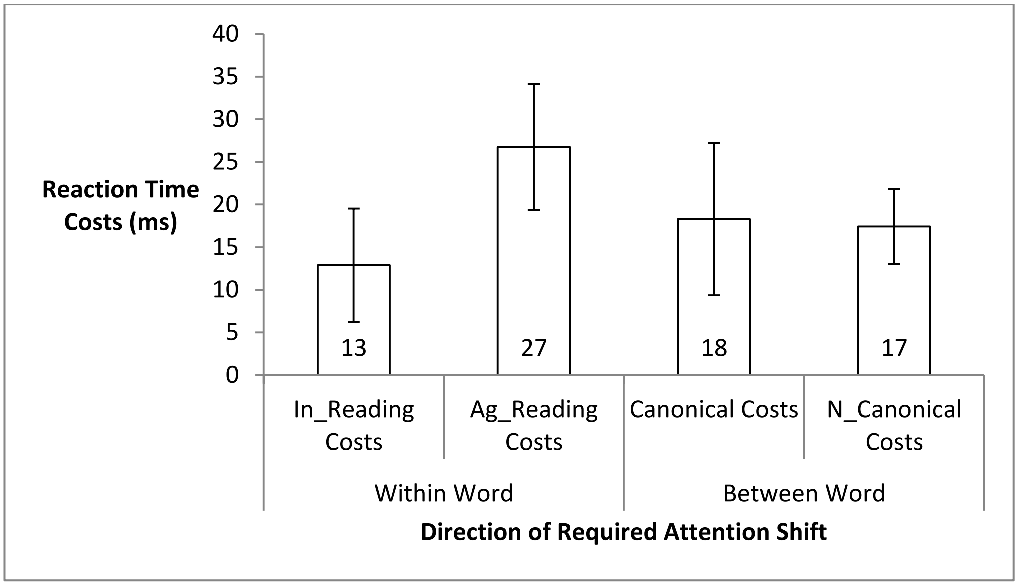


FIGURE 2-8 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 1)

Experiment 1 Discussion

It was hoped that this experiment would find an "object based effect" where cues landing anywhere within a word facilitate target detection at other locations within that word. This would have been evident in a reaction time benefit for "Invalid Within" trials. No such benefit was found.

Unexpectedly there was an effect of reading direction on the reaction time costs data. Participants' encountered less reaction time cost when shifting their attention in accord with reading direction than when they shifted their attention against reading direction. The word stimuli were only presented in one orientation so this effect cannot be separated from the possibility that participants are simply good at left to right attention shifts, or are better at responding to targets on the right. Indeed the overall reaction time data from each of the target quadrants indicates a preference for targets that occur on the bottom right.

In order to determine whether this effect is driven by the reading direction mandated by the word stimuli, or a simple directional or right-sided preference, a new study which presents the words in a novel orientation would need to be conducted.

Experiment 2 Method

Expect where stated, experiment 2 was identical to experiment 1.

Participants

Participants were 10 females and 6 males from the University of Dundee community who were paid in course credits. Their ages ranged from 17 to 39. All self-reported as fluent in both written and spoken English.

Stimuli

Each array covered approximately 3.50 º x 4.75 º

Design

The stimulus arrays were configured in a novel top-to-bottom writing mode.

Procedure

The procedure for experiment 2 is illustrated in figure 2-9.

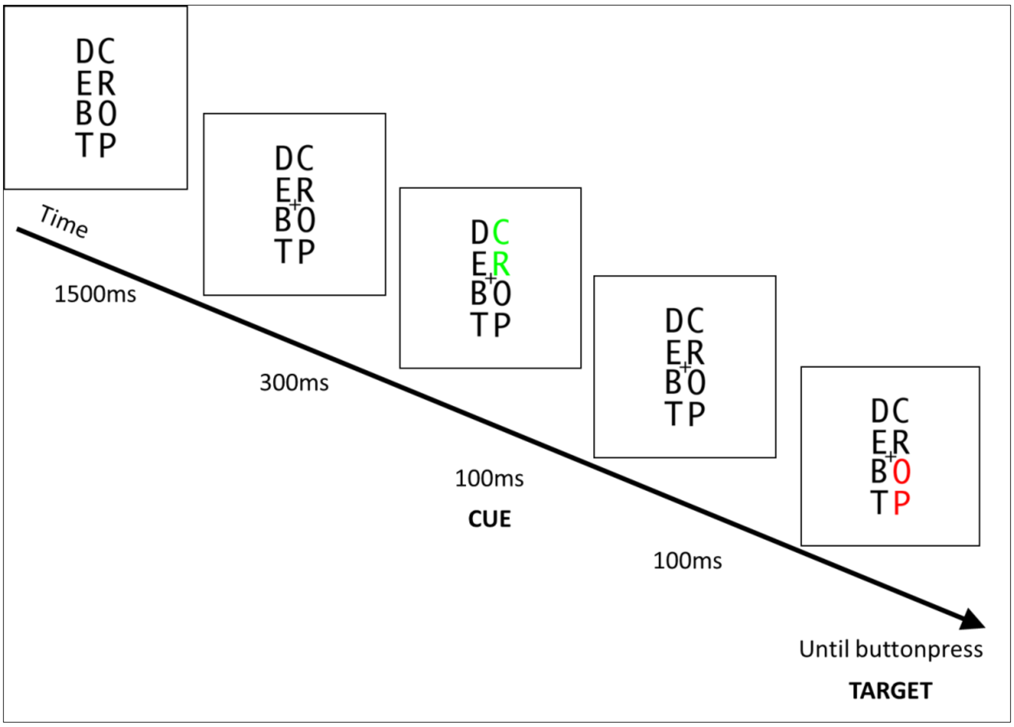


FIGURE 2-9 - EXPERIMENT 2 TRIAL SEQUENCE, ILLUSTRATING AN INVALID-WITHIN WORD. NOT DRAWN TO SCALE. THE TASK WAS TO PRESS THE BUTTON AS SOON AS RED LETTERS WERE DETECTED.

Experiment 2 Results

Performance and Filtering Information

An analysis of error rates amongst the 16 participants was conducted. Overall the retained participants issued the correct response on 96% of all trials. On trials where a response was required, the correct response was issued on 98% of trials. On catch trials the error rates were slightly higher with 88% of all responses being the correct one. A 100-700ms filter was used to remove reaction times which were considered unlikely to be the product of the rapid target detection processes of interest in this study. 99% of the correct responses remained after the application of this filter. In total, 95% of all responses issued by participants were retained after the application of error and reaction time filters.

4 additional subjects were tested but not included in this dataset due to very high error rates. This was due to high catch trial errors (70%, 64%, 39% and 51% correct respectively). As with the horizontal version, an arbitrary threshold was set at 75% correct responses on catch trials. Subjects who did more poorly than this were removed from the data.

Reaction Times - Validity

Non-erroneous reaction times were analysed using a one-way repeated measures ANOVA, with 3 levels (Valid, Invalid In and Invalid Between) (see Figure 2-10). There was a significant main effect of Validity, ($F(2, 20)=4.245$, $p=.024$). Planned simple comparisons found that Invalid In differed significantly from Valid, ($F(1, 15)=5.865$, $p=.029$). Invalid Between differed marginally significantly from Valid trials, ($F(1, 15)=4.241$, $p=.057$). Invalid In and Invalid Between trials did not differ significantly from one another in post-hoc Bonferoni analyses.

As with the Horizontal data these results indicate that responses were fast when the cues and targets were in the same location, but slow in all other situations. Once again, this is not what would be predicted by the hypothesised “within-object benefit”.

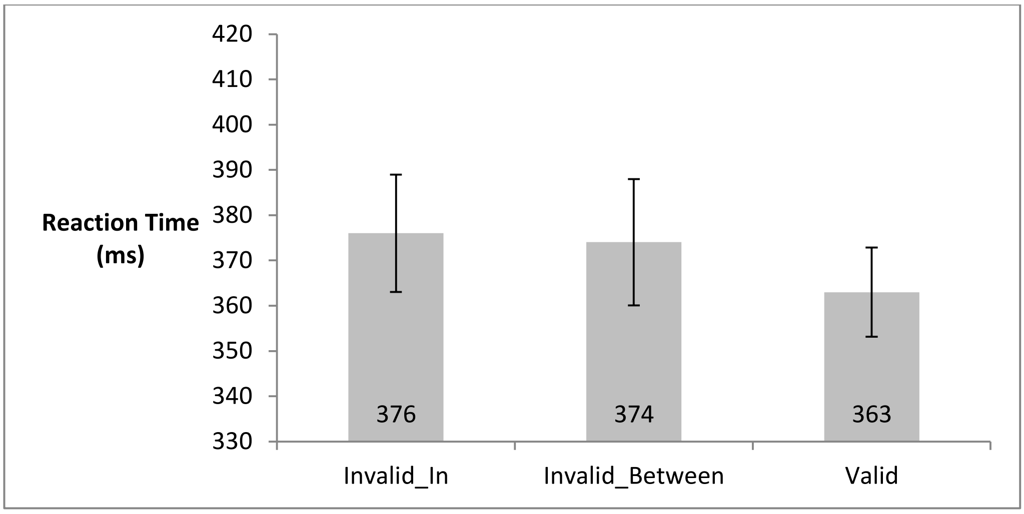


FIGURE 2-10 - EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 2)

Reaction Times – Target Location

An analysis was conducted to see whether participants had a preference for responding to targets in particular locations. A one-way repeated measures ANOVA with 4 levels (Bottom Left (BL), Bottom Right (BR), Top Left (TL), Top Right (TR)) was carried out (see Figure 2-11). There was a significant effect of target location, ($F(1, 15)=6.566$, $p=.022$). Post-hoc Bonferonni analysis found that BR differed significantly from TL ($p=.023$) and BL differed significantly from TL ($p=.034$). As with the horizontal version of the study, responses to targets in the bottom right location appeared to be fastest.

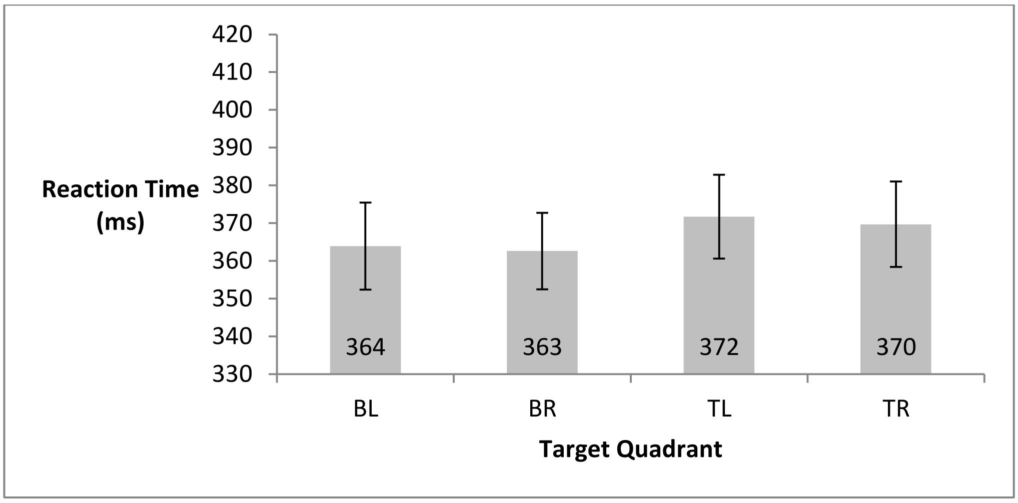


FIGURE 2-11- EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 2)

Reaction Times - Direction of Attention Shift

An analysis was conducted to see if reaction times differed in the invalid trials as a function of the direction of attention shift mandated by the cue/target relationship (see figure 2-13). For consistency, within and between word attention shifts were analysed separately. For the within word attention shifts, top to bottom attention shifts were labelled “In Reading Direction” and bottom to top shifts were labelled “Against Reading Direction”. For the between word shifts, left to right shifts were labelled “Canonical” (since they respect typical reading direction) and right to left shifts were labelled “Non canonical”. These naming conventions are illustrated in figure 2-12.

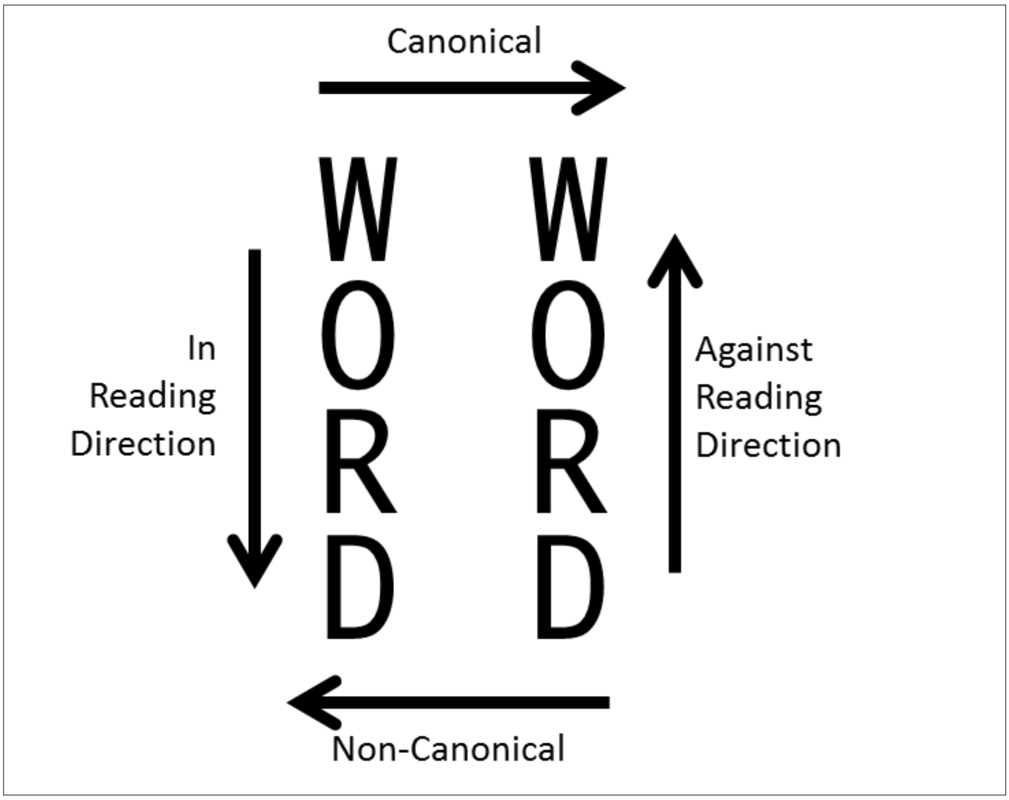


FIGURE 2-12 - NAMING CONVENTIONS FOR THE DIRECTION OF ATTENTION SHIFTS MANDATED IN INVALID TRIALS (VERTICALLY ORIENTED ARRAYS)

Within Word Shifts

A paired samples t-test was conducted on the reaction time data from within-word attention shifts. There was no significant effect of reading direction ($t(15)=1.341$, $p=.122$, 2-tailed).

Between Word Shifts

A paired samples t-test was conducted on the reaction time data from between-word attention shifts. There was no significant effect of canonicity, ($t(15)=0.419$, $p=.681$, 2-tailed).

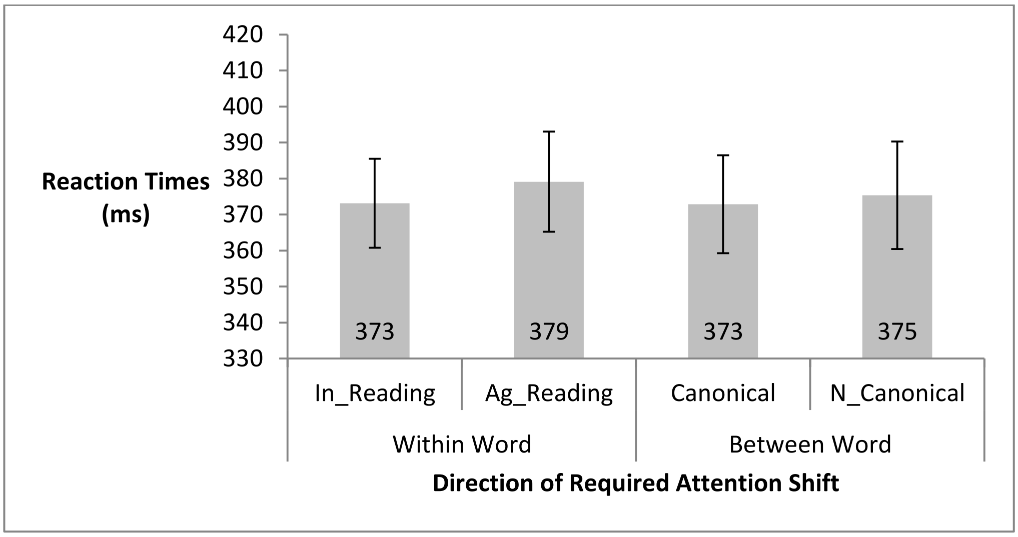


FIGURE 2-13 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIMES (EXPERIMENT 2)

Reaction Time Costs – Within vs. Between Word Attention Shifts

A paired samples t-test was conducted on the RT cost associated with both classes of invalid trial when compared with valid trials using the same cue (see Figure 2-14). There was no significant effect of Invalid In vs. Invalid Between, ($t(15)=0.575$, $p=.574$, 2-tailed).

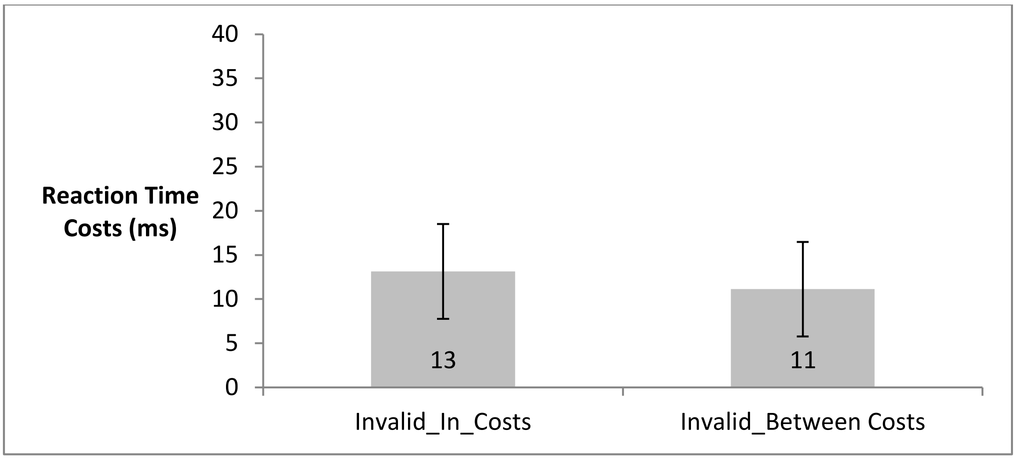


FIGURE 2-14 - WITHIN VS. BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME COSTS (EXPERIMENT 2)

Reaction Time Costs – Direction of Attention Shifts

The RT costs measure was again applied to the directional analysis (see Figure 2-15).

Within Word Shifts

A paired samples t-test was carried out on the RT costs data from within-word attention shift trials. There was a significant difference between in and against reading direction trials, ($t(15)=3.350$, $p=.004$, 2-tailed). As in the horizontal version of the study, participants were experiencing less reaction time cost when moving their attention in accord with reading direction than when they were moving against it.

Between Word Shifts

A paired samples t-test was carried out on the RT costs data from the between-word attention shift trials. There was no effect of canonicity, ($t(15)=0.591$, $p=.563$, 2-tailed). Again, as in the horizontal version of the study, participants showed no preference for canonical or non-canonical between word attention shifts.

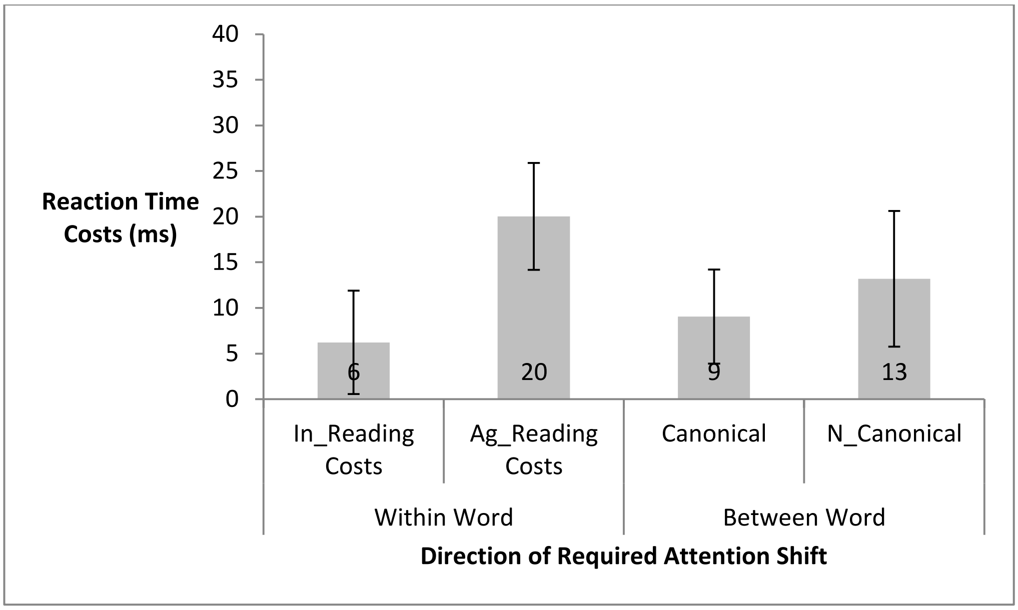


FIGURE 2-15- EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 2)

Experiment 2 Discussion

In accord with the results of experiment 1, no effect of object based attention was found on word processing. Invalid targets in the same word as the cue were processed just as slowly as invalid targets inside a different word. However the reading direction effect upon costs found in experiment 1 was also found when using the novel, vertical word orientation used in this experiment.

Participants encountered less cost when moving their attention in accord with reading direction, than when they moved their attention against reading direction. The fact that this effect has been found with both horizontally and vertically presented words means it does not reflect a simple preference for making left-to-right attention shifts. While reading direction was indeed left-to-right in experiment 1, it was top-to-bottom in this experiment. Thus it appears as if it was indeed the reading direction mandated by the word stimuli that was driving the effect of reaction time costs in both experiments 1 and 2.

Combined Analysis of Experiment 1 (Horizontal) and 2 (Vertical)

The reading direction cost effect found in both experiments was of considerable interest. On the surface, it looked very much as if word orientation was irrelevant and that the presented reading direction alone was driving this effect. An analysis was carried out to see if word orientation was indeed irrelevant (see Figure 2-16). As with the separate analysis, within and between word attention shifts are analysed separately.

Within Word Attention Shifts (Experiments 1 and 2)

A 2(orientation) by 2(reading direction) mixed factorial ANOVA was carried out on the RT costs data from the within-word attention shift data from Experiments 1 (horizontal) and 2 (vertical). There was a significant effect of reading direction, ($F(1,28)=20.904$, $p<.001$). There was no significant interaction, ($F(2, 28)=0.001$, $p=.990$). There was no significant effect of orientation, ($F(1, 28)=0.618$, $p=.438$).

Between Word Attention Shifts (Experiments 1 and 2)

A 2(orientation) by 2(reading direction) mixed factorial ANOVA was carried out on the RT costs data from the between-word attention shift data from Experiments 1 (horizontal) and 2 (vertical). There was no significant effect of canonicity, ($F(1, 28)=0.087$, $p=.770$). There was no significant interaction, ($F(1, 28)=0.203$, $p=.656$). There was no significant effect of orientation, ($F(1, 28)=0.763$, $p=.390$).

Overall it appears as though participants were experiencing less reaction time cost for within word attention shifts when prompted to shift their attention in accord with reading direction than against it, but there was no difference in terms of how they shifted attention for between word shifts. The orientation the stimuli were presented does not have a significant impact on this effect.

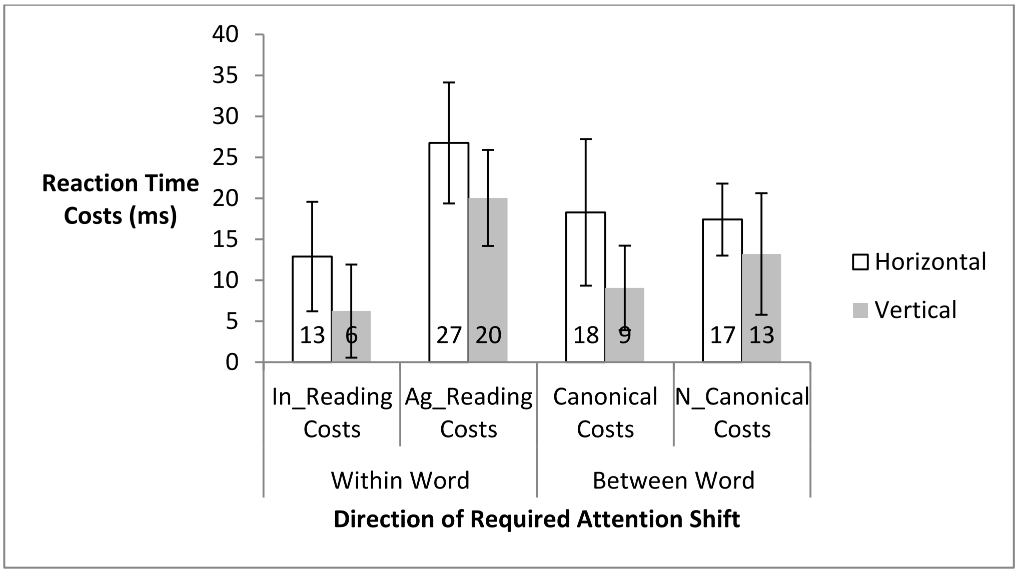


FIGURE 2-16 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENTS 1 AND 2 COMBINED)

Experiments 1 and 2 Discussion

Li and Logan (2008) demonstrated that cues anywhere within a word could facilitate target detection even in non-cued locations within that word. This was hypothesised to be a case of object based attention as demonstrated by Egly, Driver and Rafal (1994). The words were being treated in the manner you would expect for a contiguous object on-screen, despite lacking visual contiguity. But would this effect hold for English? If it could be established as a general principle then it would suggest that words are treated similarly to objects by the human attentional system. It may also support the idea that the part of the brain devoted to visually identifying objects becomes specialised for the task of reading and that the evolutionary heritage of this region shows through in the form of object based effects when dealing with single words.

In both the horizontal (experiment 1) and vertical (experiment 2) tasks it was found that there was a significant effect of validity, with responses to valid trials being the fastest. This demonstrates that attention deployment within a word was successfully manipulated. This in and of itself shows that attention deployment within single words is not uniform but can be at different levels. Crucially, there was no reaction time benefit found for invalid trials within a word when looking at untransformed reaction times alone. This is contrary to what would have been expected if there was an object based effect like Li and Logan found. This may possibly be attributed to an effect of target location on reaction times. Reaction times were not uniform across the whole array, with faster reaction times found for invalid trials when the target occurred near the end of the word. When invalid responses were calculated as the relative cost compared to valid trials (thereby mitigating any location bias) it was found that invalid within-word trials that respect reading direction incurred less cost compared to those that went against reading direction.

Importantly, participants did not show a preference for shifts of attention in one direction or another except when these shifts occurred along the length of a word. That is, it wasn’t that participants simply liked moving their attention from left to right, as the RT cost benefit was not present in the vertically oriented trials when such a shift reflected a between word attention shift. When the words were presented in this orientation, the left to right RT cost benefit of the horizontal experiment became a top to bottom RT cost benefit, in accord with the reading direction mandated by this new orientation. When the attention shift was in accord with the reading direction imposed by the word, there was a benefit compared to going against reading direction. When the attention shift was moving between words, there was no difference between a shift in either direction.

This is quite different to what Li and Logan found, and was unexpected. The word was not being treated as an object in the traditional sense in that there was no within over between object cueing advantage. Li and Logan found that a cue anywhere within a word would facilitate target detection anywhere within that same word. This was not observed in this study. This study did find that people are good at moving their attention from the beginning to the end of a word, and less good at moving from the end to the beginning. It should be noted that Li and Logan never analysed their data looking for reading direction effects, so it may be that this is found in Chinese too – but what is without question is that this study did not observe the within-word benefit that was found in Chinese. In addition, the reaction times displayed by the participants in this study were very different to those observed by Li and Logan. In all conditions the participants in this study consistently responded to the onset of the target with a reaction time close to 350-380ms. Li and Logan's participants tended to take around 450-520ms to respond in all conditions.

The lack of a gross within-word benefit in this study cannot be attributed to lack of statistical power, as Experiments 1 and 2 combined had more participants than Li and Logan used. This leaves two possibilities which are not necessarily mutually exclusive. It is possible that Chinese is simply more dimensionally plastic than English. In some areas, for example Taiwan, Chinese is still often written top-to-bottom, and readers are exposed to Chinese texts in both orientations on a daily basis, although it is becoming less common even there. However, even in areas where vertical writing is rare, it is still very common for signage. Also, not all Chinese characters are written from left to right but are instead assembled in a non-linear fashion, and are not necessarily read left to right either. This variability may make dimensional aspects of a word relatively less important when compared to English. English words are always written from start to end with very little break in this routine save to dot the ”i”s and cross the ”t”s. They are also always read left to right. The beginning to end attention shift may be more important in English. It is sufficiently entrenched that it will map onto a novel orientation (top to bottom) as seen in this study. A second possible explanation for our divergent results relates to list context. Li and Logan tested several of their participants in a mammoth 2 hour testing session, allowing the testing to be completed in a single day. Within this 2 hour period, horizontal and vertical trials were randomly ordered. For reasons of practicality the participants in this study were tested in 1 hour experiments with only a single orientation presented, and with different subjects tested for each orientation of writing. It may be that seeing words written in 2 different orientations caused the Chinese participants to regard orientation (and perhaps beginning to end attention shifts) as less important than they otherwise would. Conversely our blocked (i.e., between-subjects) design amplified the relative salience of dimensional aspects of the stimuli.

The current findings to a certain extent disagree with other previous literature on attention deployment within words. Sieroff and Posner (1988) found that real words were relatively insensitive to cues being placed inside them. They argued that words were treated as largely indivisible objects, with any local effects largely overwritten by top down influences. They did find a small effect of cuing on the left hand side of words, but in this experiment valid cues facilitated target detection regardless of where they were located. Mapelli, Umilta, Nicoletti, Fanini and Capezzani (1996) found that for both horizontally and vertically written words there was a benefit for targets occurring at the start of real words. Our participants were better at detecting targets at the ends of words when the cue had fallen at the start. However, Mapelli et al. (1996) was not a cuing study and their participants were hunting for target letters within words. One could argue that Experiments 1 and 2 observed Mapelli et al's word-beginning advantage in the form of more effective cuing at that location, and that the reading direction effect was actually a benefit derived from where the cue fell rather than the target location. That is, participants were better at detecting and processing invalid cues at near word beginnings and so had already completed this process at target onset, leaving them ready to respond to the target at the end of the word.

There were a number of design issues with this study that will need to be addressed. First and foremost, participants only ever saw the same 20 words, repeated over and over again during the experiment. This represented very poor ecological validity since real reading never involves tasks like this. This study may in fact tell us very little about how people read, and instead tell us about how people allocate attention to stimuli they have seen repeatedly. It could quite legitimately be argued that the participants in these experiments were not actually "reading" as is commonly understood. They were certainly visually processing the words to some extent, which is of course part of "reading" so the results may still be informative as to this process, but the distinction should be born in mind. Participants were instructed beforehand not to ignore the word, and to reinforce this, they were periodically asked to describe the content of the last seen array. Nonetheless, it cannot be denied that the level of processing applied to the stimuli words in these two experiments is considerably less than would usually be found in a reading experiment. Additionally, there was very little experimental control exercised over the intensity of the stimuli. Since the cues and targets were an illumination of the first or last two characters of a word, the number of illuminated pixels on any trial will depend on the word used. For example, when the cued word was "WAGE" and the cue landed on the letters "WA", there was more surface area illuminated than when the cued word was "PINE" and the cued letters were "PI". Follow up studies which will correct these issues are planned.

Conclusions

These experiments did not find an object based effect when participants were reading single words in English. If individual English words were truly treated as objects within the visual field, then it would be expected that there would be object based facilitation of target detection when cues fall within the same word. We did not observe this. Facilitation occurred in reading direction only, and was only visible when the data was transformed into RT costs. Clearly saying "words are objects" cannot be the whole story.

A potential explanation is that English readers, on seeing a written word, will make a beginning to end attention shift. It has long been known that human beings display attentional asymmetries which favour both reading and writing direction (i.e. in English attention is biased to the right). This could be learned from the motor process of writing, and it is found to be reversed in languages which write right to left (Rayner, 2009). These results may indicate that this between word attentional asymmetry may also reflect a within word attentional asymmetry as well. This attention shift is not accompanied by an eye movement – readers tended to read the words in a single fixation. This hypothesis presents a number of testable predictions. First and foremost, it suggests there should be a time course effect. Depending on when target onset occurs during their beginning to end attention shift, participants' response times should be modulated. Secondly, this effect may be modulated by the level of salience given to the dimensional structure of words. Depending on whether the horizontal and vertical trials are presented mixed together or separately may have a large effect on the results.

An object based account of visual word processing cannot explain the results found in these two experiments. English readers seem to display a preference for moving their attention in accord with reading direction when a word is present in the stimulus array, but when the cuing leads them between words they do not prefer one direction of travel over another. A tentative hypothesis is suggested. English readers, when presented with single words will make a beginning to end covert attention shift. If the reading direction can somehow be made less salient within an experiment, then a more object based approach would be expected. To do this, a way of making English more like Chinese will need to be found. Nonetheless, an object based approach is not hypothesised to be the normal mode of reading for English readers. Future studies will explore these issues.

3. Experiments 3-7 - “Refining the Design”

Section 1 Experiments 3 (Small Dot Words as Objects) and 4 (Small Dot Placeholders)

Experiment 3 Introduction

While the results of experiments 1 and 2 were extremely interesting, there were some problems when it came to interpreting those results. As was discussed previously, the same 20 words were used repeatedly throughout the experiment. As a result it could be argued that the experiment did not study actual reading at all, but some other process related to repeatedly viewing the same stimulus. Furthermore, there was a lack of control over the size of the cues and targets. Finally, the experiments lacked a “baseline” condition, where participants were presented with a similar task that did not involve words. As a consequence of these issues, it was decided to create a new experiment which would attempt to replicate the findings of the original, while exercising more rigorous experimental control.

A number of changes were planned. First and foremost, participants now only saw each word once during the experiment. The illuminated letters of Experiments 1 and 2 were replaced with small coloured dots which could appear between the first or last two letters of either word. To try and reduce fatigue and make it easier to select unique words for each trial, the experiment was streamlined by trimming the number of trials from 560 down to 144, and the brightness of the background was reduced considerably. To improve validity the design was changed from a blocked horizontal and vertical between subjects design, to a mixed presentation within subjects design. A comparison between the stimulus arrays of experiments 1, 2 and 3 is provided in figure 3-1.

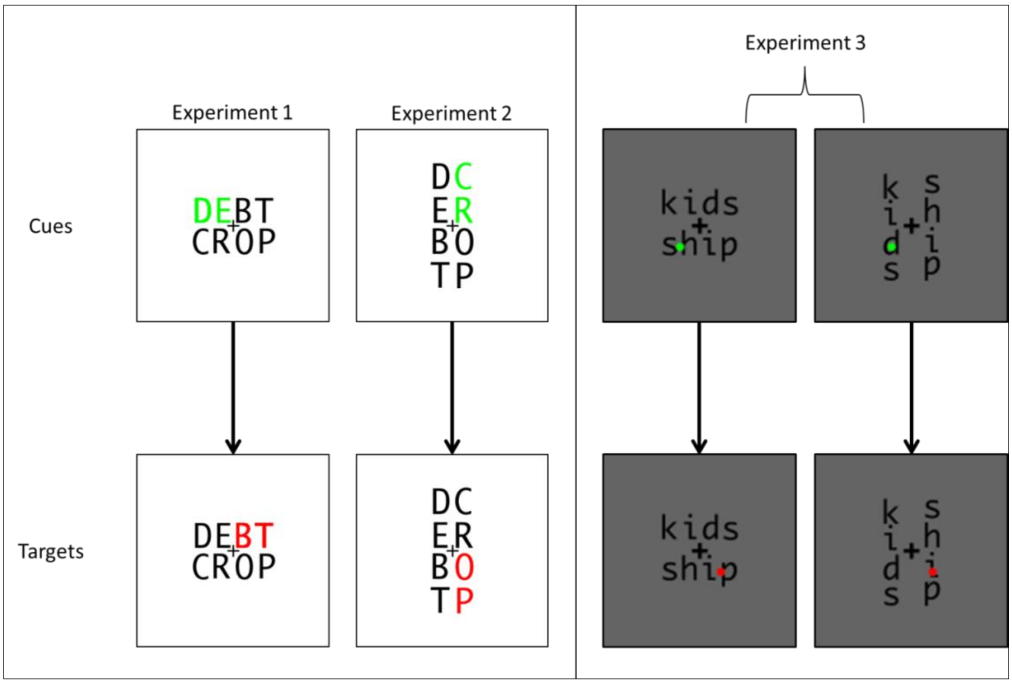


FIGURE 3-1 - COMPARISON BETWEEN EXAMPLE ARRAYS FROM EXPERIMENTS 1, 2 AND 3. IN EXPERIMENTS 1 AND 2 ORIENTATION OF STIMULUS ARRAYS WAS TREATED AS A BETWEEN SUBJECTS FACTOR. IN EXPERIMENT 5, BOTH ORIENTATIONS OF ARRAYS WERE INTERMIXED IN THE EXPERIMENT.

Experiment 3 Methods

Participants

The participants in this study were 21 female and 4 male students from the University of Dundee. They were paid in course credits for their time. Their ages ranged from 17 to 27. All participants were fluent in English. This experiment utilised a within subjects design so all participants were exposed to all conditions of the stimuli.

Apparatus

As Experiment's 1 and 2, except that the display refresh rate was increased to 100hz.

Stimuli

288 4-character words with a lemma frequency of at least 200 per 16 million were selected using the CELEX word database (Baayen, Piepenbrock &

Gulikers, 1995) (see Appendix II). The 288 stimuli words were used to create 144 test arrays containing 2 words each. The word arrays were randomly assigned to the different conditions (catch, valid, invalid in, invalid between). The mean lemma frequency of the words in each of the experimental conditions (valid vs invalid_in vs invalid_between, excluding catch trials, 240 words in total) did not differ significantly from one another ($F(2, 239)=0.238$, $p=.789$). Each of these arrays was used only once per subject. The letters were printed lowercase in 46 point Monaco and measured 1º x 1.6º of visual angle. Each array covered approximately 4.8º x 4.3º (horizontal word condition) or 4.2º x 6.7º (vertical word condition) and the fixation cross measured 1º by 1º. Cues and targets were dots approximately 0.5º by 0.5º, which appeared on top of the stimuli words. Cue and target positions were in the centre of each of the 4 quadrants comprising the array. These locations would place the cues and targets on top of the first or last 2 letters of one of the words in the array. Cue and target coordinates were the same in both the horizontal and vertical version of the experiment. Screen background was grey (RGB values: 100/100/100; luminance: 22.14cd/m2) and letters were black (0/0/0, 8.415 cd/m2). Targets were dots that were red (255/0/0, 36 cd/m2) and cues were green (0/255/0, 50.76 cd/m2). Stimuli arrays were assembled from several bitmaps and controlled using a variable grid. Individual bitmaps were created for each word, the fixation cross, the cue and the target.

Design

The experiment consisted of an individually randomized sequence of 144 trials: 72 valid trials (cue and target were the same two letters), 24 invalid-within trials (cue and target were different letter pairs in the same word), 24 invalid-between trials (cue and target were in different words but never in diagonally opposed letter pairs, to maintain equidistance between cue and target across all invalid trials; see Figure 1), and 20 catch trials (no target appeared). All stimulus arrays appeared only once per subject. Since effects of cuing direction were of interest, the occurrence of word arrays in each of the possible curing directions for invalid trials (left to right, right to left, top to bottom, bottom to top) was counterbalanced between subjects in the hope of counteracting any item based effects. Catch trials and Valid trials used the same word arrays for all subjects. In the horizontal condition of the experiment the arrays were configured in the traditional left-to-right writing mode of English. In the vertical condition of the experiment, the array was configured in a more novel top-to-bottom writing mode

Task and Procedure

After giving informed consent the eye tracker was calibrated on the participant's dominant eye, determined via majority result from the Miles, Porta, and Camera tests (Roth et al., 1992). Peripheral vision and non-dominant eye were occluded with blinkered spectacles.

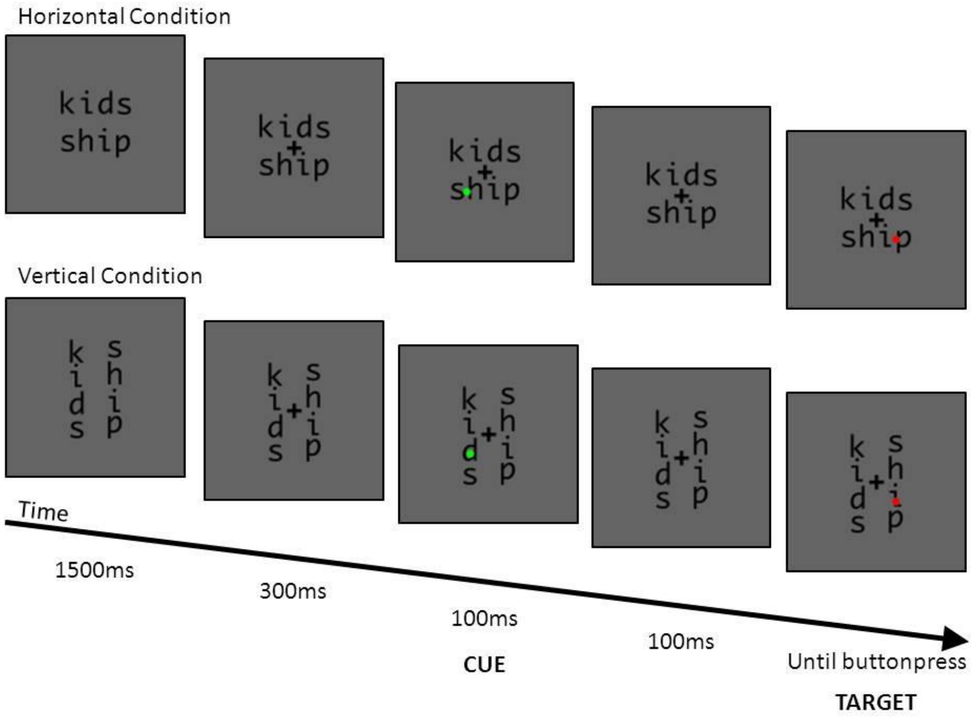


FIGURE 3-2 - EXPERIMENT 3 TRIAL SEQUENCE, ILLUSTRATING AN INVALID-BETWEEN TRIAL IN THE VERTICAL CONDITION, AND AN INVALID-WITHIN WORD TRIAL IN THE HORIZONTAL CONDITION. NOT DRAWN TO SCALE.

Figure 3-2 gives a schematic representation of trial events. Eye position was recorded throughout a trial. The start array for each trial contained two words. These were presented for 1500ms, followed by an additional fixation cross for 300ms. Participants were told to read the words and then fixate the cross. A small green dot was overlaid onto the first or last 2 letters of one of the words for 100ms to cue attention to this location. Following a further 100 ms of displaying the word array with no cues or targets, a red target would appear over the first or last two characters one of the words. The trial proceeded only if fixation was within the region in which the cues and targets would appear during this cue-target onset asynchrony, or else an error message appeared and the trial was discarded. The time from the target onset to the button press was the reaction time (RT). Participants were instructed to respond as fast as possible to each target and to refrain from responding in catch trials. Responses were issued via a gamepad held in front of the participant, as close to their midline as possible. The response button was pressed with the dominant hand. If no response was issued a new trial started after 3000 ms.

Experiment 3 Results

For consistency this and all subsequent experiments will be subjected to the same analyses as experiments 1 and 2.

Performance & Filtering Information:

Participants generally did very well at the task, with 95% of all responses being rated as correct from retained subjects. On trials where a response was required 97% of all responses were correct from retained subjects. Error rates tended to be a bit higher for catch trials where no response was required with 86% of responses from retained subjects being correct. The 100-700ms reaction time filter used in experiments 1 and 2 was found to be too conservative for use in this experiment, removing too much data. Consequently, a filter was applied to remove outliers which retained only those scores which fell within 2.5 Standard Deviations of mean reaction time for each individual subject. Over 98% of all correct responses were retained by this filter. Altogether, 94% of all responses issued were included in this dataset after the application of error and reaction time filters.

2 additional subjects were tested but not included in this dataset due to very high error rates on Catch Trials (both only got 71% correct). 75% was the minimum number of correct catch trials to meet the criteria for inclusion. Any less than this and it was concluded that the participants reaction times did not truly reflect a response to target onset, but rather that their responses were anticipatory.

Reaction Times - Validity

Non-erroneous RTs were analysed with a 2 (orientation) by 3 (validity) repeated measures ANOVA. A marginally significant effect of orientation was found ($F(1, 22)=3.450$, $p = .077$). There was no significant effect of validity ($F(2, 44)= 1.195$, $p=.312$). There were no significant interactions ($F(1.397, 30.731)=0.579$, $p=.565$; Greenhouse Geisser Corrected). The trends generally ran in the expected directions with valid trials being the faster in both orientations then both invalid in and invalid between trials but this effect was not significant. Additionally, reaction times for vertical trials were almost completely flat. These results indicate that this experiment did not reliably cue attention to one specific location of the array. These results are illustrated in Figure 3-3.

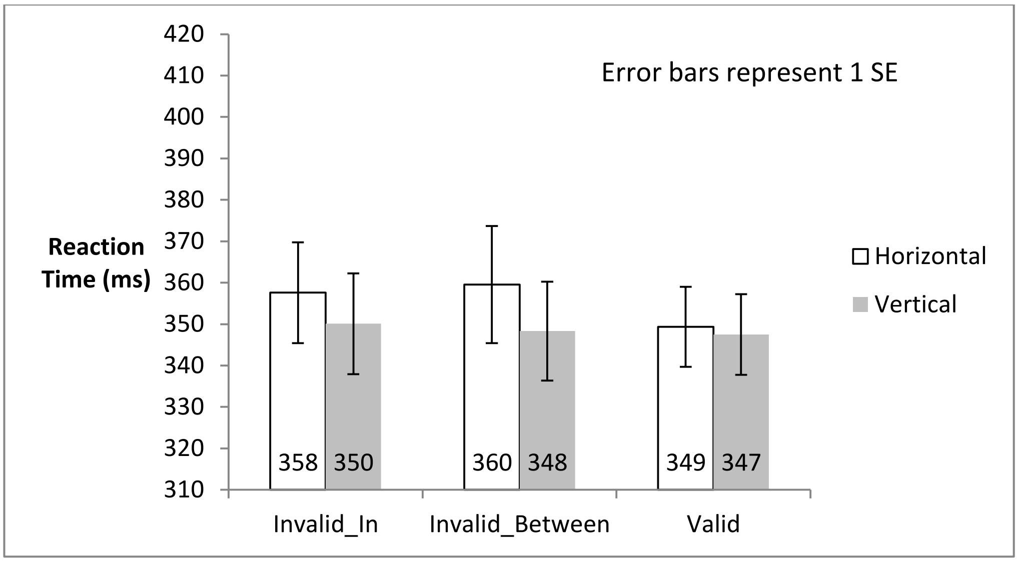


FIGURE 3-3 - EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 3)

Reaction Times – Target Location

An analysis was conducted to see if participants had a preference for respond to targets in particular locations (bottom left (BL), bottom right (BR), top left (TL), top right(TR)). Data from both valid and invalid trials were included in this analysis. A 2 (orientation) by 4 (target quadrant) repeated measures ANOVA found no significant effect of orientation ($F(1, 22)=2.565$, $p=.124$.) There was no significant effect of quadrant ($F(3, 66)=1.380$, $p=.257$). There was however a significant interaction of orientation x quadrant ($F(3, 66)=3.640$, $p=.017$). This seems to have been driven by the fact that vertical RTs were faster than horizontal RTs in every quadrant except bottom right. These results are illustrated in Figure 3-4.

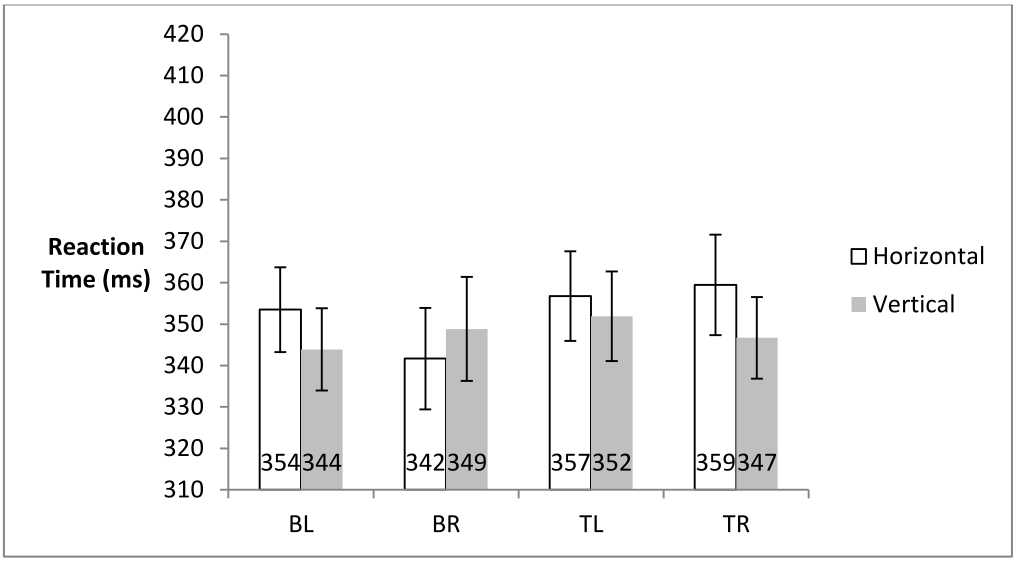


FIGURE 3-4 - EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 3)

Reaction Times - Direction of Attention Shift

An analysis was conducted looking at trials where the cue and target were not in the same location only, and which treated within word shifts and between word attention shifts separately. As before, in this analysis direction of attention shift was recoded based on how it related to reading direction (in reading direction, or against), or how it related to shifts between words (left to right and top to bottom were "canonical", whereas right to left and bottom to top were "non-canonical").

Within Word Shifts

A 2 (orientation) by 2(reading direction) repeated measure ANOVA was carried out on the data from within word attention shifts. There was a marginally significant effect of orientation ($F(1, 22)=4.018$, $p=.057$) with vertical trials yielding faster reaction times. There was also a significant effect of reading direction ($F(1, 22)=4.746$, $=.040$.) with trials that mandated a shift in accord with reading direction yielding slower reaction times. There were no significant interactions $F(1,22)=0.489$, $p=.492$.

Between Word Shifts

A 2 (orientation) by 2 (canonicity) repeated measures ANOVA was carried out on the data from between word attention shifts. There was no significant effect of orientation $F(1, 22)=1.733$, $p=.202$. There was a significant effect of canonicity ($F(1, 22)=5.124$, $p=.034$) with trials that mandated a non-canonical between word attention shift yielding faster reaction times. There were no significant interactions $F(1,22)=0.283$, $p=.600$

The results from both the within word and between word reaction time analyses are illustrated in Figure 3-5.

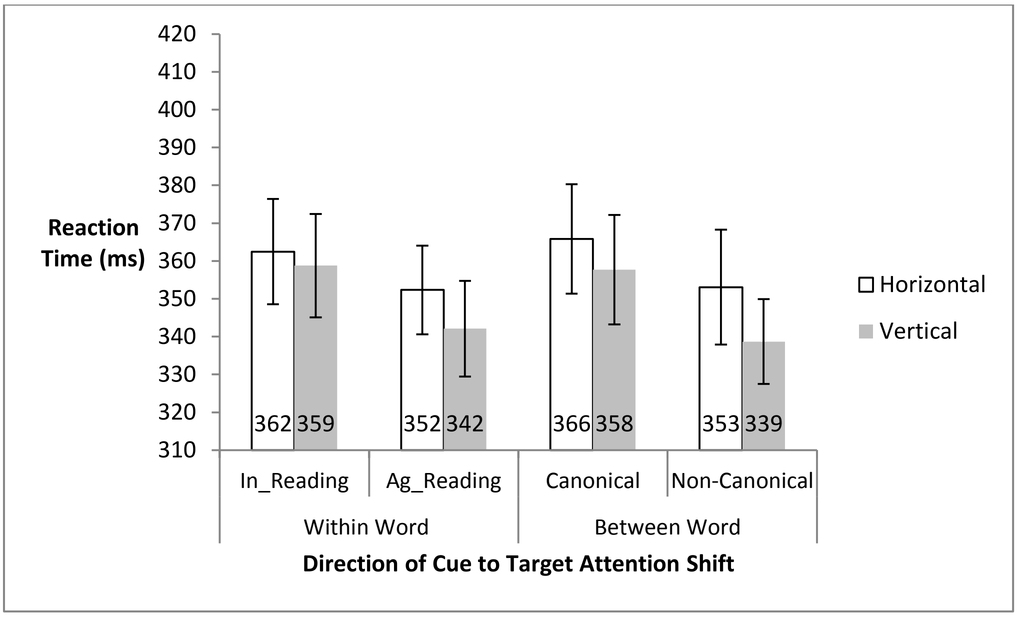


FIGURE 3-5 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME (EXPERIMENT 3)

Reaction Time Costs – Within vs. Between Word Attention Shifts

An analysis was conducted to explore the size of the costs associated with having to move your attention to a new location, compared with not having to move your attention at all. The reaction time of a valid trial using the same cue was subtracted from the reaction time of an invalid trial.

A 2 (orientation) by 2 (invalid within word costs vs. invalid between word costs) repeated measures ANOVA found no significant effect of orientation ($F(1, 22)=0.678$, $p=.419$). There was also no significant effect of invalidity ($F(1, 22)=.270$, $p=.609$) nor were there any interactions ($F(1, 22)=0.540$, $p=.470$). These results are illustrated in Figure 3-6.

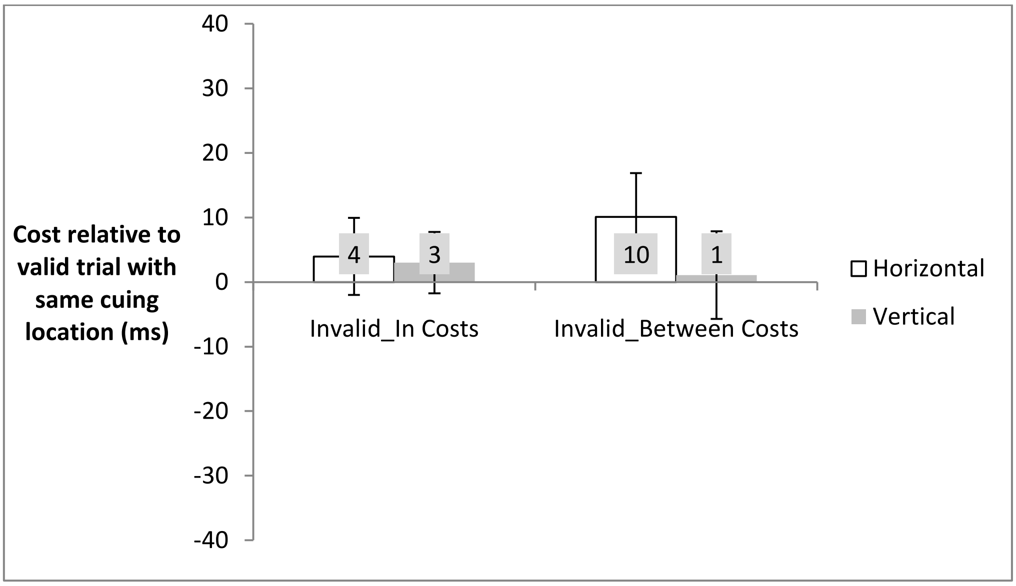


FIGURE 3-6 - WITHIN VS. BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME COSTS (EXPERIMENT 3)

Reaction Time Costs – Direction of Attention Shift

As in the previous experiments, within word and between word attention shifts were analysed separately to allow an exploration of the effects of direction.

Within Word Shifts

A 2 (orientation) by 2 (reading direction) repeated measures ANOVA was carried out on within word attention shifts. There was no significant effect of orientation ($F(1, 22)= 0.023$, $p=.882$). There was no significant effect of reading direction ($F(1,22)=0.285$, $p=.599$) and there were no significant interactions ($F(1,22)=0.015$, $p=.905$)

Between Word Shifts

A 2 (orientation) by 2 (canonicity) repeated measures ANOVA was conducted on between word attention shifts. There was no significant effect of orientation (F(1, 22)=0.871, p=.361), There was no significant effect of canonicity (F(1, 22)=0.158, p=.695) and there were no significant interactions (F(1, 22)=1.637, p=.214).

No effects reached significance. These results are illustrated in Figure 3-7.

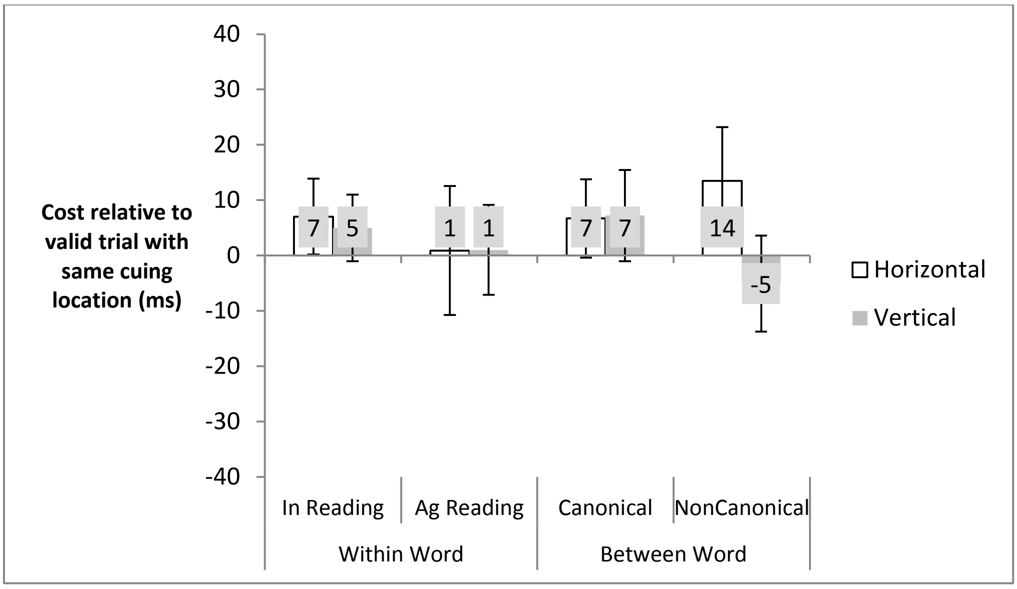


FIGURE 3-7 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 3)

Experiment 3 Discussion

There were a number of findings in Experiment 3 which were unexpected. Most importantly, there was no significant effect of validity. That means that it cannot be claimed that attention was successfully cued to a particular location. Without this, any discussion of object based effects becomes very problematic indeed. If it cannot conclusively be shown that participants attended to the cue, making inferences about how they respond to the target is very difficult. Indeed, it is much more difficult than if this were a simple target detection study with no cue, since you cannot rule out that the cue has had an effect, but one that is hard to detect. Furthermore, what effects did reach significance were in entirely unexpected directions. For example, unlike

Experiments 1 and 2 there was an effect of cuing direction on the untransformed RT scores. However, this ran in the opposite direction to what would have been predicted – the participants were faster making attention shifts that ran contrary to reading direction. Without an effect of cuing it is not possible to make inferences about object based effects or reading direction / canonicity effects, since it cannot be shown that the participants attention was drawn to a particular location or object prior to the onset of the target.

Experiment 4 Introduction

At the same time as experiment 3, an experiment was created to try and account for the importance of lexical effects. This experiment utilised (using different subjects to experiment 3) "placeholders" instead of words. These were black rectangles occupying the same slots as the letters in the lexical version of the experiment, and they were of approximately the same size. Aside from the absence of word stimuli, the design was otherwise identical to experiment 3.

Experiment 4 Methods

Unless otherwise stated, the methods employed were the same as in Experiment 3.

Participants

The participants in this study were 11 female and 5 male students from the University of Dundee. They were paid in course credits for their time. Their ages ranged from 17 to 24. All participants were fluent in English. This experiment utilised a within subjects design so all participants were exposed to all conditions of the stimuli.

Stimuli

Each array consisted of 8 "placeholder" boxes arranged in the same configuration as 2, 4-letter words. The boxes were chosen so as to match the letter stimuli from the previous experiment in terms of overall size. The placeholder boxes measured approximately 0.9º x 1.4º of visual angle. Each array covered 4.6º x 4.1º (horizontal array condition) or 3.5º x 6.5º (vertical array condition) and the fixation cross measured 1º by 1º. Since the placeholders were not subject to the same extremes of size variability as the letters ("i" vs "w" for instance), the placeholder array wound up being very slightly more compact than the lexical array, but each individual placeholder was consistent with the size of the average letter used in Experiment 3. The same "letter" spacing was used as in Experiment 3.

Task and Procedure

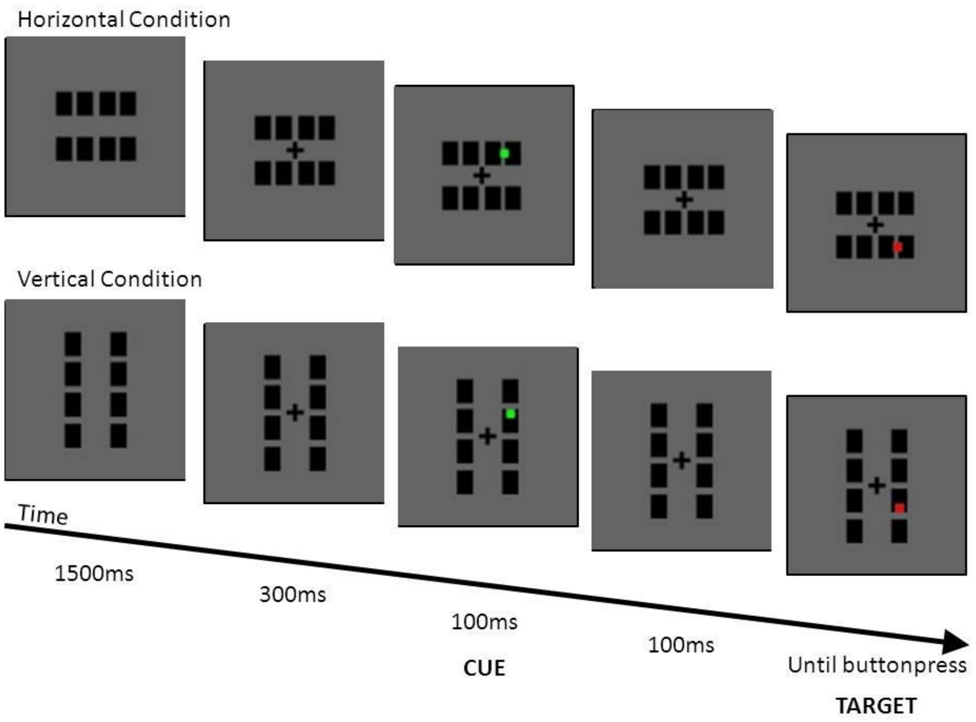


FIGURE 3-8 - EXPERIMENT 4 TRIAL SEQUENCE, ILLUSTRATING AN INVALID-WITHIN "WORD" TRIAL IN THE VERTICAL CONDITION, AND AN INVALID-BETWEEN "WORD" TRIAL IN THE HORIZONTAL CONDITION. NOT DRAWN TO SCALE.

Figure 3-8 gives a schematic representation of trial events. The start array for each trial contained two rows of 4 placeholders, arranged as if they were 2 4-character words. These were presented for 1500 ms, followed by an additional fixation cross for 300 ms. Participants were told to look at the array and then fixate the cross. A small green dot was overlaid onto the first or last 2 placeholder boxes of one of the "words" for 100ms to cue attention to this location . Following a further 100 ms without cue or target present, a red target would appear over the first or last two placeholder boxes in one of the "words". The time from target onset to the participant pressing the respond button was the reaction time (RT).

Experiment 4 Results

Performance & Filtering Information:

As before, participants generally did very well at the task, with 94% of all responses being rated as correct from retained subjects. On trials where a response was required 95% of all responses were correct from retained subjects. Error rates tended to be higher for catch trials where no response was required with 86% of responses from retained subjects being correct. A filter was applied to remove outliers which retained only those scores which fell within 2.5 Standard Deviations of correct reaction times for each subject. 95% of all correct responses were retained by this filter. Altogether, 90% of all responses issued were included in this dataset after the application of error and reaction time filters. This indicates a slightly higher error rate for the placeholders version of this task compared to the words version of the task.

3 additional subjects were tested but not included in this dataset due to very high false alarm rates on Catch Trials (46%, 67% and 67% correct respectively). As in previous experiments, 75% correct was the minimum number of correct catch trials to meet the criteria for inclusion. Any lower than this and it was concluded that the participants' reaction times did not

truly reflect a response to target onset, but rather that their responses were anticipatory.

Reaction Times - Validity

Non-erroneous RTs were analysed with a 2 (orientation) by 3 (levels of validity) repeated measures ANOVA. There was no significant effect of orientation ($F(1,12)=1.207$, $p=.294$), or validity ($F(2, 24)=0.327$, $p=.724$). There were also no significant interactions ($F(2, 24)=0.779$, $p=.470$).

Cuing does not seem to have been successful with valid trials being only slightly faster than invalid between trials in the horizontal orientation, and only slightly faster than invalid in trials in the vertical orientation. These results indicate that this experiment did not reliably cue attention to one specific location of the array, as with the previous experiment. These results are illustrated in Figure 3-9.

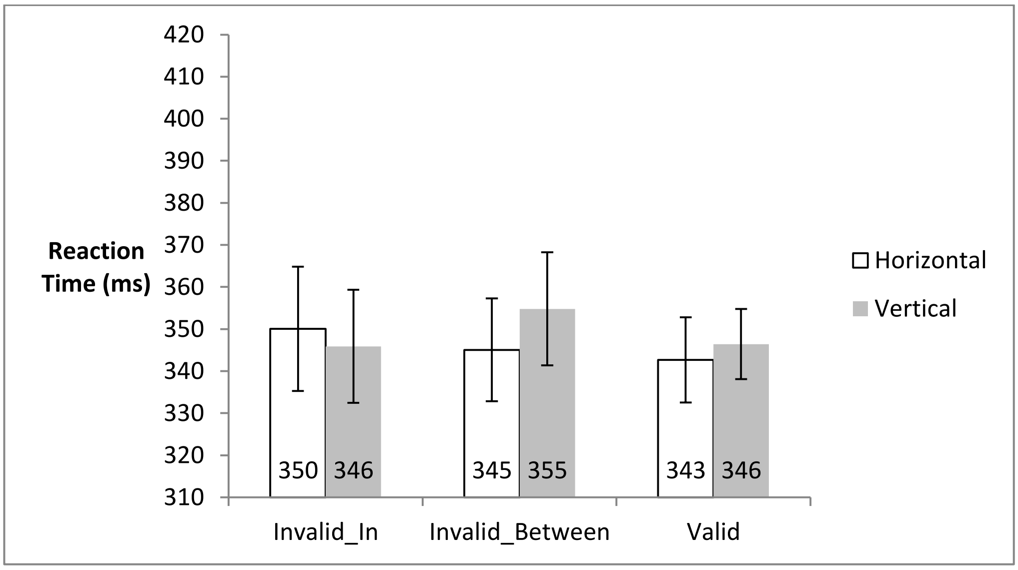


FIGURE 3-9 - EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 4)

Reaction times – Target Location

An analysis was conducted to see whether participants had a preference for responding to targets in particular locations. Both valid and invalid targets were included in this analysis. A 2 (orientation) by 4 (target location) repeated measures ANOVA was carried out. There was no significant effect of orientation (F(1, 12)=2.605, p=.133). There was no significant effect of target location (F(3, 36)=0.735, p=.538). There was no significant interaction (F(1.660, 19.926)=0.806, p=.440, Greenhouse-Geisser corrected). No effects of target location were observed. These results are described in Figure 3-10.

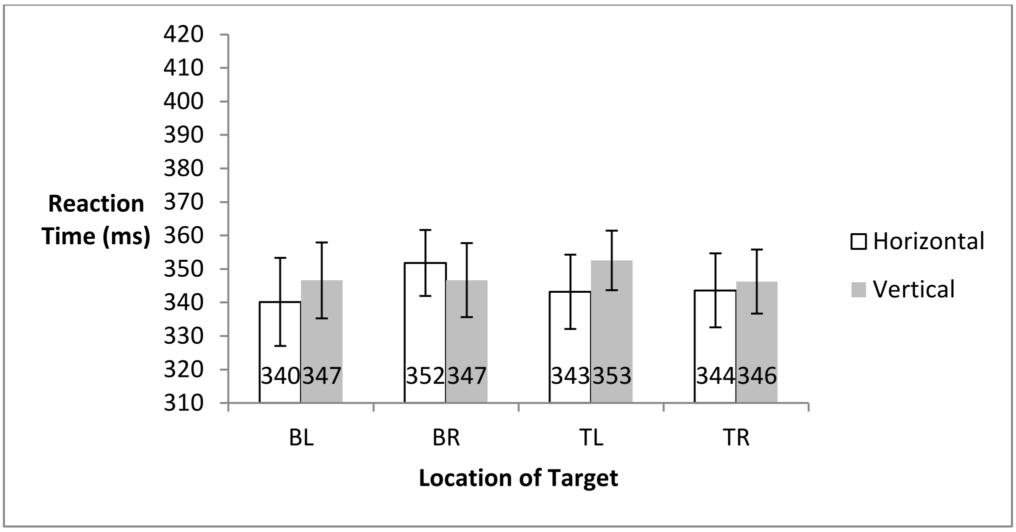


FIGURE 3-10 - EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 4)

Reaction Times - Direction of Attention Shift

For the sake of consistency these data were analysed as if they were from word arrays, as in previous experiments. The data were derived from trials where the cues and the targets were not in the same location, and "reading direction" and "canonicity" were treated as two separate analyses. As before, in this analysis direction of attention shift was recoded based on how it related to reading direction (in reading direction, or against), or how it related to shifts between words (left to right and top to bottom were "canonical", whereas right to left and bottom to top were "non-canonical").

Within Word Shifts

A 2 (orientation) by 2 (reading direction) repeated measures ANOVA was carried out on the within word attention shift data. There was no significant effect of orientation (F(1, 12)=0.500, p=.493). There was a significant effect of reading direction (F(1, 12)=13.230, p=.003). There were no significant interactions (F(1,12)=0.378, p=.550). These data indicate that contrary to our expectations, participants responded significantly more slowly when cued to move their attention in accord with reading direction than against.

Between Word Shifts

A 2(orientation) by 2(canonicity) repeated measures ANOVA was carried out on the between word attention shifts. There was no significant effect of orientation (F(1,12)=1.454, p=.251). There was no significant effect of canonicity (F(1,12)=2.707, p=.126). There were no significant interactions (F(1, 12)=1.003, p=.336). No significant effects on reaction time relating to between word shifts were found at all.

The data for both reading direction and canonicity effects are illustrated in Figure 3-11:

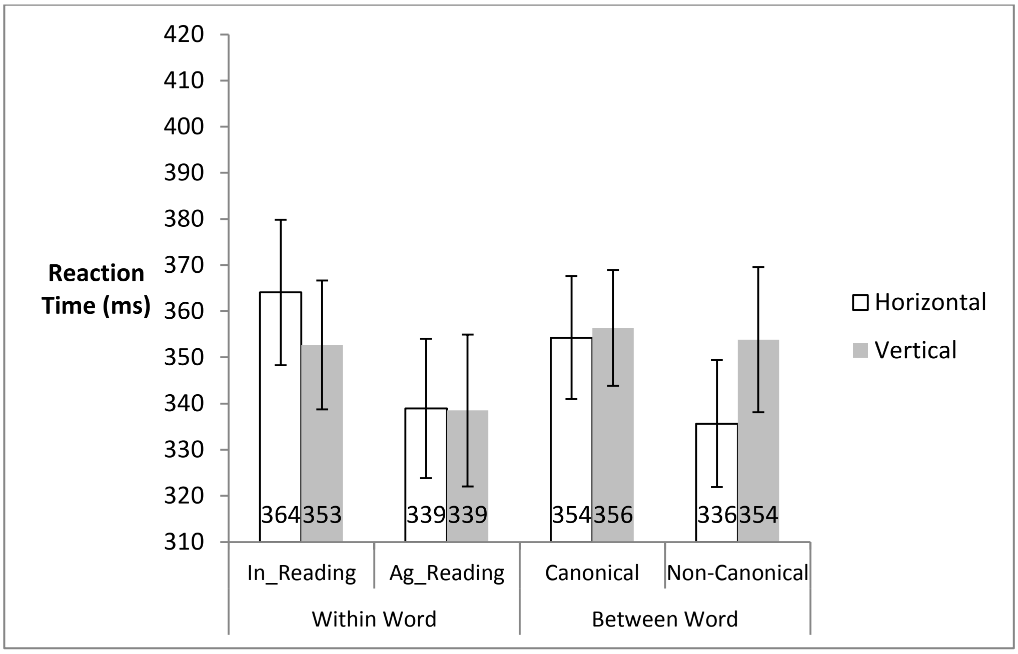


FIGURE 3-11 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIMES (EXPERIMENT 4)

Reaction Time Costs – Within vs. Between Word Shifts

An analysis was conducted to explore the size of the costs associated with having to move your attention to a new location, compared with not having to move your attention at all. The reaction time of a valid trial using the same cue was subtracted from the reaction time of an invalid trial.

A 2 (orientation) by 2 (Invalid within word or Invalid between word) repeated measures ANOVA was conducted. There was no significant effect of Orientation (F(1, 12)=0.215, p=.651). There was no significant effect of Invalidity (F(1, 12)=0.215, p=.615). There were no significant interactions (F(1, 12)=1.537, p=.239). No effects on reaction time cost were observed. These results are illustrated in Figure 3-12.

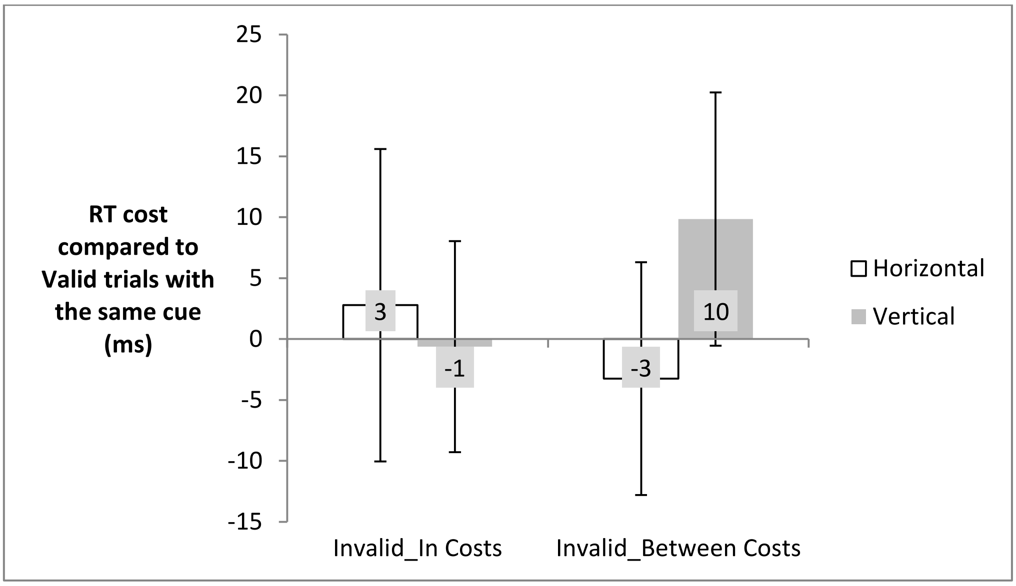


FIGURE 3-12 - WITHIN VS BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME COSTS (EXPERIMENT 4)

Reaction Time Costs – Direction of Attention Shift

As in the previous experiments, within word and between word attention shifts were analysed separately to allow an exploration of the effects of direction.

Within Word Shifts

A 2 (orientation) by 2(reading direction) repeated measures ANOVA was carried out on the within word attention shifts. There was no significant effect of orientation ($F(1, 12)=0.089$, $p=.771$). There was a marginally significant effect of reading direction ($F(1, 12)=4.530$, $p=.055$). There were no significant interactions ($F(1, 12)=2.843$, $p=.118$). It would appear that with these archetypal "words" participants incurred less cost when cued to move their attention against reading direction than when they were cued to move their attention in accord with reading direction.

Between Word Shifts

A 2 (orientation) by 2 (canonicity) repeated measures ANOVA was carried out on the between word attention shifts. There was no significant effect of orientation ($F(1, 12)=0.969$, $p=.344$). There was no significant effect of canonicity ($F(1, 12)=0.688$, $p=.423$). There were no significant interactions ($F(1,12)=2.003$, $p=.182$). No significant effects on between word attention shifts were observed.

These results are illustrated in Figure 3-13.

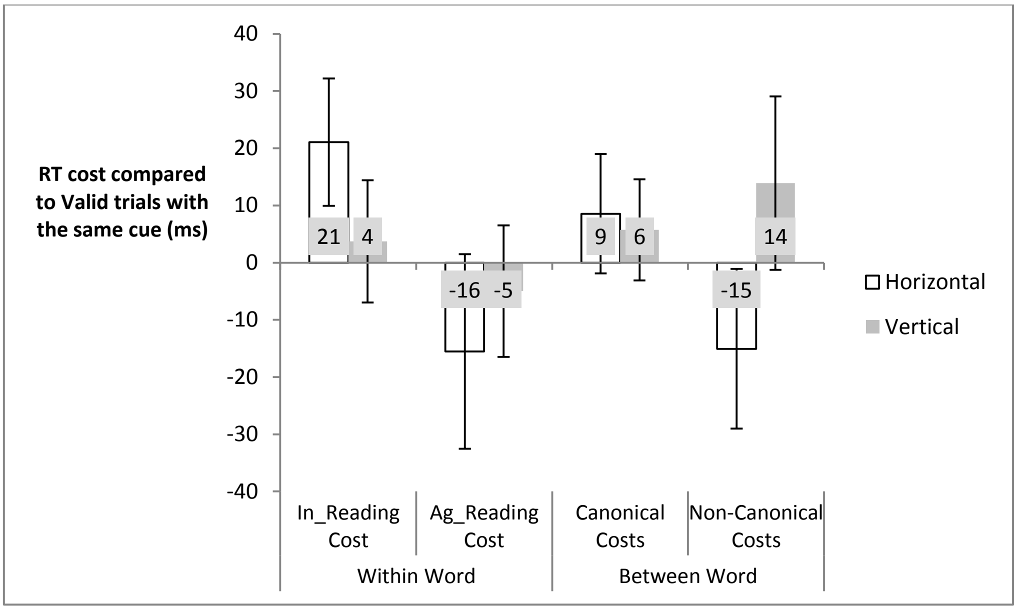


FIGURE 3-13 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 4)

Experiment 4 Discussion

As with Experiment 3, this experiment failed to demonstrate a main effect of validity. Accordingly, it is impossible to make any claims about object based effects, since it cannot be conclusively demonstrated that attention was being drawn to the cue. In another result which lined up with Experiment 3, there was an unexpected directional effect on unfiltered reaction times where participants were fast at moving attention from the end of a “word” to the start, but slow to move attention from the start to the end. However, since it cannot be shown that participants had attended to the cue, this may simply reflect a bias toward responding to targets in particular locations. There may be underlying perceptual biases that are not wholly related to the location of the cue, but are to do with how the placeholder stimuli are processed. It is not possible to draw more specific claims from this data.

Experiment 3 and 4 Discussion

Experiments 3 and 4 were failures. They did not successfully replicate the findings of Experiments 1 and 2. Looking at the validity data, it is clear that the trends run in broadly the right direction. Valid trials were generally fast, and invalid trials were generally slow, even though the effects did not reach significance. Recruitment constraints meant that Experiment 3 (25 participants) and Experiment 4 (16 participants) both had less participants than Experiments 1 (14 participants) and 2 (16 participants) combined, so statistical power may have been an issue. However it was concluded that statistical power alone could not account for the lack of significant effects in this experiment, particularly the almost flat reaction times found in the validity data indicating almost no effect of cuing. It was concluded that the cue was of insufficient intensity to produce the large effect of cuing previously observed. The best way to correct this was to increase the magnitude of the cue and target stimuli by making them bigger. Rather than using small dots overlaid on the word stimuli, cues and targets would now be large flashes of colour that occurred behind the word and placeholder stimuli.

Section 2 – Experiments 5 (Big Dot Words as Objects) and 6 (Big Dot Placeholders)

Experiment 5 Introduction

Since Experiments 3 and 4 were unsuccessful in their attempt to reproduce the effects found in Experiments 1 and 2 while using a more rigorous methodology, a new set of experiments was created. These were identical to Experiments 3 and 4, but the intensity of the cue and target stimuli was increased by making them much larger. To prevent these much larger cues and targets from occluding the word stimuli they were changed from being overlaid on the word stimuli as in Experiments 3 and 4, to being presented behind the word stimuli. The size increase would, it was hoped, increase the magnitude of the effects to a size detectable by the type of study being employed here. A comparison between the arrays used in Experiment 3 and Experiment 5 is provided in figure 3-14.

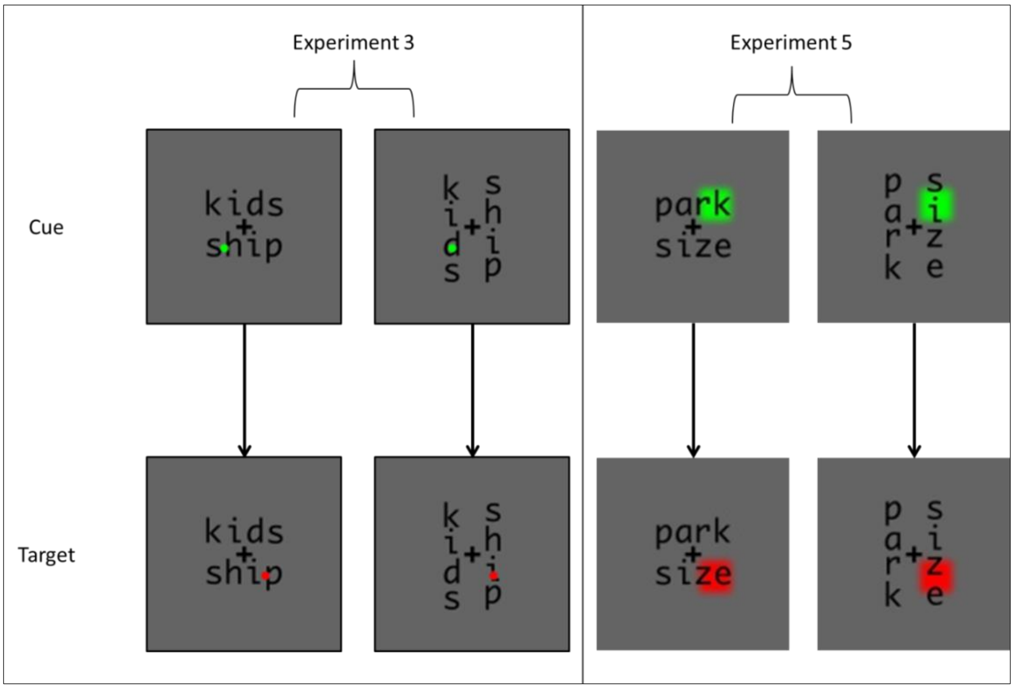


FIGURE 3-14 - COMPARISON BETWEEN THE STIMULUS ARRAYS USED IN EXPERIMENTS 3 AND 5

Experiment 5 Methods

Unless otherwise stated, the methods used were the same as Experiments 3 /4.

Participants

The participants in this study were 25 female and 7 male students from the University of Dundee. They were paid in course credits for their time. Their ages ranged from 17 to 40. All participants were fluent in English. This experiment utilised a within subjects design so all participants were exposed to all conditions of the stimuli.

Stimuli

Cues and targets were colour patches approximately 2.7º by 2.7º

Task and Procedure

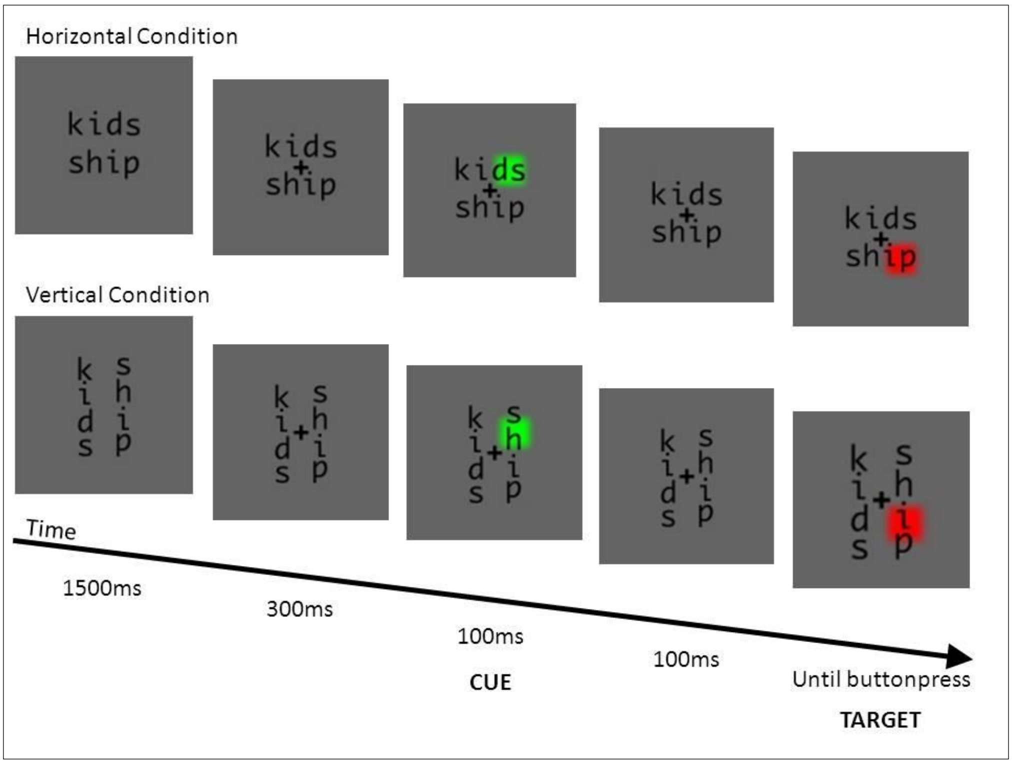


FIGURE 3-15 - EXPERIMENT 5 TRIAL SEQUENCE, ILLUSTRATING AN INVALID-BETWEEN WORD TRIAL IN THE HORIZONTAL CONDITION, AND AN INVALID-WITHIN WORD TRIAL IN THE VERTICAL CONDITION. NOT DRAWN TO SCALE

Figure 3-15 gives a schematic representation of trial events.

Experiment 5 Results

Performance & Filtering Information:

As in previous experiments error rates were very low with 94% of all responses being rated as correct from retained subjects. On trials where a response was required 96% of all responses were correct from retained subjects. Error rates were higher for catch trials where no response was required with 86% of responses from retained subjects being correct. A reaction time filter removed outliers with scores outside the 100-700ms range. Less than 2% of correct responses were affected by this. This produced results almost identical to the 2.5SD filter used in Experiments 3 and 4, while being easier to implement and more consistent with Experiments 1 and 2. Altogether, over 92% of all responses issued were included in this dataset after the application of error and reaction time filters.

9 additional subjects were tested but not included in this dataset due to very high error rates. In the case of 4 of them this was the result of poor eye tracker calibrations or poor eyesight. The remaining 5 were removed due to poor performance on Catch Trials (67%, 71% and 58% and 67% correct respectively). As in previous experiments, 75% was the minimum number of correct catch trials to meet the criteria for inclusion. A false alarm rate higher than this was considered indicative that a participant's reaction time did not truly reflect a response to target onset, but rather that their responses were anticipatory.

Reaction Times - Validity

Non-erroneous RTs were analysed with a 2 (orientation) by 3 (levels of validity) repeated measures ANOVA. There was no significant effect of orientation ($F(1,31)=1.465$, $p=.234$). There was a significant effect of validity ($F(2,62)=3.163$, $p=.049$). There was also a significant interaction between orientation and validity (F(1.624,50.352)=3.507, p=.047) (Greenhouse-Geisser correction applied due to lack of sphericity).

Planned comparisons were carried out to explore the nature of the interaction. It was found that Invalid In trials only differed marginally from valid trials in terms of reaction time (p=.059) when both orientations were considered, whereas Invalid Between trials differed reliably from Valid trials (p=.038). The observed interaction seemed to load entirely on the comparison between Invalid In and Valid trials (p=.001) and not at all on the comparison between Invalid Between and Valid (p=.458). Thus on Horizontal Trials only, Invalid In trials were very fast.

An effect of cuing was found where valid trials were responded to fastest in both orientations. However, whereas Invalid Between trials were slow in both orientations, Invalid In trials were only slow in the vertical orientation. When Invalid In trials were presented in the horizontal orientation they were responded to extremely fast, almost as fast as valid trials in fact (360ms vs. 358ms). This is evidence for the hypothesised "Within word benefit" where a cue landing anywhere within a word will facilitate target detection elsewhere within that word. These results are illustrated in Figure 3-16.

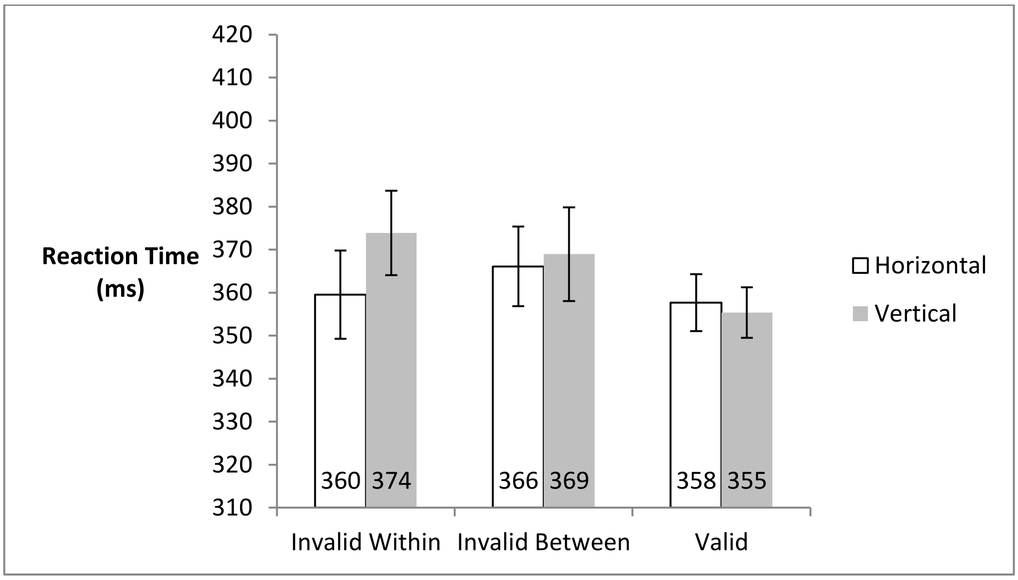


FIGURE 3-16 - EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 5)

Reaction Times - Target Location

An analysis was conducted to see whether participants had a preference for responding to targets in particular locations (BL=Bottom Left, BR =Bottom Right, TL= Top Left, TR = Top Right). Both valid and invalid targets were included in this analysis. A 2 (word orientation) * 4 (target location) repeated measures ANOVA was run. There was no significant effect of word orientation (F(1,31)=0.210, p=.650). There was a significant effect of target location (F(3, 93)=8.549, p<.001). There was no significant interaction (F(3,93)=0.888, p=.450). Targets located in the bottom right were consistently responded to fastest in both orientations. These results are described in Figure 3-17.

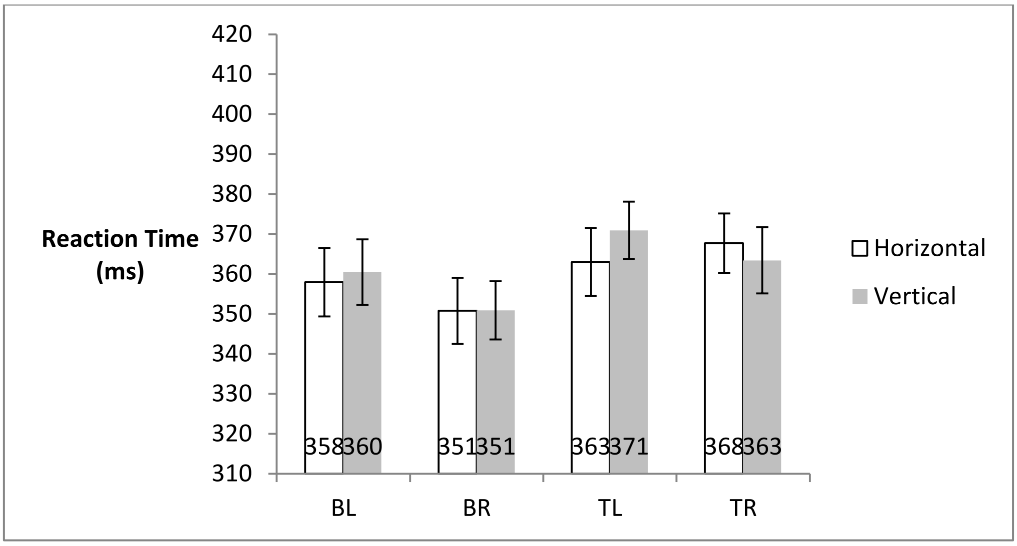


FIGURE 3-17 - EFFECT OF TARGET LOCATION ON REACTION TIMES (EXPERIMENT 5)

Reaction Times - Direction of Attention Shift

These data were derived from trials where the cues and the targets were not in the same location, and "reading direction" and "canonicity" were treated as two separate analyses. As before, in this analysis direction of attention shift was recoded based on how it related to reading direction (in reading direction, or against), or how it related to shifts between words (left to right and top to bottom were "canonical", whereas right to left and bottom to top were "non-canonical").

Within Word Shifts

A 2 (orientation) by 2(reading direction) repeated measure ANOVA was carried out on the data from within word attention shifts. There was a significant effect of orientation (F(1, 31)=8.407, p=.007). There was no significant effect of reading direction (F(1, 31)=0.723, =.402). There were no significant interactions (F(1,31)=2.115, p=.156). Participants tended to respond more quickly to horizontally oriented trials, but there were no effects of reading direction on RTs from within word attention shifts.

Between Word Shifts

A 2 (orientation) by 2 (canonicity) repeated measures ANOVA was carried out on the data from between word attention shifts. There was no significant effect of orientation (F(1, 31)=0.167, p=.685). There was a significant effect of canonicity (F(1, 31)=4.859, p=.035). There were no significant interactions (F(1,31)=0.138, p=.713). Participants were faster at making canonical between word attention shifts than they were at making non-canonical between word attention shifts. Orientation did not affect the reaction times from between word attention shifts.

The data for both reading direction and canonicity effects are illustrated in Figure 3-18:

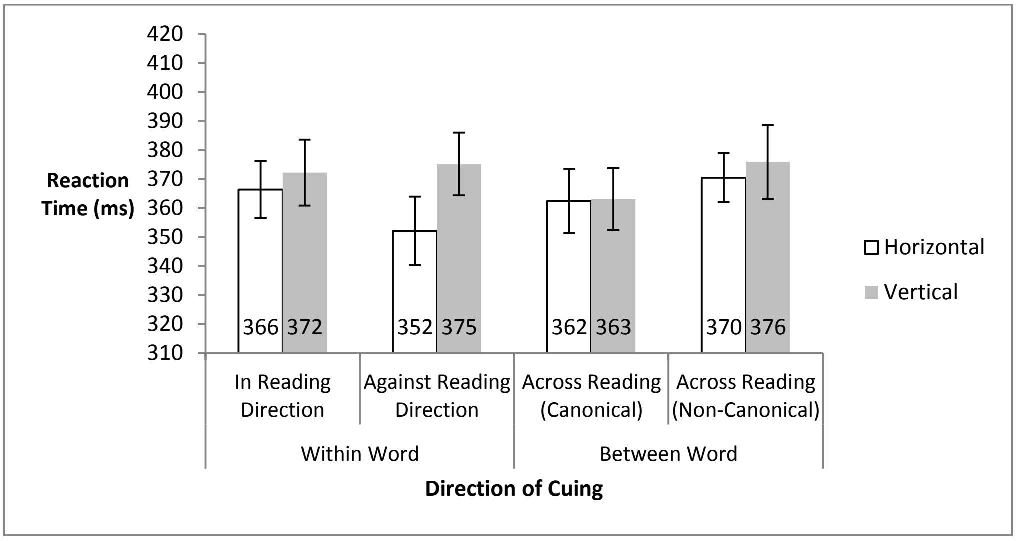


FIGURE 3-18 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIMES (EXPERIMENT 5)

Reaction Time Costs - Within vs. Between Word Attention Shifts

An analysis was conducted to explore the size of the costs associated with having to move your attention to a new location, compared with not having to move your attention at all. The reaction time of a valid trial was subtracted from the reaction time of an invalid trial using the same cue.

A 2 (orientation) by 2 (Invalid In or Invalid Between) repeated measures ANOVA was conducted. There was a significant effect of Orientation (F(1, 31)=4.285, p=.047). There was no significant effect of Invalidity (F(1, 31)=0.197, p=.660). There were no significant interactions (F(1, 31)=2.551, p=.120). Costs tended to be bigger in vertically oriented trials, but no significant difference was found between the two classes of invalid trials. These results are illustrated in Figure 3-19.

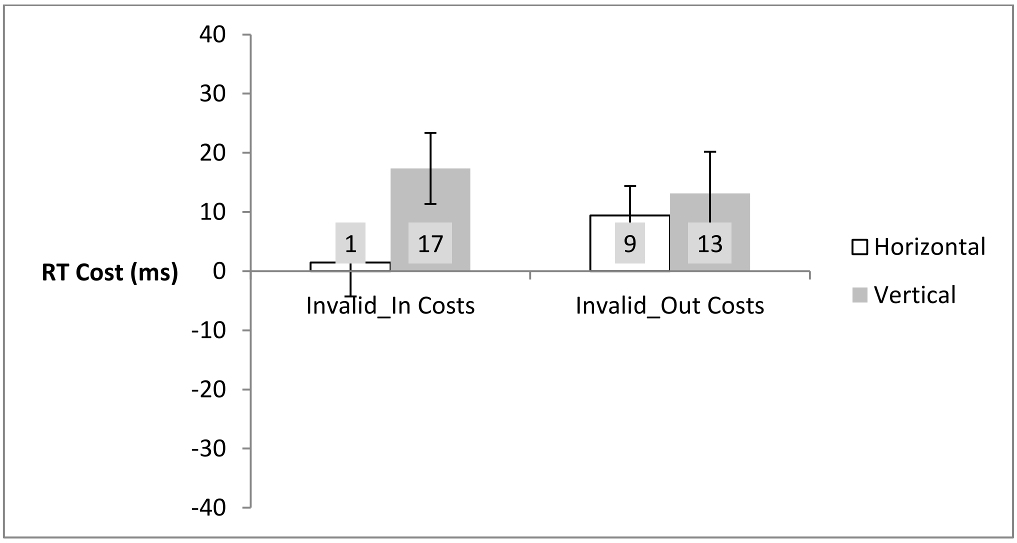


FIGURE 3-19 - WITHIN VS. BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME (EXPERIMENT 5)

Reaction Time Costs – Direction of Attention Shift

As in the previous experiments, within word and between word attention shifts were analysed separately to allow an exploration of the effects of direction.

Within Word Shifts

A 2 (word orientation) by 2(reading direction) repeated measures ANOVA was carried out on the costs data from within word attention shifts. There was a significant effect of orientation (F(1,31)=9.904, p=.004). There was no significant effect of reading direction (F(1,31)=0.382, p=.541). There was a marginally significant interaction (F(1,31)=3.702, p=.064). Participants incurred more costs on vertically oriented trials, and in particular on the against reading-direction trials.

Between Word Shifts

A 2(word orientation) by 2(canonicity) repeated measures ANOVA was carried out on the costs data from between word attention shifts. There was no significant effect of orientation (F(1,31)=0.286, p=.597). There was a significant effect of Canonicity (F(1,31)=10.328, p=.003). There were no significant interactions (F(1,31)=0.002, p=.968).

As with the reaction time data, orientation seems to have had no effect on the costs for between word attention shifts. There was a significant effect of Canonicity where canonical between word attention shifts incurred significantly less cost than non-canonical between word attention shifts. These results are illustrated in Figure 3-20.

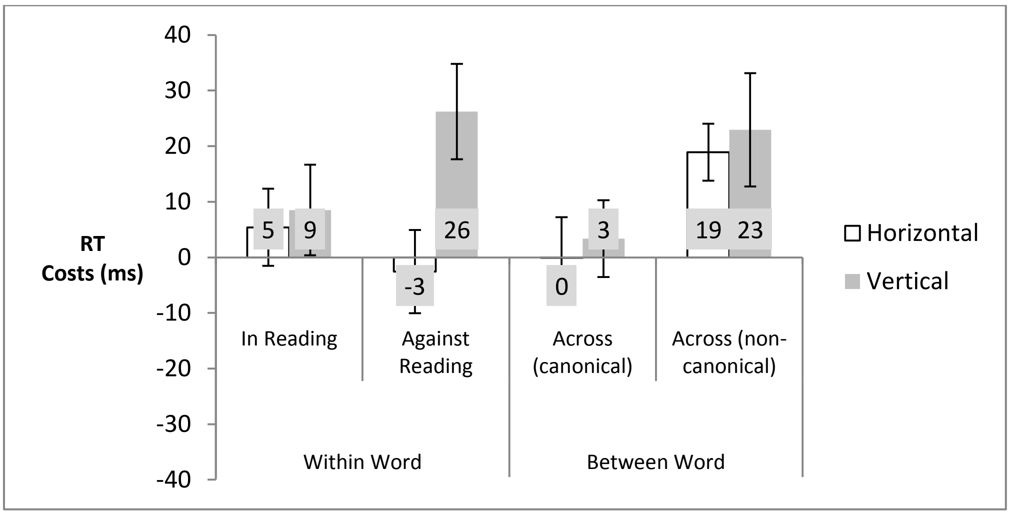


FIGURE 3-20 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 5)

Experiment 5 Discussion

This experiment did not successfully replicate Experiments 1 and 2, since there was no reading direction effect on the reaction time costs data. However, rather unexpectedly this experiment was partially successful in replicating Li and Logan's (2008) Chinese experiment, using a typologically different language, English. Whilst they found that in both the horizontal and vertical orientations invalid cues within the same word as the target facilitated reaction times, this experiment found this effect only in the horizontal orientation. For horizontally oriented words, invalid cues that occurred inside the same word as the target facilitated target detection reaction times up to a level that was almost indistinguishable from true valid cuing. This indicates that a cue landing anywhere within a horizontally oriented English word will elevate attention levels to the whole word and thereby facilitate target detection in non-cued locations. This supports the idea that words can be treated like objects because this is an "object based effect". However, this effect was not present when the words were oriented vertically.

Since it can be shown that English words have attentional properties of the sort that would normally be associated with objects, this can be seen as evidence for the role of object based attention in reading. However it is of interest that this experiment was unsuccessful in demonstrating this effect in the vertical orientation, where invalid but within word cues were responded to just as slowly as invalid different word cues. The fact that Li and Logan (2008) managed to show this effect in Chinese, whereas this experiment was unsuccessful in doing so for English may be related to the properties of the two languages. It is evident that characters in English and Chinese are very different visually, but they are also processed in different ways. In Chinese there are radicals embedded inside characters that provide phonological and semantic information about that character to the reader, and they are not necessarily read in a strictly linear, left to right fashion. Likewise up until fairly recently Chinese could legitimately be written either left to right, or top to bottom. This is now rarer in mainland China (although still very common in signage) but still regularly encountered in other Chinese reading countries. Conversely, top to bottom writing is fairly novel in English. As a consequence it is fair to say that Chinese readers will be much more receptive to seeing Chinese written top to bottom than English readers will be to seeing their language written top to bottom. In English, it is hypothesised that the object based representation of a word which produces these effects is only activated when viewing the word in the familiar orientation. This would imply that when written in the vertical format, English words are decoded using an alternative method which does not produce object based attentional effects.

There are some criticisms that could be levelled at this study. In order to have the same size, shape and location of cues/targets between the horizontal and vertical trials it was unavoidable that there would be a better fit in one orientation, in this case it was the horizontal orientation (see Figure 15). There is a possibility that this poor fit may go some way to account for the differences between the horizontal and vertical trials. Also, the question of why Experiment 5 found such radically different results compared to Experiments 1 and 2 remains to be addressed.

Experiment 6 Introduction

Using the larger cues and targets employed in Experiment 5, this experiment tried once again to find an object based effect in non-lexical stimuli, as had been tried unsuccessfully in Experiment 4.

Experiment 6 Methods

Unless otherwise stated, the methods employed were the same as Experiment 5.

Participants

The participants in this study were 9 female and 6 male students from the University of Dundee. They were paid in course credits for their time. Their ages ranged from 17 to 38. All participants were fluent in English. This experiment utilised a within subjects design so all participants were exposed to all conditions of the stimuli.

Stimuli

Each array consisted of 8 "placeholder" boxes arranged in the same configuration as 2, 4-letter words. The boxes were chosen so as to match the letter stimuli from the previous experiment in terms of overall size. Unlike in Experiment 4, the placeholder boxes were now hollow (see Figure 3-21). For consistency with Experiment 5 it was important that the cue/target flashes appear behind the placeholder stimuli. Solid boxes would have obscured too much of the cues and targets, so they were made hollow. Seizing an opportunity to improve the design, the thickness of the placeholder box line was weighted so that for each box, approximately the same number of black pixels was illuminated as there were per letter in the lexical versions of the experiment. The placeholder boxes measured 0.9º x 1.4º of visual angle. Each array covered 4.6º x 4.1º (horizontal array condition) or 3.5º x 6.5º (vertical array condition) and the fixation cross measured 1º by 1º. Each individual placeholder was consistent with the size of the average letter used in experiments 3 and 5.

Design

The design was identical to Experiment 5 except that the placeholder arrays stood in for real words. For the purposes of further discussion these arrays will be discussed as if they were words, so “within word” will be taken to mean events occurring inside one horizontal or vertical group of placeholders, and “between word” will be taken to mean events that occur between groups.

Procedure

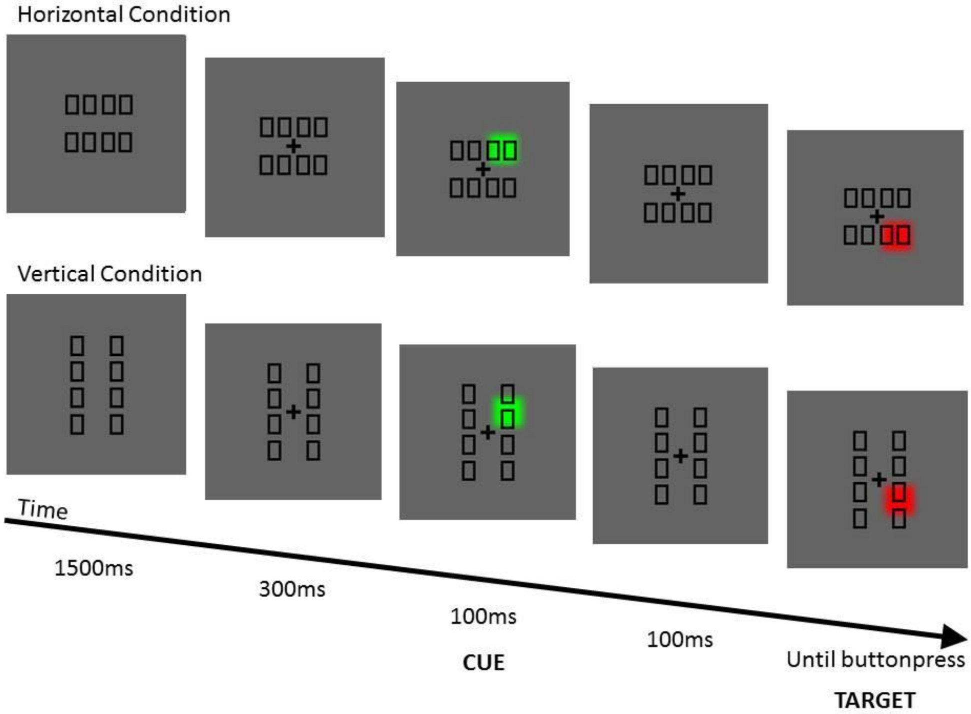


FIGURE 3-21 - EXPERIMENT 6 TRIAL SEQUENCE, ILLUSTRATING AN INVALID-BETWEEN" WORD" TRIAL IN THE HORIZONTAL CONDITION, AND AN INVALID-WITHIN "WORD" TRIAL IN THE VERTICAL CONDITION. NOT DRAWN TO SCALE

There were only two arrays in this experiment, either the horizontal or the vertical. Aside from that, the procedure was identical to Experiment 5. Like Experiment 5 the participants were encouraged not to ignore the placeholder arrays by periodically being asked to describe the last array they saw.

Experiment 6 Results

Performance and Filtering Information

Error rates were similar to previous studies, with 95% of all responses being rated as correct from retained subjected. On trials where a response was required participants responded correctly on 96% of trials. As with previous studies, the error rate for catch trials where no response was required was somewhat higher, with a correct (non) response being issued on 88% of trials. It was necessary to abandon the 100-700ms reaction time filter used in

Experiment 5 as it removed too much data. A filter which removed reaction times greater than 2.5SD from the mean was used. Just over 2% of correct responses were affected by this filter. Altogether approximately 93% of all responses issued were included in this dataset after the application of error and reaction time filters.

4 additional subjects were tested but were not included due to problems with their data. In the case of two of them this was due to not completing the experiment in its entirety. A further subject had very poor eye tracker calibrations which triggered many errors. The final participant was removed due to a high catch error rate of nearly 30% (i.e. only 70% correct). The minimum correct response rate for catch trials was 75%.

Reaction Times - Validity

Non-erroneous RTs were analysed with a 2 (orientation) by 3 (levels of validity) repeated measures ANOVA. There was no significant effect of orientation ($F(1, 14)=0.667$, $p=.428$), validity ($F(2,28)=0.269$, $p=.766$), nor was there a significant interaction ($F(2, 28)=1.790$, $p=.186$). These results are illustrated in Figure 3-22.

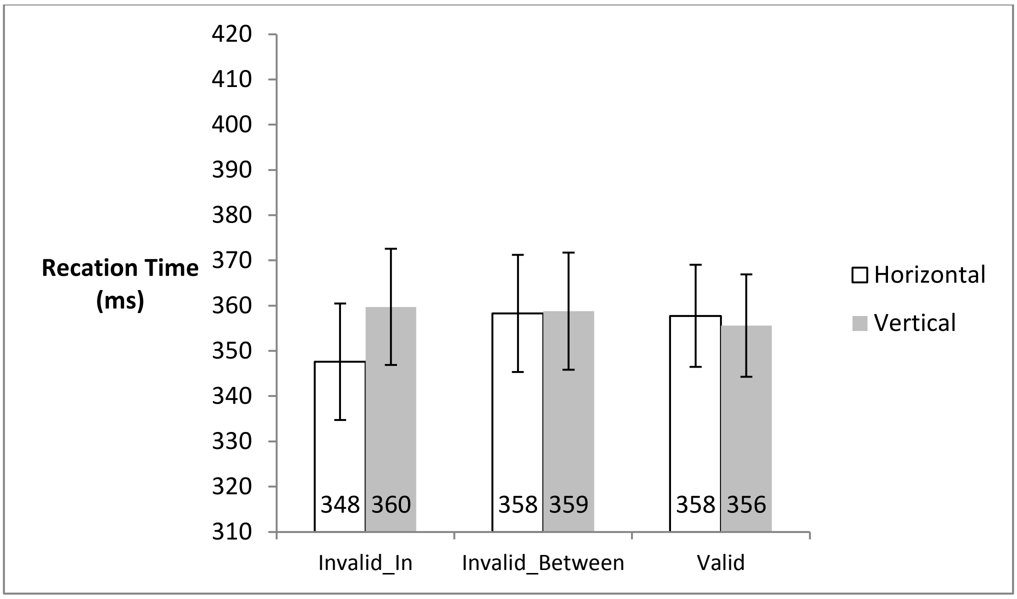


FIGURE 3-22 - EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 6)

Reaction Times – Target Location

An analysis was conducted to see whether participants had a preference for responding to targets in particular locations (BL=Bottom Left, BR=Bottom Right, TL=Top Left, TR=Top Right). Both valid and invalid targets were included in this analysis. There was no significant effect of orientation ($F(1,14)=0.100$, $p=.756$), nor were there any significant interactions ($F(3, 42)=1.272$, $p=.296$). There was however a significant effect of target quadrant ($F(3, 42)=3.541$, $p=.023$). Responses issued to targets on the bottom appear to be faster. These results are illustrated in Figure 3-23.

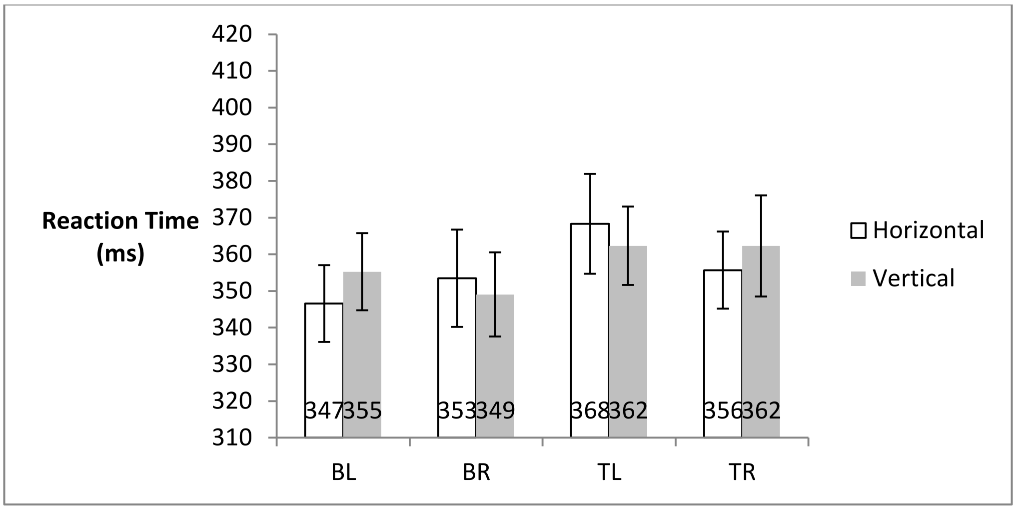


FIGURE 3-23 - EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 6)

Reaction Times - Direction of Attention Shift

As with Experiment 4, these data were analysed as if they were from actual “words”. These data were derived from trials where the cues and the targets were not in the same location, and "reading direction" and "canonicity" were treated as two separate analyses. As before, in this analysis direction of attention shift was recoded based on how it related to reading direction (in reading direction, or against), or how it related to shifts between words (left to right and top to bottom were "canonical", whereas right to left and bottom to top were "non-canonical").

Within Word Shifts

A 2 (orientation) by 2 (reading direction) repeated measure ANOVA was carried out on the data from the within word attention shifts. There was no significant effect of orientation ($F(1, 14)=2.061$, $p=.173$). There was no significant effect of reading direction. ($F(1,14)=1.814$, $p=.199$). There was however a significant interaction ($F(1, 14)=6.741$, $p=.021$).

For vertical arrays only, against reading direction attention shifts are noticeably slower than with reading direction shifts.

Between Word Shifts

A 2 (orientation) by 2 (canonicity) within subject ANOVA was carried out on the between words attention shift data. There was no significant effect of orientation ($F(1, 14)=0.003$, $p=.956$). There was no significant effect of canonicity ($F(1, 14)=2.830$, $p=.115$). There were no significant interactions ($F(1,14)=0.084$, $p=.776$).

The data for both reading direction and canonicity effects are illustrated in Figure 3-24.

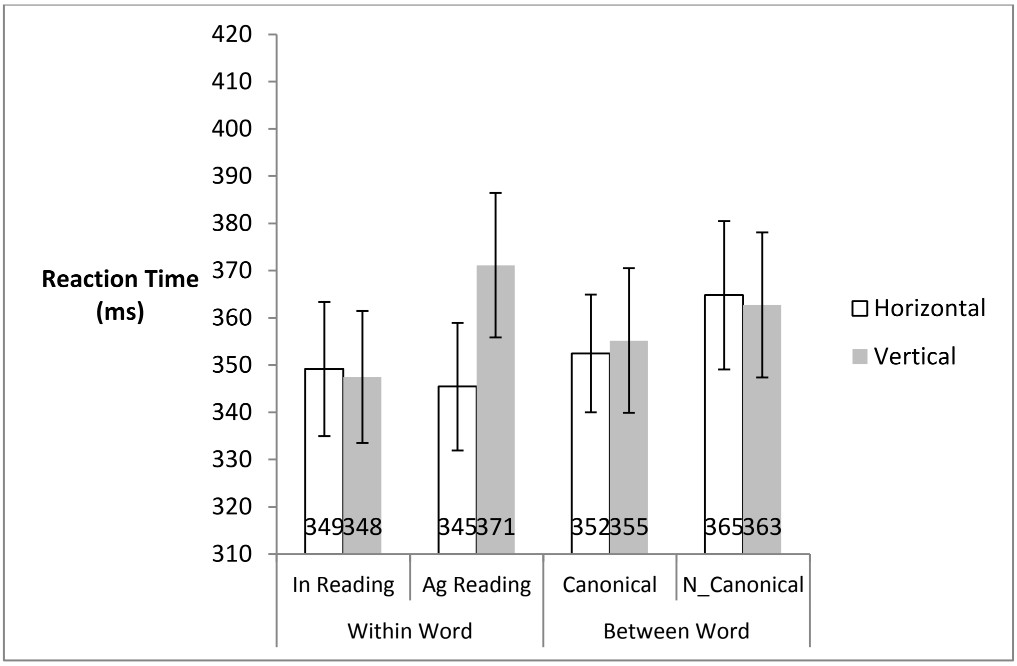


FIGURE 3-24 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME (EXPERIMENT 6)

Reaction Time Costs – Within vs. Between Word Attention Shifts

An analysis was conducted to explore the size of the costs associated with having to move your attention to a new location, compared with not having to move your attention at all. The reaction time of a valid trial using the same cue was subtracted from the reaction time of the invalid trial being studied.

A 2 (orientation) by 2(Invalid In or Invalid Between) repeated measures ANOVA was carried out. There was no significant effect of orientation (F(1, 14)=2.592, p=.130) or invalidity (F(1, 14)=0.652, p=.433), nor were there any significant interactions (F(1, 14)=0.806, p=.384).

These results are illustrated in Figure 3-25.

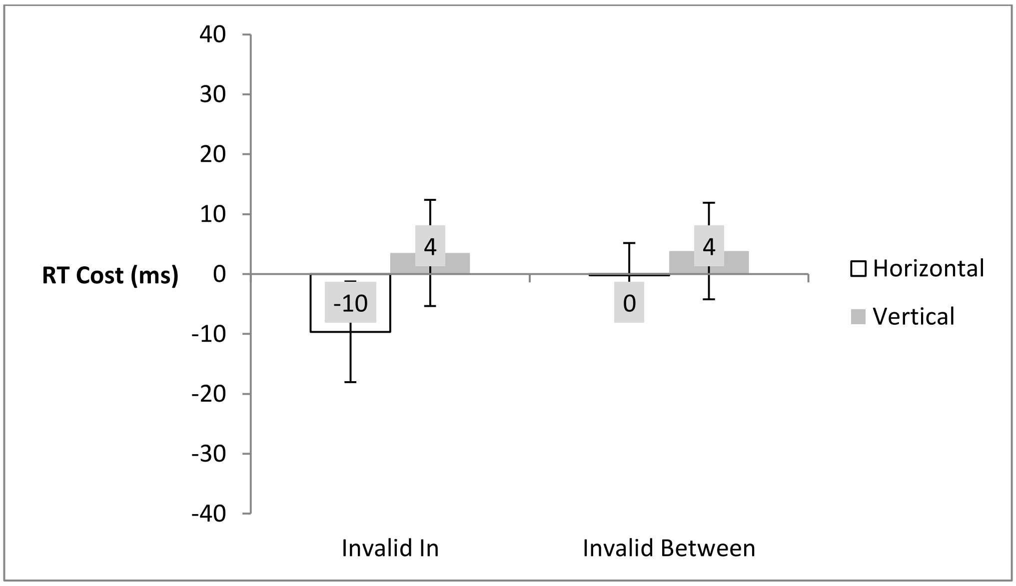


FIGURE 3-25 - WITHIN VS. BETYWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME COSTS (EXPERIMENT 6)

Reaction Time Costs – Direction of Attention

Within Word Shifts

A 2(orientation) by 2 (reading direction) ANOVA was carried out on the costs data from the within word attention shifts data. There was no significant effect of orientation (F(1, 14)=2.870, p=.112). There was a marginally significant effect of reading direction (F(1, 14)=4.282, p=.058). There was a significant interaction (F(1, 14)=6.574, p=.022).

On vertical trials only there were big costs associated with moving attention against reading dir. This mirrors what was seen in the untransformed RT data.

Between Word Shifts

A 2(orientation) by 2 (canonicity) within subjects ANOVA was carried out on the costs data from the between word attention shifts. There was no significant effect of orientation (F(1, 14)=0.334, p=.573). There was a significant effect of canonicity (F(1, 14)=8.978, p=.010). There was no significant interaction (F(1, 14)=0.552, p=.470).

Non canonical trials incurred more cost for both orientations.

These results are illustrated in Figure 3-26.

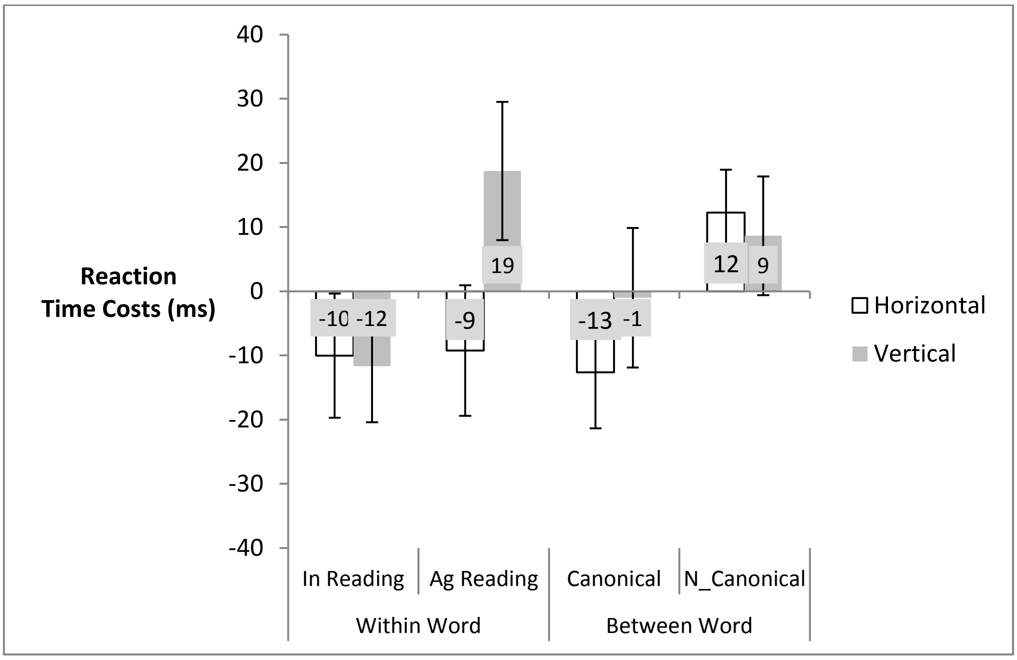


FIGURE 3-26 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 6)

Experiment 6 Discussion

Once again, an attempt to show an object based effect, or indeed any form of successful cuing using non-lexical stimuli has failed. Not only did this experiment not show an object based effect, there was no significant effect of cuing at all. This makes interpreting further results problematic, since it cannot conclusively be demonstrated that participants were attending to the cue at all.

Although none of the main effects reached significance, it is worth noting that the trend for Invalid In trials ran in the same direction as it did for the lexical Experiment 5 – there was more “within object benefit” for horizontal than vertical trials. This is something that may be worth investigating in a later experiment, since it might imply that what is driving the effect found in Experiment 5 is not solely to do with the stimuli being words. There may be a low level effect present here which the study was not sensitive enough to detect.

The results of this study combined with Experiment 4 suggest an interesting conclusion – the largely task-irrelevant words used in the lexical versions of the experiment were clearly shaping the attentional distribution of subjects. Experiments 5 and 6 were largely identical, and yet Experiment 5 generated fairly strong results and Experiment 6 failed to do so. This is particularly interesting since Sieroff and Posner (1988) suggested that actual words should be less susceptible to different types of attentional cuing due to top-down influences. The reverse in fact seems to be true. When word stimuli are present, attention is concentrated and the effects of cuing are amplified. However it should be noted that while Experiment 5 had 32 participants, Experiment 6 had only 15 due to constraints related to participant recruitment, so there may be an issue with statistical power. Nonetheless, the fact that the essential main effect of validity wasn’t even present in trends after 15 participants suggests that the attentional processes at play in the two stimuli appear to be different.

The only other effect of interest is that when looking at the directional effects, for both the untransformed RT data and the costs data there was an interaction between word orientation and direction of cuing for within-word attention shifts only. Vertical trials were relatively slow when they involved moving against “reading direction”, that is from bottom to top. The rationale for looking at costs was that valid trials should serve as a control group, since they are meant to be fastest. In this case they were not the fastest, so interpretation of the costs data becomes problematic. But once again it is interesting to observe a trend that is similar to one of the earlier experiments in this thesis, in this case Experiments 1 and 2, but in this instance it is found with non-lexical stimuli. This may be further evidence that much of the results of this thesis to date are driven by processes that have nothing to do with the stimuli being lexical in nature. However, it cannot be denied that the effects seem rather more pronounced with word stimuli and easier to detect.

Section 3 – Explaining discrepancies in results – Experiment 7 (Blocked Words as Objects)

Experiment 7 Introduction

While Experiments 5 and 6 were somewhat more successful than 3 and 4, their results present a new problem. Experiment 5 generated an entirely unexpected result, where horizontal trials only displayed what appeared to be the “within object benefit” originally sought in Experiments 1 and 2, but not the reading direction cost effect actually found in Experiments 1 and 2. This begs the question of why Experiment 5 found different results from Experiments 1 and 2?

The most likely explanation is that the differences between the experiments execution can explain the differences in the results. Since it had been originally hoped that the series of experiments beginning with Experiment 3 would replicate Experiments 1 and 2, somewhat less care than was ideal was taken to keep the designs consistent. Indeed, it was hoped that some differences in the designs would serve to illustrate the robustness of the effect when it was successfully replicated. Since Experiment 5 found something quite unexpected, this presents a problem of identifying the cause.

Experiments 1 /2 and 5 differed in the following ways:

TABLE 3-1 - DIFFERENCES BETWEEN EXPERIMENTS 1/2 AND EXPERIMENT 5

Difference	Experiments 1 and 2	Experiment 5
Design	Between subjects presentation for array orientation – participants only ever saw horizontal OR vertical words	Within subjects mixed presentation for array orientation – participants saw BOTH horizontal and vertical words
Cues / Targets	Changes in the colour of either the first two or the last two letters in a word.	Changes in the background colour behind the first two or the last two letters of a word
Stimuli	20 upper case words repeatedly used	144 lower case words used only once
Length	560 trials long, took approximately 45 minutes	144 trials long, took approximately 20-25 minutes
Background	Display background was white	Display background was grey

It was decided to try and adopt a more methodical approach in the hope of unravelling the discrepancy between Experiments 1/2 and 5. Accordingly, Experiment 7 would explore only a single one of these differences, starting with what was perceived to be the most likely.

The effect of background colour was considered the least likely explanation, since this change was only meant to address eye fatigue. The difference in length was also not considered a likely explanation since Experiment 5 still managed to show significant results even with less trials, and the trends ran in very different directions. If it were a statistical power issue, the trends should have run in the same direction but not reached significance. The difference between the word stimuli was considered a possible explanation but not a likely one. The trends observed with the placeholder studies implied that the effects so far must be at least partly driven by factors irrelevant to the words status. The type of cue and target being used was considered a highly probable candidate, since it essentially drew participants' attention to different features of the word. The "character" cue/targets drew attention to the sub-word units (letters) within a word, whereas the "colour patch" cue/targets drew attention to a part of a whole word. Nonetheless, the biggest difference between the studies was considered to be the design. Participants in Experiments 1 and 2 only ever saw one orientation of array, either horizontal or vertical. Participants in Experiment 5 saw both horizontal and vertical trials mixed together. It is a well-known finding that the blocking context of a stimulus can affect how participants allocate attention to the arrays, and costs can be incurred when more "switching" is required (Marí-Beffa, Cooper & Houghton, 2012). It was decided that Experiment 7 would focus on the design issue.

Due to recruitment constraints it was not practical to make this a full between subjects design. Instead, the blocking context of the stimuli would be changed. This experiment would be identical to Experiment 5 except in how the stimuli were arranged. Participants would see 72 trials of one orientation, followed by 72 trials of the other orientation. The presentation order of the horizontal and vertical trials would be counterbalanced between participants.

Experiment 7 Method

Except where stated, this experiment was identical to Experiment 5.

Participants

The participants in this experiment were 26 females and 6 males from the University of Dundee community. Their ages ranged from 17 to 33. All participants were native speakers of English, although one was additionally bilingual in French. This experiment utilised a within subjects design, so all participants were exposed to all conditionals of the experiment.

Task and Procedure

This experiment was the same as Experiment 5 except in one regard – the way in which in the individual trials were presented. In Experiment 5 horizontal and vertical trials were randomly intermixed during the experiment. In this experiment they are blocked, with the only randomisation used being of trial order within blocks. The presentation order of horizontal and vertical trials was counterbalanced between subjects.

Experiment 7 Results

Performance & Filtering Information

Prior to filtering, the responses from the retained participants showed an overall correct response rate of over 95%. On trials where a response was required, over 96% of responses were correct. As in previous experiments, the correct response rate for catch trials tended to be somewhat lower, with 89% of responses being correct. As with Experiment 5 a 100-700ms reaction time filter was applied to those trials where a response was required in order to remove outliers. Less than 3% of correct responses were affected by this filter. Overall, nearly 93% of all responses issued made it into the final dataset.

2 additional subjects were tested but were not included in the final dataset due to poor performance on the catch trials (50% correct and 71% correct respectively). As with previous experiments, participants had to get a minimum of 75% of the catch trials correct.

Reaction Times - Validity

Non-erroneous RTs were analysed with a 2 (orientation) by 3 (levels of validity) repeated measures ANOVA. There was no significant effect of orientation ($F(1, 31)=1.439$, $p=.239$). There was a significant effect of validity

(F(2, 62)=4.656, p=.013). There was no significant interaction (F(1.449, 44.911)=0.841, p=.404, Greenhouse-Geisser corrected).

Planned comparisons were used to explore the significant effect of validity. It was found that the valid trials were significantly faster than both Invalid In trials (p=.004) and Invalid Between trials (p=.025).

Cuing appears to have been successful in this experiment, with valid cuing yielding the fastest RTs. However, unlike Experiment 5, there is no detectable benefit found for Invalid targets that occur inside the same word as the cue. Nor is there any detectable effect of the different word orientations. These results are illustrated in Figure 3-27.

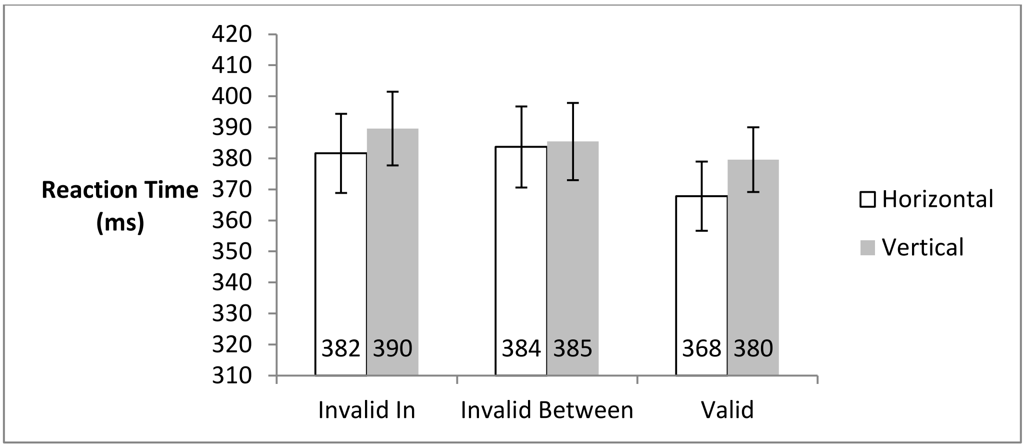


FIGURE 3-27 – EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 7)

Reaction Times – Target Location

An analysis was conducted to see whether participants had a preference for responding to targets in particular locations (BL=Bottom Left, BR=Bottom Right, TL=Top Left, TR=Top Right). Both valid and invalid targets were included in this analysis. A 2 (orientation) by 4 (target location) repeated measures ANOVA was run. There was no significant effect of orientation (F(1, 31)=0.622, p=.436), nor was there a significant effect of the location of the target (F(3, 93)=0.713, p=.547). There was also no significant interactions (F(3, 93)=0.335, p=.800).

Unlike previous experiments which showed an impact of where the target was located, this study did not find any effect of target location on overall reaction times. These results are illustrated in Figure 3-28.

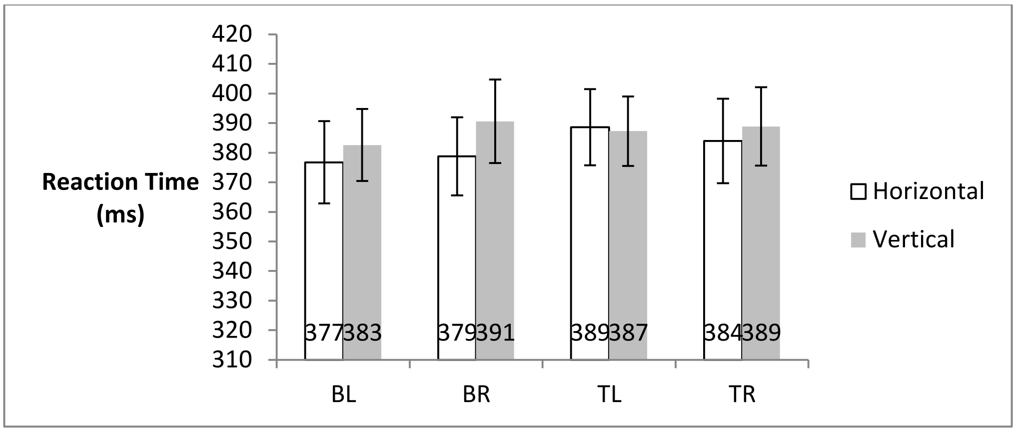


FIGURE 3-28 – EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 7)

Reaction Times - Direction of Attention Shift

Within Word Shifts

A 2 (orientation) by 2 (Reading Direction) within subjects ANOVA was carried out on the data from within word attention shifts. There was no significant effect of orientation ($F(1,31)=1.219$, $p=.278$). There was no significant effect of Reading direction ($F(1,31)=1.968$, $p=.171$). There were no significant interactions ($F(1,31)=0.275$, $p=.604$).

Between Word Shifts

A 2(orientation) by 2 (canonicity) within subjects ANOVA was carried out on the data from the between word attention shifts. There was no significant effect of orientation ($F(1,31)=0.100$, $p=.754$). There was no effect of canonicity ($F(1, 31)=0.001$, $p=.997$). There were no significant interactions ($F(1, 31)=0.436$, $p=.514$).

None of the effects in this analysis reached significance. These results are illustrated in Figure 3-29.

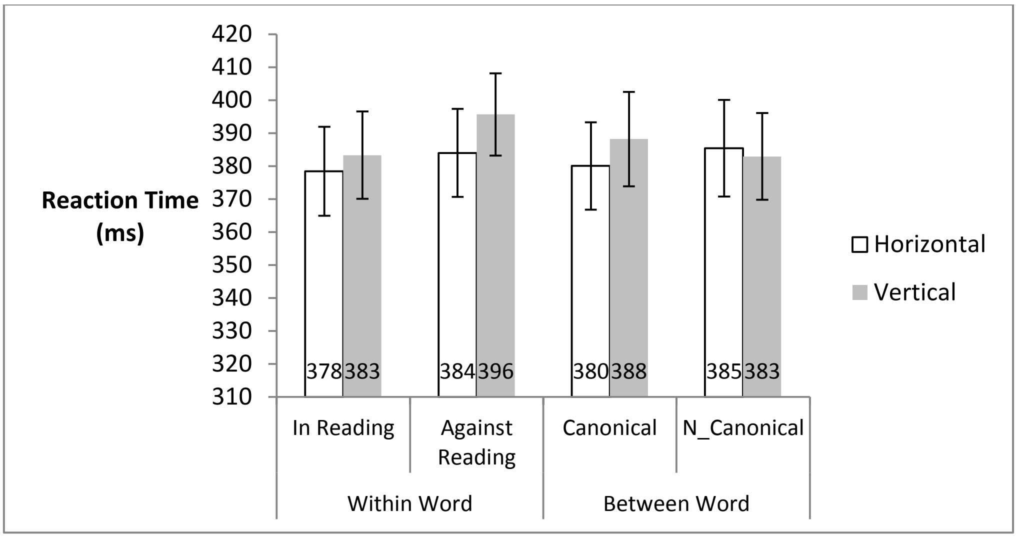


FIGURE 3-29 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME (EXPERIMENT 7)

Reaction Time Costs – Within vs. Between Word Attention Shifts

An analysis was conducted to explore the size of the costs associated with having to move your attention to a new location, compared with not having to move your attention at all. There was no effect of orientation (F(1, 31)=1.022, p=.320), nor was there any significant effect of the different levels of validity (F(1, 31)=0.007, p=.933). There was also no significant interactions (F(1, 31)=0.184, p=.671).

None of the effects in this analysis reached significance. These results are illustrated in Figure 3-30.

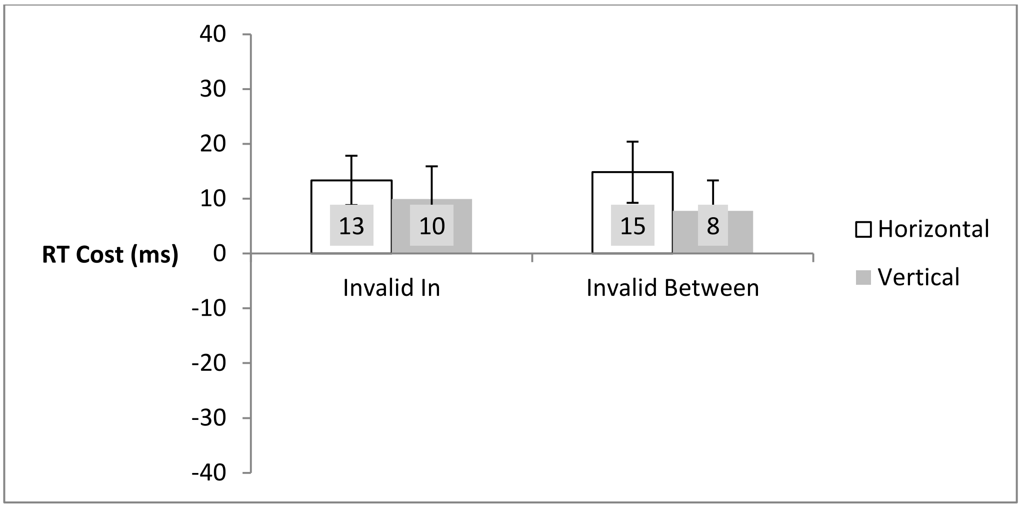


FIGURE 3-30 - WITHIN VS. BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME COSTS (EXPERIMENT 7)

Reaction Time Costs – Direction of Attention Shift

Within Word Shifts

A 2 (orientation) by 2 (Reading Direction) within subjects ANOVA was carried out on the within word attention shift costs data. There was no significant effect of orientation (F(1, 31)=0.211, p=.649). There was no effect of Reading Direction (F(1, 31)=1.837, p=.185). There were no interactions (F(1, 31)=0.048, p=.829)

Between Word Shifts

A 2 (Orientation) by 2 (Canonicity) within subjects ANOVA was carried out on the costs data from the between word attention shift trials. There was no significant effect of Orientation (F(1, 31)=2.886, p=.099). There was no effect of Canonicity (F(1, 31)=0.718, p=.403). There were no interactions (F(1, 31)=1.643, p=.209)

None of the effects of direction of attention shift on reaction time costs reached significance. It is of interest however that the reading direction trends ran in the same direction as Experiments 1 and 2, where moving against reading direction was more costly. These results are illustrated in Figure 3-31.

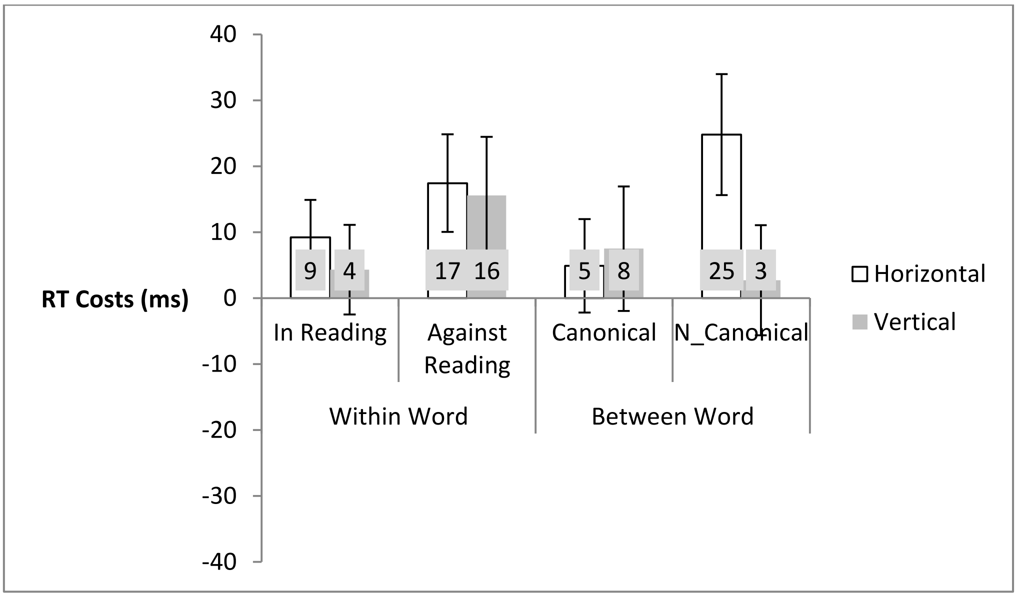


FIGURE 3-31 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 7)

Experiment 7 Discussion

Experiment 7 did find a significant main effect of validity. This indicates that this experiment was successful in cuing attention to particular locations. However, unlike either Experiments 1/2 or 5, there were no additional significant effects. There was no detectable within-object benefit as in Experiment 5, nor was there a significant reading direction effect on reaction time costs as in Experiments 1 and 2. As a result, this experiment has failed to achieve its goal of explaining the difference in results found in Experiments 1/2 and 5. In all likelihood, this means that the blocking context of the experiments is not responsible for the discrepancy in their results.

While none of the effects beyond the main effect of validity reached significance, it is of note that the reading direction effects upon reaction time cost did run in the same direction as in Experiments 1 and 2. It is tempting to tentatively suggest that this makes Experiment 7 more like Experiments 1 and

2 in its results than it is like Experiment 5. However, the effect was very far from significance, so it would be unwise to read too much into it.

The only issue that may undermine this interpretation of these results is one of statistical power. As with all of the experiments from #3 onwards, the number of trials each participant was exposed to was approximately ¼ of what the equivalent participant saw in Experiments 1 and 2. This may have some impact on the statistical power. However, Experiment 5 successfully demonstrated a significant effect utilising this reduced design, and both Experiments 5 and 7 had approximately the same number of participants as Experiments 1 and 2 combined. This resulted in the same number of data points for entry into the ANOVA. Both were designed in such a way that, while trimmed, both still had several individual trials making up each score for each participant on key measures. And of course, all of the experiments run to date have utilised reaction time filters to remove individual scores considered unlikely to be the result of the process that was the intended target of study. While Experiment 7's results may be somewhat less sensitive than those employed in Experiments 1 and 2, it seems unlikely that that is the only explanation. It had been decided beforehand that this experiment would stop when it had around 30 good participants to be in keeping with the experiments it was being compared with. To continue expanding the study in the hope of eventually yielding the desired result smacked of academic dishonesty, so it was decided to not seek additional participants. For the purposes of this thesis, it was concluded that the discrepancy between Experiments 1/2 and 5 cannot be explained by the blocking context alone. Accordingly, a new study was designed to explore the effects of the second most likely explanation highlighted in table 1 – the type of cue and target employed.

Chapter 3 General Discussion

Experiment 3 was designed to replicate the findings of Experiments 1 and 2 while using a more robust design, in particular the use of cues and targets of a fixed size. It failed. Instead of replicating the reading direction effect on costs, it found nothing at all. Experiment 4 was run concurrently with Experiment 3, and was designed to provide a control using non-lexical stimuli. It also failed to find anything of note. The conclusion that was reached was that the cues and targets in Experiments 3 and 4 were of insufficient intensity to produce the desired effects. Accordingly these experiments were repeated with much larger cues and targets. The resulting experiments were Experiments 5 (word stimuli) and 6 (non-lexical stimuli). Experiment 5 found an unexpected "within object" effect for horizontally presented words. Cues appeared to facilitate target detection at non-cued locations, providing that location was within the same word and it was oriented in the traditional horizontal format. Experiment 6 found nothing of note. It was concluded that the presence of word stimuli appears to modulate attention to the stimuli arrays, producing the effects of cuing, reading direction and within object effects observed in previous experiments. The main question raised by these findings is why did Experiment 5 find results that were different to Experiments 1 and 2? Several possible explanations were identified in Table 3-1 which hinged on the differences between Experiments 1/2 and 5. Experiment 7 sought to address one possibility – that the differences were to do with the way the stimuli were blocked together. Experiments 1 and 2 each addressed only one possible orientation of the stimulus array. No participant saw both orientations. Experiment 5 on the other hand used a within subjects design with random intermixing of both orientations of array. Experiment 7 used a hybrid of these two designs; a within-subjects blocked and counterbalanced presentation. Using this design, the results obtained did not match those from Experiment 1, 2 or 5. Accordingly it was concluded that the blocking context alone cannot account for the discrepancy in the results of Experiments 1/2 and 5. Future experiments will address other possible explanations for the discrepancy.

4. Experiment 8 - "Attentional Gradients Across Words"

Experiment 8 Introduction

The pressing question that has arisen at this stage of the thesis is why the results of experiment 1/2 and 5 appear to contradict one another. Experiments 1 and 2 found no "within object" benefit, and an effect of reading direction upon reaction time costs, whereas Experiment 5 found an apparent within object benefit for horizontally oriented words, and no reading direction effects. Experiment 7 was a variation on the "Words as Objects" paradigm that explored whether the use of different blocking contexts in the two sets of experiments explained the difference in results. The results of experiment 7 indicated that blocking context alone was unlikely to account for these results.

Accordingly a new experiment was designed. This was designed to test the hypothesis that the second most likely candidate explanation in Table 3-1 of the previous chapter (the types of cues and targets used) was responsible for the different results observed in Experiments 1/2 and 5. Experiments 1 and 2 used a character illumination cue/target, where the first or last two letters of a word would change colour to either green or red to indicate a cue or target respectively. This was considered problematic, since the size of the illuminated area varied considerably depending on what letters were being illuminated. To correct this, Experiment 5 used background colour change cues and targets. An area behind the first or last 2 letters of a word would turn green or red to indicate a cue or target respectively. These colour patches were always of a fixed size.

It is possible that these two different types of cue/target may actually be doing rather different things attentionally. The character illumination cues and targets make the orthographic structure of the word highly salient, and may have contributed to the reading direction effect observed in Experiments

1 and 2. The background colour change cues on the other hand make the "wholeness" of the word rather more salient, since they illuminate a part of the word comprising two characters. This may have contributed to the findings of a "within object benefit" in Experiment 5. In short, character illumination cues may contribute to a letter by letter decoding of a word, whereas the larger background colour patch cues may contribute to a more holistic decoding of the word.

The failures of Experiments 3, 4 and 6 to find any significant results had also raised the question of whether the "Words as Objects" paradigm was a rather insensitive measure, prone to returning null results. Experiments 1-7 as a whole also revealed that studies that look for object based effects appear to be highly prone to problems of noise and hard to detect effects. Since Experiment 8 was dealing specifically with the question of how different cues and targets modulate attention across word arrays, it was decided to try and utilise a different paradigm to explore the question of what the different cues/targets do to a participant's attention. This particular experiment did not need to show an object based effect to show that the cues and targets can affect how attention is allocated. Since the question of interest here was how attentional distributions across words are affected, there is a well-established canon of experimental designs that can be borrowed from. In the end it was decided to use a design similar to that utilised by LaBerge (1983) and Tydgat and Grainger (2009). A single word would be displayed on screen, with cues and targets that can occur at any of its letter positions. The cues and targets would be in the same location most often, and among the invalid trials there would be an equal number of trials at each non-cued location. The type of cue/target would be a between subjects manipulation, with some only ever seeing the character illumination cue/targets, and some only ever seeing the background colour patch cue/targets. The dependent measure in this study is how the target detection times vary across the length of the stimuli words. If the cue/target type truly is modulating attention in a qualitative way, then the shape of the reaction time function across words should change between the two conditions of cue/target type.

Experiment 8 Method

Changes from Previous Studies

Since it was possible that this study may find the same reading direction effects as found in Experiments 1 and 2, the words were made longer to increase the magnitude of reading direction shifts and (hopefully) make them easier to detect. The words in this experiment were all 6 characters long instead of the 4 used in previous studies. In a further refinement, the grey background of Experiments 3-7 was replaced with the white background of Experiments 1 and 2. It had been found that the grey background, coupled with a dimly lit lab, markedly increased the rate of eye tracker errors due to higher fluctuations in pupil diameter. After consulting with SR Research (the eye tracker's manufacturer), it was decided to run this experiment against an off-white background and with a better illuminated lab. Finally, the original design called for very long word presentation durations, and very long timeouts. It was concluded that this added nothing to the design, save to make the experiment take longer and enhance fatigue. On the basis of widely accepted fixation durations for relatively common words, it was concluded that 500ms initial word presentation duration should be ample for reading and understanding to have occurred (Rayner, 2009). Likewise, the 3000ms timeout on responses of the original trials was considered excessive, and this was trimmed down to 1000ms.

Participants

Participants were 38 females and 11 male members of the University of Dundee community who received course credits or payment for their time. Their ages ranged from 17 to 34 years old. All participants were native speakers of English, although one participant was additionally bilingual in German. This was a mixed factorial design with all participants exposed to all stimuli and conditions, with the exception of cue/target type. This was a between subjects factor with 24 participants being exposed to the "Background Colour Patch" cue/target type, and 25 participants were exposed to the "Character Illumination" cue/target type.

Apparatus

Stimuli were presented through a 19" monitor running at 100hz and responses were recorded via a button box, with the response button pressed by the dominant hand. An SR Research Eyelink 2000 desk based eye tracker running SR Research Experiment Builder software version 1.10.165 (Experiment Builder, 2013) recorded monocular eye position at 2000hz. A desk mounted chin rest kept participant's eyes 76cm from the centre of the screen and both their peripheral vision and vision in their non-dominant eye were eliminated through blinkered spectacles.

Stimuli

636 6-character high frequency words were selected using the CELEX word frequency database (Baayen et al., 1995). All words had a written frequency of at least 50 per 16 million (see appendix III). Words were randomly assigned to the different conditions (catch, valid, invalid). Written frequency of the words in the experimental conditions (valid vs. invalid, excluding catch trials, 540 words in total) did not differ significantly from one another ($t(538)=1.383$, $p=.167$, 2-tailed). Words were presented in the centre of the screen and cues and targets could occur at any of their 6 letter positions. Each word was paired equally often with a "background colour patch" cue/target as with a "Character Illumination" cue/target type. Letters were printed in 48pt Monaco monospaced font and measured approximately 1° x 1.5° of visual angle. Completed words were approximately 7° of visual angle wide and 1.5° of visual angle tall. The fixation cross was approximately 1° by 1° of visual angle. Screen background was a very light grey (RGB values: 240/240/240, luminance 77.04cd/m^2) and the letters composing the words were either black (RGB values: 0/0/0, 6.3577.04cd/m^2) or red (255/0/0, 20.70cd/m^2) when being used as a target, or green (0/255/0, 36.00cd/m^2) when used as a cue. When background colour patches were used instead of character illumination, the

RGB and luminosity values of those patches were identical to those found with character illumination. Each individual scene was created by a control grid. The programme knew where each individual letter should be positioned on screen, and at what time. The identity, colour and any positional offsets needed were controlled by a grid containing the necessary values.

Design

The experiment consisted of an individually randomised sequence of 636 trials: 360 valid trials (cue and target were in the same location), 180 invalid trials (cue and target were in different locations) and 96 catch trials (no target appeared). The cues in this experiment were of the same reliability level as found in previous studies – on trials where a response was required the cue indicated the correct target location on 66.67% of trials. The same group of words were used for valid trials in all subjects, but their occurrence in the different cue/target position possibilities were fully counterbalanced between subjects. Likewise the same group of words were used for invalid trials in all subjects, and their occurrence in the different cue/target position possibilities was partially counterbalanced. In this case there were too many permutations for a full counterbalance, so the word list was chopped in half and the cue/target position associations were swapped after half of the participants were tested. All participants saw the same words for catch trials. Cue/target type was manipulated as a between subjects factor, so half of the participants only ever saw “Background Colour Patch” cue/targets and half only ever saw “Character Illumination” cue/targets.

Task and Procedure

After giving informed consent the eye tracker was calibrated on the participant’s dominant eye determined via majority result from the Miles, Porta and Camera tests (Roth et al., 1992). In cases where participants declared significant differences in visual acuity, data was collected using their stronger eye. All participants were tested using an eye that had normal visual acuity. As in previous experiments, participants were informed that they would be periodically asked about the identity of the word they saw on screen in order to encourage actual reading of the words. Participants who showed evidence of ignoring the onscreen words would have their data removed.

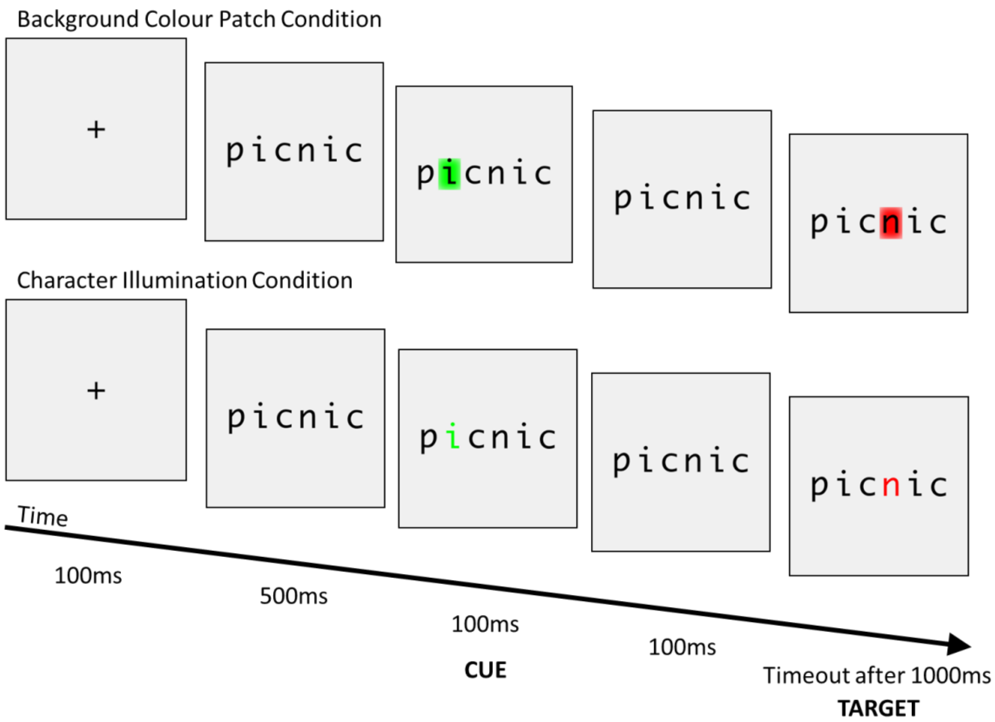


FIGURE 4-1 - EXPERIMENT 8 TRIAL SEQUENCE SHOWING IDENTICAL “INVALID” TRIALS IN THE BACKGROUND COLOUR PATCH CONDITION AND THE CHARACTER ILLUMINATION CONDITION. NOT DRAWN TO SCALE.

Figure 4-1 gives a schematic representation of trial events. Participants were first presented with a fixation cross which appeared onscreen for 100ms. Following the offset of the fixation cross, a word would be displayed in the centre of the screen for 500ms. After this, a green cue would appear at one of the 6 letter locations for 100ms. Eye movements were recorded and the trial would be discarded as an error trial if participants were not looking at the word at this stage. A Cue-Target Onset Asynchrony of 100ms elapsed in which no cues or targets appeared, followed by the onset of the red target at one of the six letter positions. Participants were to respond to the onset of the target by pressing a button on the button box as quickly as possible. If no response occurred within 1000ms, the trial timed out and was labelled as an error. On some trials no target would appear (catch trials). Here the correct response was to do nothing and wait for the next trial to begin. Responding on catch trials was classed as an error. After the completion of this trial, the next trial would begin. A check determining whether a recalibration was necessary occurred automatically every 10 trials, and also on the first 5 trials to ensure correct calibration. At seven points during the experiment the experimenter would halt the experiment in order to ask the participant to verbally identify the word from the last trial. These responses were recorded by the experimenter and failure to get at least half of these questions correct would result in the removal of a participant's data for failing to read the display words.

Experiment 8 Results

Performance and Filtering Information

An analysis of the error rates amongst the 49 participants was conducted. Overall the participants responded correctly on 98% of trials. On trials where a response was required, 99% of responses were correct. On catch trials 91% of responses were the correct (non) response. The 100-700ms filter used in some studies was found to remove too much data in this case. A reaction time filter which removed all scores greater than 2.5 standard deviations from a participant's own mean was applied. 98% of correct responses were retained after the application of this filter. Overall 96% of all trials were included in this analysis.

No participants needed to be removed due to high error rates, although 5 further participants took part in the experiment without their data being included in the analysis. The reasons for their removal were serious problems with obtaining a good calibration with the eye tracker, coupled in one case with a very high error rate on the word reading check.

Reaction Times - Validity

Non-erroneous reaction times were analysed using a 2(cue/target condition) by 2(levels of validity) mixed factorial ANOVA. A significant effect of validity was found (F(1, 47)=25.045, p<.001). There were no significant interactions (F(1, 47)=0.842, p=.363). Cue/target type did not reach significance. (F(1, 47)=1.981, p=.166).

Attention was successfully cued since reaction times were consistently fastest in the cued location. While Background Colour Patch reaction times were noticeably faster than Character Illumination reaction times, this difference did not reach significance. This non-significant difference would be expected to be significant with sufficient statistical power and is believed to be a result of the greater stimulus intensity of the Background Colour Patch cues and targets. These results are described in Figure 4-2.

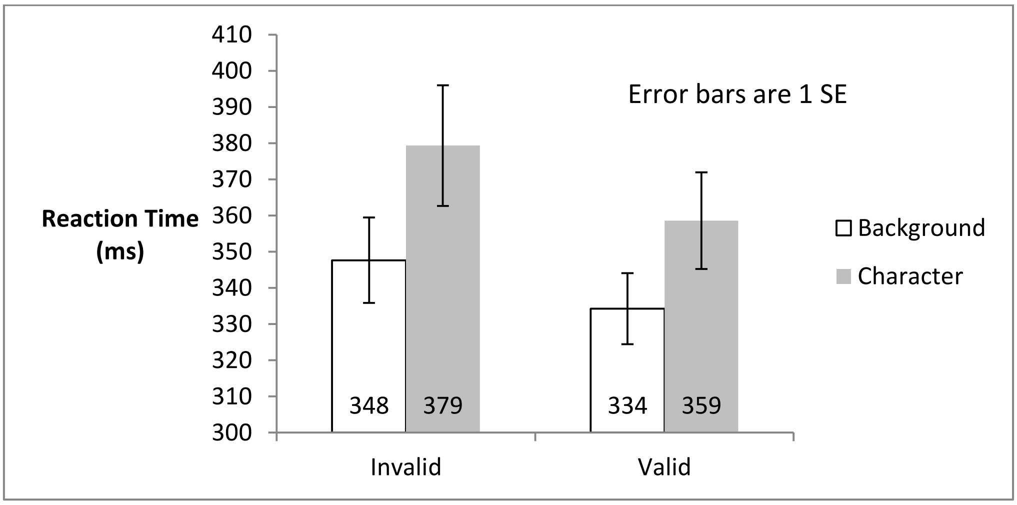


FIGURE 4-2 - EFFECT OF VALIDITY ON REACTION TIMES (EXPERIMENT 8)

Reaction Times – Valid Target Location

One of the key questions this experiment sought to answer was whether the different types of cue and target would change the way attention was allocated to the words. To study this, an analysis was run on the valid reaction times from each of the 6 possible cue/target locations, split by cue/target type (1= first letter position, 6 = last letter position).

A 2(Cue/Target Type) by 6(Cue/Target Location) mixed factorial ANOVA found a significant main effect of Cue/Target Location ($F(1, 47)=16.315$, $p<.001$.) There was no significant interaction ($F(1, 47)=0.61$, $p=.806$) and cue/target type also did not reach significance as a between subjects factor ($F(1, 47)=1.899$, $p=.175$).

The only effect of note here is that for both conditions, cue/target locations near the middle of the word were consistently responded to more quickly. The results are described in Figure 4-3.

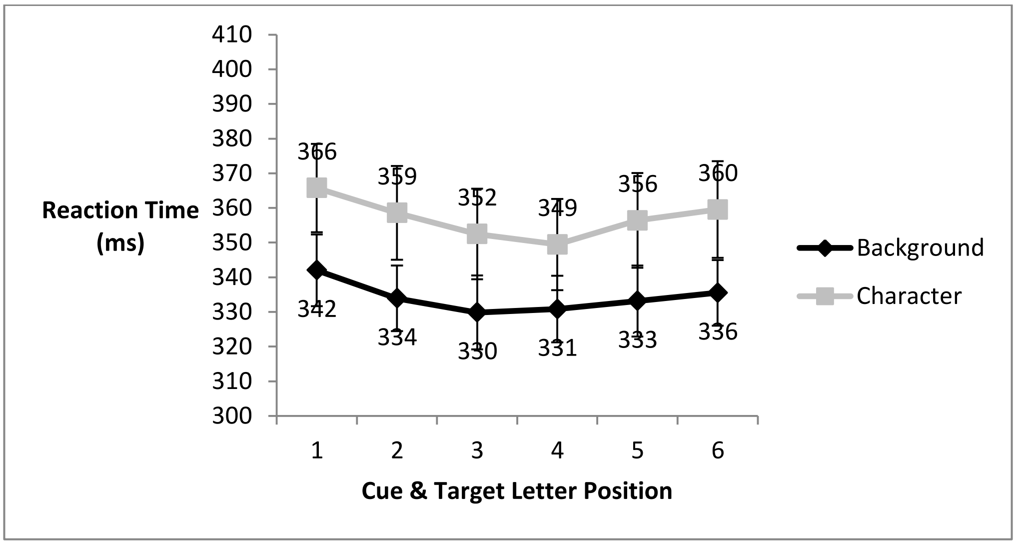


FIGURE 4-3 - EFFECT OF TARGET LOCATION ON VALID TRIAL REACTION TIMES (EXPERIMENT 8)

Reaction Times - Target Location (position 4 cues only)

For the purposes of comparing with LaBerge (1983) an analysis was conducted on the data from cues that appeared in position 4 only. Thus, the reaction times for position 4 are valid whilst all others are invalid (1= first letter position, 6 = last letter position). This should provide a useful comparison since in LaBerge's study, targets only ever appeared in the central position.

A 2(Cue/Target Type) by 6 (target position) mixed factorial ANOVA was carried out on the data for cues located in position 4 only. There was a significant effect of letter position (F(3.964, 186.290)=7.859, p=0.001, Greenhouse-Geisser Corrected). There was no significant interaction (F(3.964, 186.290)=1.477, p=.211, Greenhouse-Geisser Corrected). There was no significant effect of Cue/Target type (F(1, 47)=1.269, p=.266).

Mirroring the results of found with valid trials only, this analysis revealed no systematic modulation of how attention was allocated to the stimuli based on cue/target type. Reaction times were fastest at the cue location as would be expected, but there was no interaction between target position and cue/target type. Within the framework of LaBerge's global vs. local processing, a flatter reaction time function would be expected if background colour patches induce more global processing. These results are described in Figure 4-4.

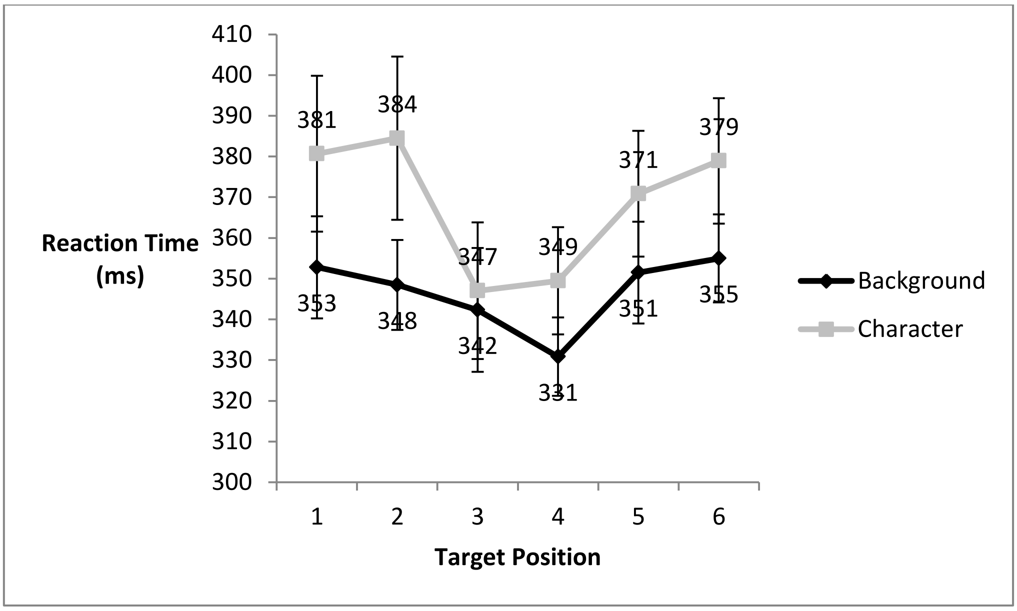


FIGURE 4-4 - EFFECT OF TARGET LOCATION ON REACTION TIMES - POSITION 4 CUES ONLY (EXPERIMENT 8)

Reaction Times – Direction of Attention Shift

In keeping with previous studies, an analysis was conducted to see what effects (if any) of the direction of the mandated attention shift there were. Mandated attention shift is defined as the direction of attention shift from the cue location to the target location mandated by the type of trial. This analysis only looked at invalid trials (since only these required a shift from cue to target). The size of the shift was not controlled. For example, a shift from position 1 to position 2, or from position 1 to position 6 were both classed as "in reading direction" attention shifts.

A 2(cue/target type) by 2(direction) mixed factorial ANOVA found no significant effect of direction ($F(1, 47)=0.317$, $p=.576$). There was no significant interaction $F(1, 47)=0.023$, $p=.880$. Cue/Target Type Condition also did not reach significance as a between subjects factor $F(1, 47)=1.980$, $p=.166$. These results are described in Figure 4-5.

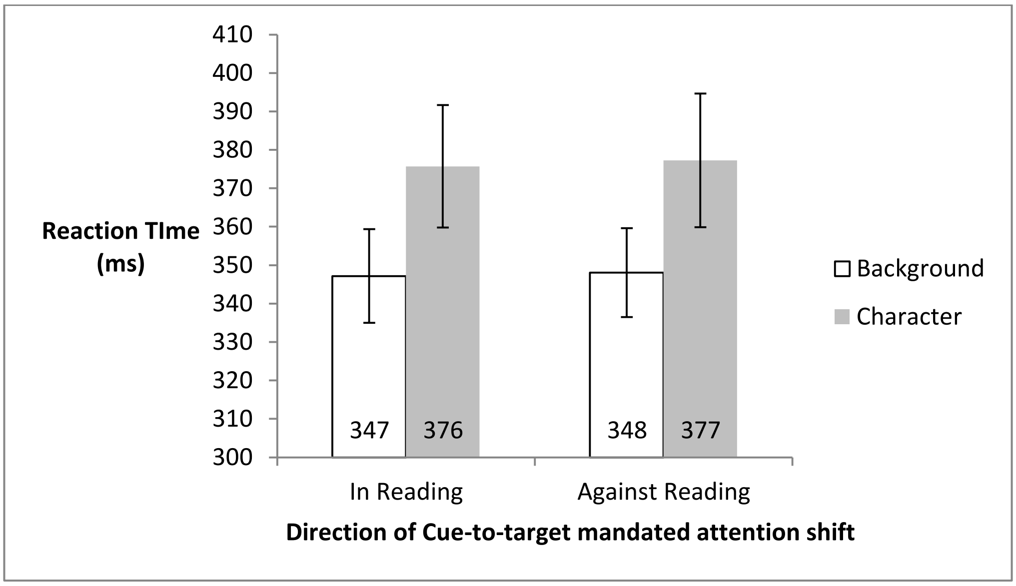


FIGURE 4-5 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME (EXPERIMENT 8)

Reaction Times – Direction of Attention Shift (extreme points only)

Since in the above analysis a shift of one character was considered equal with a shift of 5 characters, there was a concern that any directional effects may have been obscured by dilution by the smaller shifts. Accordingly it was decided to re-run the above analysis using only the extreme points of the word, that is shifts from the very beginning (position 1) to the very end (position 6) and vice versa.

A 2 (cue/target type) by 2(direction) mixed factorial ANOVA found no significant effect of direction ($F(1, 47)=1.320$, $p=.256$). There was no significant interaction ($F(1, 47)=0.008$, $p=.930$) and there was no significant effect of cue/target type condition ($F(1, 47)=2.280$, $p=.138$). These results are described in Figure 4-6.

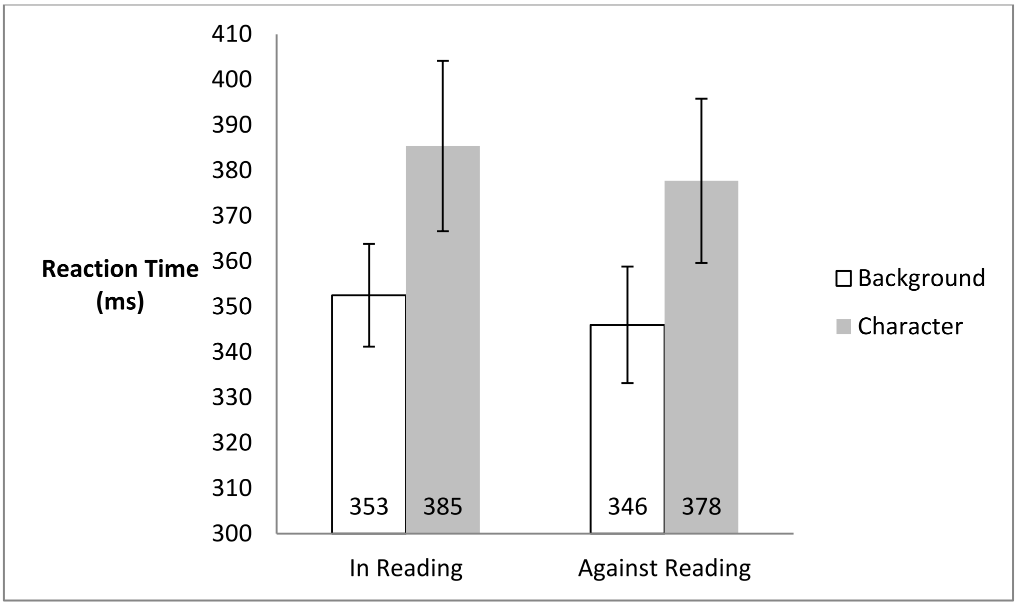


FIGURE 4-6 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME - EXTREME POINTS ONLY (EXPERIMENT 8)

Reaction time Costs – Direction of Attention Shift

The directional analysis was re-run looking at costs data.

A 2 (cue/target type) by 2(direction of attention shift) mixed factorial ANOVA was run on the costs data from invalid trials. No significant effect of direction was found (F(1, 47)=1.320, p=.256). There was no significant interaction (F(1, 47)=0.008, p=.930) and there was no significant effect of cue/target type condition (F(1, 47)=2.280, p=.138). These results are described in Figure 4-7.

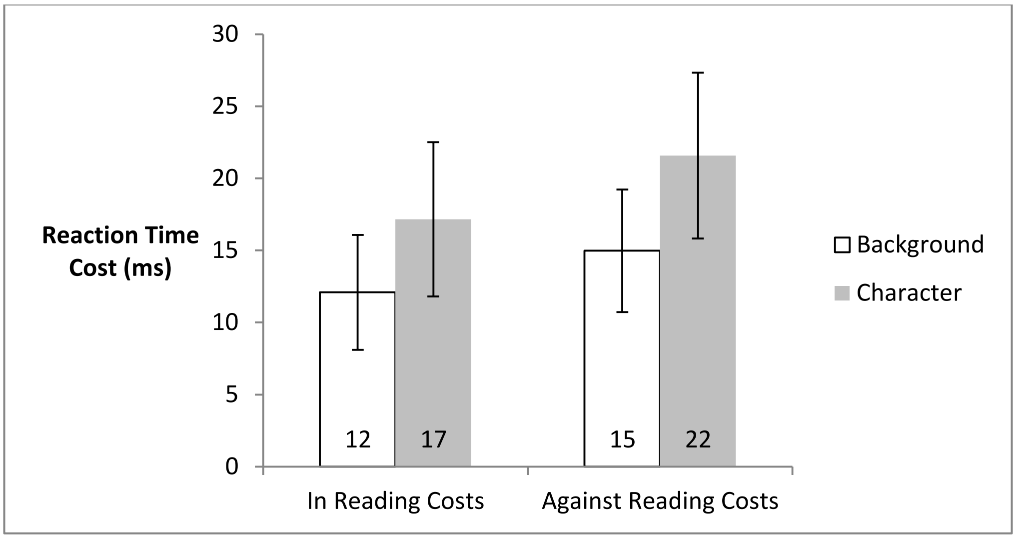


FIGURE 4-7 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 8)

Reaction Time Costs – Invalid Cue Locations

A 2(cue/target type) by 6(cue location) mixed factorial ANOVA was run on the costs data from invalid trials. The analysis found no significant effect of cue location (F(4.027, 189.265)= 0.568, p=.724 Greenhouse Geisser corrected). There was a marginally significant interaction between cue location and cue/target type condition (F(4.027, 189.265)=2.270, p=.063 Greenhouse Geisser corrected). There was no significant effect of cue/target type condition (F(1, 47)=0.783, p=.381).

This analysis gave the reaction time penalty of having to shift attention away from the cued location to somewhere else. The scores for each cued location were the average of each possible invalid trial for that cue location minus each invalid trial's equivalent valid trial. Across all subjects, there was no significant effect of cue location, nor did the effect of the different cues and targets reach significance. However, there was a marginally significant interaction where Background Colour Patch subjects encountered relatively more cost when shifting attention away from the middle of a word, and Character Illumination subjects encountered relatively less cost when doing so. These results are illustrated in Figure 4-8.

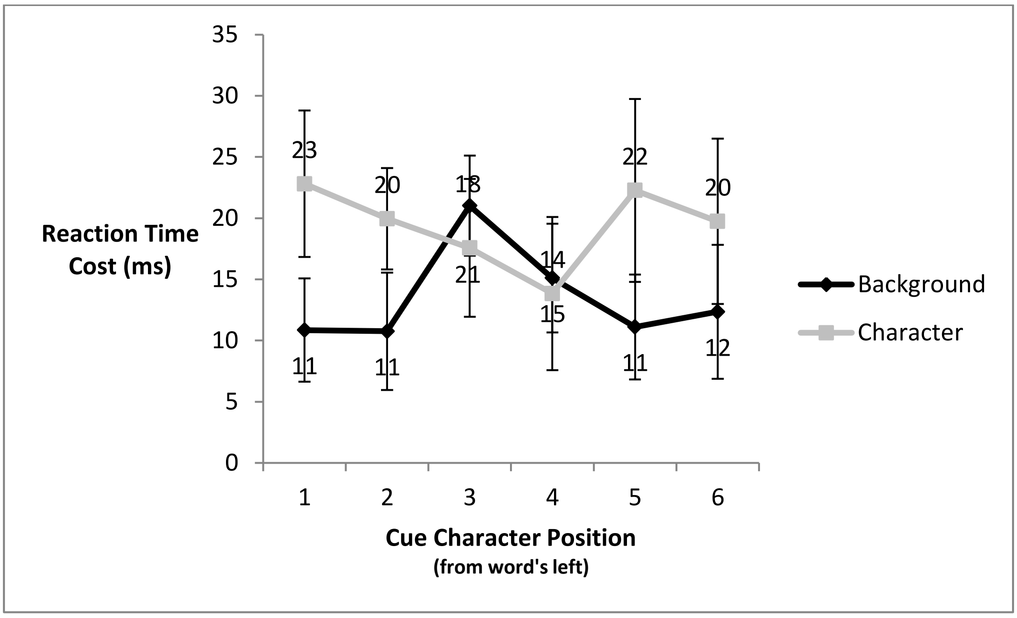


FIGURE 4-8 - EFFECT OF CUE LOCATION ON REACTION TIME COST - INVALID TRIALS ONLY (EXPERIMENT 8) NOTE: UPPER COST VALUES ALL RELATE TO "CHARACTER" TRIALS, WHILE LOWER FIGURES ALL RELATE TO "BACKGROUND" TRIALS

Experiment 8 Discussion

In this experiment, attention was successfully drawn to the cued location. This was evident from the significant effect of cuing on response time. However, the hypothesis was that the type of cue/target would modulate the allocation of attention across the word. Experiments 1 and 2 in this thesis found an effect of reading direction on reaction time costs. Experiment 5 found an "object based effect" on reaction times. One theory for why these otherwise similar experiments found different results was that the types of cue and target used drove the differences. Experiments 1 and 2 used the illumination of characters within a word as the cues and targets, whereas Experiment 5 illuminated a region behind those characters. In this experiment both types of cue and target were used (in a between subjects design). If those cue/target types were driving the discrepancy between Experiments 1/2 and 5, it was expected that this would manifest itself as a relatively flat target detection time function across the whole word when a background colour patch target was used, and a more uneven distribution of reaction times when a more "local" character illumination cue/target was used. Accordingly an interaction between cue/target type and target position was expected. This was not found when looking at all valid trials, or looking at both invalid and valid trials for centrally presented cues only. There was a significant effect of target position, with targets in the centre of words being detected fastest, but no interaction with the type of cue/target. When looking at the costs data however, there was a marginally significant interaction between cue/target type and target location. Background colour patch targets incurred more reaction time cost in the centre of words than character illumination targets, which may indicate that the type of cue/target used was modulating attentional allocation to an extent. Nonetheless, this was not in accord with what was expected, with neither condition experiencing what could be described as flat reaction times that would be indicative of more "global" processing.

Like many of the previous experiments comprising this thesis, this experiment contradicts the findings of Sieroff and Posner (1988) in that it does indeed appear to be possible to cue attention to specific parts of real words. Sieroff and Posner stated that words are relatively insensitive to cueing effects due to top down influences. This does not appear to be the case here. In another key regard however the results of this study fit in with previous literature, although not in the way that was hoped for. LaBerge (1983) found that when assessing the reaction times for target detection at each letter position, a "V" shaped function is expected when the participants are performing a single letter categorisation task, and reaction times across the word were relatively flat when they were asked to categorise the whole word. The reaction time function observed here broadly resembles LaBerge's "V", with the fastest reaction times being found in the centre of the word. The similarity was even greater when looking at the data for position 4 cues only. As might be expected reaction times were always fastest at the cue location. It had been hoped that the larger background colour patch cues would induce a flatter reaction time function similar to what LaBerge observed with the whole word categorisation task, however this was not the case. Functionally, both the cue/target types seem to have been similar to LaBerge's letter categorisation task in how they modulated attention. Attention is drawn to a small part of the word, and processing seems to be accordingly local. Interestingly, LaBerge specifically had participants focus on the central letter of the word in his letter categorisation task – this went some way to explaining his "V" shaped function. Yet, in the valid analysis in this experiment, there was no such requirement to focus on the central letter; participants had to detect targets that occurred in any possible location. Still something similar to the LaBergian "V" shaped function in reaction times was observed (although admittedly much less pronounced). This could perhaps be explained by the fact that participants were told to focus on the centre of the screen at the start of the experiment, and this was where the middle of the word would later be located. That is, they were consistently fast at detecting targets that appeared nearer to where they were looking. When looking at centrally presented cues only, the data much more closely resembled LaBerge's, with a pronounced "V" shaped function for both background colour patch and character illumination cues/targets. Certainly, the background colour patch cues/targets did not induce anything that looked like "global" processing, at least not in a way that was recognisably similar to what LaBerge described. The only difference between the different types of cue and target was that the larger background colour patches were detected slightly (and not significantly) faster than the smaller character illumination cues and targets. Stimulus intensity alone can explain this.

There are several ways in which these findings can be accounted for. In the first instance, this experiment may simply have failed to demonstrate what it set out to – that cues and targets of different types qualitatively modulate attention distribution to words. Attention may simply be allocated to words in a consistent fashion, regardless of what types of cue and target are used. This would mean that the differences between Experiments 1/2 and 5 cannot be explained by the different cues and targets used, and that this possibility should be eliminated from future enquiries. While this possibility cannot be denied, there were a number of other possible explanations. The core assumption of this experiment might have been false: "object based processing" of the kind observed in Experiment 5 may be something quite different from LaBerge's whole word processing and may produce quite different effects. There is no particular reason why "object based processing" should produce the flat reaction time function hoped for in this experiment. It is a fairly large assumption that if a word is being processed as an object, it will have a flatter reaction time function across its letter positions than a word that is being processed more locally.

LaBerge's study was a simple target detection task. Participants were asked to process a word in a particular way (either categorising the whole thing, or identifying single characters) and then detect the onset of a target as quickly as they could by pressing a button. This study was similar in that it had targets appearing at different positions inside a word, but quite different in that it did not feature a direct manipulation of how the word was being processed, and also in that there was a mostly reliable cue provided prior to the onset of the target. What effects these differences would have on the hunt for a LaBerge-type effect are unknown. It is easy to imagine that the onset of the cue could be overpowering any top-down attentional mapping which might otherwise have revealed itself. That is, after showing participants the word and allowing it to shape where their attention was allocated, immediately their attention was drawn to a focal point, undermining the inherent effects of the word on attention. Given that this experiment did not have multiple “objects” in the array, using a cuing paradigm designed to detect a “within object benefit” was unwise. Further, even if this experiment had managed to compel participants to adopt an attentional strategy consistent with what was observed in Experiment 5 (an object based strategy), there is no particular reason to expect that this would have produced a flatter reaction time function compared to a more “local” processing strategy. Experiment 5 did not explore reaction times for individual letter positions, so how such a processing strategy would affect reaction times to individual letters within a word is unknown. Finally, unlike all previous experiments, this experiment only embedded cues and targets in 1 letter at a time. This meant that right away participants were pushed toward a more “local” processing, so it is perhaps not surprising that both types of cues/targets exhibited the results that were predicted for “local” processing of the word. The background colour patches will have been disproportionately affected by these changes. In previous experiments the background colour patches were contiguous changes that “joined” two letters in a single region. This may well have encouraged a more holistic processing of the word. Conversely in this experiment, the background colour patches were simply a brightening around a single letter that did not extend into the space occupied by adjacent letters. Also, there is a possibility that this experiment did find some evidence for the types of cue and target modulating how attention is allocated qualitatively: the marginal interaction on costs data across the 6 letter positions. Background colour patch cues and targets appeared to experience more cost in shifting attention away from the central locations compared to character illumination cues/targets. While this was not the anticipated effect, this may still reflect differences in how the different cues and targets induced participants to process the words.

There are a number of conclusions that can be drawn from this study. In the first instance, this experiment was successful in cuing attention to a specific location in a word. However, it was not possible to reject the null hypothesis when it came to the prediction that background colour patch cues/targets will induce more global processing of a word than character illumination cues/targets. At the very least this means that any differences in attentional processing induced by the different cue/target types are not of the sort observed by LaBerge, where the shape of the reaction time function across the word is modulated. However, it does not mean that there were no differences in the type of processing the different cues/targets induced. A positive result for this experiment would have been fairly compelling evidence for the modulation of attention by the different cue/target types, but unfortunately a null result is not evidence for the absence of this modulation. This paradigm was, on reflection, ill-suited to detecting the kinds of effects sought since it did not deal with within vs. between word attention shifts. Accordingly a different experiment will need to be used to explore the attentional effects of different types of cues and targets, and this experiment will need to focus on explaining the same types of effects that have been observed in Experiments 1-7.

5. Experiments 9 and 10 - “The Role of Low Level Visual Features –Symbol Words as Objects”

Experiment 9 and 10 Introduction

The focus of the latter half of this thesis has been trying to explain the differing results of experiments 1/2 and experiment 5. The first two experiments found no object based effect, but an effect of reading direction on reaction time costs. Experiment 5 found no reading direction effect, but did find an object based effect for horizontally presented words only. The difference in the results was presumed to be a result of the differences between the experiments, outlined in table 3-1. Experiment 7 was concluded to have discounted the possibility of blocking context being to blame for the differences. Experiment 8 was supposed to discount the possibility of cue/target type being responsible. However there was a question over whether experiment 8 was an adequate test for discounting the possible role of cue/target type.

Experiment 8 differed markedly from those that went before it, using a LaBerge (1983) style paradigm to measure target detection speed in multiple places across a single word. Experiments 1-7 however looked for object based effects in arrays containing 2 words. Accordingly, just because experiment 8 did not show a significant difference in reaction time distributions for the different cue/target types, does not mean that such a difference would not be present in the type of task used in experiments 1-7. It was decided to readdress this issue.

Since so many of the interpretive problems encountered in this thesis to date have stemmed from small differences in experimental procedure, the most elegant solution was to return to the experimental methodology of experiments 1 and 2 insofar as was possible. One key possibility that has not been addressed by any of the experiments to date is that all of the observed effects stem from processes that have nothing to do with words per se. The observed effects may simply be the product of combining the Egly type of paradigm with stimuli that are "word like". While experiments 4 and 6 did try and find effects using non-lexical stimuli and failed, the "placeholders" used in that experiment really were quite different from the characters that normally compose words. If stimuli that are more "letter like" could be found, a significant result may be forthcoming while using non-lexical stimuli. It was decided to re-run experiments 1 and 2 using symbol strings rather than words. A comparison between the stimulus arrays used in this experiment and those from previous experiments is provided in Figure 5-1. 20 words composed of symbols will be created and used repeatedly throughout the experiment. The same number of trials (560) as was used in experiment 1 and 2 will be reproduced. Two experiments will be run, one for horizontally oriented stimuli (Experiment 9) and one for vertical (Experiment 10). The only departure from the methodology of experiment 1 and 2 is that within each experiment, cue/target type will be manipulated as a between subjects factor.

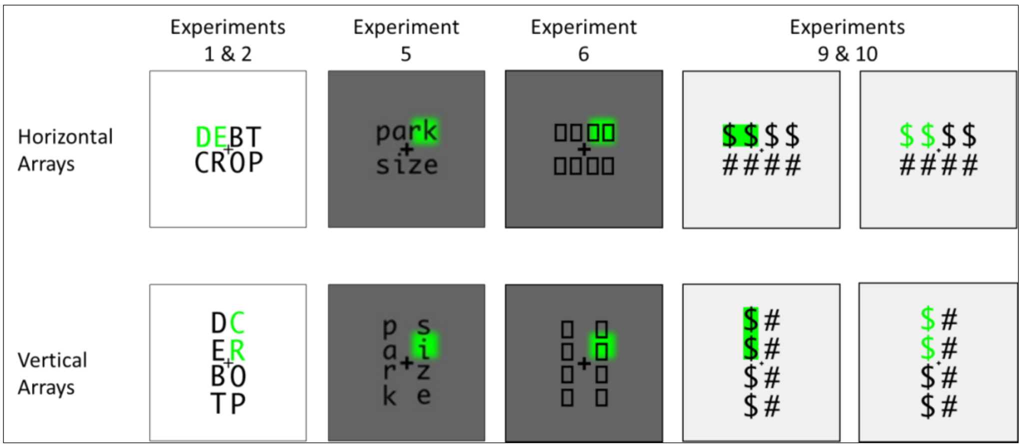


FIGURE 5-1 - EXAMPLE ARRAYS WITH CUES COMPARING THE STIMULUS ARRAYS USED IN EXPERIMENTS 1/2, 5, 6 AND 9/10. NOT DRAWN TO SCALE.

It is hoped that by "returning to our roots" with these final two experiments the following two questions can be addressed: what happens when a "words as objects" style paradigm is run using symbol strings and what is the effect of the differing cue/target types on responses to these non-lexical stimuli? If these experiments find any effects that are similar to those found in previous experiments, it will mean that these effects are unlikely to be related to the stimuli being words per se. If these experiments find a "reading direction effect" or an "object based effect" while using symbol strings, this would imply that lower level visual grouping processing are driving these effects in the previous experiments. Accordingly, this would further suggest that there is nothing special about words at all when it comes to this type of paradigm. This is a crucial question which needs to be resolved before this thesis can be said to have reached a conclusion. While addressing this, one final attempt will also be made to resolve the question of what exactly the different types of cue and target are doing to participants' attentional distribution. It is hoped that the relatively "content free" symbol strings will eliminate any noise generated by top down effects and allow a clear signal of the effect of the cues and targets to be detected.

No specific predictions are made, but it is hoped that results that mirror those of either experiments 1/2 or experiment 5 will be found, and that a clear effect of cue/target type will also be observed. If both these criteria are met, it should be possible to explain the discrepancy in results to date and reach a final conclusion about what is driving the effects observed so far.

Experiment 9 Method

Participants

Participants were 7 male and 17 female members of the University of Dundee community who received course credits or payment for their time. Their ages ranged from 18 to 47 years old. All participants were fluent in English. Half (12) of the participants saw only "Character Illumination" cues/targets and half (12) saw only "Background colour patch" cues/targets.

Apparatus

Stimuli were presented through a 19" monitor running at 100hz and responses were recorded via a button box, with the response button pressed by the dominant hand. An SR Research Eyelink 2000 desk based eye tracker running SR Research Experiment Builder software version 1.10.165 (Experiment Builder, 2013) recorded monocular eye position at 2000hz. A desk mounted chin rest kept participant's eyes 76cm from the centre of the screen and both their peripheral vision and vision in their non-dominant eye were eliminated through blinkered spectacles.

Stimuli

20 letter-like symbols were selected (see Appendix IV). Attempts were made to avoid symbols such as ";" which have little in common with English letters. Each of the selected symbols would be used to create 4 character "words" (for example $$$$) printed in 48pt Monaco font. This yielded 20 words. These were paired off to create 10 word pairs. Words were presented horizontally in the centre of the screen, with one word above the mid-point and one below. Word occurrence in these primary or secondary positions was fully counterbalanced within subjects. A fixation cross appeared in the centre of the screen. Cues and targets were either large colour patches which appeared behind the first or last two letters of a word, or changes in colour of the first or last two letters of a word. Individual symbols were approximately 1° x 1.5° of visual angle. Completed words were approximately 6° of visual angle wide and 1.5° of visual angle tall. The fixation cross was approximately 0.27° by 0.27° of visual angle. Screen background was a very light grey (RGB values: 240/240/240, luminance 77.04cd/m^2) and the letters composing the words were either black (RGB values: 0/0/0, 6.35cd/m^2) or red (255/0/0, 20.70cd/m^2) when being used as a target, or green (0/255/0, 36.00cd/m^2) when used as a cue. When background colour patches were used instead of character illumination, the RGB and luminosity values of those patches were identical to those found with character illumination. Each individual scene was created by a control grid. The grid defined where each individual letter should be positioned on screen, and at what time. The identity, colour and any positional offsets needed were controlled by the grid.

Design

The experiment consisted of an individual randomised sequence of 560 trials: 320 valid trials (cues and targets were in the same location), 80 "Invalid in" trials (cues and targets were in different locations but still inside the same word), 80 "Invalid between" trials (cues and targets were in different locations and in different words) and 80 Catch trials (no target appeared). All word pairs appeared proportionately represented in all 4 types of trial, and were presented with an equal number of cues and targets from all possible locations. Cue/target type was manipulated as a between subjects factor, so half of the participants only ever saw "Background Colour Patch" cues/targets and half only ever saw "Character Illumination" cues and targets.

Task and Procedure

After giving informed consent the eye tracker was calibrated on the participant's dominant eye determined via majority result from the Miles, Porta and Camera tests (Roth et al., 1992). In cases where participants declared significant differences in visual acuity, data was collected using their stronger eye. All participants were tested using an eye that had normal visual acuity.

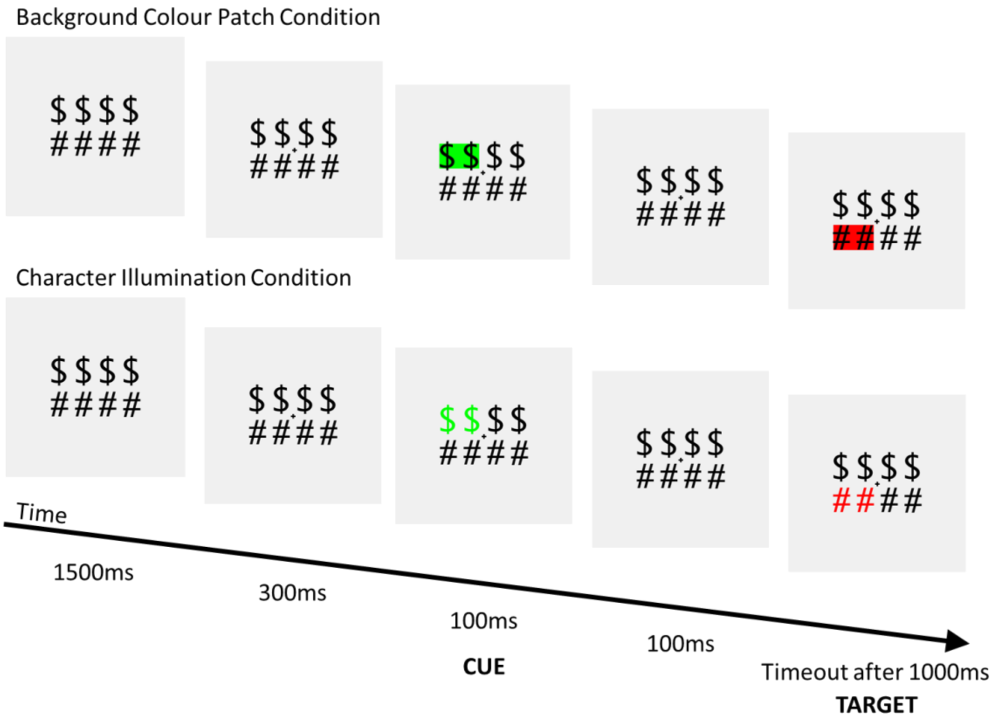


FIGURE 5-2 – EXPERIMENT 9 TRIAL SEQUENCE SHOWING IDENTICAL "INVALID OUT" TRIALS IN THE BACKGROUND COLOUR PATCH CONDITION AND THE CHARACTER ILLUMINATION CONDITION. NOT DRAWN TO SCALE.

Figure 5-2 gives a schematic representation of trial events. Participants were first presented with the "words" in the centre of the screen for 1500ms. This was followed by a screen also displaying the fixation cross for 300ms. Participants were instructed to look at the fixation cross when it appeared, and failure to do so would result in their response on that trial being discarded. The participant would then see the green cue for 100 ms. Following a 100ms cue target onset asynchrony of 100ms, the red target would then appear. It would remain on screen until participants pressed the target detection button, or the display timed out after 1000ms.

Experiment 9 Results

Performance and Filtering Information

An analysis of the error rates amongst the 24 participants was conducted. Overall participants responded correctly on 97% of trials. On trials where a response was required, 98% of trials were correct. On catch trials the correct (non) response was issued on 90% of trials. A 100-700ms reaction time filter was applied to the trials where a response was issued. 99% of correct responses were retained after the application of this filter. Overall 97% of all trials were included in this analysis.

No participants needed to be removed due to high error rates. 6 additional participants began the experiment but were not included in the data file due to high numbers of eye tracker errors brought on by failing to sit still, wearing mascara, or failing to follow the experimenters instructions carefully.

Reaction Times - Validity

A 2 (Cue/TargetType) by 3 (levels of validity) mixed factorial ANOVA was carried out. There was a significant main effect of validity (F(2, 44)=4.477, p=.017). There was no significant effect of Cue/Target Type (F(1, 22)=1.551, p=.266). There was no significant interaction(F(2, 44)=0.404, p=.670).

Simple planned comparisons found that when analysing both types of Cue/Target Type together invalid within trials were not significantly different from valid trials (F(1,22)=1.786, p=.195). Invalid between trials were significantly slower than valid trials (F(1, 22)=6.866, p=.016). There were no significant interactions between cue/target type and any level of validity. Post-hoc Bonferoni t-tests found that invalid in trials were responded to significantly faster than invalid between trials when the background colour patch cue/target type was used (t(11)=-2.412, p<.05 one-tailed) but not when the cue/target type was character illumination (t(11)=0.868, p>.05)

These results look very much like the "within object benefit" first observed in experiment 5. invalid within trials are not significantly different from valid trials, whereas invalid between trials are, suggesting that a target being in the same word as the cue is conferring a reaction time benefit on target detections. The post-hoc analysis suggests that this effect is being driven largely by the background colour patch trials. These results are described in figure 5-3.

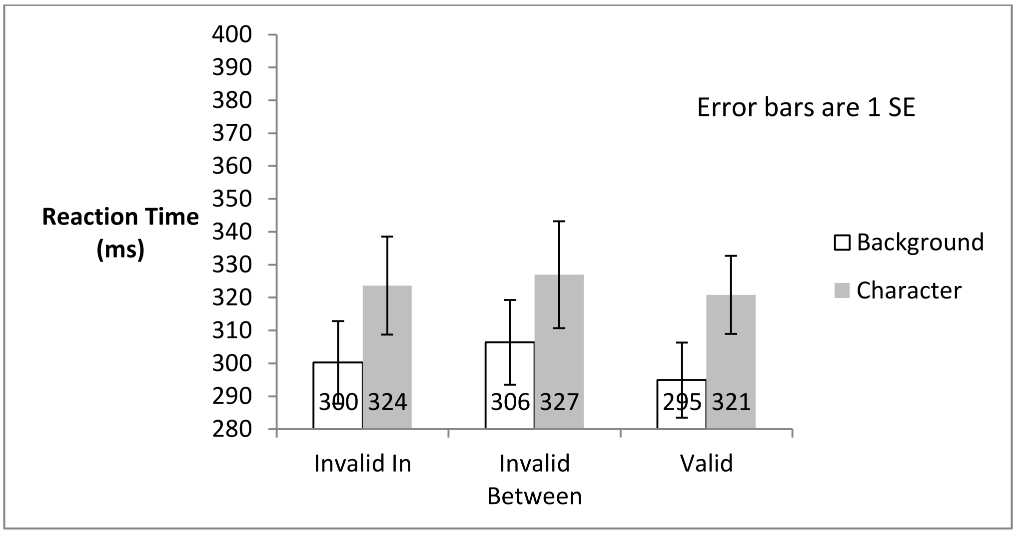


FIGURE 5-3 - EFFECT OF VALIDITY ON REACTION TIMES (EXPERIMENT 9)

Reaction Times – Target Location

A 2(Cue/TargetType) by 4(Target Location) mixed factorial ANOVA was conducted on all correct and filtered response trials. There was a significant effect of Target Location (F(3,66)=9.995, p=.001). There were no significant interactions (F(3,66)=0.244, p=.865). There was no significant effect of Cue/Target Type (F(1,22)=1.979, p=.173). Post-hoc Bonferroni analyses found that bottom left (BL) differed significantly only from top left (TL) (p=.001). Bottom right (BR) differed significantly from top left and top right (TR) (p=.001 and .044 respectively). There were no other significant differences. This continues a pattern observed across several versions of this study – participants tend to be fastest at responding to targets in the bottom right position. These results are described in figure 5-4.

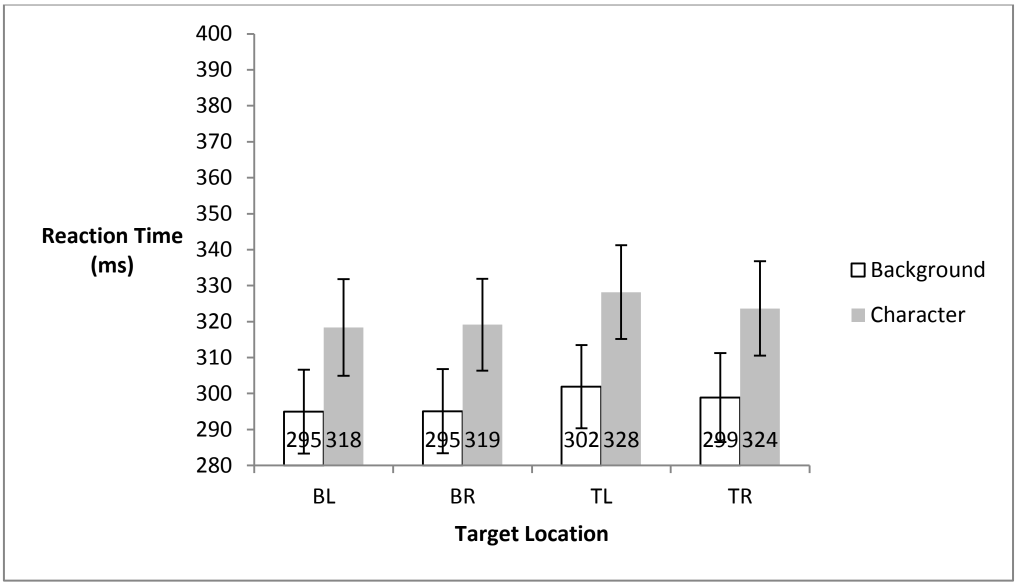


FIGURE 5-4 - EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 9)

Reaction Times - Direction of Attention Shift

As with previous experiments, the within word and between word shifts are analysed separately.

Within Word Shifts

A 2 (Cue/Target Type) by 2 (Reading Direction) mixed factorial ANOVA was carried out on the within word attention shift data (Invalid Within). There was a significant effect of reading direction (F(1, 22)=5.578, p=.027). There was no significant interaction (F(2,22)=0.016, p=.901). There was no significant effect of Cue/Target Type (F(1,22)=1.145, p=.245).

Between Word Shifts

A 2 (Cue/Target Type) by 2 (Canonicity) mixed factorial ANOVA was carried out on the between word attention shift data (Invalid Between). There was no significant effect of Canonicity (F(1, 22)=0.010, p=.921). There was no significant interaction (F(1,22)=1.566, p=.224). There was no significant effect of Cue/Target Type (F(1,22)=0.975,p=.334).

Trials where participant had to shift their attention in accord with reading direction had faster reaction times than trials where they had to shift their attention against reading direction. This effect has not been observed before. These results are described in figure 5-5.

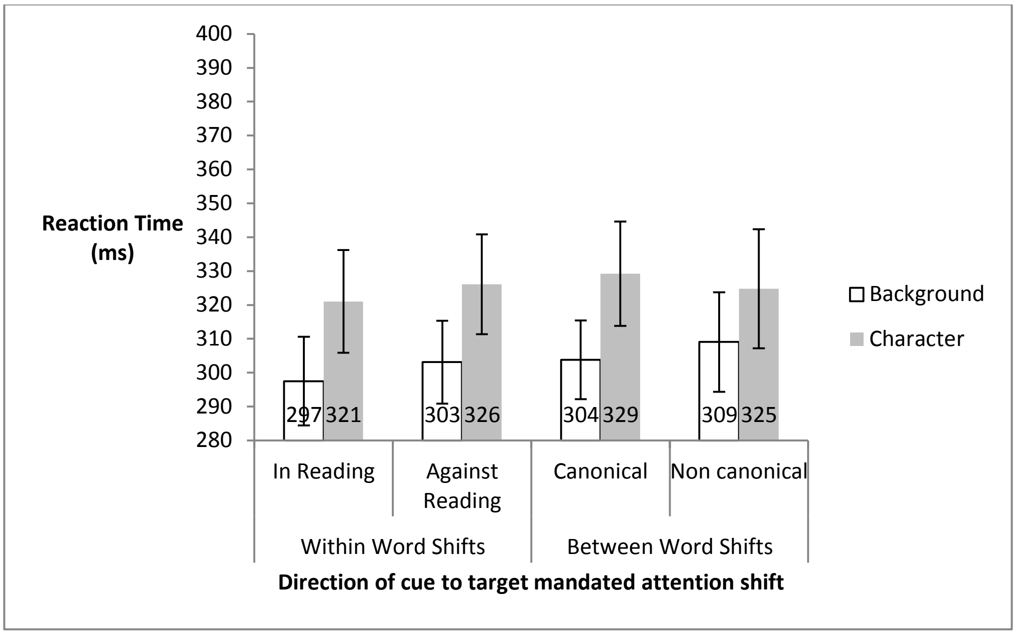


FIGURE 5-5 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIMES (EXPERIMENT 9)

Reaction Time Costs – Within vs. Between Word Attention Shifts

A 2(Cue/Target Type) x 2(Levels of invalidity) mixed factorial ANOVA was conducted on the RT Costs of Invalid Trials compared with Valid trials using the same cue. There was a marginally significant effect of Invalidity ($F(1, 22)=4.153$, $p=.054$). There was no significant interaction ($F(1, 22)=0.322$, $p=.570$). There was no significant effect of Cue/Target Type ($F(1, 22)=0.433$, $p=.513$).

It appears that Invalid Between trials were incurring marginally more cost than Invalid In trials for both types of Cue and Target. This effect has not been observed before. These results are described in figure 5-6.

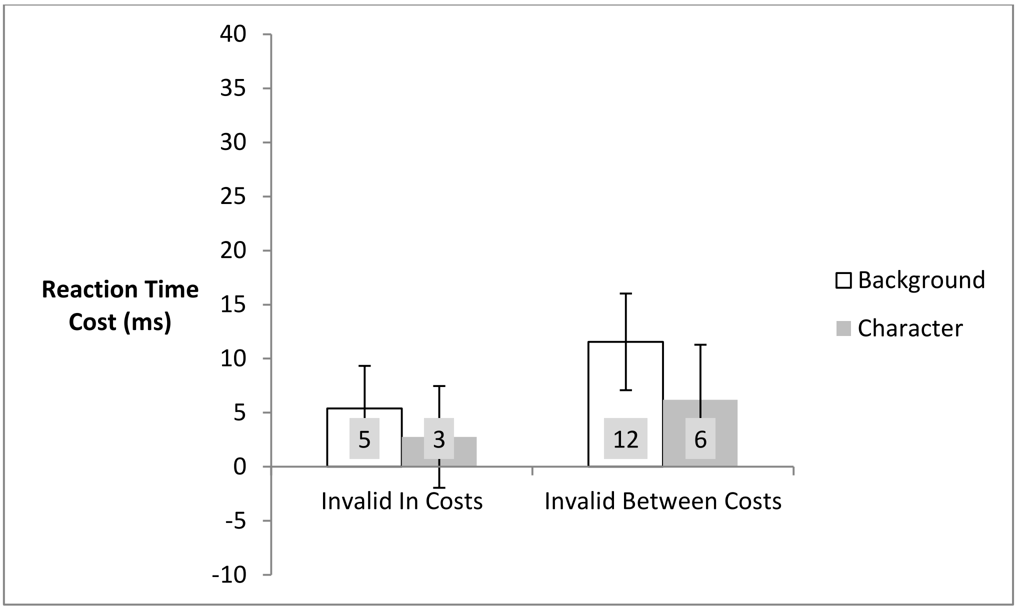


FIGURE 5-6 - WITHIN VS. BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME COST (EXPERIMENT 9)

Reaction Time Costs – Direction of Attention Shift

Within Word Shifts

A 2(Cue/Target Type) by 2(Reading Direction) mixed factorial ANOVA was carried out on the RT costs of attention shifts within a single word. There was a marginally significant effect of Reading Direction ($F(1, 22)=3.774$, $p=.065$). There were no significant interactions ($F(1, 22)=0.026$, $p=.873$). There was no significant effect of Cue/Target Type ($F(1, 22)=0.186$, $p=.670$).

Between Word Shifts

A 2(Cue/Target Type) by 2(Canonicity) mixed factorial ANOVA was carried out on the RT costs of attention shifts between words. There was a marginally significant effect of Canonicity ($F(1, 22)=3.794$, $p=.064$). There were no significant interactions ($F(1, 22)=0.466$, $p=.502$). There was no significant effect of Cue/Tar Type ($F(1,22)=0.627$, $p=.437$).

These results are reminiscent of experiments 1 and 2 in that both types of cue/target incurred more cost when going against reading direction than when going with. These results are described in figure 5-7.

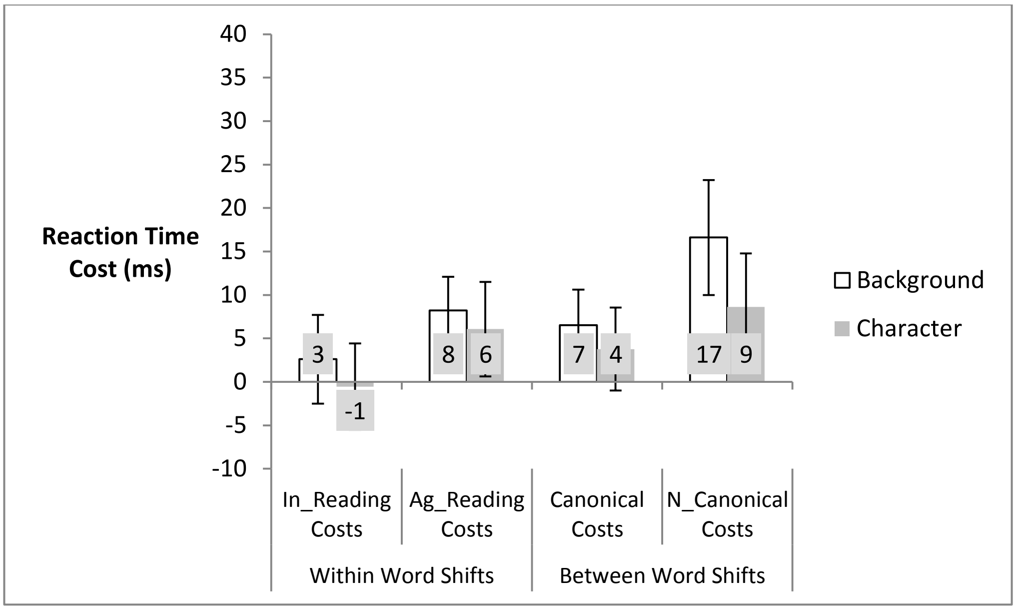


FIGURE 5-7 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 9)

Experiment 9 Discussion

The two questions in the introduction of this chapter asked what the effect was of using symbol strings in a "Words as Objects" style paradigm, and what the effect was of the different types of cue and target. This experiment seems to have been successful in addressing both of these questions. It does indeed seem to be possible to produce results that are remarkably similar to those found in earlier "lexical" experiments, even when using non-lexical stimuli. The results in this case look very similar to those observed in experiment 5, where invalid between trials were much slower than valid trials, but invalid in trials were not. This constitutes an object based benefit, where a reaction time benefit for detection is conferred on targets that are inside the same word as the cue, in a manner that cannot be explained by spatial attention. The effect of the different cue/target types seem to have been to amplify this object based benefit. The character illumination cues/targets seemed to have a much smaller within object benefit as evidenced by the invalid in vs. invalid between comparison being non-significant, whereas this comparison was significant when using the background colour patch cues/targets. Of further interest were the effects of reading direction. On untransformed reaction times a significant benefit was found for invalid trials where the participant was compelled to move their attention in accord with reading direction, compared to relatively slower responses when the participants had to move against reading direction. This is the first experiment in this thesis that has successfully demonstrated this effect on reaction times without the need to transform the data into costs. This effect was also present in the reaction time costs data, albeit as a marginal effect. These effects were in accord with what was observed in experiments 1 and 2, where participants were faster at moving with reading direction. That these effects were demonstrated in an experiment with a main effect that was very similar to experiment 5 illustrates that these effects are not mutually exclusive. In terms of the between word shifts, the effects found mirrored experiment 5; canonical shifts were less costly than non-canonical. The results found in this study appear to be a hybrid of experiments 1/2 and 5.

These findings can explain some of the more confusing findings to date. The main effect of validity looked very much like the object based effect found by experiment 5. However, only those trials which used background colour patches exhibited an effect large enough to render a comparison between invalid in trials and invalid between trials significant. This suggests that the background colour patch cue/target type amplifies (or renders easier to detect) the object based benefit. Since this was the type of cue/target used in experiment 5 but not experiments 1 and 2 (which used the character illumination cues/targets), this offers a likely explanation for why experiment 5 found an object based effect and experiments 1 and 2 did not. It should be noted however that there are a number of different ways of quantifying a within object benefit, and a direct comparison between invalid in and invalid between trials is only one of them. This is the only experiment in this thesis where this comparison yields a significant effect – although that lends credence to the idea that this was a particularly pronounced incarnation of the object based benefit. It should also be noted that the character illumination cues/targets also seemed to be contributing to the object based effect. As to why this was found in this study and not experiments 1 and 2 is an interesting question. It is possible that top down influences from the word derived stimuli in experiments 1 and 2 overrode the tendency to form object based representations. By "top down influences", an effect similar to those identified by Caramazza and Hillis (1990) is suggested. Known words come packaged with a variety of pre-learned information, some of which refers to the spatial characteristics of the word. When these representations are activated, they will tend to interfere with spatial phenomena that are specific to this occurrence of the word. The background colour patch cues/targets are apparently more potent generators of object based effects than the character illumination cues/targets. This added potency may explain why Experiment 5 was successful in finding an object based effect while Experiments 1 and 2 were not. The combination of top-down interference from known words, and a weaker type of cue/target may explain the null results of Experiments 1 and 2. In this experiment (Experiment 9) the lack of lexical stimuli may actually have made it easier to detect these results due to a reduction in interference from the aforementioned top down influences. The reading direction effects on both the costs data and the untransformed reaction times were strongly reminiscent of those found in experiments 1 and 2. The fact that this effect can coexist with the main object based benefit suggests that the original theory posited to explain the differences between experiments 1/2 and 5 is inadequate. It was hypothesised that the character illumination cues/targets induced a local, letter-by-letter decoding, whereas the background colour patches forced a more "global" processing of the sort that might yield an object based effect. This may reflect reality to an extent in that the different types of cues/targets may nudge participants toward those decoding strategies, however the fact that the object based effect appeared to be reflected in the scores for both types of cues/targets suggests that such an effect, if present, is not absolute. While it certainly seems like the background colour patches may indeed amplify an object based effect, this has not prevented the reading direction effect from being found. Accordingly the presence of one does not preclude the presence of the other as the local vs. global account would imply. A parsimonious explanation is that the background colour patches amplify object based effects, but do not prevent reading direction effects from forming. Another factor which would offer a likely explanation is that the reading direction effects were then further amplified through the repeated use of the same stimuli, and possibly the character illumination cues/targets also helped make letter level analyses more salient. The reading direction benefit does seem more pronounced for character illumination cues/targets in this study, although the effect does not approach significance. This would explain why no hint of reading direction effects was observed in experiment 5 – it used different arrays on every trial and did not use character illumination cues/targets.

There are some problems with this experiment. Since this experiment uses both the type of cue/target and the repeated stimuli presentation of experiments 1 and 2, it is not possible to separate the potential effects of these two factors. However since object based effects have been observed without repeated stimulus presentation (Experiment 5) and since reading direction effects have only been observed with repeated stimulus presentation (Experiments 1, 2 and 9) a parsimonious explanation can be arrived at: the object based effects are not related to the repeated use of the same stimuli, but the reading direction effects are. It would be a role for future studies to confirm this experimentally.

This study demonstrated effects previously associated only with word stimuli while using non-lexical symbol arrays. An object based facilitation effect was found where targets occurring inside the same word as the cue experienced a reaction time benefit. Further, reading direction effects were found where it was faster and less costly to move one’s attention in accord with reading direction than against it. It is believed that object based effects are common when dealing with tasks of this sort, and that using actual word stimuli may in fact make them harder to detect due to top down influences, particularly when combined with character illumination cues/targets.

Conversely the background colour patch cues/targets appear to make object based effects more pronounced. The reading direction effects appear to be largely driven by repeated exposure to the same stimuli, since the previous studies in this thesis which did not do this found no such effect.

Experiment 10 Method

Except where stated, experiment 10 was identical to experiment 9.

Participants

Participants were 8 male and 18 female members of the University of Dundee community. Their ages ranged from 18 to 50. All participants were fluent in English. Half (12) of the participants saw only the “Character Illumination” cues/targets and half (12) saw only the “Background Colour Patch” cues and targets.

Stimuli

The symbol words were oriented vertically in this experiment.

Task and procedure

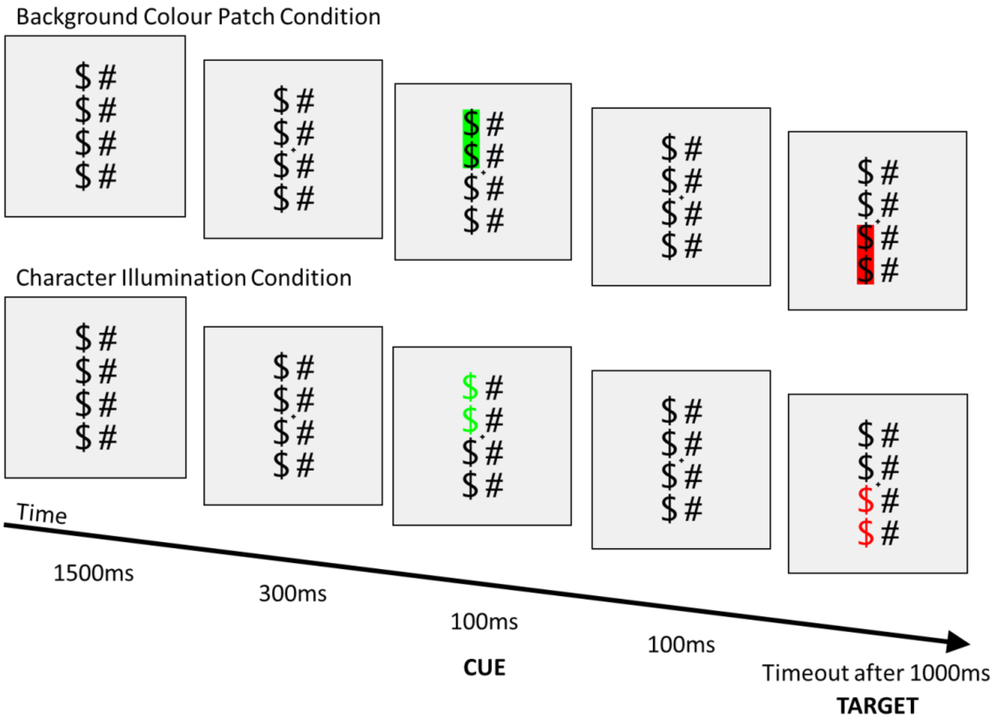


FIGURE 5-8 - EXPERIMENT 10 TRIAL SEQUENCE SHOWING IDENTICAL "INVALID IN" TRIALS IN THE BACKGROUND COLOUR PATCH CONDITION AND THE CHARACTER ILLUMINATION CONDITION. NOT DRAWN TO SCALE.

Figure 5-8 gives a schematic representation of trial events.

Experiment 10 Results

Performance and Filtering Information

An analysis of error rates amongst the 24 participants was conducted. Overall participants responded correctly on 97% of all trials. On trials where a response had to be issued, the correct response was issued on 97% of trials. On catch trials the correct (non) response was issued on 90% of all trials. A 100-700ms reaction time filter was applied to remove outliers. 99% of correct responses were retained by this filter. Overall, of all responses issued, 96% were included in this analysis.

No participants needed to be removed due to high error rates. 4 further participants were tested but were not included in the final dataset due to very high error rates, or a level of English competency that fell below the "fluent" requirement clearly stated in the experiment advertisements.

Reaction Times - Validity

A 2 (Cue/Target Type) by 3 (Levels of Validity) mixed factorial ANOVA was carried out. There was a significant main effect of validity ($F(1.384, 30.441)=8.145$, $p=.004$, Greenhouse-Geisser corrected). There were no significant interactions ($F(1.384, 30.441)=0.855$, $p=.397$ Greenhouse-Geisser corrected). There was a marginally significant effect of Cue/Target Type ($F(1,22)=3.782$ $p=.065$). Simple planned comparisons found that when analysing both Cue/Target Types together that both invalid in and invalid between differed significantly from valid trials (($F(1,22)=6.280$, $p=.020$) and ($F(1,22)=12.857$, $p=.002$) respectively). There were no interactions found by the simple planned comparisons.

For consistency with experiment 9, a Bonferoni corrected t-test was carried out to see if there was a significant difference between invalid in and invalid between trials when considering the different cue/target types separately. There was no significant difference when background colour patches were used ($t(11)=0.799$, $p>.05$) nor when character illumination cues were used ($t(11)=0.893$, $p>.05$).

The overall effect here is much closer to that witnessed in experiments 1 and 2. There is no detectible object based benefit, and both classes of invalid trial seem to be responded to as slowly as one another. These results are described in figure 5-9. The marginal effect of cue/target type seems to indicate that participants were consistently responding to the background colour patch targets faster. This is unsurprising since there were the physically larger stimuli, which should facilitate detection.

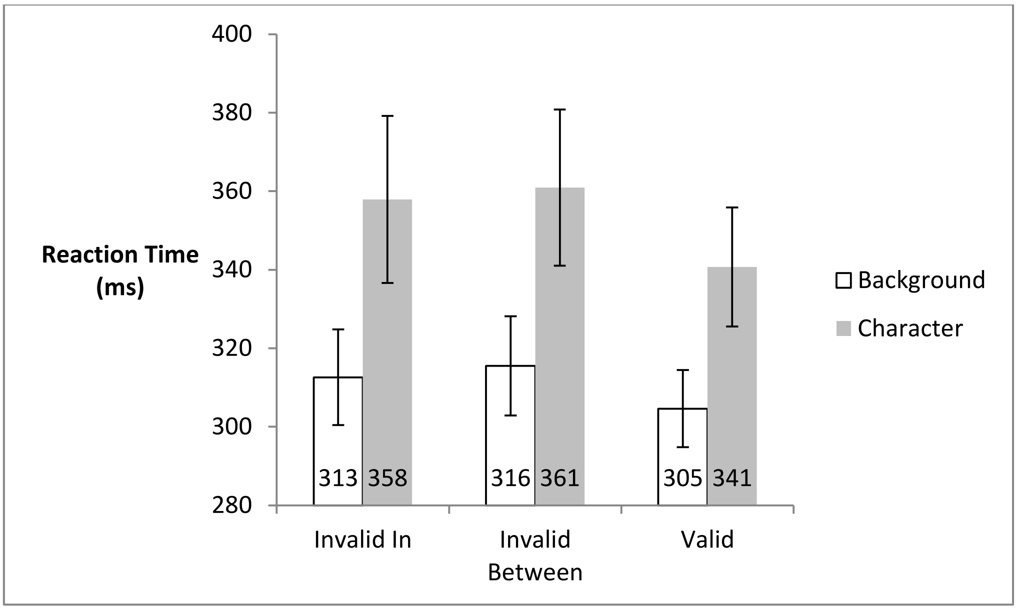


FIGURE 5-9 - EFFECT OF VALIDITY ON REACTION TIME (EXPERIMENT 10)

Reaction Times – Target Location

A 2(Cue/Target Type) by 4(Target Location) was carried out on all trials where a response was issued (BL= Bottom Left, BR = Bottom Right, TL = Top Left, TR = Top Right). There was a significant effect of target location (F(3,66)=3.039, p=.035). There was a significant interaction between Cue/Target Type and Target Location (F(3,66)=2.822, p=.045). There was a marginally significant effect of Cue/Target Type (F(1,22)=3.935, p=.060).

Post hoc Bonferoni t-tests found that when analysing both Cue/Target Types together, RTs in any one quadrant did not differ significantly from those in any other.

Nonetheless, the significant interaction seems to indicate that while RTs were relatively flat across all quadrants for background cue/target types, they varied from quadrant to quadrant for character illumination cue/target types. These results are described in figure 5-10.

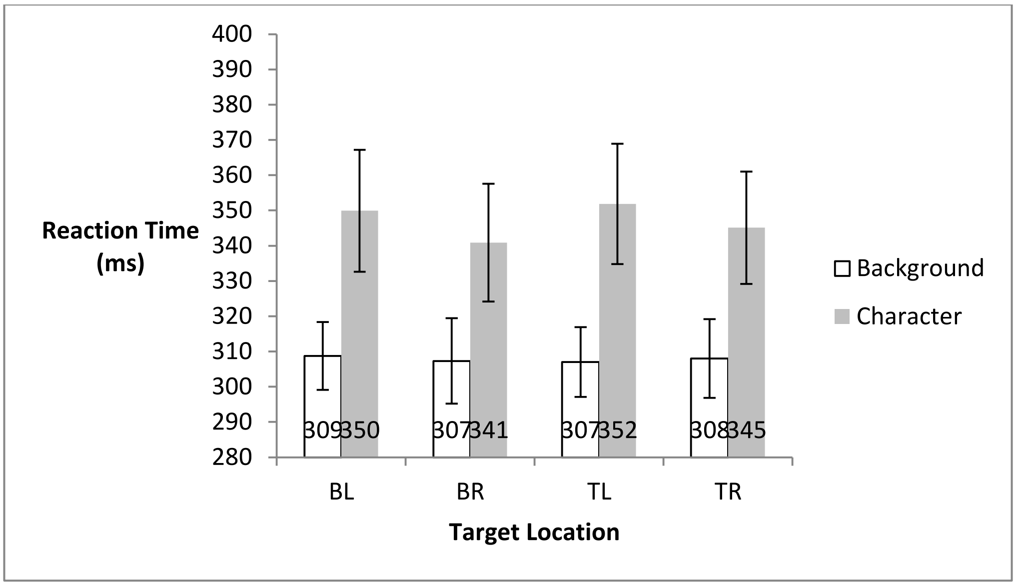


FIGURE 5-10 - EFFECT OF TARGET LOCATION ON REACTION TIME (EXPERIMENT 10)

Reaction Times - Direction of Attention Shift

As with previous studies, the within word and between word attention shifts were analysed separately.

Within Word Shifts

A 2 (Cue/Target Type) by 2 (Reading Direction) mixed factorial ANOVA was carried out on the within word attention shifts only. There was no significant effect of Reading Direction (F(1,22)=0.438, p=.515). There was a significant interaction between reading direction and Cue/Target Type (F(1, 22)=10.177, p=.004). There was a marginally significant effect of Cue/Target Type (F(1, 22)=3.406, p=.078).

Between Word Shifts

A 2 (Cue/Target Type) by 2 (Canonicity) mixed factorial ANOVA was carried out on the between word attention shifts only. There was no significant effect of Canonicity (F(1,22)=0.078, p=.783). There were no significant interactions (F(1, 22)=2.290, p=.144). There was a marginally significant effect of Cue/Target Type (F(1,22)=3.714, p=.067).

Of interest here is the interaction found for within-word shifts. Background colour patch cues/targets had a faster reaction time when moving against reading direction, whereas character illumination cues/targets had a faster reaction time when going with reading direction. This is potentially informative, since the character illumination cues/targets were the ones used in experiment 2, the only vertical array study to find an effect of reading direction (although this was on RT costs instead of raw RTs). These results are described in figure 5-11.

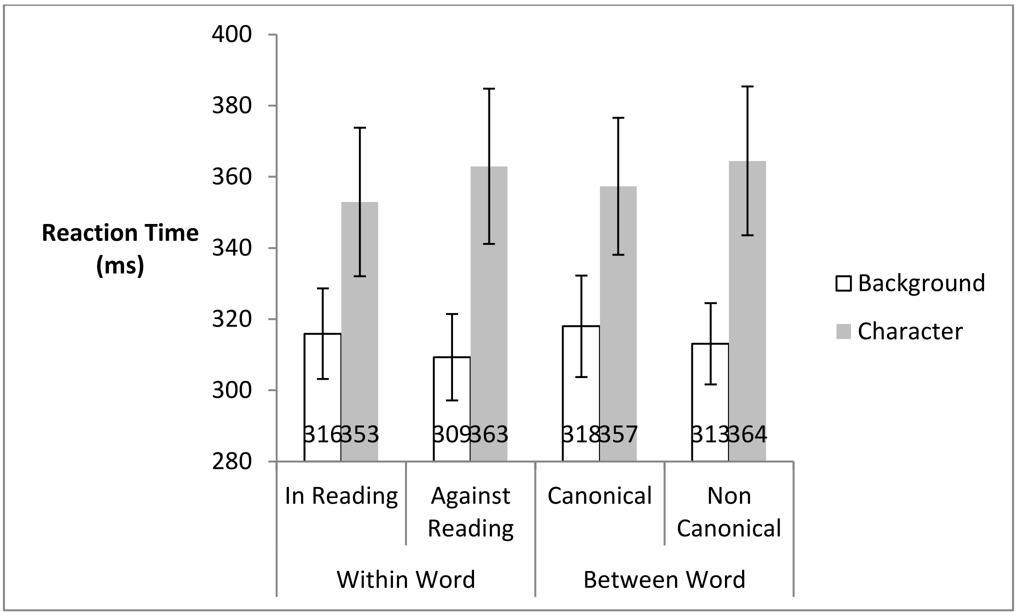


FIGURE 5-11 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME (EXPERIMENT 10)

Reaction Time Costs – Within vs. Between Word Attention Shifts

A 2 (Cue/Target Type) by 2 (Invalid In or Out) mixed factorial ANOVA was carried out on the costs of the 2 classes of Invalid trial when compared with Valid trials using the same cue. There was no significant effect of Invalidity ($F(1, 22)=1.305$, $p=.266$). There were no significant interactions ($F(1,22)=0.001$, $p=.988$). There was no significant effect of Cue/Target Type ($F(1,22)=1.054$, $p=.316$).

These results are described in figure 5-12.

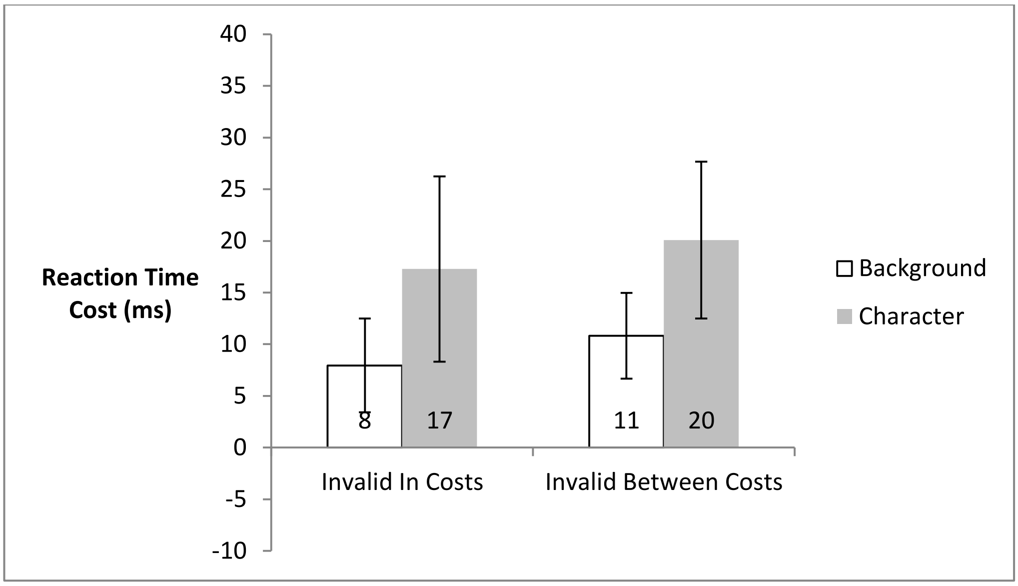


FIGURE 5-12 - WITHIN VS. BETWEEN WORD ATTENTION SHIFTS - EFFECT ON REACTION TIME (EXPERIMENT 10)

Reaction Time Costs – Direction of Attention Shift

Within Word Shifts

A 2(Cue/Target Type) by 2(Reading Direction) mixed factorial ANOVA was carried out on the costs data from within word attention shifts. There was no significant effect of Reading Direction ($F(1,22)=0.873, p=.360$). There was a significant interaction between Reading Direction and Cue/Target Type ($F(1,22)=6.808$, $p=.016$). There was no significant effect of Cue/Target Type ($F(1,22)=0.860$, $p=.364$).

Between Word Shifts

A 2(Cue/Target Type) by 2(Canonicity) mixed factorial ANOVA was carried out on the costs data from between word attention shifts. There was no significant effect of Canonicity ($F(1,22)=0.785, p=.382$). There was a marginally significant interaction between Canonicity and Cue/Target Type ($F(1,22)=3.921$, $p=.060$). There was no significant effect of Cue/Target Type ($F(1,22)=1.143, p=.297$).

The within word interaction found on the untransformed RT data is still present here. Character Illumination cues/targets incur noticeably more cost going against reading direction than with, whereas Background colour patches incur less cost going against reading direction. A similar interaction was found for the between word shifts, where non-canonical between word shifts incurred more cost for Character Illumination cues/targets, but less for background colour patch cues/targets. These results are described in figure 5-13.

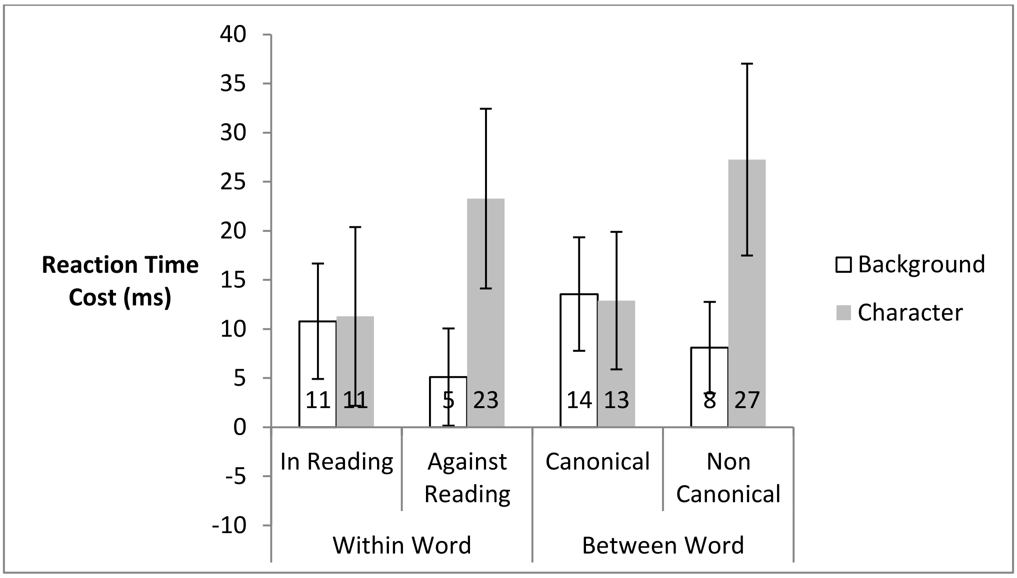


FIGURE 5-13 - EFFECT OF DIRECTION OF ATTENTION SHIFT ON REACTION TIME COSTS (EXPERIMENT 10)

Experiment 10 Discussion

In this experiment the main effect of validity seemed to more closely the pattern of Experiments 1 and 2. The two classes of invalid trial were slow when compared to valid trials, and the different types of cue/target type did not seem to affect this pattern of results. There was an interesting interaction found on response times at the different possible target locations, with background colour patch targets being flat and fast, whereas character illumination targets were much more variable in how quickly they were responded to; this effect was essentially what Experiment 8 was looking for. Cue/target type was modulating the reaction time function across the length of the word, but in the vertical orientation rather than the horizontal orientation that Experiment 8 examined. On the untransformed reaction time data there is an interaction between reading direction and cue/target type, with background colour patch cues/targets eliciting being faster when going against reading direction, while character illumination cues/targets elicited were faster when going with reading direction. This same interaction was found on the costs data as well, with character illumination trials being more costly when moving against reading direction, whereas background colour patch trials were less costly when moving against reading direction. Also, a similar interaction was found on the costs data from the between word shifts. For character illumination cues/ targets the costs were in the direction one would expect, costs were higher in the more novel (non-canonical) attention shift, whereas for the background colour patch cues/targets the opposite was true.

The results of this study provide evidence for the idea that the types of cue and target modulate how attention is deployed to the arrays. The interactions found for the reading direction RT and costs effects, and on the between word shift canonicity data, clearly demonstrate that the types of cue and target used are affecting how participants process the arrays. In particular it appears that the character illumination cues/targets biases participants to make attention shifts associated with reading (left to right and top to bottom) whereas the background colour patch targets do not. Further, it appears that this pronounced modulation of attention by the cues and targets is only present in the vertically oriented arrays. Experiment 9 did not observe this same effect when using horizontally orientated arrays. This explains why experiment 8 failed to find an effect of cue/target type on attentional allocation to words: it is only present when the words are displayed vertically. This suggests that when words are presented in their traditional format (written left to right) top down influences (that is, pre-existing knowledge about the word) overwrite local effects produced by the parameters of the experiment, whereas when the word is presented in a more novel orientation it is more malleable in how attention is allocated to it. These top down influences appear to be crucial for the formation of an object based effect, since of the experiments that have successfully demonstrated such an effect (experiments 5 and 9) none have found an effect when using vertically oriented stimuli.

This experiment neatly resolved one of the open questions presented by experiment 9: what is the contribution of the different cue/target types to the reading direction effects? In the vertical orientation at least, the different types of cues/targets modulates the nature of the reading direction effects. Even so, the absence of such effects in experiment 5 makes it likely that such effects can only be detected when using the same stimuli presented repeatedly over many trials. This calls into question the real world applicability of the reading direction effects. Do they have any bearing on real world reading where words are not presented repeatedly?

This study largely replicated the findings of experiments 1 and 2. No object based effect was observed, but effects on reading direction were. Participants exposed to character illumination were faster and incurred less cost when prompted to move their attention in accord with reading direction than when they were prompted to move their attention against reading direction. For participants who were exposed to the background colour patch cues and targets this did not appear to be the case, indeed the results ran in the opposite direction, although not as strongly. It is concluded that stimulus arrays are less vulnerable to top down influences when presented in a novel vertical orientation, and that when presented in this format the type of cue/target used has a greater impact on how attention is allocated to the stimuli.

Experiments 9 and 10 General Discussion

Experiments 9 and 10 appear to have been a success. The effects of experiment 1/2 and 5 can be replicated using non-lexical stimuli. The results of experiments 9 and 10 can best be described as a “hybrid” of those found in experiments 1/2 and 5. The object based effect found in experiment 9 was much stronger when using background colour patch cues and targets, so it appears that the object based effect of experiment 5 was likely amplified by its use of background colour patch cues and targets. Experiments 1, 2, 9 and 10 all found reading direction effects, whereas experiment 5 did not. This is likely due to the use of the same stimuli over and over again in those 4 experiments, but not in experiment 5. The reading direction effect of experiments 1 and 2 was likely produced or amplified by the use of repeatedly presented stimuli and, in the vertical orientation at least, the use of character illumination cues and targets as evidenced by the modulation found in experiment 10. When presented in a novel orientation, words are apparently less susceptible to top down influences are more subject to local influences. In this case attention to vertically oriented words was modulated by cue/target type, whereas this did not happen with horizontally oriented words.

There is one major problem with the findings of experiments 9 and 10. The hope is that these findings can inform the results found in the "word" experiments (1, 2, 3, 5, 7 and 8). Since the results look very similar to the most successful of these studies, it is not unreasonable to conclude that a similar process must be occurring. However this is not necessarily the case. While those earlier experiments may have produced results based on the real words participants were presented with, the results in this study could be the result of an entirely different process that nonetheless produces similar looking results. The effects in the word presenting experiments may have been driven by a lexical access process, whereas the effects in experiments 9 and 10 may have been driven by gestalt grouping principles. Since the words in this experiment were composed of repeating symbols (e.g. $$$$) then they could have been formed into visual objects through the gestalt principle of similarity (Wade & Swanston, 2001). However, since real words are also composed of highly similar elements that are in close proximity it is not unreasonable to conclude that these gestalt grouping principles, if they have played a role in experiments 9 and 10, must also have played a role in the other experiments. This does not exclude the possibility that there are top-down word based effects on top of the lower level gestalt perceptual effects (indeed this seems likely), but for the most part it appears that the “words as objects” effects found to date, and the reading direction effects observed are largely driven by low-level perceptual grouping processes. They are not to do with the stimuli being words per se, otherwise the same effects could not have been demonstrated using stimuli that are not words. This does not mean that the results of these studies are uninformative, since it is likely that these same low level perceptual processes form a part of real world reading, just as they form a part of processing symbol strings in experiments 9 and 10. Given that the object based effect appeared if anything more pronounced using non-lexical stimuli in Experiment 9, it seems likely that the use of actual word stimuli serves to make these effects harder to detect. Nonetheless, it also seems likely that (hard to detect or not) the same low level processes that produced the object based and reading direction effects in Experiments 9 and 10 were also at work in Experiments 1, 2 and 5. That is, although these low-level perceptual processes are not contingent on the stimuli being words, it still plays a role in the processing of those word arrays.

6. Overall Discussion – "Are words like objects?"

What did this series of experiments find?

This project began by looking for an "object based" benefit for words. Using an Egly, Driver and Rafal (1994) style paradigm, the hope was to demonstrate that allocating attention anywhere within a word elevates attention to the whole word. That is, words are treated in the same way attentionally as other visual objects.

Experiments 1 and 2 sought to demonstrate this effect by showing participants two words and embedding cues and targets inside them. The cues and targets could be one of three types: Valid (cue and target are in the same location), Invalid In (cue and target are in different locations, but still inside the same word) and Invalid Between (cue and target are in different locations and different words). The words in Experiment 1 were oriented in their traditional horizontal orientation, whereas the words in Experiment 2 were in a more novel vertical orientation. These experiments failed to find the anticipated within-object benefit. Instead, an entirely unexpected effect of reading direction was found on the reaction time costs data (transformed reaction times where the time for the equivalent valid trial using the same cue is subtracted from the reaction time for the invalid trial being studied). The participants in these experiments experienced less cost when moving their attention in accord with reading direction. This was true in both the horizontal and vertical orientations. It was concluded that due to learned responses from reading and writing, words facilitate attention shifts that are in accord with, but not against, reading direction. There were however a number of problems with Experiments 1 and 2. Notably they used the same 20 words over and over again, which meant the task lacked ecological validity for an experiment that concerns itself with reading. Further there was poor experimental control over the magnitude of the cues and targets since they were colour changes of the individual characters which comprised the words. Accordingly their magnitude varied according to which characters were being illuminated.

Experiments 3 and 4 were designed to address the perceived weaknesses of Experiments 1 and 2. Different words were used on every single trial, and cues and targets of a fixed magnitude (small overlaid dots of colour) were used. Experiment 3 used words in an attempt to replicate the findings of Experiments 1 and 2. Experiment 4 was identical to Experiment 3 with the exception that non-lexical stimuli were used. These were rectangular “placeholders” of approximately the same size and shape as letters. These experiments were both unsuccessful. Not only did they not find the expected reading direction effects, they did not even show a main effect of validity whereby the fastest reaction times were found on trials where participants did not have to move their attention. This indicated that in these experiments, attentional cuing had been unsuccessful. If the cues were failing to draw participants’ attention, then it was impossible to reach conclusions about the data in these experiments. On examination of the data, it was concluded that the most likely explanation for the failure to find any effects was that the cues and targets were of insufficient magnitude to attract attention. It was decided to modify the cues and targets and then re-run these experiments.

Experiments 5 and 6 were re-runs of experiments 3 and 4 with much larger cues and targets. Instead of small dots of colour overlaid on the words, the cues and targets were now large colour patches in the background behind the words. Experiment 5 was much more successful than Experiment 3. A main effect of validity was found, and more interestingly an object based benefit for within word targets was found, but only for words which were displayed horizontally. Experiment 5 did not find the reading direction effect found in Experiments 1 and 2. It was concluded that when presented in its canonical orientation, words can indeed be processed like objects and display object based benefits. Experiment 6 was identical to Experiment 5, except that instead of words, the arrays were composed of “placeholders” which occupied the slots used by letters in the lexical version of the experiment. As with experiments 3 and 4, this experiment failed to find even a main effect of validity. Given that this experiment had far larger cues, and had far more participants than the equivalent Experiment 4, the lack of a main effect of validity must have been coming from something other than statistical power or cue/target magnitude. Given that an almost identical experiment (Experiment 5) did find effects using word stimuli, it was concluded that the most likely explanation was that word stimuli serve to enhance attention allocation to the stimuli arrays. The non-lexical placeholder stimuli did not draw enough attention to the arrays in order to facilitate cuing. The remaining experiments of this thesis were devoted to explaining the discrepancy in results between Experiments 1/2 and 5.

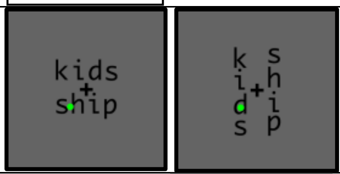
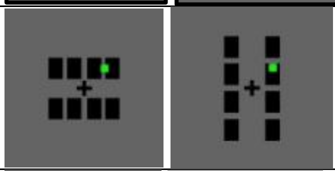
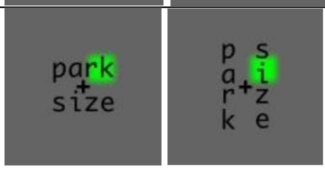
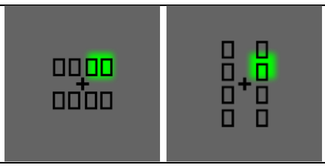
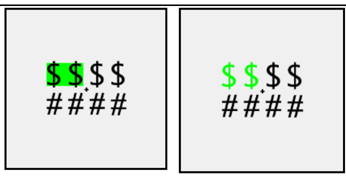
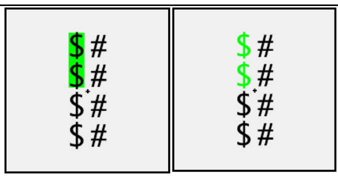
Experiment 7 sought to test the hypothesis that the differences between Experiments 1/2 and 5 were down to blocking context. Experiments 1 (horizontal presentation) and 2 (vertical presentation) were a between subjects manipulation of word orientation. Experiment 5 on the other hand used a within subjects mixed presentation. Experiment 7 was identical to Experiment 5, except that horizontal and vertical trials were blocked together. A within subjects design was still used, although which orientation was seen first by each participant was fully counterbalanced. While this experiment did show a significant main effect of cuing, it did not replicate the results of either Experiments 1/2 or 5. The trends for reading direction effects on costs ran in in the same direction as Experiments 1/2 but did not reach significance. It was concluded that the mixed presentation mode of Experiment 5 actually served to enhance sustained attention by participants and, consequently, any effects which may depend on it. Blocking context alone was considered an unlikely explanation for the discrepancies between Experiments 1/2 and 5.

Experiment 8 sought to test the hypothesis that the type of cue and target used could explain the differences between Experiments 1/2 and 5. Experiments 1 and 2 had used character illumination cues and targets, whereas Experiment 5 used background colour patches. Hypothetically, the character illumination cues and targets may have been inducing more “local” processing by drawing attention to the letter sub-components of the word, whereas the background colour patches were encouraging a more “global” processing. This experiment presented only a single horizontally oriented 6-letter word displayed in the centre of the screen at any one time, with cues and targets appearing at any of its 6 letter positions. The type of cue and target was manipulated between subjects. There was a significant main effect of validity which indicates that the participants’ attention was being successfully cued. However, the looked for interaction between target location and cue/target type was not found. If the cue/target type was truly modulating attention deployment, then the shape of the target detection reaction time function across the 6 letter positions should have been different. It wasn’t. There was a small (non-significant) difference in reaction time induced by the greater intensity of the background colour patches, but no interaction. This was taken as evidence that the types of cues and targets were not responsible for the differences between Experiments 1/2 and 5. However, there was some concern that this experiment was ill suited to discover the effects being sought. Previous experiments had all concerned themselves with object based attention in two-word arrays. Experiment 8 concerned itself solely with attention deployment of attention inside a single word presented in its canonical orientation. While the types of cue and target did not seem to produce any meaningful modulation of attention deployment in this case, that does not mean they would not modulate attention in an experiment that used a paradigm similar to those used in Experiments 1-7.

Experiment 9 sought to re-examine the possible role of cue/target type in the modulation of attention in a “words as objects” paradigm. This experiment was a return to the roots of this project, with a design that closely mirrored that of Experiment 1, with the exception that cue/target type was manipulated as a between subjects variable, and that the stimuli words were composed solely of symbol strings. This experiment found a significant effect of validity, indicating successful cuing. Also there was within object benefit effect that closely resembled that found by Experiment 5. This effect was much more pronounced when the background cues/targets were used, indicating a possible reason why Experiment 5 (background colour patch cues/targets) found the effect whereas Experiments 1/2 (character illumination cues/targets) did not. There was also a marginally significant effect of reading direction on reaction time costs data which ran in the same direction as the one found in Experiments 1/2. It was tentatively concluded that the type of cue/target used could serve to amplify the within object benefit, while the reading direction effects were driven by the repeated presentation of the stimulus words. Experiment 10 continued this theme, but in the vertical dimension. It was almost a direct replication of Experiment 2, again save for the fact that the stimuli words were composed of symbol strings and that cue/target type was manipulated as a between subjects variable. Again a main effect of validity was found indicating successful cuing. However this time no object based effect was found, mirroring Experiment 5 where this effect was not found on vertical trials. There was an effect of reading direction on costs, but interestingly it differed depending on the type of cue and target used. When character illumination cues and targets were used, a “standard” reading direction effect which mirrored Experiments 1 and 2 was found (more costly to move attention against reading direction). When background colour patch cues and targets were used, a reversed reading direction effect was found. This was taken as conclusive evidence for the type of cue and target used modulating attention to the stimuli in a “words as objects” style paradigm. Again the fact that the reading direction effect was found here and not in the vertical trials of Experiment 5 was attributed to the repeated stimulus presentation used on Experiments 1, 2, 9 and 10, but not 5. This also served to explain why Experiment 8 did not find modulation of attention based on the type of cue/target used: these effects are much more pronounced in the novel vertical orientation.

The results of all 10 Experiments in this thesis are summarised in table 6-1.

TABLE 6-1 - SUMMARY OF ALL 10 EXPERIMENTS IN THIS THESIS

Experiment	Example Arrays	Results	Conclusions
1 “Horizontal Words as Objects” (horizontal only)		Found a reading direction effect on reaction time costs data where shifts moving in reading direction were less costly.	Words themselves act as a cue to shift attention in accord with reading direction. Some aspects of the design were criticised for being sub-optimal, leading to the subsequent experiments.
2 “Vertical Words as Objects” (vertical only)			
3 “Small Dot Words as Objects” (mixed orientations)		No main effect of validity indicated that cuing was unsuccessful in this experiment.	Data relating to reading direction or object based effects cannot be interpreted without a main effect of validity. It was concluded that the cue/target intensity was likely too low for the intended purposes.
4 “Small Dot Placeholders” (mixed orientations)			
5 “Big Dot Words as Objects” (mixed orientations)		A “within object benefit” found for horizontal words. No reading direction effects.	Words are sometimes treated like objects.
6 “Big Dot Placeholders” (mixed orientations)		No main effect of validity.	Given the similarity with experiment 5, it was concluded that words help focus attention on this task.
7 “Blocked Words as Objects” (blocked orientations)	As experiment 5	Main effect of validity, no object or reading direction effects.	Blocking context alone cannot account for discrepancy between Experiments 1, 2 & 5
8 “Attentional Gradients Across Words” (horizontal only)		Main effect of validity, no interaction between cue/target type and RT function.	Cue/target type does not appear to explain discrepancy between Experiments 1, 2 and 5 – but a very different paradigm was used.
9 “Symbol Words as Objects (Horizontal)” (horizontal only)		Main effect of validity, object based effect on horizontal words, reading direction effects.	Cue/target type can explain differences between Experiments 1, 2 and 5. Repeated stimulus use accounts for reading direction effect.
10 “Symbol Words as Objects (Vertical)” (vertical only)		Main effect of validity, interaction of cue/target type and reading direction.	Cue/target type modulates reading direction effects in the vertical orientation only.

How do these findings fit in with the existing literature?

The reading direction effect found in Experiments 1,2, 9 and 10 appears to be a new finding within the context of a cued target detection paradigm. The costs of moving attention in accord with reading direction are lower than the costs of moving attention against reading direction. This effect was only found in studies which used character illumination cues/targets, repeated stimulus presentation, and between subjects presentation of stimulus orientation. However Experiment 7 (which used blocked presentation of orientation, but no repeated stimulus presentation and background colour patch cues/targets) did not find a statistically significant effect of reading direction, so it is concluded that these reading direction effects are largely a consequence of that repeated stimulus presentation in combination with the types of cues/targets. By seeing the same words over and over again, and by repeatedly seeing cues and targets embedded inside those words, it is concluded that an attentional gradient is formed which facilitates reading direction attentional shifts. Cues and targets which draw attention to the letter-level components within a word appear to facilitate this process, particularly in the vertical orientation. Since this effect was only visible with massively repeated stimulus presentation, it is unknown if this process occurs during natural reading, although it would be consistent the rightward attentional gradients predicted by both the EZ-Reader model of reading (e.g. Reingold & Rayner, 2006) and the SWIFT model of reading (e.g. Schad & Engbert, 2012) . As to why this effect is only visible with repeated presentation of the same stimuli, it may be that repetition serves to amplify the effects that are otherwise present at a low level. Conversely it is also possible that the reading direction effect is simply an artefact of a particular experimental method, and that it is not informative for normal reading. This would be an interesting area for further study, although finding a way of dissociating whether this is a “real” effect or an artefact of experimental design would be problematic. Additionally, while this is a novel finding within the context of a cued target detection paradigm looking primarily at covert shifts of attention, it should be noted that there is a well-known effect dealing with words and overt shifts of attention. For example Pynte, Kennedy and Murray (1991) made the observation that words themselves can act as a cue to shift overt attention under certain circumstances. Using an eye tracker it is possible to compel participants to fixate a part of a word other than their usual "Preferred Viewing Position" (PVP) which tends to be just left of centre. When participants were forced to fixate the end of words, they tended to make a saccade back towards the start of that word. Thus, the word itself acted as a cue to shift attention. However, if the ends of words act as a cue to fixate the beginning, this does run somewhat contrary to the findings of this study that found that cues at the beginning of words and targets at the end incur less cost or were faster than cues at the end and targets at the beginning. However, it is possible that a cue at the end of a word acts as a prompt to re-fixate that word, and it is the act of planning and executing this re-fixation that interferes with target detection at the start of the word. Further study would be needed to see if this reading direction cued target detection effect is in fact the same thing as the suboptimal viewing position eye movement effect. This study did not look at the probability of re-fixations for different classes of trial, although it is something that would be potentially informative as to the question of whether this thesis's "reading direction" effect is the same thing as a sub-optimal viewing position effect on re-fixations. If this were the case, a greater probability of re-fixation would be expected on the against reading direction trials compared to the in reading direction trials.

When compared to the results of Li and Logan (2008) the results of these studies are more varied. Experiments 1 and 2 failed to find Li and Logan's "within word benefit" altogether, Experiment 5 found it but only in the horizontal orientation and Experiment 9 also found it, but again only in the horizontal orientation. This would suggest that the processing of English words is fundamentally different from the processing of Chinese words. While Chinese words are capable of showing a within word/object benefit in both the horizontal and vertical orientation, English words only seem to show this effect in the canonical horizontal orientation. The likely explanation for this lies in the different characteristics of the two languages. Written Chinese does not directly relate to the phonology of the spoken language (although it does have phonological components) whereas written English does. The need to perform grapheme to phoneme conversion may explain the difference in object based effects. Perhaps decoding the phonology of English interferes with the formation of an object based representation when the word is written vertically? Also, Chinese words are composed of far fewer individual characters than English words. Being composed of comparatively fewer elements may facilitate an object based encoding of those words. That is, it may become harder to class a word as an object the more discrete elements it is composed of. This is consistent with what Lamy, Carmel, Egeth and Leber (2006) found when looking at object based effects. Additionally Chinese words do not have spaces between them, so they may be identified as words using quite different mechanisms. In Chinese, the boundaries of a word can only be identified after the word itself has been identified, which suggests that in Li and Logan's study, the attentional grouping into "objects" was very much a top-down effect. Whereas thanks to the spaces in English, word boundaries can be identified long before the word itself has been processed, suggesting that the effects reported in this thesis are likely to be a more bottom-up process. This observation is particularly interesting when considering the findings of Liu et al. (2011) who observed that there are two complementary types of "object based attention" at work in Li and Logan style paradigms: one a top-down form based on word identity and a second bottom-up form based on Gestalt grouping principles. They found that the Gestalt process was more sensitive to the blocking context of the experiment and was weakened by random intermixing of trial classes. Given the differences between English and Chinese it is likely that the latter Gestalt process was largely responsible for the findings in this study. That this effect is more sensitive to task constraints than the top-down lexically defined process may go some way to explain many of the difficulties encountered in this thesis. One point Liu et al.

(2011) drew particular attention to is that two character Chinese words are usually compound words, akin to English words like “Cow-boy”. The English words used in this thesis were not compounds, so there is no true analogue to Liu et al’s hypothesised “top down” grouping process. It is likely that if any such a top down process occurs with the word stimuli in this thesis, it operates on very different principles. A further point of comparison between this study and Li and Logan is that Chinese can also be written in either the horizontal or vertical orientation, whereas English is almost exclusively written horizontally. Vertical writing in Chinese is now less common in mainland China, but still seen frequently in signs and book spines. Certainly vertical writing will be considered much more canonical for Chinese readers than it will be for English readers, for whom it is a relatively novel orientation. The differences between English and Chinese discussed above may well serve to make Chinese more prone to displaying object based effects than English. For example, if the “vertical” object based effect found in Chinese is dependent on previous exposures to words in vertical orientations then the English reading participants would be put at a disadvantage , since they have much less exposure to vertical writing. This is consistent with Davis and Holmes (2005) who found standard object based attention effects disappear when using novel shapes. However, it should be noted that this effect is not contingent on having seen that particular word before. Experiment 9 used novel symbol strings, and yet participants still appeared to treat them as an object when presented horizontally. Experiment 10, which did the same thing but with vertically presented words, did not find an object based benefit. Thus it seems likely that English readers have a disposition to forming object based representations from horizontally presented text, but do not need to have seen that text before. Previous experience with written materials seems to be the determining factor here. One final point of comparison between the experiments in this thesis and Li and Logan deserves to be made – that of the methods employed. The visual angle subtended by individual characters on the screen was very similar at least in terms of width, although English letters are taller than they are wide, whereas Chinese characters are approximately square. Accordingly in Li and Logan's experiment, the text would have given the appearance of being slightly smaller onscreen. In both Li and Logan and the experiments in this thesis, the participants were subjected to a periodic (i.e. not on every trial) reading check to try and emphasise the importance of reading the stimuli words. As discussed elsewhere, it can be argued that such intermittent checking does not actually make reading all that "important" to the participants and certainly makes reading of considerably lesser importance than would be found in the typical reading experiment. Finally, Li and Logan told their participants to focus on *accuracy* (although they did tell them RT's were being recorded) whereas the instructions given throughout this experiment emphasised the importance of *speed*. In the verbal instructions given to participants both speed and accuracy were described as important. The relatively different weighting given to speed and accuracy is another point that must be borne in mind when comparing this thesis with Li and Logan (2008). It is likely that at the very least, this difference contributed to the markedly slower reaction times observed by Li and Logan, although the intrinsically slower reading times (per character) observed by Chinese readers was considered the dominant explanation for this difference. It is unknown if or how instructing participants to focus on speed or accuracy will modulate the effects found in this thesis.

The results of these studies also supports the notion of there being top-down influences in reading as suggested by Reicher (1969) and Johnston and McClelland (1974). Words come from a relatively constrained stimulus set that we are highly familiar with. Consequently we utilise prior knowledge when processing words and this process can override local perceptual effects to an extent. When the stimulus arrays were composed of actual words, this seems to have an effect on how attention is allocated to them. Experiment 5 successfully found an effect of validity and an object based benefit, whereas Experiment 6 which was identical save for the fact that the words were replaced by placeholders, found no significant effects. This suggests that the presence of words in the arrays served to concentrate attention in such a way as to produce these effects. Indeed Auclair and Sieroff (2002) did find that real words modulated how attention was allocated to arrays – specifically that real words induced a wide distribution of attention to cover the whole word. The specifics of how the absence of a word-like attentional modulation would induce the null result of Experiment 6 are unknown, although this is considered to be factor responsible since it reflects the only difference between Experiment 6 (null results) and Experiment 5 (various significant results). However, the experiments comprising this thesis did not find the same results as Sieroff and Posner (1988) who found that the top down influence of words was so profound that it overrode almost all attempts to induce cuing within a word. Most of the experiments in this thesis did find a significant effect of validity; that is, attention could be drawn to a specific location within a word. However it is of interest to note that the effects seemed much more pronounced when using non-lexical symbol strings in Experiments 9 and 10. It seems as though a certain degree of word-likeness is required to adequately concentrate attention for these tasks (a criteria the placeholders stimuli failed to meet) but once this threshold is reached, the use of actual words may serve to dampen effects.

The results of this thesis do not agree with LaBerge (1983). He found that when words were processed as a whole, reaction times across the word were fast and flat (reaction times from each letter position in the word were all equally fast). In all experiments comprising this thesis there have been noticeable differences in reaction times across the word stimuli. This may not reflect a contradiction with the results of LaBerge's study. He also found that when local processing of the words was enforced, the reaction times did indeed differ within a word. This may indicate that despite attempts to encourage "reading" in all of the experiments in this series, the participants were not processing the whole word to a sufficient degree to induce LaBerge-style flat reaction times. Experiment 8 was intended to demonstrate that background colour patch cues and targets induce a more flat reaction time gradient across words, and that character illumination cues induce a more local processing of the words, effectively mirroring the findings of LaBerge. Experiment 8 was not successful at doing this however. For both types of cue/target, reaction times were faster nearer the centre of the word. Neither of the cue/target types induced reaction times that were noticeably "flatter". While Experiments 9 and 10 demonstrated that the types of cue and target did indeed modulate how a within object benefit manifests itself, it is an open question as to whether the cue/target type modulates attention in the way observed by LaBerge. Experiment 10 using the novel vertical presentation mode did indeed find modulation of the reaction time function across the word's length by the cue/target type, but this effect was not observed in experiments using the canonical horizontal presentation mode. LaBerge style "whole word" processing may reflect an entirely different process to the object based and reading direction effects demonstrated in Experiments 5 and 9.

The results of this thesis do however agree with the findings of Prinzmetal and Millis-Wright (1984) and Prinzmetal, Treiman and Rho (1986). These studies found that words, pseudowords and familiar acronyms appear to be processed as a unit by the human attentional system, illustrated by the type of errors people make when processing words. The findings of this thesis certainly suggest that there does seem to be a demonstrable "reading unit", where a group of letters comprising a word (Experiment 5) or a word-like unit (Experiment 9) are processed as a singular entity, evidenced by the within-object benefit observed. It is of note that Experiment 9 did not use real words at all, and yet still found object-like processing. This may indicate two things: either Prinzmetal et al.'s experiments were too conservative and these effects can also be found with symbol strings, or the object based processing explored in this thesis is a separate type of "perceptual unit" to that observed by Prinzmetal et al. Certainly the symbol strings of Experiment 9 do not meet any of the criteria Prinzmetal et al. identified for their perceptual units (legal bigrams, familiarity, morphological and orthographic constraints). The object based effects found in this thesis may relate to a different process. Since searching for object based effects with words is a relatively novel area of research, this is a recurring problem. While it is possible to draw commonalities with existing research which has found similar effects, it cannot be conclusively shown that they come from the same process. Further, the observed effects may relate to the same process as Prinzmetal et al's "perceptual units" when using word stimuli, and a different process when using symbol strings. Experiment 9 may have found object based effects for quite different reasons to Experiment 5. This criticism will be addressed in the forthcoming section.

At its inception, this thesis was heavily inspired by the work of Deheane, particularly the theories expounded in Dehaene (2009). The idea that words are very much like objects at the neurological level was taken as a strong indicator that they may also be like objects at the behavioural level and show object-based attentional effects. During the course of this PhD, I have since become rather more equivocal in how much of a leap I am willing to make from neurological data to behavioural outcomes. Nonetheless, it cannot be denied that this line of thinking was a major source of inspiration early on, and accordingly it deserves to be drawn to some conclusion. Of particular interest to the works of Dehaene is the finding of this thesis that object based effects, when they are found in English, are only found with horizontally presented text. Dehaene specifies that the neurological representations of words are formed through exposure, although he does not specify the exact mechanism. Given that English readers have very little exposure to vertical writing it is not then surprising that the object based effects of English words would only be found in their canonical orientation. Tydgat and Grainger (2009) expanded on Dehaene's theory by describing a system of reading specific receptive fields that are specially tuned for detecting letters and allowing them to be formed into words. Crucially these receptive fields are oriented horizontally in the part of the visual field used for reading single words. While the authors are clear that they mean "receptive fields" to be interpreted in the computational sense (although they are open to a neurological interpretation), this offers a potential explanation as to why this thesis only found object based effects with horizontally oriented words: it was only in this orientation that we have detectors that allow the formation of normal word representations. If this is true then it implies that object based attentional grouping is at least part of the normal processing of English words, since it is dependent on a normal reading orientation being used, and is not found when participants are forced to form their word-based attentional groupings by more novel means.

The preceding papers seem to imply that the object based effect found in Experiments 5 and 9 is a newly observed effect of words on attention. Additionally, the fact that the same effect was found for words (Experiment 5) and symbol strings (Experiment 9) suggests that, if it is caused by a single process, that process is not to do with the stimuli being a word per se. That is not to say that this process is not informative to how human beings read – a low level perceptual process which can be demonstrated using both words and symbol strings may still be crucial to the process of reading even if it is not unique to the process of reading. It is hypothesised that some sort of perceptual grouping process , probably derived from Gestalt grouping principles, (see Wade & Swanston, 2001), is responsible for the perceptual chunking into "objects" observed in Experiments 5 and 9. While a certain degree of word-likeness seems to be required for the process to occur, it also appears that top-down influences from real words can serve to make this effect hard to detect (for example the null result of Experiment 7). The effect was relatively easy to find in Experiment 9 however. This object chunking process seems to act only upon things that meet a certain level of word-likeness: placeholder arrays were inadequate. For English readers, it also only seems to operate when text is presented in its familiar horizontal orientation, probably because the receptive fields hypothesised by Tydgat and Grainger (2009) only detect words when they are presented horizontally. That is, the individual "letter detectors" are arranged horizontally along a retinotopic frame of reference. They are not arranged in a way that is conducive to detecting vertically written words, or at least not without turning the head 90 degrees, or reading the words one letter at a time. Since this effect has been observed only in 2 out of 10 experiments further speculation about the constraints acting on this process is not possible. The seeming contradiction between only finding object based effects with word-like stimuli, while real words seeming to dampen object based representations would be an interesting area for further study.

A recurring finding throughout this series of experiments is that presenting English words in a relatively novel vertical orientation seems to produce qualitatively different results from presenting them in their canonical horizontal orientation. It is not merely that processing is slower or less efficient; there are fundamental differences in the type of processing the words are subjected to. While Li and Logan (2008) were able to demonstrate their object based effect in both the horizontal and vertical orientations, this series of experiments have only succeeded in demonstrating such an effect in the horizontal orientation. This is consistent with the claims of Mapelli, Umilta, Nicoletti, Fanini and Capezzani (1996) who found that the horizontal orientation is the "canonical" orientation for English and that some attentional effects are specific to this orientation. This does not appear to be the case in Chinese, or at least not to the same extent. Again, this is likely to do with the orientation of the receptive fields hypothesised by Tydgat and Grainger (2009).

Potential Problems

The first potential problem when interpreting these results is the possibility that Experiments 5 and 9 may have found the same object based effects for entirely different reasons. Experiment 5 may have displayed an object based effect due to lexical processing, whereas Experiment 9 may have displayed an object based effect due to the Gestalt principles of similarity and proximity. Certainly the symbol strings of Experiment 9 were composed of 4 identical characters, so grouping by similarity will have been a strong process. While this cannot be denied as a possibility, for Experiment 9 to have so effectively simulated the results of Experiment 5, the different process employed would have had to exactly duplicate the results. That an entirely different process could produce such similar results seems unlikely in the extreme. More likely is that Experiments 5 and 9 employed overlapping processes, with some held in common and some unique to each experiment. While the letters composing the words in Experiment 5 were not nearly as similar as the symbols of Experiment 9, they were nonetheless reasonably similar inasmuch as they were all letters. Accordingly, even if the Gestalt principle of similarity was more pronounced in Experiment 9, it was still likely to contribute to the effect observed in Experiment 5. Due to consistent spacing, the grouping principle of proximity will have been of equal intensity in both experiments. The letters used in Experiment 5 will have been more familiar than some of the quite esoteric symbols used in Experiment 9, and anything to do with lexical access will have been unique to Experiment 5. Given how much easier it was to find the desired effects using symbol strings compared to words, it seems likely that any effects of lexical access serve to reduce object based effects for that word, likely due to the influence of top down factors (ironically the very same top-down factors which were the basis of the object-based effect found by Li and Logan, 2008). In the language of Caramazza and Hillis (1990), the internal representation of a word appears to interfere with the lower level perceptual processes (e.g. Gestalt Grouping, responding to Cues etc.). Nonetheless, at the very least it seems likely that object based effects are part of what goes on in real reading.

Grouping by similarity cannot explain the object based effects by itself. If that were the case, Experiment 6 (which used absolutely identical placeholder stimuli) should also have found such an effect. Instead it found no effect of cuing at all. This suggests that some additional criteria beyond similarity is needed for this effect to be demonstrated. One hypothesis is that the somewhat more “word like” stimuli of Experiments 9 and 10 allowed the object based effects to show through. The receptive fields hypothesised by

Tydgat and Grainger (2009) only respond to “characters”, although what constitutes a character is not precisely defined. On the basis of the findings in this thesis, it is suggested that the boundary between what is and is not a character lies somewhere between placeholder stimuli (not a character) and the symbol strings of experiments 9 and 10 (qualify as a character). Another possibility is that the array needs to contain two clearly delineated groups of stimuli. In Experiment 6, all 8 characters on screen were the same. In Experiments 9 and 10 there were two groups of 4. This will likely have facilitated grouping those characters together into perceptual units. These two possibilities are not necessarily mutually exclusive. Future studies using geometric shapes instead of characters could possibly tease these two possibilities apart, although caution would be needed since Experiment 6 demonstrated that effects of cuing appear greatly reduced in entirely non-lexical arrays.

The next issue that needs to be addressed is that there are a number of different ways of characterising an “object based effect”. Li and Logan (2008) used a 2 (row) by 2 (column) by 3 (validity) ANOVA coupled with a planned comparison between invalid in and invalid between trials. This was not used in this thesis for two reasons: a 3 way ANOVA seemed needlessly complex when a 2 way would suffice and it was necessary to first establish that there was in fact a main effect of validity (the fast valid trials provided a good control condition). Accordingly, the planned comparison utilised in this thesis instead looked at both levels of invalid trial compared to valid trials. This can be characterised as the difference between comparing two new drugs with one another directly, or instead comparing both of them to a control substance of known properties. Egly et al. (1994) on the other hand defined an object based benefit in terms of the reaction time costs associated with both classes of invalid trial. This is very similar to the analysis in this thesis labelled “Reaction Time Costs – Within vs. Between Word Attention Shifts”. This analysis only came back (marginally) significant in one of the experiments (Experiment 9). For the experiments in this thesis, an object based effect is defined as a situation where invalid between trials differ significantly from valid trials, but invalid in trials do not. Partly this choice was to do with the magnitude of the effects found; only Experiment 9 displayed an effect big enough that a direct invalid in/invalid between comparison would be returned significant (and then only using a one-tailed analysis). This choice was also made since it allowed the invalid trials to be compared to a control condition. If everything was working as it should, the valid trials should be responded to fastest so they make a good control. Consequently, in 3 experiments looking at object based effects, there are 3 different ways of defining that effect statistically. This is less than ideal. What they do have in common is all of these analyses look for a reaction time benefit on invalid in trials compared to invalid between trials, however that is defined. The analyses in this thesis are consistent with that aim. The use of different ways of defining an object based effect can be attributed to the fact that these effects are rather difficult to pin down. Of course, the most important thing is consistency – once you have chosen a definition you must stick with it. On deciding to use valid trials as a control comparison, this decision was stuck with throughout all 10 experiments.

One glaring omission in this series of experiments is that no information at all has been gleaned about how either the reading direction or the object based effects change over time. Originally it had been hoped to create an experiment with a variable cue-target onset asynchrony to observe how the reading direction and object based effects develop over time. Like most cognitive experimental effects it is likely that there is a point in time before which such effects cannot be observed, and a presentation duration after which they disappear altogether or indeed turn into inhibitory effects that run in the opposite direction. Since it took 10 experiments to nail down the observed effects, there was not time to explore the time course of the reading direction and object based effects. All experiments that found either the reading direction or the object based effects presented the “words” onscreen for 1500ms prior to very short duration (100ms) cues and targets. This would be an interesting area for further study.

One of the most pressing criticisms that could be levelled at this series of experiments is that they do not reflect real “reading” at all. All of the experiments in this thesis involved presenting words, or word-like stimuli, in the centre of a screen either one or two at a time. This is very far removed from reading as it usually occurs. While it is certainly the case that one cannot learn everything about reading by only conducting studies looking at single word perception, it can still be argued that these sorts of studies have a role to play. If scientists are interested in how the perceptual system treats single words, they (at least sometimes) need to look at them in isolation in order to avoid the noise generated by large bodies of text. It is certainly a risk, indeed it is likely, that the processing of single words by themselves will be qualitatively different from those same words when embedded in text. This limits the kinds of inferences that can be made. However, it is also very likely that much of the low level processing of those words will be conducted in the same way as when it is embedded in text, and this processing will be much more readily observable when dealing with single words. It is also worth noting that “reading” will likely involve a great many processes that are nothing to do with reading, one of which is likely to be object processing. Indeed, it may be possible to “read” without utilising the full range of processes humans usually employ. This is likely with readers who have some form of dyslexia for example, since at least part of the usual process of reading is inaccessible to them. In an more extreme example Grainger, Dufau, Montant, Ziegler and Fagot (2012) demonstrated a form of “reading” in Baboons, despite them having no knowledge of the alphabetic, semantic or phonological significance of what they were reading. This implies that it is possible to partly dismantle the process of reading into its constituent sub-processes. One of the arguments made by this thesis is that that object based processing is one of the most important of those sub-processes, and it likely explains much of what Grainger et al.'s Baboons were doing. It may also be informative in how dyslexics with phonological problems are nonetheless able to sight read.

More problematic than the fact that the words are presented by themselves in the middle of the screen is the question of how the participants were processing those words. LaBerge (1983) and Johnston and McClelland (1974) demonstrated that how a word is processed can have profound impacts on how attention is allocated to that word. Participants can selectively process part of a word, or they can process the whole thing. To make these experiments as close to real reading as possible, it had been hoped to push participants toward "whole word" processing by requiring them to read the stimulus words. This was not enforced on every trial but rather by a check at a periodic interval. Thus for most trials it is fair to say that the participants were subjecting the words to considerably less processing than they would in a true reading scenario. The reaction time functions found in Experiment 8 did not look like those obtained by LaBerge in his "whole word" processing condition. While it has not been conclusively demonstrated that this processing mode has anything to do with the object based attention studied here, it is nonetheless true that it cannot be conclusively shown how participants were processing the stimulus words in this series of experiments. If a different method of attending to the words could be induced, quite different results may be found.

In most psycholinguistic research the data is analysed using what is known as the F1 (participants) x F2 (items) criterion. That is two separate ANOVA analyses, one using the traditional "by participants" method of calculating scores and the other treating individual items in the dataset as if they were the participants. If both of these analyses come back significant it is generally taken as an indication that the experiment has yielded a real effect which is generalizable both to other participants and other sets of stimuli. While the studies in this thesis all use a standard F1 ANOVA, an F2 ANOVA is not performed in any of the experiments in this thesis. This means that the possibility of significant effects disappearing in an item analysis cannot be ruled out. Were this found to be the case, it would indicate that the observed effects were being driven by a subset of the items used and were not present for all the items in the stimulus set. This would typically be a much bigger problem for traditional psycholinguistic experiments where the status of the word stimuli is the independent variable, since it raises the possibility of a systematic error. In these experiments the occurrence of a word array was fully counterbalanced so that it occurred in the different conditions equally often, greatly reducing the potential for a systematic error. Nonetheless, it is still possible that only some of the word arrays in this experiment produced, for example, reading direction effects. The reason an item analysis was not done was because item effects are outside of the scope of this thesis, but it is however considered very likely that they exist. For example words with a higher lexical frequency may exhibit a more pronounced object based effect, or words with different phoneme boundaries may affect how attention is shifted within them. That said, since demonstrating the main object based effect at all was so challenging, the effects of individual items was considered beyond the timeframe of this project. If such an analysis revealed that individual items were affecting results, these effects would need to be quantified. Doing so effectively would be the work of another PhD thesis by itself. Consequently the matter was left to rest. Since an item analysis has not been done, it must be acknowledged that these findings are unlikely to generalise to all word stimuli. However, this does not mean the findings of this thesis cannot be generalised at all. The effects of interest have been demonstrated with several different stimuli sets. Experiments 1 and 2 demonstrated a reading direction effect using one stimuli set, Experiment 5 demonstrated an object based effect with another and Experiments 9 and 10 demonstrated both using still another stimuli set. Clearly these effects have at least some generalizability. The specifics of how individual items modulate these effects are a matter for future researchers.

Finally there is an issue of cue reliability. From the early work of Michael Posner it has been understood that the reliability of cue in pointing to the target location can have profound effects on how participants attend to the stimuli. If the cue is not reliable enough, participants will tend to ignore it altogether. All of the experiments in this thesis used the same level of cue reliability. On 66% of trials where a response was required, the cue and the target were in the same location. This was chosen as a compromise. A reliability level which would encourage participants to “trust” the cue was needed, but also one which would allow some study of the all-important “Invalid” trials. Thus there had to be a reasonable amount of data produced that did not involve valid trials. Waechter, Besner and Stolz (2011) and Risko, Stolz and Besner (2005) both found that manipulating the level of cue reliability affects how participants allocate their attention to the stimuli. Broadly speaking, the less reliable the cue is, the more widely participants allocate their attention. In the case of 100% reliable cues, participants’ attention to things outside the cued region is greatly reduced or eliminated altogether. It is unknown what effect changing the level of cue reliability would have on the effects studied in this thesis, although it is considered highly likely that there would be an effect. If for example cue/reliability was increased to 85%, it seems very probable that effects such as the reading direction effect (where participants are cued to one end of a word, but the target appears at the other) would be altered. This is a matter future researchers may wish to address.

Future Directions

On the basis of the findings in this thesis, several suggestions can be made for future area of study. In particular it would be interesting to define what exactly constitutes the “object based” grouping found in Experiments 5 and 9. For example, is this effect found simply when there are two discrete groups of stimuli onscreen? If participants are presented with one “word” composed of 4 triangles and another “word” composed of 4 squares, will they attentionally group them into objects which display the object based effects found in this thesis? What happens if similarity is manipulated? Words could also be composed of more/less similar shapes to see if this modulates the size of the effect (for example pentagons vs hexagons, rectangles vs parallelograms etc.). If this were found to be the case, it would have interesting implications for how these effects are interpreted when dealing with real words. It would imply that the effect found was driven purely by a perceived “two groups of 4” attentional mapping. That would then raise the question of why visually dissimilar letters forming words appear to be able to simulate the very obvious similarity of geometric shapes. If the proposed study was unsuccessful in finding object based effects, the lack of generalizability to geometric shapes would imply there is something special about the stimuli used in this thesis. While Experiment 5 used letters and Experiment 9 used symbols to demonstrate an object based effect, they were both unambiguously “characters” – that is marks humans use for writing. This may have some special significance for the object based effects found. Were this found to be the case, this might suggest some motor involvement in demonstrating object based effects. Are the effects only found with things humans have experience of writing?

Another potential study would be a more in-depth exploration of whether the “reading direction” effects can be simulated with non-lexical stimuli. It was hypothesised in this thesis that the reading direction effects appeared to be driven by repeated use of the same stimuli, and further amplified by the use of character illumination cues and targets. If this truly is the case, then it should be a simple matter to demonstrate this effect using groups of stimuli that are not words by modulating levels of repetition and cue/target type. This could be explored as part of the experiment proposed above using geometric shapes. If successful, a follow-up experiment could use each stimulus array only once to see if the reading direction effect disappears.

A further suggestion is to study how object based effects change over time. One of the original research ideas following the completion of experiments 1 and 2 was to vary the time course of the experiment. Due to the 10 experiments it took to finally reach a conclusion regarding the findings of Experiments 1 and 2, this was not done. It is entirely possible that varying the initial presentation duration of the words, or the time between cue and target, will affect the magnitude and direction of object based effects. It is quite possible that the timings used in this thesis were in fact sub-optimal for finding these effects and are partly responsible for the many null results. If the time course of object based effects could be more precisely defined, future research would struggle less to display the effects they wished to study.

As discussed in the “Potential Problems” section above, one thing not explored by this thesis was the potential impact of different types of word stimuli on both the object based effects and reading direction effects. A study is proposed to deal specifically with this issue. A very large corpus of stimuli should be selected, the words from which should then precisely labelled for word type, word frequency, phoneme boundaries and morphological regularity. Ideally this corpus should contain numerous representative words from extreme ends of the scale on all of the criteria of interest. A standard “Words as Objects” paradigm should then be run using these stimuli. While a standard F1 x F2 ANOVA could be used to identify whether the words were modulating the effects of interest, coupled with follow-up analyses (e.g. factor analysis) – moving over to Linear Mixed Effects modelling for the analysis would allow both the presence of item effects and the nature of those effects to be explored in a single analysis. For a study such as this it is likely that a very large experiment containing more trials than have been used to date, and using more subjects, will be needed to attain the needed statistical power for such a detailed analysis.

Finally, a study exploring the effect of cue reliability on object based and reading direction effects is proposed. The experiments in this thesis used only one level of cue reliability: cue and target were in the same location on 66% of trials that required a response. It is likely that manipulating this figure will affect the results obtained, since cue reliability is known to be closely linked to how attention is distributed to stimulus arrays. A standard "Words as Objects" paradigm is proposed with a 3 level between subjects factor: Cue reliability. Cue reliability levels of 50%, 70% and 90% should be used to provide a good range from cues that are highly reliable, to cues that are not reliable at all. On the basis of published research (e.g. Waechter et al, 2011) it is considered likely that participants in the 50% reliability condition will adopt a much wider attentional distribution than those in the 90% reliability condition. How this different attentional distribution will modulate the object based effects is unknown. One potential problem with this experiment is that the different conditions would each yield different numbers of invalid trials for study (which are essential when studying object based and reading direction effects). The number of trials used in all versions of the experiment would need to be very large to ensure that even the 90% reliability condition still yielded sufficient data points for analysis.

Conclusions

Sometimes readers of English words appear to display a reading direction "reaction time cost" effect. This appears to be modulated by both the repetition of the stimulus words and the types of cue/target used. Reading direction effects were only observed in experiments which repeatedly used the same stimulus arrays throughout the experiment. On horizontal trials the effects were consistently in the direction of being less costly to shift attention in accord with reading direction. On vertical trials only, when character illumination cues/targets were used, less cost was incurred moving attention with reading direction, whereas when background colour patch cues/targets were used less cost was incurred going against reading direction.

It also appears that in at least some circumstances words are indeed processed like objects, as evidenced by their displaying an object based benefit. This object based processing appears to be modulated by a number of different things, including the type of cue/target used and the lexical status of the word (word vs. symbol string). Background colour patch cues/targets elicited bigger object based effects than character illumination cues and targets, and non-lexical symbol strings appeared to have a more pronounced object based benefit than real words.

Object based processing of real words is likely a low-level perceptual process that doesn't have much to do with the visual stimulus being a word per se, but is nonetheless likely to be important for real world reading. The process by which object based representations of words or word-like stimuli are formed is probably governed by Gestalt grouping principles such as proximity and similarity.

Both the reading direction effect and the object based effect are new findings in English for an experiment using a cued target detection paradigm. These results have the potential to add to the literature on both object and word processing. This opens up an exciting new avenue of research which has the potential to explain much of the low-level attentional processes used to decode written English words.

References

Adelman, J. S. (2011). Letters in time and retinotopic space. *Psychological Review*, *118*(4), 570–82.

Adelman, J. S., Marquis, S. J., & Sabatos-DeVito, M. G. (2010). Letters in Words Are Read Simultaneously, Not in Left-to-Right Sequence. *Psychological Science*, *21*(12), 1799.

Auclair, L., & Sieroff, E. (2002). Attentional cueing effect in the identification of words and pseudowords of different length. *The Quarterly Journal of Experimental*, (55A (22), April 2012), 445–463.

Baayen, R. H., Piepenbrock, R., & Gulikers, L. (1995). The CELEX lexical database (release 2)[cd-rom]. *Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania [Distributor]*. Philidelphia, PA: Linguistic Data Consortium, University of Pennsylvania [Distributor].

Bains, W. (2012). Comment on “Orthographic processing in baboons (Papio papio)”. *Science (New York, N.Y.)*, *337*(6099), 1173; author reply 1173.

Besner, D., Risko, E. F., & Sklair, N. (2005). Spatial attention as a necessary preliminary to early processes in reading. *Canadian Journal of Experimental Psychology = Revue Canadienne de Psychologie Expérimentale*, *59*(2), 99–108.

Besner, D., & Stolz, J. (1999). Context dependency in Stroop’s paradigm: When are words treated as nonlinguistic objects? *Canadian Journal of Experimental Psychology*, *53*(4), 374–380.

Biederman, I. (1987). Recognition-by-components: a theory of human image understanding. *Psychological Review*, *M*(2), 115–147.

Calvo, M. (2009). Lateralised covert attention in word identification. *Laterality*, (April 2012), 37–41.

Caramazza, A., & Hillis, A. E. (1990). Levels of representation, co-ordinate frames, and unilateral neglect. *Cognitive Neuropsychology*, *7*(5), 391–445.

Connor, C. (2005). Neuroscience: Friends and grandmothers. *Nature*, *435*(June), 1036–1037.

Davis, G., & Holmes, A. (2005). Reversal of object-based benefits in visual attention. *Visual Cognition*, *12*(5), 817–846.

Dehaene, S. (2004). Evolution of human cortical circuits for reading and arithmetic : The “ neuronal recycling ” hypothesis . In S. Dehaene, R.

Duhamel, M. Hauser, & G. Rizzolatti (Eds.), *From monkey brain to human brain*. Cambridge, Massachussetts: MIT Press.

Dehaene, S. (2009). *Reading in the Brain*. *The science and evolution of a human invention*. New York: Viking.

Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron*, *56*(2), 384–98.

Dehaene, S., & Cohen, L. (2011). The unique role of the visual word form area in reading. *Trends in Cognitive Sciences*, *15*(6), 254–62.

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: a proposal. *Trends in Cognitive Sciences*, *9*(7), 335–41.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology. General*, *123*(2), 161–77.

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Research*, *42*(5), 621–36.

Fiez, J., & Petersen, S. (1998). Neuroimaging studies of word reading. *Academy of Sciences of the United*.

Fischer, M. (2000). Word centre is misperceived. *Perception*, *29*(1991), 337–354.

Fischer, M. H. (1996). Bisection performance indicates spatial word representation. *Brain Research. Cognitive Brain Research*, *4*(3), 163–70.

Fischer, M. H. (2004). Orthographic contributions to perceived word center. *Brain and Language*, *88*(3), 321–330.

Flowers, D. L., Jones, K., Noble, K., VanMeter, J., Zeffiro, T. a, Wood, F. B., & Eden, G. F. (2004). Attention to single letters activates left extrastriate cortex. *NeuroImage*, *21*(3), 829–39.

Funes, M., Lupiáñez, J., & Milliken, B. (2007). The modulation of exogenous Spatial Cueing on Spatial Stroop interference: Evidence of a set for "cue-target event segregation." *Psicológica*, 65–95.

Goodale, M. A., & Milner, A. D. (2004). *Sight unseen: an exploration of conscious and unconscious vision*. Oxford: Oxford University Press.

Grainger, J., Dufau, S., Montant, M., Ziegler, J. C., & Fagot, J. (2012). Orthographic processing in baboons (Papio papio). *Science (New York, N.Y.)*, *336*(6078), 245–8.

Grainger, J., Dufau, S., Montant, M., Ziegler, J. C., & Fagot, J. (2012). Response to Comment on "Orthographic Processing in Baboons (Papio papio)." *Science*, *337*(6099), 1173–1173.

Haxby, J. V, Gobbini, M. I., Furey, M. L., Ishai, a, Schouten, J. L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science (New York, N.Y.)*, *293*(5539), 2425–30.

Inhoff, A. W., Pollatsek, A., Posner, M. I., & Rayner, K. (1989). Covert attention and eye movements during reading. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, (769850741).

James, K. H., James, T. W., Jobard, G., Wong, A. C. N., & Gauthier, I. (2005). Letter processing in the visual system: different activation patterns for single letters and strings. *Cognitive, Affective & Behavioral Neuroscience*, *5*(4), 452–66.

Johnston, J. C., & McClelland, J. L. (1974). Perception of letters in words: seek not and ye shall find. *Science (New York, N.Y.)*, *184*(4142), 1192–4.

Jordan, H., & Tipper, S. (1998). Object-based inhibition of return in static displays. *Psychonomic Bulletin & Review*, *5*(3), 504–509.

Jordan, H., & Tipper, S. P. (1999). Spread of inhibition across an object's surface. *British Journal of Psychology*, *90*(4), 495–507.

Just, M. a, & Carpenter, P. a. (1980). A theory of reading: from eye fixations to comprehension. *Psychological Review*, *87*(4), 329–54.

Kriegeskorte, N., Mur, M., Ruff, D. a, Kiani, R., Bodurka, J., Esteky, H., … Bandettini, P. a. (2008). Matching categorical object representations in inferior temporal cortex of man and monkey. *Neuron*, *60*(6), 1126–41.

LaBerge, D. (1983). Spatial extent of attention to letters and words. *Journal of Experimental Psychology. Human Perception and Performance*, *9*(3), 371–9.

Lamy, D., Carmel, T., Egeth, H. E., & Leber, A. B. (2006). Effects of search mode and intertrial priming on singleton search. *Perception & Psychophysics*, *68*(6), 919–32.

Lamy, D., & Egeth, H. (2002). Object-based selection: the role of attentional shifts. *Perception & Psychophysics*, *64*(1), 52–66.

Li, X., & Logan, G. D. (2008). Object-based attention in Chinese readers of Chinese words: beyond Gestalt principles. *Psychonomic Bulletin & Review*, *15*(5), 945–9.

Lindell, A., Arend, I., Ward, R., & Norton, J. (2007). Hemispheric asymmetries in feature integration during visual word recognition. *Laterality*, (April 2012), 37–41.

Liu, D., Wang, Y., & Zhou, X. (2011). Lexical- and perceptual-based object effects in the two-rectangle cueing paradigm. *Acta Psychologica*, *138*(3), 397–404.

Luo, C., Lupiáñez, J., Funes, M., & Fu, X. (2011). The modulation of spatial congruency by object-based attention: Analysing the "locus" of the modulation. *The Quarterly Journal of …*, (April 2013), 37–41.

Mapelli, D., Umilta, C., Nicoletti, R., Fanini, A., & Capezzani, L. (1996). Prelexical Spatial Representations. *Cognitive Neuropsychology*, *13*(2), 229–256.

Marí-Beffa, P., Cooper, S., & Houghton, G. (2012). Unmixing the mixing cost: contributions from dimensional relevance and stimulus-response suppression. *Journal of Experimental Psychology. Human Perception and Performance*, *38*(2), 478–88.

Marmolejo-Ramos, F. (2009). Reading between the lines: The activation of background knowledge during text comprehension. *Pragmatics & …*, 1–52.

Marr, D. (1983). *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. Henry Holt and Company.

Müller, M., Malinowski, P., Gruber, T., & Hillyard, S. (2003). Sustained division of the attentional spotlight. *Nature*, 0–4.

Pegado, F., Nakamura, K., Cohen, L., & Dehaene, S. (2011). Breaking the symmetry: mirror discrimination for single letters but not for pictures in the Visual Word Form Area. *Neuroimage*, *55*(2).

Posner, M., & Cohen, Y. (1984). Components of visual orienting. *Attention and Performance X: Control of …*.

Price, C. J., & Devlin, J. T. (2003). The myth of the visual word form area. *NeuroImage*, *19*(3), 473–481.

Price, C. J., McCrory, E., Noppeney, U., Mechelli, A., Moore, C. J., Biggio, N., & Devlin, J. T. (2006). How reading differs from object naming at the neuronal level. *NeuroImage*, *29*(2), 643–8.

Prinzmetal, W., & Millis-Wright, M. (1984). Cognitive and linguistic factors affect visual feature integration. *Cognitive Psychology*, *16*, 305–340.

Prinzmetal, W., Treiman, R., & Rho, S. (1986). How to see a reading unit. *Journal of Memory and Language*, *25*, 461–475.

Proverbio, a M., & Adorni, R. (2009). C1 and P1 visual responses to words are enhanced by attention to orthographic vs. lexical properties. *Neuroscience Letters*, *463*(3), 228–33.

Pynte, J., Kennedy, A., & Murray, W. S. (1991). Within-word inspection strategies in continuous reading: Time course of perceptual, lexical, and contextual processes. *Journal of Experimental Psychology: Human Perception and Performance*, *17*(2), 458–470.

Rayner, K. (2009). *Eye movements and attention in reading, scene perception, and visual search. Quarterly journal of experimental psychology (2006)* (Vol. 62, pp. 1457–506).

Reicher, G. M. (1969). Perceptual recognition as a function of meaninfulness of stimulus material. *Journal of Experimental Psychology*, *81*(2), 275–80.

Reichle, E. D., Pollatsek, A., & Rayner, K. (2006). E–Z Reader: A cognitive-control, serial-attention model of eye-movement behavior during reading. *Cognitive Systems Research*, *7*(1), 4–22.

Reingold, E. M., & Rayner, K. (2006). Examining the word identification stages hypothesized by the E-Z Reader model. *Psychological Science*, *17*(9), 742–6.

Risko, E. F., Stolz, J. a, & Besner, D. (2005). Basic processes in reading: is visual word recognition obligatory? *Psychonomic Bulletin & Review*, *12*(1), 119–24.

Roth, H., Lora, A., & Heilman, K. (1992). Effects of monocular viewing and eye dominance on spatial attention. *Brain*, *125*, 2023–2035.

Schad, D. J., & Engbert, R. (2012). The zoom lens of attention: Simulating shuffled versus normal text reading using the SWIFT model. *Visual Cognition*, *20*(4-5), 391–421.

Seghier, M. L., & Price, C. J. (2011). Explaining left lateralization for words in the ventral occipitotemporal cortex. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *31*(41), 14745–53.

Sieroff, E., & Posner, M. (1988). Cueing spatial attention during processing of words and letter strings in normals. *Cognitive Neuropsychology*, *5*(4), 451–472.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology*, *81*(1), 174–6.

Subbiah, I., & Caramazza, A. (2000). Stimulus-centered neglect in reading and object recognition. *Neurocase*, *6*(1), 13–31.

Tamura, H., & Tanaka, K. (2001). Visual response properties of cells in the ventral and dorsal parts of the macaque inferotemporal cortex. *Cerebral Cortex (New York, N.Y. : 1991)*, *11*(5), 384–99.

Tanaka, K. (2003). Columns for complex visual object features in the inferotemporal cortex: clustering of cells with similar but slightly different stimulus selectivities. *Cerebral Cortex (New York, N.Y. : 1991)*, *13*(1), 90–9.

Tatler, B. W. (2009). Current understanding of eye guidance. *Visual Cognition*, *17*(6-7), 777–789.

Theeuwes, J., Mathôt, S., & Grainger, J. (2013). Exogenous object-centered attention. *Attention, Perception & Psychophysics*, *75*(5), 812–8.

Theeuwes, J., Mathôt, S., & Grainger, J. (2014). Erratum to: Exogenous object-centered attention. *Attention, Perception, & Psychophysics*, *76*(2), 642–642.

Theeuwes, J., Mathôt, S., & Kingstone, A. (2010). Object-based eye movements: The eyes prefer to stay within the same object. *Attention, Perception, & Psychophysics*, *72*(3), 597.

Thierry, G., & Price, C. J. (2006). Dissociating verbal and nonverbal conceptual processing in the human brain. *Journal of Cognitive Neuroscience*, *18*(6), 1018–28.

Treccani, B., Cubelli, R., Sala, S. D., & Umilta, C. (2008). Spatial coding of word-initial letters: Evidence from a Simon-like task. *Psychonomic Bulletin & Review*, *15*(1), 168–173.

Turkeltaub, P., Eden, G., Jones, K., & Zeffiro, T. (2002). Meta-analysis of the functional neuroanatomy of single-word reading: method and validation. *Neuroimage*, *16*(3), 765–780.

Tydgat, I., & Grainger, J. (2009). Serial position effects in the identification of letters, digits, and symbols. *Journal of Experimental Psychology. Human Perception and Performance*, *35*(2), 480–98.

Wade, N. J., & Swanston, M. T. (2001). *Visual Perception: An Introduction*. Hove: Psychology Press.

Waechter, S., Besner, D., & Stolz, J. a. (2011). Basic processes in reading: Spatial attention as a necessary preliminary to orthographic and semantic processing. *Visual Cognition*, *19*(2), 171–202.

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: the SERIOL model and selective literature review. *Psychonomic Bulletin & Review*, *8*(2), 221–43.

Wickens, C. D. (2007). Attention to the second language. *IRAL - International Review of Applied Linguistics in Language Teaching*, *45*(3).

Wright, R. D., & Ward, L. (2008). *Orienting of attention* (1st ed.). Oxford: Oxford University Press.

APPENDIX I - Word pairs used in Experiments 1 and 2

All words had four characters, a written frequency of at least 6.39 per million, and an overall spoken and written frequency of over 6.37 per million.

Word Pairs	
Crew	Fist
Debt	Crop
Face	Dust
Flag	Heir
Goat	Hymn
Lawn	Pork
Pine	Gulf
Rice	Foam
Tank	Bird
Wage	Tool

APPENDIX II - Word pairs used in Experiments 3-7

All words had 4 characters and a lemma frequency of at least 200 per 16.3 million.

Word Pairs		Word Pairs		Word Pairs		Word Pairs	
hope	spot	roof	call	drum	cent	wish	lads
cats	tops	fist	barn	toys	tray	lamp	cell
hill	guys	sand	cave	clay	beer	wine	gulf
food	pits	runs	bays	lace	myth	dogs	ship
king	shoe	hole	palm	lake	bush	star	door
wing	tomb	wits	mood	inch	scar	lies	pine
trip	size	rose	earl	shot	sock	sink	form
milk	sort	blow	herd	mill	bags	lane	link
bone	toes	dawn	pack	cuts	drug	sigh	club
task	race	airs	ways	pond	bill	goat	back
mark	dust	arts	nail	chap	fund	kids	fall
mess	foot	band	walk	pint	town	acts	rail
rugs	game	pets	inns	duck	past	work	jams
deal	jaws	mums	moon	term	pole	fort	talk
hour	days	beds	rate	caps	furs	lens	wire
lift	tale	wage	dads	stop	feed	pain	pans
kiss	fact	view	boys	tape	crew	fork	part
dish	rows	rent	gift	teas	mask	pair	poll
rage	nuts	fire	jean	beef	ease	bits	sign
jobs	gold	bees	stem	dirt	sale	snow	male
news	dome	east	plot	type	cold	luck	lead
fish	fool	once	boat	rise	yard	oaks	lamb
camp	tube	gown	drop	pots	bull	ages	rest
pass	tool	pump	bear	chip	bids	gods	coin
ears	will	mode	maid	song	test	left	fits
keys	role	sets	tent	gaps	gear	bean	sins
leaf	rods	noon	help	zone	hens	wind	dead
shed	look	west	gate	fans	pink	mine	deck
mist	calf	step	folk	aims	burn	jail	cost
self	loan	play	bows	seal	edge	site	hats
pact	flat	park	pins	rule	cage	cops	tips
word	base	slip	bowl	bath	soil	tune	road
cast	coat	odds	glow	flow	prey	kind	bomb
risk	wars	bond	gene	fate	hold	urge	plan
cars	vans	pile	arms	ring	case	cash	tons
rats	heel	dear	cape	tear	boon	sums	ends

APPENDIX III - Word stimuli used in Experiment 8

All words were 6 characters long and had a written frequency of at least 50 per 16.3 million.

dishes	stable	agents	survey	method	hamlet
merger	months	statue	reward	bronze	traces
letter	apples	aspect	minute	bodies	temper
author	fibres	snakes	thread	frenzy	fright
saloon	packet	racket	rivers	mother	talent
vessel	shower	damage	growth	crimes	visits
glance	frames	profit	terror	factor	genius
victor	hatred	intake	ghosts	bricks	fringe
member	trades	crowds	metres	speeds	victim
plains	outfit	hazard	shells	granny	county
supply	infant	shadow	thesis	cancer	breath
miners	battle	litter	notice	circus	orange
troops	grapes	patrol	avenue	output	salary
tackle	revolt	farmer	manner	number	stress
dreams	campus	critic	cherry	ticket	scheme
muscle	hearts	titles	wicket	armour	scenes
holder	finger	beauty	strand	knives	powers
nurses	figure	cracks	breast	pistol	prison
amount	church	impact	humans	reason	escape
bushes	depths	ankles	carbon	agenda	armies
camels	remand	stairs	centre	heroes	ounces
lovers	duties	turner	regret	spring	socket
refuge	smithy	engine	potato	agency	elbows
mirror	locker	dances	drawer	hunter	cities
towers	noises	origin	tables	dozens	worlds
trends	thighs	client	artist	habits	spirit
switch	accent	saddle	doubts	grains	coffin
prayer	dealer	treaty	sounds	gloves	honour
images	floors	wisdom	valley	skirts	cotton
second	brandy	target	selves	fields	cheese
copper	regime	fences	ground	winter	weight
comedy	motion	couple	search	notion	custom
jungle	strain	tissue	losses	oxygen	chiefs
stones	rubber	garage	butter	insect	series
movies	silver	cellar	meadow	needle	sleeve

topics	wishes	thanks	barrel	threat	reader
travel	plight	styles	stance	allies	length
pillar	detail	scores	claims	places	pitman
stores	angels	bureau	inside	tenure	bottle
lesson	fabric	studio	clergy	defeat	guests
master	budget	cereal	errors	player	picnic
points	ideals	parade	blouse	judges	spread
rumour	prizes	drinks	petrol	planet	excuse
senate	salmon	review	timber	stages	parent
purity	clinic	market	memory	deputy	owners
behalf	themes	signal	pounds	coming	chairs
rulers	grants	people	waiter	models	candle
policy	groups	heaven	waters	praise	carpet
ladder	script	summer	leaves	boards	burial
pilots	sphere	stocks	planes	strike	killer
singer	nephew	region	masses	acting	angles
pieces	lights	banker	papers	demons	sailor
hunger	voices	forces	rhythm	tongue	archer
temple	voters	insult	crisis	events	ranges
shroud	nation	quarry	speech	trains	elders
circle	danger	keeper	sector	phrase	garden
relics	cinema	deaths	medium	autumn	desert
bundle	carter	parcel	debate	virtue	tonnes
screen	arches	fruits	canvas	sticks	humour
leader	horses	volume	fellow	handle	league
courts	breeze	resort	repair	racing	slaves
shares	doctor	porter	editor	assets	breach
corpse	covers	career	miller	whisky	worker
theory	houses	square	collar	priest	stands
appeal	routes	throne	equity	forest	palace
living	empire	sherry	guards	recipe	clouds
fourth	helmet	beasts	corner	motive	misery
pocket	tastes	orders	gravel	cousin	burden
riches	winner	choice	dragon	issues	rental
marble	bunker	saints	canyon	poster	wonder
prices	gambit	warmth	bishop	latter	cheeks
thrust	tracks	device	inches	excess	rocket
decade	bosses	scales	slices	course	status
horror	shapes	bucket	tribes	things	ritual
margin	ridges	mining	remark	novels	murder
shades	camera	supper	person	writer	layers
chapel	senses	pencil	powder	brains	option
stamps	luxury	colony	organs	vision	chorus
weapon	blades	arrest	export	prince	wheels

lounge	change	street	throat	midday	morale
vacuum	symbol	credit	sheets	injury	liquid
basket	regard	pupils	castle	copies	kettle
dinner	charge	plates	favour	walker	ballot
runner	debris	sunset	toilet	facade	record
youths	tennis	chance	beings	family	window
season	denial	eleven	access	string	butler
chains	wastes	plants	public	bowman	domain
cliffs	affair	rabbit	calves	whites	parish
actors	tunnel	bullet	passes	source	voyage
museum	cement	joints	wrists	health	branch
mouths	pillow	hotels	makers	stroke	closet
tricks	matter	jacket	racism	system	adults
nerves	shorts	driver	ladies	cheque	monkey
checks	sorrow	fisher	bottom	grades	summit
trials	flames	metals	sample	yellow	timing
states	dollar	jackal	smiles	rights	shifts
rescue	wounds	flower	ballet	levels	bridge
flight	shirts	sports	hedges	nights	giants
sister	velvet	poison	border	height	values
colour	object	little	cattle	estate	trucks
ghetto	blacks	limits	reform	former	female
donkey	hammer	causes	sweets	expert	secret
others	gossip	spaces	pelvis	school	blocks
friend	coffee	poetry	lawyer	lenses	legend
dancer	liquor	stream	barley	safety	skills
column	ascent	middle	wealth	angler	button

APPENDIX IV - Symbol strings used in Experiments 9 and 10

All strings were 4 characters long.

String Pairs	
====	%%%%
££££	§§§§
&&&&	¥¥¥¥
????	++++
¤¤¤¤	÷÷÷÷
!!!!	@@@@
####	$$$$
©©©©	¬¬¬¬
®®®®	¢¢¢¢
±±±±	~~~~