WORD RECOGNITION AND READING IN ARABIC

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by

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ABSTRACT

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The thesis reports six experiments investigating word recognition and reading in Arabic.

Experiment 1 looked at the word superiority effect in Arabic word recognition using brief presentations of stimuli (five-letter real words, pseudo-words, non-words, and inverted real words) in a Reicher-Wheeler task. The results of this experiment showed advantages for the recognition of words over pseudo-words and illegal non-words, and for pseudo-words over illegal non-words. Experiment 2 was a follow-up experiment that also examined the word superiority effect in Arabic by using the lexical decision task. In this experiment, participants viewed briefly presented real words and legal non-words, with the results showing that Arabic real words were recognised quicker and more accurately than non-words.

Experiment 3 investigated the landing position effects for three, five, and seven letter words in Arabic using eye movements while reading. The results showed that the preferred viewing location (PVL) is at the right of centre of words in Arabic, similar to that for Hebrew. Experiment 4 re-examined the optimal viewing position in Arabic word recognition using five-letter Arabic words and non-words in a lexical decision task. The results showed that participants recognised words most quickly and most accurately when fixating inter-letter locations at the middle of words, indicating that the OVP for Arabic word recognition is at a word's centre. Experiment 5 used the Reicher-Wheeler task and Experiment 6 used the lexical decision task to re-examine the claim that an anatomical division in the human fovea has consequences for word recognition. The findings revealed the superiority of the right visual field for words displayed outside the foveal and no asymmetries for words displayed within foveal vision.

Thus far the research has made an important advance on our understanding of processes involved in Arabic word recognition by revealing that word superiority and pseudo-word superiority effects similar to those reported in Latinate languages are also observed in Arabic, and that the OVP effect in Arabic differs from that found in English. The reading results indicate that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic.

ACKNOWLEDGMENTS

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ABBREVIATIONS

PAW   Part of an Arabic Word

WSE   Word Superiority Effect

ms   Milliseconds

cm   Centimetre

PSE   Pseudo-Word Superiority Effect

IAM   Interactive model activation

PVL   Preferred Viewing Location

I-OVP Inverted Optimal Viewing Position Effect

OVP   Optimal Viewing Position

RVF   Right Visual Field

LVF   Left Visual Field

LH   Left Hemisphere

RH   Right Hemisphere

SFT   Split-Fovea Theory

Chapter 1   Introduction

To investigate word recognition in Arabic it is essential to introduce the general background of the research topic. As the first part of this general introduction, this chapter will first define word recognition and then explain the most influential accounts of how readers recognize a word. The chapter will also introduce the tasks to be employed to assess word recognition in Arabic and explain their advantages compared to other common tasks used in this field of study, outlines the research aims, objectives, hypotheses and research questions, as well as giving information about Arabic and an overview of the thesis.

In the field of experimental psychology word recognition has substantial importance and plays a fundamental role in reading. It occurs during the transformation of visual stimuli in the visual system and gives the stimuli meaning. Word recognition is also considered as a key component of reading, whether isolated or within passages, and it is essential for developing additional skills that are associated with comprehension. Reading is considered a complex cognitive process in which readers engage in making sense of given information, such as a word based on knowledge obtainable from the text. Miller (1988) suggested some important aspects in order to achieve successful reading based upon understanding: firstly, decoding or visual information processing which changes the text into linguistic information. Secondly, there is the process of relating the textual information with previous knowledge, which remains the key to overall understanding.

One of the most influential accounts that explain how readers recognize a word comes from the studies of Cattell (1886), who proposed the earliest model of word recognition. This model was centred upon the proposal that words can be identified from their overall shape, and thus a word is recognized not simply in terms of its

component letters, but as a whole. Cattell was the first psychologist to be recognized as a leading founder of psycholinguistics, which contains the science of reading research. Cattell (1886) stated that, "I find it takes about twice as long to read (aloud, as fast as possible) words which have no connexion as words which make sentences, and letters which have no connexion as letters which make words" (Cattell, 1886, p. 64). Based on the findings of many experiments, Cattell suggested that participants had read words not making sentences at a rate of about 1/4sec. per word, compared with words making sentences at a rate of about 1/8sec. per word. Thus, the participants found it faster to read words in a sentence than words in isolation. Participants were faster at reading letters that did not make words in 1/40sec.; Cattell (1886) also reported that capital and small letters did not differ in their reading times. Therefore, this is important because it shows that research on the facilitating effects of word shape on word recognition has a very long history, dating back to the nineteenth century, and that the visual properties of the shape of a word, specifically the word overall shape, are used to recognize the word.

The contribution of word shape as an indication to word recognition was also examined by researchers (e.g., Woodworth, 1938; Underwood & Bargh, 1982), by comparing words in lower or upper case. For example, in Woodworth (1938) lowercase text was read more quickly than uppercase text (e.g., words printed in capital letters, like LIFE and LINE are harder to identify than when the same words are printed in normal lower letters, life and line). In this experiment the participant's task was to read similar lines of text, with one part totally written in uppercase and the rest written in lowercase. The findings showed that the participant read constantly quicker (by a factor of 5-10 percent) when the text was written in lowercase than when written in uppercase. This was taken as evidence to support the word shape model since lowercase text allows exceptional patterns of processing for the word-neutral characters; whereas when text is

written in uppercase, the entire letters have the same exact size or they have the same rectangular shape and so are more complicated to read. Further evidence that was provided by researchers (e.g., McCelland, 1976; Wheeler, 1970), showed that readers use the whole word unit when recognizing it. One explanation of this finding is that a word presents richer visual information than a string of nonsense letters because of their distinctive overall shapes. Therefore, these findings show that word shape information is important in allowing direct visual access while reading a word.

The processes by which the human brain reads a word are very complex and have been the topics of many research experiments in psychology. There are different types or levels of word processing, such as orthographic, phonological, and semantic levels (e.g., Ferrand & Grainger, 1994). With brief exposure durations, there is insufficient enough time for the processing of word recognition to move very far in the phonological and semantic levels, and therefore the focus of this thesis will be on how orthographic structure (e.g., IAM, McClelland & Rumelhart, 1981; the Multiple Read out Model, Grainger & Jacobs, 1996; Davis, 1999) affects recognition of letter-strings and their constituent letters (e.g., Frost, Kugler, Deutsch, & Forster, 2005; Velan & Frost, 2009). One popular attempt to explain the Word Superiority Effect (WSE) reported by Cattell and subsequently replicated in numerous studies, is that when stimuli are presented very briefly, people perceive real words better than non-words (e.g., Baron & Thurston, 1973; Jordan, Patching, & Milner, 2000; Reicher, 1969; Wheeler, 1970, this will be explored in more detail in Chapter 2). Therefore, the IAM (e.g., McClelland & Rumelhart, 1981), which remains an important and influential model of word recognition that is at the core of research in word recognition in both psychology and education. The interactive model of word recognition is a hierarchical system with separate levels for the identification of letter features, letters, and words,

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which was developed in an attempt to reproduce in a computational simulation the key findings relating to the recognition of words by humans. This included providing a computation account of the WSE and PSE. Basically, this suggests that both feature processing and word processing provide additional support to letter processing. Therefore, when a letter appears in a word, the letter is recognized more easily than when the letter appears alone or in a non-word.

There will be possible dissimilarities or similarities of processes for Arabic. For example, if Arabic readers process the letters in a word one letter at a time (in a serial manner), it should be more difficult to identify a letter in a word than that letter in isolation. If, however, Arabic readers process all of the letters in a word at once (in a parallel manner), it should be just as easy to identify a letter in a word as it is to identify that letter in isolation (these issues might be tested in further research), or may therefore result in the implementation of a serial processing strategy, from beginning letters to end letters (and therefore from right to left in Arabic), whereas words enjoy richer, more parallel processing (e.g., Allen & Emerson, 1991; Ans, Carbonnel, & Valdois, 1998; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

1.1 Word Apprehension Effect

Woodworth (1938) pointed out that familiar words, even when they were as long as 12 to 20 letters, could still be accurately identified when they were presented for 100 milliseconds. According to Neisser (1967), there are two possibilities when reading a word: all letters have to be known before a word can be recognized or just a few of the word's letters are required. For example, the necessity of identifying all the letters in a word appears to be disproved by the so-called "span of apprehension", which comprises just four or five letters if they are unrelated, but is greater if they form a word. This is called the "word-apprehension effect".

However, Neisser (1967) questioned this hypothesis and in actual fact confirms that the recognition of every one of a word's letters is unnecessary. Researchers have sometimes suggested that participants do in fact recognize all the individual letters in words and that the appearance of the word-apprehension effect in fact occurs only later in comprehension and may reflect economy in coding. For example, twelve letters (e.g., RPEENHIPNSAO) might not exceed the correct apprehension span, but they possibly overload the verbal memory. Therefore, in this way it can be assumed that the twelve letters were perceived in the same way when reorganized/rearranged according to spelling rules (e.g., APPREHENSION), and that the load of the memory is enlarged/lightened consequently since these letters can be encoded as a single string of letters that form a real word.

Although this type of recoding may provide one explanation for the word-apprehension effect when considered within brief exposure duration experiments, it does not fully explain the effect. For example, a participant can recognize even a four-letter word more correctly than a four letter non-word, even though the letters would fit easily within the span of memory. What is more, participants usually recognize words such as FOYEVER as FOREVER and DANXER as DANGER even though such words were not really presented (Pillsbury, 1897). This shows that a word is being recognized on the basis of something less than complete recognition of the entirety of its letters (Neisser, 1967).

It may happen that participants perceive just some of the letters of a particular word and then guess its identity from these letters. For example, a participant can recognise the word 'guess' from G-ESS, or the word 'letter' from LE-TER, therefore the participant can guess some letters which were not observed during the brief presentation of the word. This could be one of the ways by which words are recognized.

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Nevertheless, it cannot provide a general account of how words are recognised because it would imply a process of letter-by-letter processing that will be quite slow and require extensive use of higher order cognitive processes to guess the identities of missing or degraded letter information. By comparison, word recognition appears to be a very fast and reflexive process that does not depend on conscious reflection about the identity of individual letter, and research has provided evidence for the efficiency of cues instead of letters.

For instance, Neisser (1967) carried out an experiment in which the participant had to look at a list of three to six-letter words to search for a particular target word. This experiment task involved the participant reading and examining each word and finding out its meaning, or discovering its meaning to a sufficient extent to decide if it is one of the target words or not. The results showed that the participants recognized more than five words per second, so with less than 200 milliseconds per word and 100ms per single letter. This means that the participants had time to identify only two or three letters, thus it can be concluded that words are not constantly recognized through the identification of component letters.

Moreover, reflective explanations disagree with the letter-by-letter explanation in many cases. Even though the letter-by-letter explanation has been occasionally reported, evidence indicates that the entire word is involved in the recognition process immediately. For example, Pillsbury (1897) found that participants reported non-words (e.g., FOYEVER as FOREVER), so they saw nothing improper. It seems that the participants made a distinction between reading the whole word and perceiving particular letters from this word.

Researchers (e.g., Driver, Baylis, Goodrich, & Rafal, 1994; Humphreys & Mayall, 2001) have also highlighted the importance of the units of groups of letters

(e.g., ch, sh and th) that are smaller than complete words, when recognising the words. Therefore, this means those letters are joined into supra-letter units, which reduces the size of the whole words shape (e.g., Pring, 1981). Researchers (e.g., Jordan, 1990; Jordan, Thomas, Patching, & Scott-Brown, 2003) have also investigated the effects of visual degradation on recognizing the words. For example, Jordan, Thomas, and Scott-Brown (1999) reported an experiment in which they used a new term "illusion", which refers to when a participant sees an incomplete word as an entire and complete word, if the stimulus contains half of its original letters. This was discovered while Jordan (1995) collected examples of exterior letter combinations from four-letter English words (e.g., d--k from dark). The findings showed that participants were able to perceive words in their entirety even when perception of their component letters is prevented - "the illusory-letters phenomenon". This suggests that presenting just the exterior letter pairs of words may provide sufficient information to recognize the word and word recognition does involve identification of individual letters, but that this requires only a "cursory analysis of the physical characteristics of letters in certain positions" (p. 1415).

In order to study the word recognition processes involved in visual word recognition and reading, researchers use a number of different tasks, which are explained below.

1.2   Tasks used in Visual Word Recognition Study

This topic has been extensively investigated for over a hundred years. Various tasks have been used in these studies such as the Reicher-Wheeler task, lexical decision task, naming latency tasks and eye movements while reading.

What is the superlative task to utilize when investigating visual word recognition?

Researchers can have participants read words out loud, however this involves processes like speech production. The tasks that have been used in studying visual word

recognition, such as the Reicher-Wheeler and Lexical Decision tasks do not require reading aloud. Similarly, measuring of eye movements during reading provides a relatively direct measure of the difficulty readers have in identifying individual words without requiring reading aloud (e.g., Rayner, 1998, 2009).

1.2.1 The Reicher-Wheeler Task

The two-alternative Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970) involves participants viewing tachistoscopic presentations of stimuli before then being asked to indicate which of two alternatives was actually shown. For instance, if the word *work* was presented briefly as a stimulus, the efficiency of participants' recognition of this word may be tested by asking the participants to choose between the words *work* and *word,* where both alternatives are real words that differ by just one letter. A major advantage of the Reicher-Wheeler task is that when the two alternatives that are presented differ by just one letter, and all letter positions in words are tested an equal number of times, performance is unaffected by sophisticated guessing (Johnston & McClelland, 1973, 1978).

1.2.2 The Lexical Decision Task

The term 'lexical decision task' was coined by Meyer and Schvaneveldt (1971) after versions of this task had been used by many researchers for a number of years. It is defined as the measuring of how quickly people classify stimuli as words or non-words. Participants are instructed in this task to indicate as quickly and as accurately as possible whether the stimulus presented is a real word or a non-word by pressing the appropriate key on a keypad.

The lexical decision task can be appropriately controlled to avoid response biases. For instance, insuring a counterbalanced hand of response (e.g., Chiarello, Nuding, & Pollock, 1988; Jordan, Paterson, & Stachurski, 2009a) have argued that the

lexical decision task represents a pure measure for processing involved in recognising a word lexically. This task does not require, for instance, participants to articulate fluently by pronouncing accurately during the experiment.

1.2.3   The Naming Task

In this task the participant is presented with a stimulus word that he/she has to name out loud. Reaction time is measured from the appearance of the stimulus on the screen to the onset/start of the participant's pronunciation of that stimulus (Besner & Johnston, 1989). Researchers (e.g., Coltheart, 1978; Balota & Chumbley, 1984) have argued that the naming task involves processes that are in word production (e.g., spelling and sound rules), as an alternative of measuring the lexical task of recognising the word.

1.2.4   Why Combine the Reicher-Wheeler and Lexical Decision Tasks?

Some researchers have used overt naming to assess word recognition performance (e.g., in studies of hemispheric asymmetry) using Latinate languages (e.g., Brysbaert, 1994; Hunter, Brysbaert, & Knecht, 2007). Nevertheless, overt naming may perhaps be problematic because speech production in the vast majority of individuals is lateralised to the LH, therefore, naming can produce a spurious advantage for information projected to the left hemisphere because this information is projected to the hemisphere responsible for producing a response rather than because this hemisphere is superior for recognizing that information. However, not all tasks suffer from this problem, in particular one paradigm that has been used widely in word recognition research, the lexical decision task, requires stimuli to be identified as either words or non-words as quickly and as accurately as possible. The lexical decision may not provide the stringent controls offered by other tasks (e.g., the Reicher-Wheeler task), and may not be exclusively sensitive to processes of perception (e.g., Balota & Chumbley, 1984), however, it has been shown to be sufficiently used in word recognition when the

response hand is appropriately counterbalanced to avoid bias in responding (e.g., Chiarello et al., 1988).

1.2.5   Eye Movements While Reading

Researchers have gone further from the recognition of isolated words to a more natural context of reading. As a result of this phenomenon they have started using the eye movement paradigm. Since the twentieth century eye movement behaviour has been measured, and recent developments provide a much more accurate view of the relationship and monitored between eye movements and reading (e.g., Huey, 1908; Buswell, 1935; Rayner, 1978). Many researchers believe that the measuring of eye movements provides important information about the processing that occurs during sentence reading (e.g., Rayner, Well, & Pollatsek, 1980; Rayner & Pollatsek, 1996; Rayner, 1998; Rayner, Pollatsek, Ashby, & Clifton, 2012).

1.3   Semitic Language Characteristics

As it is well-known in the Semitic languages such as in Arabic and Hebrew words are created from triliteral roots that comprise a sequence of three consonants that express the general meaning of a word and combine with other letters (which form the word pattern) to create different inflections of meaning. In these two languages, vowel sounds are made by the use of diacritical marks, which are usually positioned under or above consonants to allow for accurate pronunciation. Nevertheless, diacritics are used mainly in beginner learners or children′s books, and are not used normally in everyday language (e.g., Abu-Rabia, 1998). The main feature of Hebrew and perhaps other Semitic languages is the three letters that are root consonants (Benuck & Peverly, 2004). Like Arabic, Hebrew is written from right to left. In particular, Arabic has the second-most widely-used alphabet in human societies, after the Latin alphabet, and yet Arabic is notably absent from word recognition research.

1.3.1 Arabic Writing Characteristics

Arabic consists of 28 characters. Characters do not contain upper and lower case and their shape depend on their position in the word (isolated, beginning, median and end) (El rube, El Sonni & Saleh, 2010). Although Arabic is considered to be the second most widely-used alphabetic language in the world after the Latin alphabet, Arabic is notably absent from word recognition research. It is important for the purposes of this research to understand the characteristics of Arabic that differ fundamentally from those of Latinate languages. Arabic is read from right to left:

(e.g., Ahmed was late for work so he could not eat breakfast.

أحمد تأخر عن العمل لذلك لم يستطع تناول طعام الإفطار هذا اليوم

◀·· *Arabic Reading Direction*).

Arabic is also formed in joined script in which spaces rarely exist between letters in word (e.g., hospital = مستشفى), even when formally printed (Elanwar, Rashwan, & Mashali, 2007), and the same word could be written with different possible letter elongations and still be read normally. For example, the Arabic word ماطر (which means rainy or wintry) can be written with these different possibilities: ماطــــــر, مــــــاطر or ر‍ــــــــاطـــــــــم, and still be read normally.

Arabic words are calligraphic (with an emphasis on the beauty of writing), with emphasis on the global rendering of the whole word rather than the detail of the letters, which are often thinned, crushed, or stretched provided that this contributes to the embellishment of the unit. On the other hand, to facilitate this calligraphic reading, diacritics and accents contribute to the understanding of the letters. Letters also in many cases have extremely similar basic forms and use dots to mark distinctions between them, such as the Arabic letters representing /t/ and /n/ (تـ & نـ) becoming the graphemes that represent /th/ and /b/ (ثـ & بـ , respectively), simply by adding or

changing the number or location of small dots within the word. Arabic allows the breakdown in PAW (Part of an Arabic Word), which could be compared to Latin syllables written separately. PAW introduces breaks in Arabic writing that have an influence on the recognition process (Belaid & Choisy, 2009). It also simplifies character comprehension and eases linear recognition. Figure 1.1 gives an example of the complexity of Arabic writing, with sub-words.
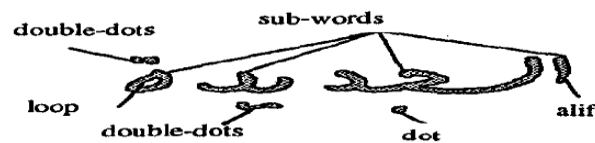
Figure 1.1. Example of Arabic writing

Source: (Belaid & Choisy, 2009, p.2)

Therefore, the Arabic letters may be connected from one side only or both sides, which depend on the word itself, also each word, may be composed of one unit (connected characters) or more. Some letters contain "ascenders" (e.g., ل) and "descenders" (e.g., ح) (El rube, El Sonni & Saleh, 2010).

In addition to this, the form of many Arabic letters is context dependent and these letters have different forms depending on where they occur in a word. For example, the letter /huh/ is represented by the following graphemes: Initial, when the character is at the beginning of a word and connected to the succeeding character (e.g., ه); Middle, when the character is in the middle of a word and connected to both preceding and succeeding characters (e.g., ﻬ); Final, when the character is at the end of a word and connected to the preceding character only (e.g., ﻪ); Isolated, when the character is alone or not connected to the preceding or succeeding character (e.g., ه). The essential shape of some letters is, however, maintained in some cases, (e.g., /Ta/ (ت); /Ba/ (ب)) (Abu-Rabia & Awwad, 2004).

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It may be that the cursive nature of Arabic decreases the distinctiveness of individual letters in words and introduces additional crowding (e.g., Pelli, Tillman, Freeman, Berger & Majaj, 2007) that might decrease letter resolution (e.g., Eviatar, Ibrahim, & Ganayim, 2004; Ibrahim, Eviatar, & Aharon-Peretz, 2002). For example, the five Arabic letters, / م -ي -ع -ل - ت/, can be written in cursive to form the word, /تعليم/. Unlike English, this means that letter shapes in the Arabic written system are context dependent, and that reading and eye movements depend on learnt characteristics of the writing system (e.g., Nazir, Ben-Boutayab, Nathalie, Decoppet, Deutsch, & Frost, 2004), so these features of Arabic may have an effect on word recognition.

Arabic words have prefixes, suffixes and also infixes so that their informativeness (and perhaps their roots) are more distributed throughout the word such as: سلطات = first; second and fourth, سفينة = سفن second; third and the final, تحصيل =حصل second; and تعبير = first; second and third, قصيدة = قصد first; second and fourth and سلط first; second and third, عبر second; third and the final. What is more, inserting diacritics where an ambiguity is suspected could be well interpreted by readers. There are six vowels in Arabic writing: (a), a, fatha, (فتحة) is indicated by a small stroke *above* the consonant, as "a"; (/) (b) i, kasra, (كسرة) is a similar stroke *under* the letter, as (/) "i" ; (c) u, damma (ضمة), is written like a miniature /waw/ above the letter, as boo. In order to indicate the absence of a vowel, a sokoon is written above the letter, as (o) "u". Usually these are considered short vowels, and they are lengthened by the addition of the long vowels which are considered part of the alphabet / (اوي) / a/ /waw/ / ya/. The replacement of letters by diacritics was added by linguists during the development of Arabic in order to facilitate clear meaning in the word. However, skilled readers usually bring considerable knowledge of literary Arabic to texts and usually read them without vowels, but "children and inexperienced adult readers read Arabic with vowels in the early stages of

their reading experience" (Abu-Rabia, 1998, p. 106). However, little is known about the processes underlying Arabic word perception.

1.4   Why this Research is Important

Research in word recognition is predominantly done in Latinate languages, with only limited extant work in non-Latinate languages. It is, therefore important to look at Arabic in greater detail and investigate these interesting phenomena.

As there is a large percentage of inefficient readers with varying degrees of reading difficulties, it is highly relevant to take up this subject, investigate this phenomenon and suggest ways to improve upon the reading performance of readers through this study. It would greatly help Arabic readers if the findings observed for the Latinate languages (e.g., English and French and perhaps other languages) are considered in detail/depth and applied in the context of the Arabic language. The degree of the universality of word recognition research would reveal the extent of the cognitive processes that are obviously hidden in the eye movement patterns. The research to be conducted would greatly aid the improvement of the word recognition processing of Arabic readers and the globally debated topic of reading and its importance in affiliating reading worldwide.

The potential effects of this research are that it would be one of the first studies to deal with word recognition and eye movements during reading of Arabic, and examine if the findings observed for Latinate languages (e.g., English and French) are also true for Arabic. There has been almost no research conducted into this topic of word superiority, visual field presented words, optimal viewing position and reading processes in Arabic reading, thus the results of this study will provide valuable information about the processes involved in the understanding of normal Arabic reading processes that will be of considerable interest to the research community worldwide.

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The present research is designed to gain an insight into the word recognition processes in a language that has some unique features and has not been extensively investigated.

1.5   Research Aims

The aim of the present study is primarily to look at basic processing in word recognition and reading, as established from research primarily in Latinate languages, for Arabic. The focus will be on examining the word recognition of skilled readers of Arabic using a range of standard paradigms (the Reicher-Wheeler task, lexical decision task, and eye movements while reading). The knowledge gains from the thesis will hopefully contribute to our understanding of the processes involved in Arabic word recognition. The research objectives can be summarised as follows:

1. To establish if word superiority, which means that people are more accurate in recognizing a letter in the context of a word than they are when a letter is presented in isolation, or when a letter is presented within a non-word (discussed in more details in chapter 2), as found in Latinate languages (e.g., English and French) are also observed for Arabic.

2. A further important issue is the significance of fixation locations in Arabic word recognition during reading words in sentences or in isolation, and whether this is similar to the results found in Latinate languages such as English and French.

3. To investigate landing position effects and eye movement behaviour during reading in Arabic, and the influence of word length on landing position and fixation probabilities, and the effect of initial fixation location on re-fixation probability and fixation durations.

4. To re-assess and to provide novel evidence that an anatomical division in the human fovea has consequences for word recognition.

1.6   Overview of This Thesis

This thesis (consisting of ten chapters) begins with the introduction, which outlines the research aims, objectives, hypotheses and research questions, as well as giving information about Arabic and an overview of the thesis.

Chapter 2 will begin by providing information about word recognition. It will review what has been found in relevant research. In this chapter the different approaches that have been developed to explain the WSE and PSE will be investigated. The main theme that arises from this chapter is that recognising a written word is not just reading, but it is more intricate and requires more demands on visual processing than distinguishing pictures or faces. This chapter also reviews relevant research which examined whether alphabetic languages (e.g., Arabic) with visual properties are fundamentally different from Latinate languages that also produce word superiority effects. As it will be discussed, the superiority effects reported for Latinate languages are also observed in Arabic.

Chapter 3 will outline the first two experiments in the current research. The study described in this chapter forms the basis of the article *Revealing the superior perceptibility of words in Arabic* published in the journal *Perception* (39(3), 426-428).

Chapter 4 will begin by providing information about the importance of fixation location in word recognition. It will review what has been found in relevant research. In this chapter the different approaches that have been developed to explain the preferred viewing position in naturalistic reading will be discussed. The main theme that arises from this chapter is that readers have a preferred viewing location (PVL) within words during the normal reading of a text, which means that there is a tendency for eye fixations to land between the beginning and middle letters of words during reading.

Chapter 5 will outline the third experiment in the current research. The study described in this chapter forms the basis of the work, *Reading Arabic text: Effects of word length on landing positions and fixation durations*, a poster presented at ECEM, Marseille, 21-25 August 2011.

In Chapter 6, attention will be turned to the important issue of how fixation location affects the recognition of individual words. In this chapter, a number of studies will be described which suggest that there is an optimal viewing position (OVP), which means that participants have faster responses and quicker naming times when words are fixated just to the left of their centre.

Chapter 7 will outline experiment four. The study described in this chapter forms the basis of the article *Evaluating hemispheric divisions in processing fixated words: The evidence from Arabic* published in the journal *Cortex* (doi: 10.1016/j.cortex.2011.02.012)

Chapter 8 will discuss hemispheric asymmetries in word recognition. In this chapter a number of studies that provide evidence for superior left hemisphere (LH) word recognition capabilities will be discussed, which means that words in alphabetic languages are processed more efficiently when presented at extrafoveal locations in the right visual hemifield (and so project directly to an observer's left cerebral hemisphere, LH) than when presented at extrafoveal locations in the left visual hemifield (and so project directly to an observer's right cerebral hemisphere, RH). Some researchers have claimed that word recognition is affected fundamentally by the precise location at which a word is fixated because a precise split in hemispheric processing at the point of fixation causes all letters to the left and right of fixation to project to different, contralateral hemispheres, and this has an effect on word recognition; therefore evidence for and against this view will be discussed.

Chapter 1 Introduction

In Chapter 9, experiments five and six will be outlined. The study described in this chapter forms the basis of the article *Evaluating Effects of Divided Hemispheric Processing on Word Recognition in Foveal and Extrafoveal Displays* published in the journal *PLoS ONE* (6(4), e18131).

Finally, Chapter 10 discusses the main theme that emerged from the findings of the current research. This chapter also highlights the limitation of the current study and the possible areas of future research. The general conclusions derived from the present research-led experiment point towards the significance of the findings put forward and effectively lead to the completion of the thesis.

Chapter 2   The Word Superiority Effect

This chapter provides an introduction to research on the Word Superiority Effect (WSE). The first section discusses pioneering work that examined perceptual processes in word recognition. In the second section, attention turns to letter-based approaches to word recognition. This section provides an overview of key models of word recognition (e.g., the Interactive Activation Model) that have previously been used to account for the effects of word superiority and pseudo-word superiority in Latinate languages such as English, and that therefore may provide the basis for accounting for counterpart effects in Arabic.

2.1   The Work of Cattell (1886) and Pillsbury (1897)

Since the nineteenth century (e.g., Cattell, 1886; Pillsbury, 1897), investigations of the perceptibility of alphabetic stimuli (e.g., English and French) have inspired considerable interest in how the physical characteristics of words are processed. A common question that has arisen relates to whether we see a word as a complete pattern or the sum of its letter parts. However, the research that has addressed this question over many years has been largely based on the Latin languages and formulated an approach to word recognition in terms of the characteristics of this alphabet. In particular, the view that words are seen as a complete pattern has been motivated by the possibility that readers attend to the pattern of ascending, descending, and neutral letters that are present in a word in order to recognise words. In the Latin alphabet, letters such as "l", "b", "k", "h", and "d" that project above the main body of letters are ascenders, whereas those such as "j", "y", "p", "q", and "g" that project below the main body of letters are descenders, and other letters such as "a", "e", "o" and "s" are considered to be neutral letters. Various accounts have been proposed to explain how this information might be used during word recognition. One account draws attention to the fact that in Latinate

languages letters have particular shapes of ascending, descending, and neutral characters and that combinations of these ascending, descending, and neutral characters might produce characteristic pattern in words. For example, "elephant" is composed of a particular sequence of ascending, descending, and neutral characters, therefore, one approach has been to argue that perhaps the reader uses this information about the pattern of the ascending, descending, and neutral characters to recognize the word.

By comparison, other approaches emphasise the envelope, or overall word shape that is created by the outline of ascending, descending, and neutral letter shapes, and propose that this information provides an important visual cue to the identities of words. For instance, Cattell (1886) argued that because these letter patterns in words are highly recognisable, words are immediately recognised on the basis of their shape, as a result of frequent exposure over time.

Pillsbury (1897) reported a series of experiments in which the participants viewed stimuli that were incomplete as whole words. The incomplete words were real words (e.g., chimney) in which a letter string was formed by replacing one of the letters (e.g. chimnzy), or by completely omitting one letter with an "x" typed over it, and the participants were exposed to the word for a duration of 0.2 seconds. Pillsbury found that under this condition, the extended presentation time, recognition of words did not depend on perception of their component letters as letter strings that form a real word, as with either the removal or replacement of one or two letters the word is still perceived. However, participants might use the other letters to work out the identity of the missing letters and therefore the identity of the word, without the need of the shape of the word as Pillsbury claims (e.g., Jordan, Thomas & Scott-Brown, 1999).

What is important about this work is that it has stimulated considerable interest in how the physical characteristics of words are processed. Clearly this has major

importance for the current research purpose, since one of the major aims of the current research is to determine whether the word superiority effect exists in Arabic. Therefore, it is clearly important to review previous word superiority research in more detail.

2.2   The Word Superiority Effect and Pseudo-Word Superiority Effect

The Word Superiority Effect (WSE) was first discussed by Cattell (1886), but is also a major feature of influential work by Reicher (1969) and Wheeler (1970). The WSE refers to the finding that, when viewing time is limited, the physical characteristics of words actually provide a more perceptible display than other types of alphabetic stimulus (e.g., non-words) (e.g., McClelland & Rumelhart, 1981; Grainger, 2008; Reicher, 1968; Wheeler, 1970). It is commonly accepted that this superiority effect reflects the efficiency of visual word perception. The word superiority effect is due to the ability of words to activate lexical entries in a way that unpronounceable non-words do not.

Similarly, the Pseudo-word superiority effect (PSE) (e.g., Carr, 1986; McClelland & Rumelhart, 1981) refers to the perceptual advantage that pronounceable non-words (e.g., dulk) have over a single letter or a letter in random letter string non-words (e.g., dlku). It is argued this is due to the ability of pseudo-words to partially activate processes normally involved in word perception (e.g., Baron & Thurston, 1973; Carr, 1986; McClelland & Rumelhart, 1981) and to provide partial activation to entries in the mental lexicon. The advantage for pseudo-words over single letters or random letter strings suggests that the recognition of the words might rely on features that are greater than individual letters, derived from supra-letter or configural analyses of letter groups and whole words (e.g., Jordan, 1990; Patching & Jordan, 2005).

The word superiority effect has usually been examined by using a tachistoscopic presentation as the exposure duration times of the stimuli presentations require careful

control. For example, previous word superiority experiments used the two-alternative Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970). This task involves brief displays (e.g., 17ms) of words followed by a forced choice between two alternatives that differ by one (critical) letter. For example, if "word" was displayed as the target, "word" and "work" may then be displayed as alternatives and participants would be required to indicate which alternative had been displayed as the target. However, some researchers (e.g., Rumelhart & Siple, 1974), argued that participants can use the information from some letters in a particular word to increase/improve their perceptual processing of other parts (that is, other letters) of the same word.

Therefore, to suppress influences of guesswork, which may artifactually advantage words, in such tasks, the correct response containing the critical letter (in this case "word") cannot be deduced from other parts of the stimulus (w-o-r) (e.g., Johnston, 1978). The Reicher-Wheeler task measures performance using two letters alternatives, based on which the test subject has to guess/predict the occurrence of the remaining letters in the stimulus. For example, the choice alternative may be "C" or "T" for testing five letters in the stimulus "TABLE", where the other alternative "CABLE" would equally often appear, and for testing the first letter in the unrelated stimulus "TBLEA", where "CABLE" would equally be expected to have been the stimulus. This approach prevents participants from determining the accurate answer using information from any other letter of the string and by using appropriate/suitable stimuli which allow any letter position to be tested during the display.

2.3   Reicher (1969) and Wheeler (1970)

Reicher (1969) evaluated identification performance for letters by presenting a single letter in one of four potential locations on one or two letter, four-letter words, and four-letter non-words. For example, the target letter (e.g., E) was either shown in a word

(e.g., READ), a string of letters in a non-word (e.g., AEDR), or in isolation. This presentation (three display durations) was then followed by masking fields and immediately a pair of the letters (e.g., E/O), one of which was the target (e.g., E), or the other was another letter (e.g., O) that in the word condition would fit in with the remainder of the letters to also form a word (e.g. ROAD). The presentation also included a row of dashes to indicate the display location that was being tested. The participant's task was to decide which of the two letters (e.g., E/O) had been shown in any of the five positions (e.g., (-E---) or (-O---)). This target appeared an equal number of times in any of the four locations in words, and participants did not know in advance where the target letter would be shown in a particular trial. Participants were more accurate in identifying a letter in the context of a word than they were when presented within a non-word or a letter in isolation. Reicher suggests that one possible reason for the higher performance of word stimuli over letter stimuli is that letters are forgotten more rapidly than words are and there is no previous information effect on participants' performance.

Similarly, an experiment was carried out by Wheeler (1970) to examine the word superiority effect. In this experiment four-letter stimuli were read in a seven-letter stimulus field on a screen, three of them blank and the other four the stimuli. During the experiment the fixation point was shown. Stimuli consisted of words that have pair mate real words in each letter position. This allowed Wheeler to test every letter position, and the alternative for every test was also tested. As a consequence, from each of the stimulus words Wheeler created a set of five-word stimuli (e.g., one base "READ" word and the other four alternatives HEAD, ROAD, REND, and REAL). Wheeler also presented the stimuli (both words and letters) at seven screen locations and used different values (e.g., 0, 1, or 2 sec) of choice delay times (which is the period between

word/letter offset/mask onset and the choice letter's appearance). The results showed that although control conditions were used in this experiment, participants constantly recognised words better than non-words and single letters in all of the experimental conditions.

Baron and Thurston (1973) conducted a study that aimed to find out specifically what sort of information is used by the enquiry process, which is what participants have learnt about words that allow them to perceive words more easily than non-words. For example, Baron and Thurston specified several types of knowledge: word frequency in terms of visual units, word meaning, pronounceability and the spelling regularity of English words. The results showed that the word superiority effect remains equal (excluding word meaning and familiarity as factors explaining the effect) for pseudo-words and for real words, even when using the same critical letters in the trial. The findings show that the word superiority effect is caused by either the pronounceability or the consistency of spelling regularities. The findings also showed that the word superiority effect is not explained by strategies that are involved in deciding whether each alternative is correct, nor by the size of the participant's visual memory span.

Surprisingly, the results of Baron and Thurston (1973) study showed that there was no significant difference between the words and the pronounceable non-words. This may have occurred due to the use of very infrequent words in these experiments or may because of response bias in some form (e.g., Catlin, 1969). Nevertheless, in these experiments each stimulus was presented between three and five times within each session. This may have controlled any effect of the variables (e.g., word frequency and familiarity) on perceiving these stimuli; however, Baron and Thurston believed that the multiple presentation procedure did control the effects mentioned, and on this basis it

can be pointed out that this procedure has led to the isolation of the effect of pronounceability of the stimuli from those of familiarity or meaning.

Subsequent studies have shown a small and insignificant difference between words and pseudo-words. For example, McClelland and Johnston (1977) presented three types of stimuli using a forced-choice task, 96 words (e.g., DILL and DELL), 96 pronounceable pseudo-words (e.g., VILL and VELL) and 96 single letters (e.g., I and E). The results showed that the participants' performance was high in real words (80%) as well as pseudo-words (78%), and both words and pseudo-words had a significant advantage over single letters (66%). This indicates that word superiority over single letters does not involve familiarity with the stimulus.

Other studies suggest that the pseudo-word superiority effect only occurs when participants expect to see such words. For example, a study carried out by Carr, Binkoff, Kologinsky, and Eddy (1978) tested this possibility. They used tachistoscopic forced choice in which participants were told they would be presented with nothing or one type of stimuli (real words, pseudo-words or non-words). The expected stimulus type was mixed with a small number of one of the other two types (e.g., 25 percent or 75 percent of the items). The results showed that the word superiority effect always occurs, importantly, however, the pseudo-words superiority effect was obtained when participants only expected to see pseudo-words. Carr et al. (1978) concluded that words and pseudo-words could require different mechanisms. These function automatically when recognising words but are under greater control when recognising pseudo-words (Besner, Waller, & Mackinnon, 1985). Thus, it seems that participants dealt with words and pseudo-words consistently in the perceptual recognition task, as they expected to see pseudo-words (Bowers, 1996).

2.3.1 The WSE and PSE in Languages Other Than English

Grossi, Murphy, and Boggan (2009) carried out an experiment with native Italian speakers. This experiment's task was a forced-choice letter identification using real words, pseudo-words, and non-words in Italian. Stimuli were briefly presented centrally and replaced by a mask that covered all letters. The results showed that native Italian speakers showed word superiority and pseudo-word superiority effects. Lukatela, Lorenc, Ognjenovic, and Turvey (1981) used the letter identification task with Serbo-Croatian speakers to assess the word superiority effect for the Latinate form of the Serbo-Croatian language. Although the Serbo-Croatian language is written in the Cyrillic script, the Russian script, it is also sometimes written using the Latinate alphabet. This experiment used the Latinate alphabet so, even though this is a non-Latinate language this experiment was conducted using the Latinate form of these words. There were four types of stimuli: single letters, five-letter real words, five-letter pseudo-words and five-letter non-words. Members of each stimulus pair in each condition differed by just one letter (e.g., if the target word was TACKA (point) the target letters were T and M and the word MACKA (cat), and this difference occurred at each letter location in words for an equal number of stimulus pairs in each condition. The pseudo-words were created from their word's mate by changing two letters, but not the critical letter (e.g., TAZLA from the word TACKA). Non-words were created randomly by rearranging the word letters. In this experiment the participant's task was to choose which one of the two letters engaged the probe location. The results showed advantages for the recognition of words over pseudo-words and non-words and for pseudo-words over non-words, thus demonstrating that the WSE and PSE have been widely shown in languages such as English and other languages formed from the Latin alphabet.

The Reicher-Wheeler task has also been used to examine word recognition in skilled and unskilled readers. For example, Hildebrandt, Caplan, Sokol, and Torreano (1995) used a Reicher-Wheeler paradigm to look at whether fluent and adult dyslexic readers can identify letters better when these letters form a word than when such letters form either a pronounceable pseudo-word or are displayed as a single letter. This approach to studying word recognition has also been highly influential in developing computational models of the word recognition process. For example, research into the WSE and PSE has led to the development of the Interactive Activation Model of Written Word Recognition (e.g., McClelland & Rumelhart, 1981; McClelland, Rumelhart, Collins, & Smith, 1988), which remains an important and influential model of word recognition that is at the core of research in word recognition in both psychology and education.

Actually very little is known about the process of the word superiority effect in languages that use an alphabet other than the Latinate alphabet because there is a lack of research on this topic using non-Latinate languages. However, it is important to investigate these phenomena in languages that have non-Latinate alphabets. For example, in the Hebrew alphabet there is no word shape information provided (e.g., אָלֶ־ בֵּית עִבְרִי). Therefore, research into Hebrew might be fruitful because it has these characteristics.

 Similarly, Arabic is important to look at because it also has these characteristics as well as other interesting features. For example, unlike Latinate languages (and perhaps Hebrew), Arabic is formed from a cursive script in which spaces infrequently exist between letters in words, even when formally printed; this may present problems for efficient language perception (Elanwar et al., 2007). Moreover, unlike Latinate languages, Arabic is read from right-to-left rather than left-to-right and this too may be

an important distinction that might affect the process of word recognition. Therefore, in order to demonstrate that the WSE and PSE are observed for non-Latinate languages as well as Latinate languages, and in languages that are read from right-to-left as well as written in cursive script, it is important to demonstrate that such effects are observed in Arabic.

2.4   Section Summary

In summary, this section has reviewed examples of previous research that provides explanations concerning how readers recognise words. Research done in this field shows that there is a WSE and a PSE. The explanation is that information in the shape of an entire word plays an important role in reading and word recognition, mainly the WSE and PSE. Significantly, however, the results of the previous studies have shown that when alphabetic stimuli are presented very briefly, people perceive real words better than non-words. This is of considerable importance for the purposes of the current study where native Arabic readers will be presented with stimuli that contain words, pseudo-words, and illegal non-words.

2.5   Theoretical Models

From the discussion in the previous section it is clear that words have advantages over pseudo-words and illegal non-words, and that pseudo-words have advantages over illegal non-words in terms of their recognition. Giving these basic findings, it has been important to show how these effects are accounted for by the theoretical models. There are several models founded on processes in which the recognition of words is based on recognising individual letters (e.g., the Interactive Activation Model, McClelland & Rumelhart, 1981; the multiple read-out models, Grainger & Jacobs, 1996; the activation-verification model, Paap, Newsome, McDonald, & Schvaneveldt, 1982). The studies of WSE usually compare letter detection within words with single letters or

letters within non-words (Lyddy & Roche-Dwyer, 2008). The WSE influences models of word recognition by using the letter identification task. Other models such as Bayesian Reader (e.g., Norris, 2006, 2009), predicts a logarithmic relation between frequency and RT in both lexical decision, and in tasks requiring identification such as eye movements during normal reading (Norris, 2009).

There are different classes of models that account for the word superiority effect and pseudo-word superiority effect. For example, models that are based on IAM, which include McClelland & Rumelhart's 1981 model and the multiple read-out model by Grainger and Jacobs, (1996), the two stage models such as the activation-verification model by Paap et al. (1982), while Whitney's (2001) SERIOL model is one of the few models that incorporates information about hemispheric effects.

2.5.1   The Interactive Activation Model, McClelland & Rumelhart, (1981)

The interactive model activation (IAM) of word recognition is a hierarchical system with separate levels for the identification of letter features, letters, and words, which was developed in an attempt to produce a computational simulation of the key findings relating to the recognition of words. This included providing a computational account of the WSE and PSE. The WSE and PSE can be explained by this model in terms of the activation of nodes at the word level. When a reader is presented with a word, activation of the corresponding word unit provides activation to appropriate letter units and this aids performance in the task. By contrast, the presentation of an illegal non-word will not produce activation of word units and so will not facilitate performance in the letter identification task.

The pseudo-word advantage is a result of the activation of word units that share letters with the pseudo-word and hence provide feedback activation to shared letter units. Accordingly, pseudo-words are likely to activate more units at the word level than

illegal non-words. For example, people are better at perceiving the letter G in a pseudo-word context (e.g. POG) than in a non-word context (e.g., PUG), since POG partially overlaps with a number of other words (e.g., FOG and DOG) (Lete & Ducrot, 2008), therefore, the IAM incorporates the assumption that word recognition occurs through the selection of the most likely candidate on the basis of the relative strength of the units that have been activated (McClelland & Rumelhart, 1981). Pseudo-words, which constantly differ from real words by just one or two letters, can principally activate word codes producing a feedback at the letter level and sustain a pseudo-word superiority effect with the word superiority effect that this model explains.

The multiple read-out model (MROM) is based on the interactive activation model and contains a familiarity judgment mechanism (IAM; McClelland & Rumelhart, 1981). Grainger and Jacobs (1996) have developed this model of lexical decision making. According to this model the advantage of recognising the letters in a word compared to the letters in pseudo-words (WSE) is due to that recognition of the word allows accurate recognition of its constituent letters through read-out from a complete word orthographic representation in long-term memory. The pseudo-word superiority effect according to this model is because of the misperception of the pseudo-word as a real word (e.g., Grainger, 2008; Grainger & Jacobs, 2005).

2.5.2 The Activation-Verification Model, Paap et al. (1982)

Paap et al. (1982) developed an activation–verification model of letter and word recognition. Similar to McClelland and Rumelhart (1981), Paap et al. (1982) proposed a set of letters and a set of words, naming them the alphabetum and the lexicon, respectively. A further similarity between the two models is that visual stimuli infer the letter level which then supplies activation to appropriate codes at the word level.

However, Paap et al.'s model does not depend on inhibition within and between the letter-level representation and word-level representation.

Word superiority occurs because the word is more likely to stimulate word units that support accessible letters, thus increasing the recognition/perceptibility of the letters. In comparison, random strings will seldom activate a word unit, therefore, the determination of activity in the accurate letter units will not be completed through feedback. However, since pseudo-words contain some letters that are shared with real words, pseudo-words that are the same as real words will activate word units that make excitatory feedback and reinforce the letter units that provide an increase to them. Paap et al. also supposed that top-down verification is inhibited when using very brief presentations. This may force the participants to depend only on bottom-up activation or accompany it with any appropriate information that has already been processed.

These models are all letter-based, in that they are based on the idea that word recognition begins with a word's individual letters, but they differ in some aspects. For example, while IAM assumes that when a feature is detected, activation or inhibition is send for features to letters and letters send activation or inhibition to words, the activation–verification model assumes a non-interactive account in which WSE can be due to letter level or word level activation. The activation verification is a two-stage model and the mechanism by which the IAM explains the superior performance on word and pseudo-word stimuli is top-down activation or feedback. Grainger and Jacobs (1996) have developed their model using the lexical decision task. This model assumes that the WSE occurs because words can reach the critical activation level needed with a very brief presentation time.

One of the few models that incorporate information about hemispheric effect is Whitney's (2001) SERIOL model. This model provides an account of letter position

encoding that takes acount of the influence of hemispheric specialisation on the perception and encoding of letters and words.

2.5.3 SERIOL Model, Whitney, (2001)

The SERIOL model is similar to IAM; however, it also incorporates the assumption of the importance of hemispheric asymmetry. For example, according to this model physical retinal acuity decreases with increasing eccentricity from the fixation point, due to the lower attention of cones (there are approximately 17,500 cones in the central fovea). Therefore, in terms of visual acuity, objects at fixation are much better recognized than objects presented further away from the fixation point (Alpern, 1962). Whitney (2001) suggested a similar model of activation for feature nodes related to retinal location. A feature node is better activated when recognition occurs within a particular location, also called the "preferred location" for the feature node in the retina.

There are two important aspects that affect the location gradients; firstly, the scanning direction of the language, and secondly, the dominant hemisphere for language processing. So, for words in English, the gradient of visual acuity would start from the fixation point (RVF/LH) and will increase until the final letter in the LVF/RH, whereas for languages read from right to left (e.g., Arabic and Hebrew) it is reversed, according to the SERIOL model. The location gradient for the feature level becomes a temporal firing pattern across letter nodes, in which each letter position is represented via the specific timing of firing relative to other letter nodes (e.g., Whitney, 2008; Whitney & Cornelissen, 2008).

There are other flexible letter coding models such as Whitney's SERIOL model (2001), SOLAR (e.g., Davis's spatial coding model, 2010) and the Overlap model (Gomez). For example, the model of the self-organising lexical acquisition and recognition SOLAR, developed by Davis (1999), is one of the same class of models as

the interactive model activation model. Nevertheless, its ability to self-organise its learning about the features of words led to a model that is very much more complex than the interactive model. Examples of these features are mechanisms governing the learning of excitatory, inhibitory weights, word frequency means of encoding, chunking identified input and resetting the component representation (Davis, 2001, 2010). The basic assumption of the Overlap model (e.g., Gomez, Ratcliff & Perea, 2008) is that letters in the visual stimulus have distributions over positions so that the representation of one letter will extend into adjacent letter positions (Gomez et al., 2008).

Other models such as the Multi-stream model of visual word recognition (e.g., Allen et al., 2009), associates letter-level and word-level processing channels. It states that there is a race to central information processing between a whole-word and a component-letter channel, so each pathway competes to use the spatial-frequency pattern and therefore the word code would be based on the channel that dominated this race to recognize that word. There are main three stream representations of cortical pathways; the integrated multi-stream, the complete-word channel and the component-letter channel. The processing of the multi-stream goes through three different anatomical levels.

Allen and his colleagues also reported empirical evidence for the multistream model of word recognition using experiments that had been designed to evaluate the main predictions of the model. Findings demonstrate that words are not formed from component letters. Researchers (e.g., Martin, Nazir, Thierry, Paulignan & Demonet, 2006; Cotch & Mitra, 2010) have also suggested that orthographic fluency is reflected in both lower-level, sublexical, perceptual processing and higher-level, lexical processing in word recognition and reading.

Therefore, the occurrence of a word superiority effect mainly involves the sorts of entry or encoding advantage which the real word has when dealing with non-words or single letters that do not have them. Numerous studies have attempted to explain that this may be due to pronounceability, frequency, meaningfulness, orthographic regularity or the neighbourhood effect; therefore, real words tend to have more chance to be activated by these factors than other types of stimulus. The WSE and PSE have been widely shown in languages such as English and other languages formed from the Latin alphabet. Much less attention has been paid to languages formed from other alphabets. Although Arabic has the second most commonly used alphabet after the Latin alphabet, it is nonetheless notably absent from word-superiority research. Consequently, the aim of the first and the second experiments was to determine whether word and pseudo-word superiority effects, which have been shown robustly for Latinate languages, are also observed in Arabic word recognition.

2.6   Summary of Chapter 2

In summary, it has been shown from this review that people are more precise and faster in recognizing a letter when it is presented in the context of a real word than when the same letter is presented alone or also when it presented within non-words. Importantly, however, in the studies that have investigated the WSE and the PSE, one methodological such as the work of Reicher (1969) and Wheeler (1970) now commonly referred to as the Reicher–Wheeler task, and one theoretical such as the work of McClelland (1979) and McClelland and Rumelhart (1981), provided an explanation by which a letter-based model (e.g., IAM) of visual word recognition could capture the word and pseudo-word superiority effects in Latinate languages such as English. These set the scene for experiments that build on this research by investigating the word and

pseudo-word superiority effect in Arabic word recognition. It is important to demonstrate whether such effects are observed in Arabic.

Chapter 3   Experiments 1 & 2: The Word-Superiority Effect

Chapter two discussed how the word superiority effect (WSE) refers to the advantage that skilled readers have in recognising real words over single letters and strings of letters that do not form words in two-alternative forced choice tasks, and presented several accounts that provide valuable information on the word-superiority effect. The most important theme that came out from this discussion was that this word superiority effect reflects the efficiency of the process by which words are perceived. These effects have been widely shown in languages such as English and others formed from the Latin alphabet (e.g., Lukatela et al., 1981; Grainger & Jacobs, 1994; Grainger et al., 2003; Grossi et al., 2009). However, an important question concerns whether similar effects are obtained in experiments based on alphabets other than the Latinate alphabet. In particular, focus in the present research is on Arabic. The characteristics of Arabic that distinguish it from languages such as English that are based on the Latinate alphabet were discussed in chapter two. In particular, Arabic is written in a cursive script in which spaces infrequently exist between letters in words, even when formally printed. This cursiveness is important because it presents less clearly segregated letters (in comparison to printed Latinate alphabets), therefore readers may rely less on the identity of individual letters when reading Arabic words perhaps compared to English. Secondly, unlike Latinate languages, Arabic is read from right-to-left rather than left-to-right and this may have an important contribution that will become clear later in the chapter.

The present chapter therefore contains two experiments that were conducted to determine whether the word superiority effect exists for Arabic. Experiment 1 used the two-alternative Reicher-Wheeler task in which stimuli were displayed briefly in the centre of a screen. A major advantage of the Reicher-Wheeler task is that when the two

alternatives that are presented differ by just one letter and all letter positions in words are tested an equal number of times, performance is unaffected by sophisticated guessing (Johnston & McClelland, 1973) (see Chapter 2 for discussion). Furthermore, many other studies using this task have shown the WSE in English and other Latinate languages (e.g., Grainger & Jacobs, 1994; Grainger et al., 2003; Grossi et al., 2009).

Experiment 2 was conducted as a further investigation of the WSE in Arabic by utilising the lexical decision task; this allowed determination of whether an Arabic WSE is also observed when using this technique.

In the field of experimental psychology the WSE strongly suggests that participants are more accurate and faster in recognizing a letter when it presented in the context of a real word than when the same letter is presented alone or also when it is presented within non-words. Researchers have also found superior perceptibility when a letter is presented within the context of a pronounceable non-word than when it is presented within an unpronounceable non-word (PSE). This effect was first noted by Cattell (1886), and then followed by the important work of Reicher (1969) and Wheeler (1970). The WSE has since been extensively investigated in the context of the recognition processes involved during presented words and non-words.

Several explanations state that WSEs are likely to occur even without the facilitation of an individual letter, whereas the letter-based models suggest that the letter is more important than the entire word. The WSE and PSE have always been tested by utilising a tachistoscopic experimental task, in order to control the duration. The occurrence of a word superiority effect mostly involves types of entry or encoding advantages that real words have, but non-words or single letters do not. Paap et al.'s (1982) AVM favours a non-interactive account in which the WSE is due to letter level or word-level activation. Even though reading at least involves lexical and linguistic processes, it generally

depends basically on visual information. Therefore, it seems vital to understand the nature of one such aspect, visual input, which is necessary for reading and understanding of words. There are a large number of published studies (e.g., Ament & Bazin, 2001; Patching & Jordan, 2005; Whittaker & Lovie-Kitchin, 1993) that describe the link between visual function and the perception of linguistic stimuli (Jordan, McGowan & Paterson, 2011). Although this research is clearly important, much of the information about the processes that underlie word superiority in alphabetic languages is derived from languages in which text is read from left to right, and in which individual letters are typically clear and readily segregated. Therefore, little is known about whether alphabetic languages with visual properties fundamentally different from Latinate languages which also produce word superiority effects.

Consequently, the aim of the first two experiments is to determine whether word and pseudo-word superiority effects, which have been shown robustly for Latinate languages, are also observed in Arabic word recognition. Following previous word superiority research, Experiment 1 used the two-alternative Reicher-Wheeler task (Reicher 1969; Wheeler 1970) to suppress influences of guesswork which may artifactually advantage words (e.g., Johnston, 1978). Previous WSE research has also suggested that the distinctive features of letters tend to appear in different spatial positions for inverted letters, called inverted words (e.g., Koler, 1969; Egeth & Blecker, 1971). For example, one study found that when participants made decisions regarding letter pairs their responses were slower when the letters were shown upside down (Grover & Egeth, 1976). The advantage of inverting letters, with Arabic characteristics, is that the same letters were used; they were presented in a manner that is not readily identifiable. For completeness, four types of stimuli were used in the experiment: real words, pseudo-words, non-words and inverted words.

3.1 Predictions

Existing research that has investigated the WSE and PSE in Latinate languages (e.g., Baron & Thurston, 1973; Grainger et al., 2003; Grainger & Jacobs, 1994; Grossi et al., 2008; Lukatela et al., 1981) has found that when stimuli are presented very briefly, people perceive real words better than non-words. Previous research has sometimes also shown a smaller advantage for pseudo-words over non-words (e.g., Carr, 1986; McClelland & Rumelhart, 1981), and also when participants made decisions regarding letter pairs their response was slower than when the letters were shown upside down (e.g., Grover & Egeth, 1976). It is expected that the same result will be found in the current experiment. Moreover, it is also expected that Arabic participants will find it difficult to read Arabic words when they are inverted. Therefore, in order to demonstrate that WSE and PSE effects are observed for non-Latinate languages as well as Latinate languages and in languages that are read from right-to-left and are written in a cursive script, it is important to demonstrate that such effects are observed in Arabic.

3.2 Experiment 1: The Reicher-Wheeler Task

3.2.1 Method

Participants: Twenty postgraduate students at the University of Leicester took part in this experiment. All the participants who took part in this experiment reported being native readers of Arabic. Furthermore, all the participants had normal or corrected to normal vision, as assessed by a Bailey-Lovie chart.

 Stimuli: There were 400 stimuli in total, comprising 50 pairs of five-letter Arabic words taken from the Arelex database (Boudelaa & Marslen-Wilson, 2010), (e.g. مصبیدة – فصبیدة), 50 pairs of pronounceable pseudo-words were created by re-arranging the order of letters in the Arabic words (e.g. مدبصنة – فدبصنة), 50 pairs of illegal non-words, also created by re-arranging the order of letters in words (e.g. مأبصد- فأبصد),

and 50 pairs of inverted words (e.g. ירטולק – ירטולק). The advantage of using inverting

letters is that the same letters were used, however, they are presented in a manner that

makes them not readily identifiable. Members of each stimulus pair in each condition

differed by just one Arabic letter, and this difference occurred at each letter location in

words for an equal number of stimulus pairs in each condition.

Apparatus: Stimuli were presented in random order on a high-definition

monitor, and a Cambridge Research Systems VSG 2/5 card controlled stimulus

presentations and timing. Responses were made via a Cambridge Research Systems

CT3 keypad. The experiment was conducted in a sound-attenuated and darkened room

and the displays were observed using a chinrest to ensure a constant viewing distance.

Procedure: Participants were first tested for visual acuity, determined using a

Bailey-Lovie eye chart. They were then seated 70cm directly in front of the monitor on

which the stimuli were presented. The stimuli were displayed such that each stimulus

was subtended 1.36 degrees of the horizontal visual angle, on a computer screen. When

the participants were ready to view each stimulus, a stimulus (e.g., تعليم) was flashed up

briefly (17ms) at the centre of the screen. This then disappeared and two choices, the

stimulus and its pair mate (e.g. تعليم and تعليق), were presented on the screen one above

the other, and the participants indicated which string had been shown by pressing the

appropriate key on the keypad (they pressed the upper key on the keypad, the one

furthest from him or her, if he or she thought it was the upper choice, or they pressed

the lower key, the key nearest to him or her, if he or she thought it was the lower choice

they saw). After the participant made their choice, the fixation dot reappeared for the

next stimulus. Each alternative differed in just one letter position (and all letter positions

were tested equally often for words, pseudo-words, non-words, and inverted words) so

that performance with words could not be artificially advantaged by participants

guessing the correct response from other parts of the display (Johnston, 1978). The participants were asked to respond as accurately as they could. There were two sessions with a break between them. Each session lasted approximately 15-20 minutes.

3.2.2 Results and Discussion

Mean accuracy for stimuli in each condition is shown in Figure 3.1. Data were analysed using a one-way repeated measures Analysis of Variance (ANOVA), which revealed that there was a significant difference in accuracy across conditions, $F(2, 57) = 25.02$, $p<0.001$, $\eta^2 = .57$. Words were reported most accurately (86%) and pseudo-words (81%) were reported more accurately than non-words (78%), with the lowest reporting accuracy recorded for inverted words (71%) ($ps < 0.05$).
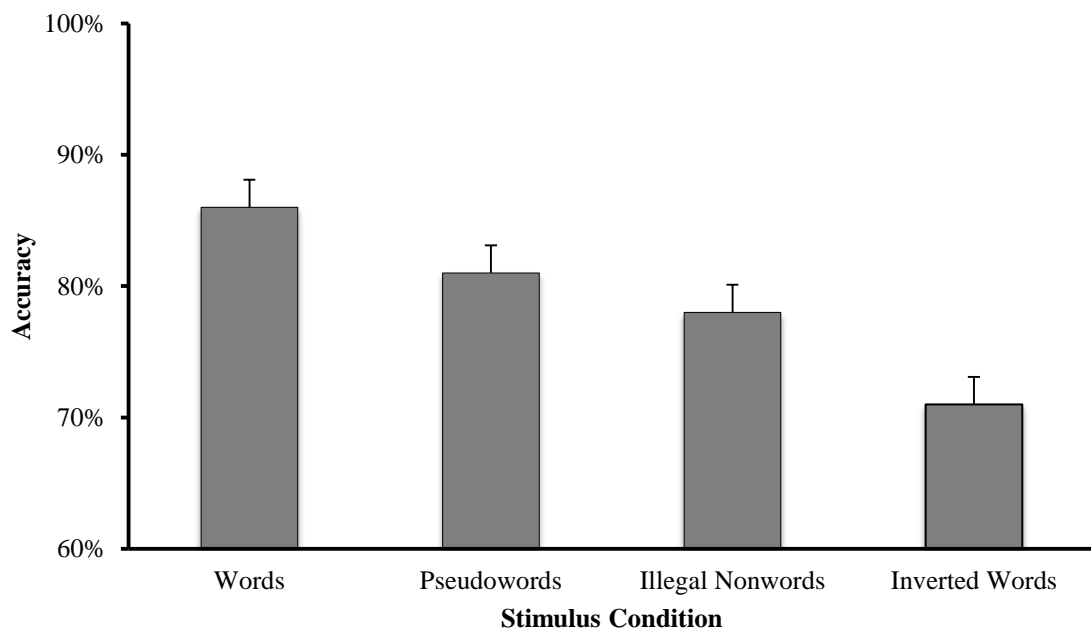
 Figure 3.1. Mean accuracy of responses for stimuli in each condition, with bars correspond to 95% confidence interval (e.g., Loftus & Masson, 1994)

The objective of this first experiment was to investigate word recognition by skilled readers of Arabic, using a standard experimental paradigm (the Reicher-Wheeler task). The results showed clear advantages for the recognition of words over pseudo-words and illegal non-words, and for pseudo-words over illegal non-words. This demonstrated

that the superiority effects that have been previously reported for Latinate languages, including English, exist in Arabic as well. The results of this experiment were consistent with that found in similar studies conducted in Latinate languages by other research using the Reicher-Wheeler task (e.g. Baron & Thurston, 1973; Chase & Tallal, 1990; Hildebrandt et al., 1995; Lete & Ducrot, 2008), which have shown similar WSEs and PSEs. Thus, the findings of the present experiment show the advantages of words over pseudo-words and non-words, and for pseudo-words over illegal non-words; this demonstrates that the superiority effects reported previously using Latinate languages are also observed in Arabic. The revealing of the WSE and PSE in Arabic show that these perceptual phenomena characterize a global feature of human alphabetic language perception that occurs even in a language such as Arabic which differs significantly from that of ubiquitous Latinate languages.

One possible explanation is directly in line with the results of previous research that examined the WSE and the PWE in English and other Latinate languages. Words were recognised better than non-words because they directly activated lexical entries. Pseudo-words partially activated lexical entries, however, non-words did not activate the lexical entries. The inverted words had the lowest recorded accuracy because of an additional difficulty in this task of not only having to identify words or non-words but also having to determine what the natural orientation of the letters was, because the letters were presented upside down.

However, some studies (e.g., Hildebrandt et al., 1995) have used the lexical decision task rather than the Reicher-Wheeler task to investigate word superiority effects. Therefore, following the previous studies and to extend the findings of Experiment 1, a different paradigm was employed.

3.3 Experiment 2: Lexical Decision Task

Experiment 1 clearly showed word superiority and pseudo-word superiority in Arabic using the Reicher-Wheeler task; however there are other methods available to investigate the word superiority effect, in particular the lexical decision task. For example, Hildebrandt et al. (1995) used the lexical decision task rather than the Reicher-Wheeler task to investigate word superiority effects. Therefore, Experiment 2 was conducted as a further investigation of the WSE in Arabic that used the lexical decision task, in order to determine if an Arabic WSE is also observed when using this technique.

3.3.1 Predictions

The results of Experiment 1 showed that native Arabic readers have shown word superior effects over pseudo-words in Arabic. If the findings of Experiment 1 are specific to the task, the Reicher-Wheeler task, then different results should be obtained in Experiment 2. If, however, the effects of the first experiment are replicated, then this will clearly show that words indeed have an advantage over pseudo-words. Therefore, it is important to further assess the superiority effects of Arabic words using a lexical decision task with appropriate stimuli and a counterbalanced hand of response. Another advantage of using the lexical decision task is that it provides a measure of reaction times for word recognition. The reaction time is one of the most common procedures for tapping into comprehension processes, and psycholinguists generally use such measures to examine the relative time-course of a process (Rayner & Clifton, 2002).

3.4 Method

Participants: Twelve postgraduate students at the University of Leicester took part in this experiment. All participants reported being native readers of Arabic and were shown to be right-handed using a revised Annett Handedness questionnaire (Annett,

2003). This is important since many people who are left-handed are also right-hemisphere dominant for language function, which may confound the results of word recognition experiments, but almost all right-handed people have left-hemisphere dominance for language function (Whitehouse & Bishop, 2008). The participants also all had normal or corrected to normal vision using a Bailey-Lovie chart, and did not take part in experiment 1.

Stimuli: Stimuli comprised 100 real Arabic words and 100 pronounceable Arabic non-words created by re-ordering letters in Arabic words. These stimuli were drawn from the stimuli used in experiment 1.

Apparatus: Stimuli were presented in random order on a high-definition monitor and a Cambridge Research Systems VSG 2/5 card controlled stimulus presentations and timing. Responses were made via a Cambridge Research Systems CT3 keypad. The experiment was conducted in a sound attenuated and darkened room, and the displays were observed using a chinrest to ensure a constant viewing distance.

Design: Each participant was shown a total of *200* experimental trials, *presented* in one session. Word recognition was assessed using manual lexical decision (with appropriate counterbalancing of hand of response). Accordingly, half of the participants responded using their right (dominant) hand to press one of two keys on a response box and the other participants used their left hand. For half of the participants in each of these groups, the left key indicated a "word" response and the right key indicated a "non-word" response; this arrangement was reversed for the other participants. Reaction times and errors were recorded.

Procedure: The experiment was conducted in a darkened room. Participants were first assessed for acuity and handedness and then seated 70cm from a display monitor. In each trial, participants were first shown a fixation point, which they were

instructed to fixate, followed by either a real Arabic word or an Arabic non-word, presented at the centre of the display as black text on a white background. The stimuli were displayed for 150ms, and participants were instructed to indicate as quickly and as accurately as possible whether the word was a real word or a non-word by pressing the appropriate key on a keypad.

The experiment lasted approximately 15-20 minutes. The first few trials were conducted as practice trials so that the participants could familiarize themselves with the procedure. The participants were instructed to accept only real words. Half of the participants were instructed to press the left key for real words responses and the right key for non-words responses; these response options were reversed for the remaining participants (Jordan , Paterson & Stachurski, 2008).

3.5   Results and Discussion

The error rates and the reaction times for the lexical decision for word and pseudo-word stimuli were assessed using a repeated measures t-test. There was a significant difference in the accuracy of responses for words and pseudo-words, $t(11) = 2.906$, $p<0.01$, such that words were recognised most accurately. In addition, there was a significant difference in reaction times, $t(11) = 5.064$, $p<0.001$, such that words were responded to more quickly than pseudo-words. The mean error rates and reaction times for words and pseudo-words are shown in Figure 3.2.
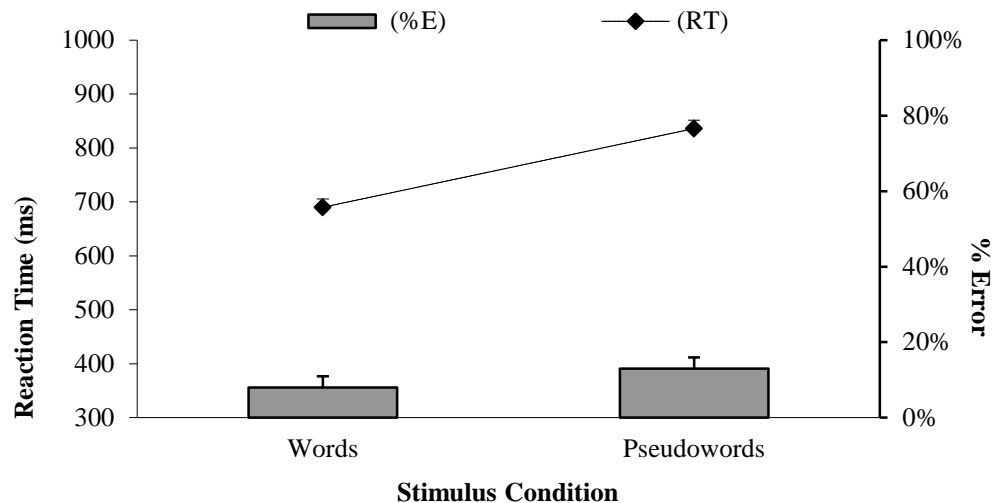
Figure 3.2. Error rates and reaction times (in ms) for Arabic words and pseudo-words in Experiment 2, with error bars indicate the standard errors of the means

The results of this experiment clearly show that native speakers of Arabic are more proficient at recognising real Arabic words than pseudo-words in the lexical decision task. The results of this experiment were consistent with that found in similar studies conducted in Latinate languages by other research using lexical decision task (e.g., Forster, 1976; Hildebrandt et al., 1995; Grainger & Jacobs, 1996). Thus, the results of this experiment provide further evidence that there is an advantage for recognising real words in Arabic and that such effects are observed in the lexical decision task as well as in the Reicher-Wheeler task.

3.6   General Discussion

The aim of the first two experiments was to investigate word recognition by skilled readers of Arabic, using two standard paradigms, the Reicher-Wheeler task and the lexical decision task. In these experiments, I have followed the research that has been conducted on word recognition in English and has involved tasks such as the Reicher-Wheeler task and the lexical decision task (e.g., Wheeler, 1970; Johnston, 1978; Hildebrandt et al., 1995; Jordan, Patching, & Milner, 2000). The main point revealed by the results of these experiments is that there is a clear advantage for words over pseudo-

words and non-words, and for pseudo-words over non-words, and the lowest reporting accuracy recorded for inverted words in the Reicher-Wheeler task. Words were recognised better than non-words because they might directly activated lexical entries. Pseudo-words may have partially activated lexical entries, however, non-words did not activate the lexical entries. The inverted words had the lowest recorded accuracy because of an additional difficulty in this task of not only having to identify words or non-words but also having to determine what the natural orientation of the letters was, because the letters were presented upside down. These findings are consistent with many findings from previous research (e.g., Baron & Thurston, 1973; Jordan, Patching, & Milner, 2000; Reicher, 1969; Wheeler, 1970), which are that when stimuli were presented very briefly, people perceive real words better than non-words or single letter strings. Furthermore, using the lexical decision task showed that Arabic real words were recognised more quickly and more accurately than pseudo-words, which is in accordance with the results described in other studies (Hildebrandt et al., 1995).

However, an important issue of concern that is not answered in this study's experiments is the nature of what determines that recognition. Recent ideas put forward by Ibrahim and Eviatar (2012) suggest that real words are recognized quickly through their global features, so their letters can be inferred quickly, whereas non-words, being new or unfamiliar stimuli, need sequential letter-by-letter processing, an alternative theory is that non-words require a serial processing strategy, from beginning letters to end letters, whereas words enjoy richer, more parallel processing (e.g., Allen & Emerson, 1991; Coltheart et al., 2001). This suggests that the perceptual advantage of Arabic real words, and perhaps in other languages also, might depend on characteristics that are greater than single letters, derived from supra-letter or configural analyses of letter groups and whole words (e.g., Allen, Smith, Lien, Kaut, & Canfield, 2009). The

findings clearly show the word superiority effect is obtained when participants are more capable in selecting letters embedded in words relative to pseudo-words (e.g., McClelland & Johnston, 1977).

These findings (Experiment 1) were obtained using the Reicher-Wheeler task, which has an advantage of minimizing the effects of guess work on performance, as a participant cannot choose the correct alternative based on an identification of the context letters or other letters on the stimuli. For example, a participant who recognizes the letters such as "-able" when table is briefly presented cannot obtain an informed estimate concerning the initial letter, as both "T" and "C" are possible completions of the context "-able".

Therefore, any word superiority effects achieved employing this procedure reveals the superior processing of the critical letter rather than the produce of knowledgeable guesswork based on the identification of the letters' context. Furthermore, performance in the lexical decision task, which counterbalanced the hand of response, showed an advantage for words over pseudo-words, in reaction times and error rates in experiment 2; this is consistent with previous research findings (e.g., Hildebrandt et al., 1995).

These findings contribute in several ways to our understanding of Arabic word recognition, and provide an important basis for more research into this topic. In particular, the experiments revealed that similar processes are involved in the recognition of Arabic words as are used to recognise words in Latinate languages, despite the very different characteristics of Arabic. Therefore, with very brief exposure duration these features of Arabic do not prevent the relative efficiency of real word perception. More broadly, the demonstration of WSE and PSE in Arabic indicates that these phenomena represent a culturally global aspect of human alphabetic language

perception that exists even in linguistic cultures in which the physical composition of words differs substantially from that of Latinate languages.

3.7 Summary of Chapter 3

This chapter reviewed two experiments that were conducted to determine whether word and pseudo-word superiority effects, which have been shown robustly for Latinate languages, are also observed in Arabic word recognition. The results that were obtained clearly show that similar processes are involved in the recognition of Arabic words as are used to recognise words in Latinate languages, despite the very different characteristics of Arabic. These results therefore demonstrate that the word superiority effect and pseudo-word superiority effect exist even in a language that differs significantly from those that use the Latinate alphabet, specifically in the characteristics of being written in cursive and lacking the importance of individual letters. Importantly, these findings for Arabic show that the WSE may rely on features that are greater than individual letters, derived from supra-letter or configural analyses of letter groups and whole words (e.g., Jordan, 1995; Patching & Jordan, 2003; Allen et al., 2009). The following chapter discusses the importance of fixation location in word recognition.

Chapter 4   The Importance of Fixation Location in Word Recognition

The previous chapter was concerned with word superiority effects in word recognition. The current chapter will focus on the importance of a precise fixation location in the process of word recognition and reading. Previous studies on eye-movement control while reading Latinate languages have yielded a key set of observations about where in a word people fixate and how fixation durations rely on this location. This chapter discusses evidence from studies of naturalistic reading that shows that readers tend to fixate a specific, or preferred viewing location within words. Several explanations from the current models of eye movement will also be discussed.

4.1   Fixation Location in Words during Reading

Much of the evidence about the role of the fixation location in word recognition comes from research that has examined the sequence of eye movements made during naturalistic reading. The analysis of eye movements while reading has dominated research in this area over the last several decades, partly because eye-tracking equipment has become more widely available and also because research has revealed that the characteristics of eye movements are highly informative of the cognitive processes that underlie skilled reading (for an overview of eye movement research, see Rayner, 1998, 2009; Rayner, Pollatsek, Ashby, & Clifton, 2012).

Reading involves making a series of rapid eye movements called saccades, separated by fixational pauses, during which visual information is acquired from the page (e.g., Rayner, 1998, 2009; Blythe, Liversedge, Joseph, White, & Rayner, 2009; Joseph, Liversedge, Blythe, White & Rayner, 2009). Saccades generally take approximately 20-35ms, and involve mainly forward movements in the text (about 85 percent to 90 percent of all saccades are progressive saccades). Fixations last approximately 200-250ms, and are often followed by the eyes making a ballistic

movement to another word (e.g., Rayner et al., 1986; Pollatsek & Rayner, 1989; Rayner et al., 2012).

In order to explain eye movement behaviour it is important to determine where and when the eyes move. If we look around a page, it seems that we are taking in a great deal of information. Significantly for reading, the types of cells (cones) that are required for visual information and identifying visual words are heavily located in a very small region of the fovea; visual acuity is therefore highest at the centre of vision. For example, when a word is presented close to the fixation point people will recognize it more rapidly and accurately than when it is presented away from this point (e.g., Rayner & Bertera, 1979). Readers tend to direct their eyes towards the centre of a word so that it can be processed in the quickest and most accurate manner (e.g., Rayner, 1979; McConkie, Kerr, Reddix & Zola, 1988). In fact, there is substantial evidence that a word becomes gradually more difficult to identify as the angular disparity between the fovea and the retinal image of a word increases (e.g., McConkie, Kerr, Reddix, & Zola, 1988b; Rayner & Morrison, 1981; Rayner & Bertera, 1979). Explaining how the reader deals with this limited acuity is one constraint on any model of eye movements. For example, according to Reichle (2011), words are identified one at a time during reading, and the process of identifying words is the "engine" that drives the eyes forward during reading (e.g., Pollatsek, Reichle & Rayner, 2006; Rayner, Ashby, Pollatsek & Reichle, 2004; Reichle, Pollatsek, Fisher & Rayner, 1998; Reichle, Rayner & Pollatsek, 1999, 2003; Reichle, Pollatsek & Rayner, 2007; Reichle, Warren & McConnell, 2009; Reichle, Tokowicz, Liu, & Perfetti, 2011; Reichle, Pollatsek, & Rayner, 2012). However, sometimes because words are very short or very common in a given language, these words can be processed in the parafoveal vision so they are skipped. Therefore, it is clear that parafoveal information is being used in reading (e.g.,

Rayner, Well, Pollatsek & Bertera, 1982). Sometimes also single fixations longest close to the word centres (e.g., Vitu et al., 2001). Researchers (e.g., Nuthmann et al., 2005) suggest that eye movement errors often lead to mislocated fixations on unintended words. These errors are more probable to result in fixations at edges than centres of words (Nuthmann et al., 2005).

It takes a participant approximately 150 to 300 ms to identify a word. Cognitive theory (e.g., Reichle, Pollatsek, Fisher, & Rayner, 1998; Reilly & Radach, 2006) assumes that cognitive factors (language processing) determines fixation durations and which words are targeted, and word identification is the mechanism that drives the eyes forward in the text. However, oculomotor theory (e.g., O'Regan, 1990; Yang & McConkie, 2001) assumes that the decisions of when to move the eyes are under local control (Reichle et al., 2012). Substantial evidence shows that only a small amount of information is acquired on each fixation, and therefore that reading involves making a sequence of fixations which each acquire a small amount of information from the text that must be integrated if the reader is to understand the text as a whole. Evidence for this comes from research in to the perceptual span, which refers to the amount of information that readers can extract from text on each fixation, and employed the gaze-contingent moving window paradigm (e.g., McConkie & Rayner, 1976; Rayner, 1975), showing that the area of text readers extract word length information from is limited on each eye fixation (e.g., McConkie & Rayner, 1975; Rayner & Bertera, 1979; Rayner, Slattery, & Belanger, 2010). For readers of English this limit seems to be a fundamental one determined by acuity limitations, research has shown that visual acuity drops off sharply with increased distance from the centre of the fovea (e.g., Rayner & Morrison, 1981), and useful information about letter identity is extracted only from a smaller region (about 7 or 8 letters) to the right of the central fixation (e.g., Rayner, Juhasz &

Pollatsek, 2007; Morrison & Rayner, 1981). For example, Rayner (1986) found that the perceptual spans for skilled and beginning readers differ, specifically at 14-15 characters and 11 characters, respectively, with both extending to the right of the fixation point (e.g., Haikio, Bertram, Hyona, & Niemi, 2009). Similarly, research shows that the perceptual span for skilled readers of English is asymmetrical around the point of fixation, and readers require 3-4 characters to the left of fixation and up to 15 characters to the right of fixation to read normally (e.g., McConkie & Rayner, 1976; Rayner, 1975); this is despite information from only five to seven character spaces to the right being used for the purpose of identification (e.g., McConkie & Rayner, 1975, 1976). Nevertheless, under challenging conditions, for instance when visual acuity is poor, the perceptual span is shortened and causes participants to make more fixations particularly as word length increases (e.g., Rayner, 1986; Rayner, 1998). Therefore, this appears to impose important restrictions on visual acuity which may be responsible for the systematic patterns of landing positions within words (Rayner, 1979, but see section 4.6 explanations of the PVL for further details).

Early studies of eye movements revealed a systematic pattern to the locations where the eyes fixate during reading (e.g., Dunn-Rankin, 1978; Rayner, 1979). Dunn-Rankin (1978) examined the eye movements during reading by asking participants to gaze into a light source for a short time and then their afterimage was used to determine gaze location. After that participants closed their eyes and a gray afterimage appeared which shifted whenever the gaze shifted. The participants' task was to mark their fixation points within words of different lengths (from 3 to 10 letters) presented on the screen, thus the participants had to mark their fixation by using the afterimage. After the middle fixation points, words of different length were joined by straight lines with the words organized in a triangular manner; the results showed that the fixation point was

fairly central and that the difference in the position of fixation increased clearly along with word length increase. Dunn-Rankin suggested that longer words might lead some participants to move their eyes to fixate more to the left so that they could readily see the first letter. By using this interesting technique (e.g., afterimage effects), Dunn-Rankin (1978) provides some suggestion that fixation locations within words might be rather precisely determined.

Subsequently, Rayner (1979) reported a pioneering study which systematically examined landing positions in words by recording actual eye movement in order to see precisely where people were looking during reading. The results showed that, independently of word length, there is a systematic preference for readers to fixate their most first fixations in words at, or just left of, the centre of words (e.g., McConkie et al., 1988; Rayner et al., 2009). Rayner (1979) labelled the position within a word where readers typically make their initial fixation during sentence reading as the *preferred viewing location (PVL)*. The findings also showed that there are systematic differences in where the readers fixate a word as a function of word length. *The effects of word length*, the number of letters in a word, on visual word recognition mainly in the parafovea are considered in terms of factors that lead to systematic differences in where readers fixate a word (e.g., Rayner, 1979; McConkie et al., 1988). Therefore, findings show that word length information must be processed in parafoveal vision (where stimuli are degraded due to acuity limitations) and that this impacts on the computation for where the eyes move (e.g., Rayner et al., 2009), and also reduces the speed of linguistic processing of those words (e.g., Rayner & Morrison, 1981; Schiepers, 1980; White, 2008).

More research has replicated the basic effect that during normal reading participants tend to fixate a position just left of a word centre more often than other

positions, and have suggested that word length information influences eye movements during reading and the location of fixation within words (e.g., McConkie & Rayner, 1976; Rayner, 1979; Just & Carpenter, 1980; Rayner, Sereno, & Raney, 1996). This means that pre-processing of word length information is an important determinant of where participant's eyes initially fixate on a word (e.g., Morris, Rayner, & Pollatsek, 1990; O'Regan, 1980; Rayner, Fischer, & Pollatsek, 1998; Deutsch & Rayner, 1999; White & Liversedge, 2006). Re-fixation saccades may also be programmed on the basis of word length. Researchers (e.g., O'Regan, 1990) argued that the re-fixation locations are established via the location of the initial fixation on a word with regard to the word length (e.g., Rayner, Sereno, & Raney, 1996; White & Liversedge, 2006).

Research (e.g., McConkie et al., 1988) has also found effects of launch site on PVL, as peak and variance of the preferring viewing location curves depend on the distance of the previous fixation location to the beginning of the current word. This peak moves closer to the start and the ending of the word for close and far launch sites respectively, and the variance of the PVL curve increases with launch site (Yan et al., 2010) (this will be further explored in section 4.4).

According to Rayner et al. (1996), the influence of word length on reading is apparent even with a single fixation on a word, in particular in terms of duration. Vitu, O'Regan, and Mittau (1990) carried out an experiment to examine the effect of word lengths on fixation duration. Target words of various lengths were embedded in the middle of a text line. Two vertical lines with a gap between them that emerged on the left side of the screen were used to ensure accurate fixation. After the participant correctly fixated the gap, the text was presented so that the third character was located where the gap had been. The results showed that there is a stronger word length effect in

55

terms of fixation duration as participants spend a longer time reading when reading longer words.

These reasons might also reduce the possibility of re-fixating words and the duration of fixation independently of the eye's initial fixation location in the word. For example, McConkie and Rayner, (1976) and Vitu et al. (1990) stated that the possibility of fixating and re-fixating a word, as well as first-pass fixation times, increase as the word length increases. Importantly, the effects of word length on initial landing position provide strong evidence that readers do process word length information in parafoveal vision, and that this influences their saccade programmes (e.g., Joseph, Liversedge, Blythe, White & Rayner, 2009). Many studies (e.g., Rayner, 1979; Vitu et al., 1990; Rayner & Fischer, 1996) have provided evidence that the actual initial fixation often falls short of the centre of the word and word length information in fact serves as a key cue in determining where to fixate next.

More critical is that the effects hold for children, in line with the argument that the processes develop early in life or are automatic. For example, Joseph et al. (2009) carried out an experiment to examine the size and effect of word length on initial fixation by comparing children and adults, and found that related to the word centre, the initial fixation moves closer to word centres for short words compared to long words. The findings also showed that when linguistic aspects were kept constant, the effect of word length on the fixation location and fixation duration constantly remained.

Word length is also considered one of the factors that yielded strong effects on the likelihood of skipping the target words (the frequency of trials in which a word was not fixated) and also the duration time spend when fixated the target words, if they were not skipped (Rayner, Slattery, Drieghe & Liversedge, 2011). For example, researchers (e.g., Rayner et al., 1996; Rayner & Duffy, 1986; Rayner et al., 1998; Liversedge et al., 2004)

have argued that word length is highly linked with word frequency. However, when the effects of word frequency are controlled, long words are less likely to be skipped than shorter words, and have longer reading times.

4.2   Skipping Effects

It has also been shown that not all words in sentences during reading are fixated; in particular, short words are skipped more often than longer words. Although eight letter or longer words are seldom skipped, words of less than three letters are skipped very often (e.g., Rayner, Binder, Ashby, & Pollatsek, 2001). Moreover, the likelihood of words being fixated shows that longer words are fixated for a longer time period than shorter words (e.g., Rayner et al., 1996; Kliegl, Grabner, Rolfs & Engbert, 2004; Juhasz, White, Liversedge & Rayner, 2008), and that skipping occurs more often with short words than with long words (e.g.,Vitu, O'Regan, Inhoff, & Topolski, 1995; Brysbaert, Drieghe, & Vitu, 2005).

Word skipping provides an insight into the processing of words in parafoveal vision, and research (e.g., Rayner, 1975; Juhasz et al., 2008; Paterson, Alcock, & Liversedge, 2011; Schotter, Angele, & Rayner, 2012) shows that participants extract information regarding the word identity to the right of fixation (for English) in parafoveal vision, and that this information is employed to plan the next saccade and to start processing the next words in a text. Studies (e.g., Drieghe, Rayner, & Pollatsek, 2005; Brysbaert et al., 2005) have also shown that if a word is skipped this is quickly pursued by a regression back to the previous location due to the initiation of an error-correcting process. The durations of fixation are affected by both foveal and parafoveal linguistic information, whereas skipping a word might be affected by linguistic information only in the parafoveal region (e.g., Drieghe et al., 2005; White, 2007; White, 2008) . The linguistic features of skipped words mean they are required to be

processed in parafoveal vision, the place in which words are degraded because of visual acuity limitations, and this may slow linguistic processing of such words (e.g., Rayner & Morrison, 1981; White, 2008).

Skipping is also influenced by word frequency and predictability, and readers will typically skip both higher frequency words more often than lower frequency words (e.g., Rayner et al., 1996), and highly predictable words more than less predictable words (e.g., Rayner & Well, 1996). The launch site of the saccade from the previous word is also important, as readers are more likely to skip words when they fixate towards the end of the previous word and therefore obtain a clearer preview of the word that ultimately is skipped. The E–Z Reader (e.g., Reichle, Pollatsek, Fischer, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003; Reichle, Warren, & McConnell, 2009) model assumes that when the eyes begin fixating word (e.g., word n*)*. It is the word (e.g., word n*)* that is being lexically processed (this refers to L1 stage). When this stage (the L1 stage) of processing word n is complete, the eye movement control system begins planning a saccade to the next word and that this is what determines word skipping (e.g., word n +1). According to the E–Z Reader, while the L2 stage of processing word (word n) begins, and when this stage is complete, attention is shifted to its next word (word n +1) (Staub, 2011b). Therefore, this model assumes that there are two stages of lexical identification (L1 and L2). The SWIFT model assumes that there is distributed attention, which can cover several words at the same time, and saccades are triggered by a random timer, but can be inhibited if word identification is difficult. This model accounts for word skipping by assuming that target words depending on lexical activity, hence higher frequency words more likely to be skipped than low frequency words (e.g., Engbert, Longtin & Kliegl, 2002; Engbert et al., 2005).

4.3   Re-fixation

Many studies (e.g., O'Regan, 1981; McConkie et al., 1989; Vitu et al., 1995; Rayner & Fischer, 1996) have found that the probability of re-fixation depends on where the eyes initially land in the word. The likelihood of re-fixation on a word is also controlled by the initial fixation, so that re-fixations are more likely to occur when those fixations are located at word boundaries compared to the centre of a word. These have been found in studies that used both normal text reading as well as with isolated words (e.g., O'Regan & Levy-Schoen, 1987; Vitu et al., 1990; Vitu & O'Regan, 1995; Rayner et al., 1996; Joseph et al., 2009). According to Vitu, McConkie, Kerr and O'Regan (2001), when no re-fixation occurs then the readers' eyes simply remain at the same position until the word is recognised and also for a constant duration regardless of the fixation location. The re-fixation possibility and initial landing position have also been found to be adjusted by orthographic familiarity (e.g. White & Liversedge, 2006).

Re-fixation probability is also likely driven mainly by acuity limitations for long words. Acuity limitations also may mean that the characteristics of parafoveal word processing are only likely to affect previous fixations for saccades launched from close to launch sites, which is the location of previous fixation, so that a word might be skipped partly if it is short and/or placed next to the current fixation (e.g., Rayner, 1975; Rayner & McConkie, 1976; Brysbaert & Vitu, 1998; Rayner et al., 2001; White & Liversedge, 2006).

Therefore, the findings show that the possibility of re-fixating a word during reading relies on where the eyes initially land in the word. The re-fixation probability is smallest when the eyes land near the word centre and close to the preferring viewing location (e.g., Vitu et al., 1995; Rayner & Fischer, 1996).

4.4   The Launch Site

The launch site has also been found to influence initial landing position (e.g., McConkie et al., 1988; Joseph et al., 2009). More research has replicated the basic effects that during normal reading the previous fixation (the launch site) affects the landing site (where the eyes fixate) (e.g., McConkie et al., 1988b; McConkie, Reddix, & Zola, 1985). For example, McConkie, Reddix and Zola (1985) asked participants to read one text lines on a computer screen on each trial. Each line contained a target word that was sometimes replaced by one of five experimental conditions. The participants were asked to read normally and told the text contained mistakes. The results of this experiment showed that the participants preferred to fixate on or just left of the word centre for words of different lengths (3, 4, 5, 6, 7, and 8). The results also showed that the location of previous fixation affected where the eyes move next (e.g., McConkie et al., 1987).

Researchers (e.g., McConkie et al., 1988; Rayner et al., 1996) have found that the launch site modulates the landing position. This may occur due to variations in time and location in the landing position as a function of the distance from the previous fixation. When the launch site moves away more from the target word the direction moves to the left (for Latinate languages that are read from left to right) and becomes more variable. McConkie et al. (1988) suggested that the preferred viewing position is the greatest point in a distribution of all fixations on the target word, and it relies on the distance between the launch site of the last saccade and the target word centre (e.g., Nuthmann, Engbert & Kliegl, 2005). Vitu et al. (2001) found that fixations located close to the word's ending are preceded by closer launch sites than fixations towards the beginning of words.

It has been shown that the distributions of fixation locations in reading are systematically associated with launch site and saccade length (e.g., McConkie, Kerr,

Reddix & Zola, 1988; Reichle, Rayner & Pollatsek, 1999). Modelling shows that the PVL can be explained by the centre of gravity effect combined with the launch site effect. As text that is away from where the eyes fixate is visually degraded relative to that nearer to fixation, research often analyses non-foveal text processing as a function of launch site. Saccades launched from further away might be less likely to be influenced by the characteristics of the critical word (e.g., Rayner, 1975; Rayner et al., 2001; McConkie et al., 1988; White & Liversedge, 2006).

4.5   Saccade Length

The eyes make short and rapid movements, called saccades (e.g., Huey, 1908), and usually move forward approximately six to nine character spaces, although there is considerable variability (e.g., Rayner, 1978; 1998; Reichle et al., 2003); there is a commonly held belief that saccade targeting is word based, therefore, each saccade aims to move the eyes to a particular word. In fact, finding such a preferring viewing position effect is largely mentioned as evidence for supporting word-based eye guidance in reading (e.g., Radach & Kennedy, 2004; Yang & Vitu, 2007; Yan, Kliegl, Richter, Nuthmann, & Shu, 2010a).

Saccade length is the distance from the previous fixation to the first fixation on the target word. The contribution of differences in saccade length to the PVP is explained by the landing position effects resulting, to a certain extent, from differences in saccade length (e.g., White & Liversedge, 2006). Research findings (e.g., McConkie et al., 1991; Vitu et al., 2001; Joseph et al., 2009) have shown that participants often target their saccades towards the word centre during reading and that landing position distributions change relative to word length. Research has also found the effects of word length on initial landing position provide evidence that participants process information about word length in parafoveal vision, and that the word length information in

parafoveal vision influences their saccade programmes (e.g., Reichle & Laurent, 2006; Joseph et al., 2009).

According to Reichle, Rayner and Pollatsek (2003), the fixation location within a word appears to be established mostly by low-level visual cues in the text, such as word length, information about the next word and the spaces between words. This has been supported by some findings. For example, the saccade length is controlled by the length of the fixated word and the word to the right of the central fixation (e.g., Rayner 1979; O'Regan, 1980; Roy-Charland, Saint-Aubin, Klein, MacLean, Lalande, & Belanger, 2012), and there is a slowing of reading when readers do not have enough information about the next words (e.g., McConkie & Rayner 1975; Pollatsek & Rayner 1982). The second factor is that even though there is some changeability in readers' eyes landing position within the word, they have a tendency to make their initial fixation approximately intermediately between the start and the centre of the word (e.g., Rayner 1979; Vitu, 1991). Therefore, findings show that readers make their saccades further into a word the longer it is, and towards the word centre during reading (e.g., McConkie et al., 1991; Joseph et al., 2009).

Rayner argued that PVL represents the location in a word that allows most efficient recognition of that word during reading (Rayner, 1979). However, the reasons for this systematic pattern of landing positions are disputed. For example, linguistic processing influences, or even determines, the types of eye movement behaviour influenced by linguistic factors are fixation durations and which word is fixated (e.g., Liversedge et al., 2006), but this may be guided by an early stage of word processing (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Pollatsek et al., 2006; Pollatsek, Reichle, & Rayner, 2006a; Reilly & Radach, 2003, 2006). While other studies show that these do not influence landing positions (e.g., Rayner et al., 2001; White, 2008). There

is also evidence for a small effect of orthographic familiarity (e.g., Hyona, 1995; Plummer & Rayner, 2012) and that the role of spacing, after word space manipulations, was found to make initial fixations land at the PVL, mainly that this pattern occurs in the absence of spaces (e.g. Rayner et al.,1998).

What is the effect of word spacing on the PVL? Rayner et al. (1998) found that PVP becomes much closer to the beginning of words, and made shorter saccades, when text lacked word spaces and the spaces between words also influence the selection of saccade targets (e.g., McConkie & Rayner, 1975; Pollatsek & Rayner, 1982; Rayner, 1986). Similarly, an experiment carried out by Paterson and Jordan (2010) found that there were clear effects of spacing manipulations on the preferred viewing position, duration of fixations and affected word identification. For example, the results showed that while in normally spaced sentences the eyes initially fixated to the left of a word's centre, they fixated close to the beginning of the words when the spacing was enlarged.

Therefore, these findings show that removing the spaces from Latinate characters strongly influences the way the eyes move during text reading and word identifications, and cause the PVP curve to decrease sharply and linearly from the start to the ending of the word (e.g., Rayner & Pollatsek, 1996; Rayner et al., 1998).

These have also been tested in un-spaced languages (for example, Chinese, Japanese and Thai), and it was found that adding spaces to text in languages that are naturally un-spaced can advantage reading in these languages (e.g., Sainio, Hyona, Bingushi, & Bertram, 2007; Bai, Yan, Liversedge, Zang & Rayner, 2008; Winskel, Radach & Luksaneeyanawin, 2009; Zang et al., 2012), and that there was a tendency for participant's eyes to fixate at the beginning rather than the centre of the word (e.g., Kajii, Nazir, & Osaka, 2001).

More recently, White, Hirotani and Liversedge (2011) carried out two experiments to examine eye movement characteristics during reading of kanji (Japanese scripts: ideographs from Chinese characters) characters. The results showed that reading times and fixation probabilities for characters were strongly influenced by visual complexity and that kanji character words showed no preferred viewing location; there is the possibility that there is just no difference for two-character words, but there may well be a PVL for longer words as shown in Kajii et al., (2001).

Yan, Kliegl, Richter, Nuthmann and Shu (2010) reported an experiment using Chinese, which is written without word boundaries. The results showed that participants tended to fixate at the word centre in single fixation cases, whereas in multiple fixation cases their tendency was to fixate at the word beginning. They also found that the duration times in two fixation cases were longer than that in single fixations cases. This is contrary to what has been found in Latinate scripts. Yan and his colleagues suggested that Chinese participants dynamically choose the start or middle of words.

Li et al., (2011) examined eye movement behaviour in Chinese. Participants were presented with either a two or four character word in the same sentence frame. The results showed that participants' eyes tended to land near the beginning of the word when they made more than one fixation and landed at the middle of the words when they made just a single fixation.

Therefore, the findings demonstrate the important role of spaces in determining PVL, and the lack of space information interferes with normal eye guidance in reading. This suggests that in the absence of clear word edges, participants simply forward their eyes to the start of the next word (e.g., Yan, Kliegl, Richter, Nuthmann & Shu, 2010; White et al., 2011), or there are just different patterns for different languages and a lack of spacing only interferes with eye guidance for languages that are usually spaced.

However, recent research in Chinese has examined whether inserting spaces between words text is helpful to readers (adults and children). Findings showed that there were no significant differences in sentence reading times between traditional, un-spaced text and spaced text (e.g., Zang et al., 2012; Blythe et al., 2012; Shen et al., 2011).

Question addressed in the present research extended these findings, and what are the potential roles of other factors in driving different types of PVL? Generally, with the bigger question of whether this holds for right to left languages, there is debate about whether the PVL appears mainly because of lexical factors, including morphological structure, or the reading direction of the language. To our knowledge, there has been only one experiment which has investigated the preferred viewing position for right to left languages. This experiment was carried out by Deutsch and Rayner (1999) and showed that the PVL is to the right of centre (that is, between the beginning and middle letters) of words in Hebrew, when the root is spread throughout the word. Like Arabic, Hebrew has non-Latinate alphabets and is read from right to left. Words in both Hebrew and Arabic are derived from a non-concatenative derivational morphology in which important letters (consonant triples that form a word's root morpheme) are spread throughout words. The aim of the present study is to determine the location of the PVL in Arabic, a right-to-left script. In particular, to which side of the word's centre is the PVL located? Is it located at the first half of the word, as in Hebrew, or in the opposite direction similar to left-right reading direction languages? The second aim of the present experiment is to investigate the influence of word length on landing position and fixation probabilities, and the effect of initial fixation location on re-fixation probability and fixation durations. Overall, the study aims to provide a better understanding of the nature of saccade targeting during reading across languages,

and also whether the mechanisms predicted by current models hold in Arabic. This is particularly important for understanding the broader implications of which mechanisms are universal and which are language-specific.

4.6   Explanations of the Preferred Viewing Location

Many views have been put forward in the literature to explain eye movement behaviour during reading of sentences. The current models provide accounts which will be discussed, but first the explanations provided in the classic papers will be reviewed. For example, Rayner (1979) suggests that the reading models of eye guidance can be separated into important types, namely constant pattern and process-monitoring models. While the constant pattern model incorporates the assumption that there is no sign of control of the stimulus or of cognitive processing for eye movements in reading, the process-monitoring model assumes that the nature of eye movements is determined by cognitive processing. McConkie and his colleagues (e.g., McConkie et al., 1988b) argued that it is important to consider that the participant's eye fixations are affected by the combination of systematic and random error in landing site distributions, which is the reason why some fixations are fixated anywhere while others are fixated centrally. They also argued that even though eye movements are controlled during reading in order to meet the requirements of language processing, experimental data showed that to some extent one characteristic of eye guidance is mostly free from cognitive control. According to their account, lexical processing is not the determinant of either the location of fixation or the length of fixation of the words (e.g., Rayner et al., 1996; Li, Liu, & Rayner, 2011).

All of the current models of eye movement control attempt to provide explanations for the effect of fixation locations in words (e.g., Reichle, Rayner & Pollatsek, 1999). For example, the SWIFT model suggests two main principles that

affect the control of eye movement behaviour during reading: the first is spatially distributed lexical processing, and the second is that saccades are triggered by a random timer, but can be inhibited if word identification is difficult (e.g., Engbert, Nuthman, Reichter, & Kleigl, 2005). According to this model the control mechanism for fixations, re-fixations and regressions is provided by these main features. This model also suggests that the two saccadic programming mechanisms (when and where to move eyes) are separated from each other. SWIFT also assumes that saccades are directed toward words that have the highest level of excitation. By comparison the E-Z Reader model (e.g., Reichle et al., 1998, 2009, 2012) proposes that the progression of the eyes during sentence reading is determined mostly by visual factors and the lexical processing of words. The E-Z Reader model explains the nature of eye movements by assuming that eye movements and attention are decoupled, therefore ccording to this model there are two stages of lexical identification and the readers are not always fixating and attending to the same word (e.g., Reichle, Rayner, & Pollatsek, 2003). Therefore, the major difference between these two models is that whereas E-Z Reader emphasizes the serial lexical processing of words, SWIFT involves parallel processing of words.

In addition, these two models have provided explanations for word skipping, therefore both SWIFT and E–Z Reader assume that sometimes skipping a word will be by accident (because of saccadic error); however, there are major differences in the way these two models regard skipping and lexical processing. For example, while the E–Z Reader incorporates an assumption that lexical processing will either take place during the previous fixation or the next fixation but not both, in the SWIFT model this processing will generally occur during a number of fixations both preceding to and following skipping (Slattery, Staub, & Rayner, 2012).

Therefore, these models explain skipping: first, E–Z Reader suggests skipping can be due to the fixation launch previous to the skipped word, so it was processed enough to allow saccade to move to the next word or as the result of saccadic error when the saccade might land away from the target word. The case of the saccade error in the E–Z Reader model assumes that attention is still situated at the skipped word and processed throughout this prior skip fixation. Second, SWIFT assumes that the word will be skipped if it has a higher level of frequency, predictability, and is shorter (see section 4.2 for more details).

In general, these models make different predictions for how many words can be processed at once (e.g., serial/parallel) processing. For example, the E-Z Reader model predicts that readers process words in a serial-sequential manner (e.g. Pollatsek, Reichle, & Rayner, 2006b). However, the SWIFT model predicts that words can be processed in a parallel manner (e.g. Richter, Engbert & Kliegl, 2006).

Thus far these models of eye movement control adequate explain how we read as our eyes move forward in a text. However, in actual fact when we begin to try to model eye movement behaviour when disruption causes regression and rereading these models start to breakdown. Therefore, there are many eye movement events during reading that are not being captured by these models. It is an aim of this study into eye movement behaviour during reading and rereading Arabic texts to hopefully push these models forward to provide clearer accounts of what is going on during a reading and re-reading process in Arabic, which has significantly different characters than those of Latinate languages such as English.

Previous research have shown that longer fixation durations occurred on fixations nearer the word centre referred to as the inverted optimal viewing position

(e.g., Vitu, McConkie, Kerr & O'Regan, 2001; Yan et al., 2010), but Rayner et al. (1996) found no effect of fixation position on single fixation duration.

4.7   Inverted OVP in Reading (in the fixation duration)

In addition to the work that looked at the location of fixations within a word, other work has looked at the consequences of fixation locations in the word in terms of the length of those fixations. Characteristic effects were observed in that fixations that are at beginnings or ends of words are typically shorter than fixations that are at the middle of words. This is described as the Inverted Optimal Viewing Position Effect (I-OVP) (e.g., Vitu, McConkie, Kerr & O'Regan, 2001; White & Liversedge, 2006; Hyona & Bertram, 2011).

This was reported by Vitu et al. (2001) when using naturalistic text reading. Vitu, McConkie, Kerr and O'Regan (2001) studied fixation location effects on fixation durations during reading by analysing eye movement data from both adult and child participants. Results showed that the participants' fixation durations were longest, rather than shortest, when the eyes fixated near the middle of the words. Vitu et al referred to this phenomenon as the "fixation duration inverted OVP effect".

There are several explanations for I-OVP effect. For example, Nuthmann, Enbert and Kliegl (2005) suggested, firstly, that an algorithm that assessed the quantities of mislocated fixations within the experimental data demonstrated that a higher number of mislocated fixations occurred near to word boundaries. Secondly, as many fixations are mislocated during reading (e.g., McConkie et al., 1988b; White, 2008), these mislocated fixations immediately generate a new saccade programme, leading to a decrease in associated durations. Thus, the I-OVP effect might appear due to a combination of cognitive and eye movement (oculomotor) processes (e.g., White & Liversedge, 2006; Hyona & Bertram, 2011).

The inverted optimal viewing position effect is unusual among a number of results from studies. For example, Vitu et al. (2001) stated that a word is supposed to be recognized most easily if it is fixated close to its centre, and the duration of the first fixation should be normally fastest when fixation is at or close to the word centre, not slowest, as considered by the inverted optimal viewing position effect. Clearly therefore, the inverted-OVP seems odd, as the general theory is that fixation duration should be shorter when processing is easier (Hutzler, Braun, & Jacobs, 2008).

4.8   What Do We Know about the Semitic Languages?

Although the majority of research has looked at the importance of fixation location in word recognition in Latinate languages, such as French and English, there is only one study, by Deutsch and Rayner (1999), that has also examined this topic in non-Latinate alphabetic languages, specifically Hebrew. Hebrew has a non-Latinate alphabet and is read from right to left. The purpose of this experiment was to examine the characteristics of the PVP in reading Hebrew by asking native Hebrew readers to read sentences containing target words. The results showed that the PVP is to the right of centre (that is, between the beginning and middle letters) of words in Hebrew when the root is spread throughout the word.

It is, therefore, of considerable interest to the researcher to establish whether the predictions hold across languages and to assess which aspects are universal or language-specific, and determine if similar PVL effects to those found in Latinate languages, or perhaps Hebrew (read from right to left), are observed during the reading of Arabic texts, which are read from right to left. Specifically, this study will investigate the patterns of eye movements that are made while reading in Arabic to determine whether there is a preferred viewing position (PVL) for reading Arabic words and, if so, whether it occurs at the same location observed in studies of reading in English. The experiment

presented here provides one of the first experimental examinations of how the specific visual characteristics of Arabic words influence eye movement behaviour during reading.

Chapter 5   Experiment 3: Preferred Viewing Location Effects in Arabic Reading

The research discussed in the previous chapter (chapter 4) shows that readers have a preferred viewing position (PVL) within words during the normal reading of a text, which means that there is a tendency for eye fixations to land between the beginning and middle letters of words during reading. Studies of the effects of fixation location in alphabetic languages have been based on Latinate languages (e.g., English and French) in which text is read from left to right and individual letters are typically clear and readily segregated. Consequently, little is known about the effects of fixation location in alphabetic languages with visual properties fundamentally different from Latinate languages.

The only study that has looked at the fixation location in Semitic languages is that by Deutsch and Rayner (1999), which examined the PVL on the reading of Hebrew texts; as shown in the previous chapter, they found that despite the fact that Hebrew is read from right-to-left rather than left-to-right, readers tended to fixate their eyes between the beginning and the middle of the word while reading. Therefore, the present study looked at Arabic in order to gain a better understanding of the effects of fixation location when reading Semitic languages.

However, no experiments dealing with the characteristics of the viewing position for readers of Arabic text have been reported, therefore an important question concerns whether a similar PVL can be obtained in experiments based on Arabic. The characteristics of Arabic that distinguish it from languages such as English that are based on the Latinate alphabet were discussed in chapter four. It is, therefore, of considerable interest to the researcher to determine if similar PVP effects are observed during the reading of Arabic texts, which are read from right to left, written in a cursive

script, and in which spaces infrequently exist between letters in words, even when formally printed.

5.1 Predictions

Based on the findings of the previous chapter it is interesting to see what sorts of patterns landing positions, re-fixation rates, skipping rates and inverted optimal viewing position effects produce when Arabic is being read, and how these compare both with the findings in languages such as English and also with the previous study that looked at a Semitic language by Deutsch and Rayner (1999). We will manipulate word length to give us a greater opportunity to examine effects of word length on landing positions, skipping/re-fixation probability and reading times. The experiment presented here provides one of the first experimental examinations of how the specific visual characteristics of Arabic words influences eye movement behaviour during reading.

5.2 Method

Participants: Twelve native Arabic speakers from the University of Leicester participated in this experiment. All participants had normal or corrected-to-normal visual acuity, as determined by a Bailey-Lovie Eye Chart.

   Apparatus: A SR Research Eyelink Tower Mounted Eye Tracker was used to record the gaze location of the participant's right eye every millisecond. Sentences began at the same position in the centre right of the screen. Target words were located close to the middle of an Arabic sentence and so appeared near to the screen centre. A 20-inch ViewSonic P227f monitor with a screen resolution of 1280 x 1024 was used to display the sentences. Although the participants were able to see the sentences with both eyes, only eye movements from the right eye were recorded via the eye-tracking device. The sentences were presented in black text on a white background. The viewing

distance was 85 cm, as one letter subtended (0.31°) so three characters subtended (0.94°), five (1.56°) and seven characters (2.19°) of the visual angle on average.

Stimuli: A total of 150 Arabic sentences were used as stimuli and each sentence included one target word with the same initial sentence frame for all three conditions (50 three-letter words; 50 five-letter words; and 50 seven-letter words matched for frequency ($t<1$) and for predictability using cloze task) which were taken from the Arelex database (Boudelaa & Marslen-Wilson, 2010). Words of three, five, and seven letters have a closely matched frequency of occurrence in the Aralex database ($F<1$, ps<.05) (Boudelaa & Marslen-Wilson, 2010). Ten additional Arabic sentences were used as practice items at the beginning of the experiment. The stimuli consisted of 50 sentence frames and the frequencies of the target words were adjusted so that they were similar within items. Also, to ensure that the words were equally predictable across conditions, neutral Arabic sentence beginnings were used so that none of the words were predictable, and also so that the sentence beginnings could be repeated without participants noticing any repetition. Ten participants (who did not participate in the main study) were given sentence fragments up to the position of the critical word, and they were asked to write down what they thought the next word might be. None of the participants guessed any of the critical words.

Each participant saw each grouping of sentence frames and target words once and the initial sentence contexts were very neutral, so that any repetition was not noticeable to the participants, giving a total of 150 Arabic words as stimuli. These were shown in three blocks each of which contained 50 target words (in the three different lengths of target word), presented in a randomized order in one session with a break between them.

Procedure: Arab readers were asked to read Arabic sentences while their eye movements were monitored during the experiment using the eye-tracker device. At the start of the experiment, the participants were informed that they should attempt to read normally. Before presentation of the trials, the eye tracker was calibrated by asking participants to fixate a dot appearing successively at three different horizontal locations on the presentation screen. This was re-done and validated if the degree of error for any point was above 0.3 degrees. The calibration accuracy was checked after every few trials during the experiment. This arrangement allowed accurate and consistent measurement of fixation location in the experiment. A chin and forehead rest were used to restrict head movements during the experiment. The participants were asked to press a button on a game pad once he/she had finished reading the sentence, and then the sentence was directly replaced by a simple yes (نعم) or no (لا) question. The participants answered by pressing a button on the game pad regarding the information from the sentence. The experimental session began with ten practice sentences. The entire experiment lasted approximately 30-40 minutes, and participants were given one break.

5.3   Results and Discussion

Fixations shorter than 80ms and longer than 1, 200ms and blinks on first-pass reading of the critical word were discarded, so a total of 1.8% of the trials were excluded. All participants achieved 82% or higher on the comprehension questions that were followed by half of the trial sentences for three-, five- and seven-letter long target words, indicating that participants properly understood the sentences. Several standard eye movement measures are reported (see Rayner, 1998, 2009). Specifically reported are skipping rate and re-fixation probability, landing positions, single fixation duration and re-fixation probability as a function of landing position. For analyses related to the critical word, repeated measures analyses were undertaken for the conditions of word

lengths (three, five and seven) across both participants (F_1) and items (F_2).

5.4   Word Length Analyses

Table 5.1 shows the mean reading times and fixation probabilities for Arabic readers on all target words. There was a reliable effect of length on the probability of word skipping, with readers tending to skip short words (0.10 for three letter words) more often than long words (0.02 five and 0.03 seven letter words), $F_1(2, 22) = 13.32$, $p < .001$, $\eta_p^2 = .55$, $F_2(2, 94) = 16.15$, $p < .001$, $\eta_p^2 = .27$. Overall, the participants skipped three-letter words more than five and seven-letter words, which was significant ($p < .01$); there was no significant difference in skipping between five-letter and seven-letter words ($p > .05$). Table 5.1 shows that first long words were more likely to be fixated than shorter words and also how low these skipping rates are compared to similar length words in experiments in Latinate languages (e.g., Rayner & McConkie, 1976; Rayner, Sereno, & Raney, 1996; Rayner, Slattery, Drieghe, & Liversedge, 2011).

There was no effect of word length on the duration of the first fixation on the critical word, ($F_1 < 1$, $F_2 (2, 94) = 1.68$, $p = .19$, $\eta_p^2 = .03$). This is consistent with the findings of Latinate studies (e.g., Hyona, Olson & Richard, 1995; Joseph et al., 2009).

As predicted, there was a highly significant effect of word length on gaze durations, $F_1 (2, 22) = 11.97$, $p < .001$, $\eta_p^2 = .52$, $F_2 (2, 94) = 15.56$, $p < .01$, $\eta_p^2 = .25$.

Consistent with the null effects in the first fixation durations and significant differences in gaze durations (e.g., Joseph et al., 2009; McDonald & Shillcock, 2003), there was also a reliable effect of word length on the probability of making one or more intra-word first pass re-fixations, $F_1(2, 22) = 25.23$, $p < .05$, $\eta_p^2 = .70$, $F_2(2, 94) = 46.98$, $p < .01$, $\eta_p^2 = .50$, there were more re-fixations made on long words compared to shorter words (all $ps < .05$).

Finally, there was a significant effect of word length on the total time for the target words overall, as shown by total word reading time, F_1 (2, 22) = 7.53, $p < .001$, $\eta_p^2 = .41$, F_2 (2, 94) = 26.00, $p < .01$, $\eta_p^2 = .36$, (All $ps < .01$). The reading times were significantly longer than the gaze durations, indicating that re-reading is important when identifying Arabic words.

There was no significant effect of word length (0.33, 0.31 and 0.36, respectively) on regressions ($Fs<1$).

To summarize, Arabic readers skipped shorter words more than longer words, and made significantly more re-fixations on longer than shorter words. For both gaze durations and re-fixation probability there were reliable word length effects.

Table 5.1. Means and standard errors (in parentheses) of eye movement measures for Arabic readers on 3, 5 and 7-letter words

Word lengths	First fixation duration (ms)	Probability of skipping	Probability of re-fixating	Gaze duration (ms)	Total time (ms)
3-letter	271 (10)	0.10 (0.02)	0.21 (0.02)	325(10)	445(32)
5-letter	261 (11)	0.03 (0.01)	0.36 (0.04)	354 (18)	519(35)
7-letter	265 (06)	0.02 (0.01)	0.46 (0.05)	397 (17)	610(47)

Note. Higher skipping rate and lower re-fixation probability occurred for three-letter words than either five- or seven-letter words.

5.4.1 Initial Fixation and Re-fixation Positions

For the landing position analyses, data for target words in all 150 experimental items were analysed. Of these items, for each participant, 50 contained three-letter words, 50 contained five-letter words, and 50 contained seven-letter words. The probability of making a re-fixation as a function of initial landing position, and the location of re-fixations as a function of initial landing position were calculated. The launch site was entered as a covariate as it has been shown to influence initial landing position (McConkie et al., 1988). Table 5.2 shows the mean landing positions for Arabic readers on three-, five-, and seven-letter words. The mean landing location uses a % centre based measure. In addition, Figure 5.1 shows landing position distributions for

participants for each of the three word lengths. There was a reliable effect of word length on initial landing position: consistent with previous research (e.g., Rayner, 1979; Joseph et al., 2009), mean landing locations moved further into a word as length increased, $F_1(2,22) = 14.09$, $p < .001$, $\eta_p^2 = .56$, $F_2(2,94) = 23.66$, $p < .01$, $\eta_p^2 = .34$, it was significantly different between three-letter words and seven-letter words ($p < .001$). This shows that there was a preference for fixations to land to the right of the centre of words when reading in Arabic. Results reflect parafoveal processing of word length and impact on saccade programming.

Saccade lengths (in visual angle) were calculated from where the previous fixation occurred to the first fixation on the target word. Analyses of saccade length showed that, in line with previous research (e.g. McConkie et al., 1988; Rayner, 1979), saccade length decreased as word length decreased. There was a significant effect of word length on saccade length, $F_1(2, 22) = 29.38$, $p < .001$, $\eta_p^2 = .73$, $F_2(2, 94) = 56.46$, $p < .001$, $\eta_p^2 = .55$, it was significantly shorter on three-letter words than on five-letter words or on seven-letter words ($ps < .01$). Overall, the saccade results replicate the previous studies conducted in English (e.g. Rayner, 1979; McConkie et al., 1988; Joseph et al., 2009), which have found that participants make saccades further into a word the longer it is. Importantly, these results also very clearly show that parafoveal processing of word length modulates saccade programming in terms of where the eyes move.

There was no significant effect of word length on launch site ($F_1 < 1$, $F_2(2, 94) = 2.23$, $p = .11$, $\eta_p^2 = .05$). This means that the effects of word length on landing position are driven by differences in saccade length (due to parafoveal processing of word length) rather than differences in launch site.

Table 5.2. Mean landing locations (characters) and saccade length and launch site (visual angles) for Arabic readers on 3, 5 and 7-letter words

Word lengths	Landing position	Saccade length	Launch site
3-letter	% 1.53 (1.54)	1.29^o (0.04)	0.72^o (0.04)
5-letter	% -3.44 (2.15)	1.39^o (0.06)	0.72^o (0.06)
7-letter	% -7.92 (2.08)	1.56^o (0.07)	0.76^o (0 .06)

Note. Standard errors in parentheses. The mean landing location uses a % centre based measure.
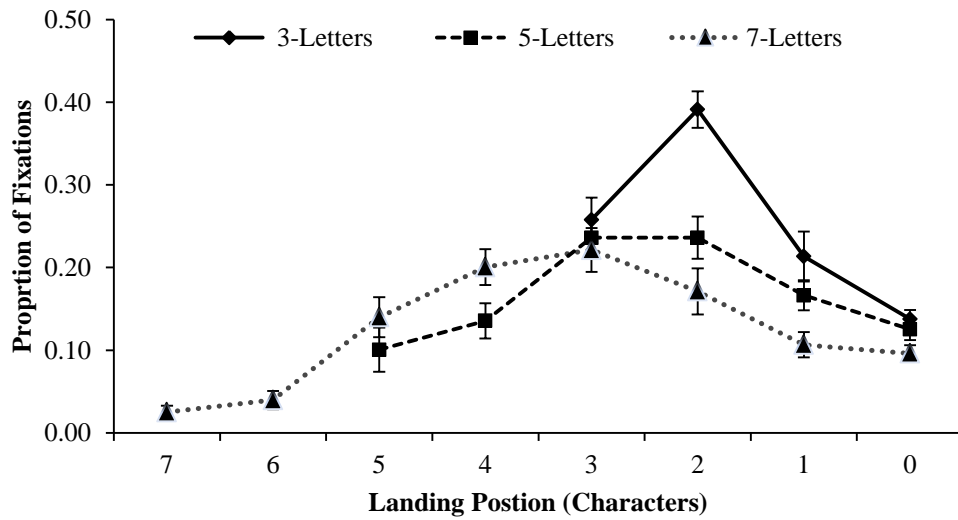
Figure 5.1. Mean initial landing locations distributions of Arabic readers for 3, 5 and 7-letter words

Position 0 is the space before the word, and landing position 1 is the first letter of the word. Error bars indicate the standard errors of the means.

Overall, the results show that there was a preference for fixations to land to the right of the centre of words when reading in Arabic. This means that landing position distributions indicate the PVL is to the right of centre of words in Arabic (at least for five- & seven-letter words), for three-letter words saccades seem to land in the centre rather than right of centre. In this respect, the findings for Arabic are similar to those for Hebrew (e.g., Deutsch & Rayner, 1999). The results also replicate previous research which has shown that participants make saccades further into a word the longer it is (e.g. McConkie et al., 1988; Rayner, 1979). The initial landing position graph looks similar to that for landing positions in English words (Rayner, 1979). For example, for

both the readers of English in Rayner's study and readers of Arabic in the present study

most frequently landed on the second letter of the three-letter words.

One difference, however, between these two data is that the PVL or the initial

landing position is to the left of the centre of a word, while in Arabic (and perhaps in

Hebrew) it is to the right of the centre (e.g., Deutsch & Rayner, 1999). The reason for

this difference is more likely due to the difference in reading direction.

5.4.2   Re-fixation Probability as a Function of Landing Position

As reported in the previous section, word length influenced the probability of re-

fixation, with more re-fixations being made by Arabic readers, on long, compared to

shorter, words. The probability of making a re-fixation as a function of initial landing

position was also examined. In order to enable us to carry out these analyses (i.e. to

have enough data in each condition) we categorised each initial landing position for

each word length as falling at the beginning, middle or end of a word. Table 5.3 and

Figure 5.2 show the re-fixation probabilities for Arabic readers for each word length as

a function of initial landing position. No items analyses are provided due to insufficient

data. A 3 (landing position: beginning, middle or end) X 3 (word length: three, five and

seven letters) 3X3 Repeated Measures ANOVA (with Greenhouse-Geisser correction)

showed a reliable effect of landing position, on word part, $F(2, 18) = 9.0$, $p < .01$:

readers made more re-fixations following initial fixations at the beginning as compared

to the middle of a word ($p < .001$), and at the middle as compared to the end of the

word, ($p < .01$). There was a significant difference of word length on re-fixation mainly

between three-letter and seven-letter words ($p < .05$). There were no reliable

interactions between landing positions and word length ($ps > .1$). This shows that these

Arabic results differ in the probability of making a re-fixation as a function of initial

landing position in words parts, from that observed in English, which found more re-

fixations at the beginning compared to the end of a word (e.g., Rayner, Sereno & Raney, 1996; Joseph et al., 2009). The results showed increased re-fixations at beginning letters, especially for five- and seven-letter words. There was no increase in fixation rate for end letters.

Table 5.3. Re-fixation probabilities as a function of initial landing position (beginning, middle or end of a word*) for 3, 5 and 7-letter words for Arabic readers

Word lengths	Beginning	Middle	End
3-letter	0.56 (0.05)	0.10 (0 .06)	0.11 (0.05)
5-letter	0.69 (0.05)	0.24 (0 .07)	0.15 (0.03)
7-letter	0.71 (0.04)	0.37 (0.05)	014 (0.03)

Note. *Using the following criteria: for seven-letter words, beginning = characters 0, 1, 2; middle = characters 3, 4, 5; end = characters 6, 7, 8. for five-letter words, beginning = characters 0, 1; middle = characters 2, 3, 4; end = characters 5, 6. for three-letter words, beginning = character 0; middle = characters 1, 2; end = character 3.
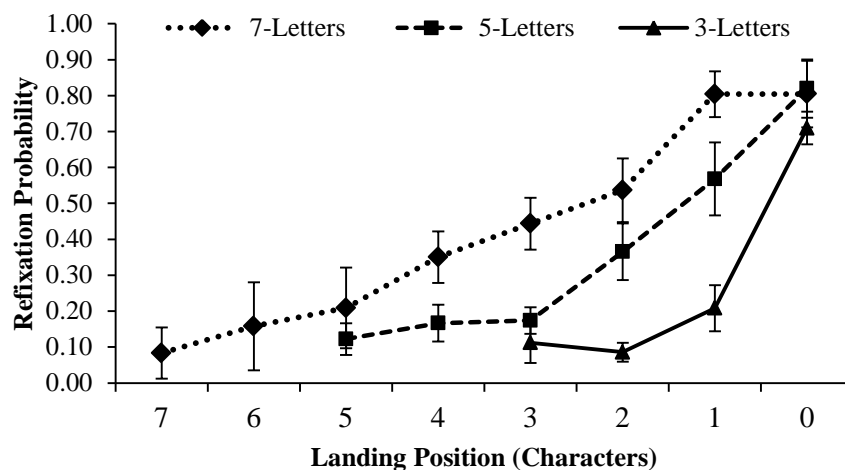
Figure 5.2. Re-fixation probability as a function of landing position on target words of different lengths (3, 5 and 7-letter words)

Position 0 is the space before the word, and landing position 1 is the first letter of the word. Error bars indicate the standard errors of the means.

The results show increased re-fixations for beginning letters but not end letters compared to middle letters, especially for five- and seven-letter words. These results were not in line with predictions, nor were they in agreement with previous research conducted into Latinate languages. For example, Rayner et al., (1996) found a general trend for fewer re-fixations towards the end, but there is still an inverted U shape and

the pattern is not particularly similar to that in this experiment.

The final additional analysis investigates whether the position of single fixations within words influences fixation durations. Previous research have shown that longer fixation durations occurred on fixations nearer the word centre referred to as the inverted optimal viewing position (e.g., Vitu, McConkie, Kerr & O'Regan, 2001; Yan et al., 2010), but Rayner et al. (1996) found no effect of fixation position on single fixation duration. The present experiment provides an opportunity to examine fixation durations in relation to fixation position for three-, five- and seven-letter Arabic words during normal reading.

5.4.3 Single Fixation Duration as a Function of Landing Position

Table 5.4 and Figure 5.3 show single fixation duration for Arabic readers for each word length as a function of initial landing position. No items analyses are provided due to insufficient data. A 3 (landing position: beginning, middle or end) X 3 (word length: three-, five- and seven- letters) 3X3 Repeated Measures ANOVA (with Greenhouse-Geisser correction) showed a reliable effect of fixation duration, on word part, $F(2, 18)$ = 13.07, $p < .001$ η_p^2 = .60: readers made short fixations at the beginning as compared to the end of the word, ($p < .01$). There was no significant difference of word length on fixation duration ($p < .05$). There were no reliable interactions between fixation duration and word length ($ps > .1$). The results suggest that fixations are longer near the word centre, showing an inverted optimal viewing position pattern (I-OVP).

Table 5.4. Single fixation duration as a function of landing position (beginning, middle or end of a word*) for 3, 5 and 7-letter words for Arabic readers

Word lengths	Beginning	Middle	End
3-letter	249 (10)	290 (16)	263 (12)
5-letter	220 (10)	284 (14)	267 (13)
7-letter	215 (08)	288 (09)	269 (17)

Note. * Using the following criteria: for seven-letter words, beginning = characters 0, 1, 2; middle = characters 3, 4, 5; end = characters 6, 7, 8. For five-letter words, beginning = characters 0, 1; middle = characters 2, 3, 4; end = characters 5, 6. For three-letter words, beginning = character 0; middle = characters 1, 2; end = character 3.
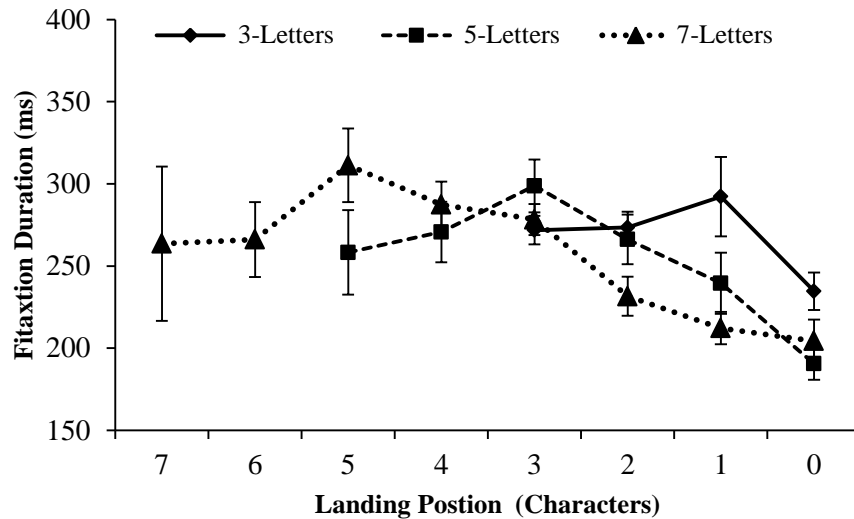
Figure 5.3. Mean duration of single fixations on target words of different lengths (3, 5 and 7-letter words)

Position 0 is the space before the word, and landing position 1 is the first letter of the word. Error bars indicate the standard errors of the means.

To summarize, there is an indication that there is an I-OVP effect for five- and seven-letter words. Fixations were also longer for landing positions at end letters than beginning letters for these words; whereas the effects were less clear for three-letter words. These results are consistent with previous findings of Latinate research (e.g., Vitu et al., 2001; White & Liversedge, 2006) which found a pattern such that single fixations nearer the word centre are longer than those towards the beginnings or ends of the word. The results are in contrast to some previous findings. For example, Rayner et al. (1996) used five- to seven-letter words and found no effect of fixation position on single fixation duration. Crucially, the results presented here facilitate resolution of the argument by providing support for the existence of the inverted optimal viewing position effects in Arabic word recognition in spite of the fact that Arabic has entirely different characters to Latinate languages such as English and French.

5.5   General Discussion

The major aim of this experiment was to examine eye movement behaviour during reading of Arabic text (read from right to left). Native speakers of Arabic read single line sentences including critical words that were three-, five- or seven-characters long. Initial sentence frames were identical across the three conditions. Word frequency and predictability were controlled. The results showed that in contrast to reading in left-to-right languages, and similar to reading in right-to-left Hebrew text (Deutsch & Rayner, 1999), the preferred viewing position tended to be at the word centre or just right of the word centre, demonstrating that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic. A possible reason that could account for why the PVP is further towards the beginning for longer words is the intended re-fixations due to acuity limitations (e.g., Vergilino-Perez et al., 2004).

The results showed that saccade length increased as word length increased and that there was no significant effect of word length on launch site. Previous research in English (e.g. Rayner, 1979; McConkie et al., 1988; Joseph et al., 2009) has shown that participants make saccades further into a word the longer it is. An explanation for this might be that as the amount of letter information that is available during a fixation increases as word length increases, therefore, in order to gain information about word boundaries and identities, the saccades length increases (e.g., Rayner et al., 1998; Paterson & Jordan, 2010). This means that the effects of word length on landing position are driven by differences in saccade length (due to parafoveal processing of word length) rather than differences in launch site. Therefore, saccade length increased as word length increased along with the null effect of the launch site, which gives support to the argument that word length is processed parafoveally.

The results also showed that when a fixation lands near a word's centre, its duration is longer than when it is positioned toward the word beginning or end (IOVP effect in fixation durations), replicating the findings of previous research by Vitu et al. (2001) and Nuthmann et al. (2005). An explanation for this might be that the participants tended to fixate for a longer time on the word centre because the word centre is the optimal location for word recognition, and thus they take advantage of the probability of having all or most letters of the word in the foveal region (e.g., Hyönä & Bertram, 2011). Another possible explanation is that as mislocated fixations are more common at word edges (word beginning or end), fixation durations show an inverted U-shape when plotted as a function of landing position, therefore, the I-OVP can be explained by mislocated saccades, as suggested by Nuthmann, Engbert and Kliegl (2005).

Further analyses examined the effect of word length on fixation probabilities (skipping and re-fixations) and the effect of word length on fixation durations. The effect of re-fixations was more surprising and showed a higher re-fixation probability for fixations at beginning rather than end letters of five- and seven-letter words. The low re-fixation probability for the end of words was unexpected and may possibly be linked to the distribution of information within Arabic words or other language-specific factors. For example, Arabic words are read from right to left, thus increased fixations at the beginning of Arabic words may be due to the left-bias in the deployment of attention, because characters will be more visible to the left of fixation (e.g., Farid & Grainger, 1996), or in view of the fact that the direction of reading determines the asymmetric nature of the perceptual span, this puts forward that linguistic processing affects eye movements. As noted previously, therefore one of the possible explanations for this result is that saccades have a tendency toward cued locations; as readers expect

information to come from succeeding words, eye movements are cued in the reading direction (e.g., Rizzolatti et al., 1987). However, re-fixation rates in Rayner et al. (1996) were attenuated for fixations at end letters in English words, so it remains unclear if re-fixation effects reflect hemispheric asymmetries in word processing. The re-fixations can also be explained by inaccurate initial positioning of eye movements (e.g., Pollatsek & Rayner, 1990; Rayner et al., 1996; Hutzlera, Braunb & Jacobs, 2008).

In line with the findings of previous studies (e.g., Liversedge et al., 2004; Rayner et al., 1996; Rayner et al., 1998), the findings show that long words have longer reading times, are less likely to be skipped, and are more likely to be re-fixated than short words (at least for three-, five- and seven-letter Arabic words). An explanation for how word length influences the possibility of a word being fixated is that parafoveal processing of word length with a basic mechanism could basically be used to target both the longest word (e.g., Reilly & O'Regan, 1998) or through parafoveal linguistic processing of words (e.g., Reichle, Pollatsek, Fisher, & Rayner, 1998; Joseph et al., 2009). Word recognition is considered to be a serial process and the mechanisms within the current models such as the E-Z Reader model (e.g., Rayner et al., 1998; Reichleet al., 1998; Reichle et al., 2003; Pollatsek et al., 2005; Reichle, Pollatsek, & Rayner, 2012) account for the fact that information is extracted from the word next to the word the reader is fixated on during reading (e.g., Drieghe et al., 2005). For example, according to this model words are identified one at a time during reading, and the process of identifying words is the "engine" that drives the eyes forward during reading (e.g., Pollatsek et al., 2006; Rayner et al., 2004; Reichle et al., 1999, 2003; Reichle et al., 2006; Reichle et al., 2009). However, sometimes because words are very short or very common in a given language, these words can be processed in parafoveal vision so they are skipped. Therefore, it is clear that parafoveal information is being used in reading

(e.g., Rayner et al., 1982). In two stages of lexical identification – L1 and L2 in the E-Z Reader model - words can also be intended to be skipped due to completion of L1 on word n+1, and this can account for linguistic influences on skipping probabilities as well as effects of word length (e.g., Reichle, Pollatsek, Fischer, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003).

Notably, there was a significant effect of word length on the gaze duration (increased for approximately 30ms as the stimulus increased by two letters) and total reading time (increased for approximately 75ms as the stimulus increased by two letters) on target words. Previous research (e.g., Vitu, O'Regan, & Mittau, 1990; Drieghe et al., 2005; Rayner et al., 2011) has shown that there is an effect of word length on gaze duration and that it is longer for long words than short words. The explanation provided for this is that when word length increases the possibility of re-fixating this word also increases (e.g., Rayner et al., 1996), which leads readers to make many fixations on a word and thus causes variability in fixation duration.

Overall, this study provides the first investigation of the effects of word length on landing position and skipping probabilities, and the effect of initial fixation location on re-fixation probability and fixation durations in Arabic. In particular, the study helps identify which aspects of the models might generally account for eye movement behaviour during the reading of Arabic. For example, the findings show that even when word frequency and predictability were controlled, the length of a word reliably influences both the location and duration of first pass fixations in Arabic readers during normal text reading. They are able to use parafoveal visual information to guide their saccades during reading, which is consistent with the E-Z Reader model in that the readers are not always fixating and attending to the same word. Word length information also influences both initial fixation positions and re-fixation positions.

Finally, further research on eye movement behaviour in reading Arabic will enable the development of models of eye movement control during reading and identify which factors are common to multiple languages, or for Arabic language specifically. For example, the current findings indicate that the effect of word length on word skipping and the existence of the PVP and the I-OVP may hold across multiple languages, whilst the effect for re-fixations, more surprisingly, shows higher re-fixation probability for fixations at beginning than end letters and a preference for fixations to land to the right of centre of words when reading in Arabic. This indicates that models of character-based languages may need to take account of the target language's visual complexity and language specific features (e.g., the E-Z Reader model does this for Chinese).

5.6   Summary of Chapter 5

This chapter reviewed an experiment that was conducted to examine eye movement behaviour during reading of Arabic text. The results obtained clearly show that the preferred viewing position tended to be at the word centre or just right of the word centre, demonstrating that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic and that the PVP is between the beginning and centre. A possible reason that could account for why the PVP is further towards the beginning for longer words is the intended re-fixations due to acuity limitations. The results demonstrate that word length has strong and independent influences on word skipping, fixation durations, and initial fixation location on re-fixation probability in Arabic.

In parallel with research examining systematically in the locations of fixations within words during reading, other research concerned with the recognition of words

presented in isolation has focused on the consequence for word recognition of fixating

different locations within words. These studies will be discussed in the next chapter.

Chapter 6   Revisiting the OVP Effect in Arabic Word Recognition

From the discussion in the previous chapter (chapter 4) it is clear that there is a preferred viewing position (PVP) when reading words in sentences, which is the tendency for eye fixations to land between the beginning and middle letters of words in Latinate languages (e.g., in English, French, and German). Another important issue is how fixation location affects the recognition of individual words. A parallel strand of research has looked at the effects of fixation position within words. This research can be traced back to pioneering work by O'Regan and his colleagues in the 1980s and 1990s (e.g., O'Regan, 1981;O'Regan, 1984a, 1984b, 1990; O'Regan & Jacobs, 1992; O'Regan & Levy-Schoen, 1987; O'Regan, Levy-Schoen, Pynte, & BrugaiU, 1984), which found, for example, that words are easier to recognise when fixated at particulare letter locations. Such fixation is usually referred to as the optimal viewing position (OVP), which means that participants have faster responses and quicker naming times when words are fixated just to the left of their centre (e.g., O'Regan, 1981; O'Regan et al., 1984).

In a series of experiments, O'Regan and his colleagues (O'Regan, 1981; O'Regan et al., 1984) investigated the optimal viewing position (sometimes also referred to as the convenient viewing effect). The general technique in these studies involved instructing participants to fixate the gap between two vertical lines and then presenting words at different offsets around this location so that a different letter in a word coincides with the gap. Much of this research was conducted in French and used words of various different lengths often ranging between five and eleven letters. These studies used a variety of methods to examine word recognition, such as naming times, lexical decision times of words and gaze duration on words.

The typical finding of this research was that words were named most quickly, lexical decision times were faster and gaze durations were shorter when participants fixated particular letter locations within words. While words were named more slowly, lexical decision times were slower and gaze durations were longer when they fixated other locations including the beginning and end of those words. The effect is also more pronounced for longer words because of the sharp curve shape as word length increases.

Other researchers (e.g., Brysbaert, Vitu, & Schroyens, 1996; Brysbaert , 1994) looked at the fixation location within the words and also locations beyond the end and the beginning of the word. They called this the extended OVP effect, and it shows that there was continuity between the performances for words presented in either the fovea or extra fovea (foveal and parafoveal presentation). Performance levels at all fixation positions were explained by the extended OVP curve, which was shifted slightly to the left. For example, Brysbaert et al. (1996) investigated recognition of words using the classic OVP paradigm in which words were presented at different eccentricities around a central fixation point, offset to the left or right so that they either straddled the fixation point at various locations or were shown entirely to the left or right of the fixation point in nearby locations. They presented 5-letter words so that the participants fixated either for four or two character spaces before the first letter of the word, on the first, middle or the last letter of the word, and also two or four character spaces after the word. A word recognition advantage was found when most (or all) letters were shown to the right of the fixation point, and these effects were interpreted as evidence for divided contralateral hemispheric projections at the point of fixation.

Consequently, what is important about these studies is the use of different techniques for studying the OVP effect, in that they looked at locations beyond (before and after) the words. These studies show these effects extend, called the extended OVP

effect, and there is greater difficulty when the word extends; this difficulty increases when the word is presented to the left visual field compared to when it is presented to the right visual field.

More recently, using a similar technique, Hunter, Knecht and Brysbaert (2007) investigated word recognition in participants who were either LH or RH dominant for language processing. They used the OVP paradigm with the word presented in such a way that each letter position was fixated. This study also showed a processing advantage when most or all of the letters in words were shown to the right of the fixation point, but only for participants with typical (that is, LH dominant) hemispheric lateralization.

Martin, Thierry, Demonet, Roberts, and Nazir (2007) also examined performance with 5-letter words that straddled a central fixation point at various locations. This research focused on the EEG, thus they were able to directly measure the brain activity of the participants. They found that participants with left-hemisphere dominance were faster at naming words fixated at the beginning but that participants with right hemisphere dominance showed a flat OVP curve.

The OVP topic has received renewed attention in recent years because of the claim that cortical projections of visual information are divided precisely at the point of fixation and this division exerts substantial effects on recognition of fixated words. For example, the studies by Van der Haegen, Drieghe, and Brysbaert (2010) and Jordan et al. (2010) have provided useful information on the parameters of the influence of divided hemispheric processing on word recognition, and the findings allow for a substantial area of bilateral overlap of up to 2.5 degrees (corresponding to up to ten letters in normal reading) (Rayner & Pollatsek, 1989), which is clearly inconsistent with the precise split claim.

6.1   Explanations for the OVP Effects

An important point is that O'Regan and his colleagues (e.g., O'Regan & Jacobs, 1992) state that visibility is probably very important, as it is a major determinant. However, this does not explain why the OVP effect in English and French is shifted towards the beginning of the word relative to the middle. Therefore, other factors must be implicated, one of which is the informative part of the word.

6.1.1   Effect of Visual Acuity

According to this explanation the optimal viewing position effect may be due to the drop-off in acuity that occurs with increased distance from the centre of the fovea and its role in letter visibility (e.g., Bouma, 1973; Hilz & Cavonius, 1974; Olzak & Thomas, 1986). It has been argued that words should therefore be recognised most efficiently when fixated near their centre. For example, O'Regan (1981) speculated that the drop of visual acuity away from the central fixation not only influences the processing of words that were presented in the extra fovea but also those presented in foveal locations.

O'Regan argued that if the drop in visual acuity has a very important role in recognising the words, it should be also easier for participants to recognise words when fixating on the central letter rather than the initial or last letter. The reasons for this is that the occurrence of the high acuity area lies around the central fixation point, so when fixating on the first letter, the last letters in the word will fall approximately one degree (about four letters in normal reading) away from the central fixation point. This is also true when a fixation is made on the last letters in the word, causing the first letters to be presented in the extra fovea. To examine this issue O'Regan et al. (1984) carried out experiments and found that participants have faster responses, and quicker naming times, when words are fixated just to the left of their centre.

However, this does not explain why the OVP in English and French is to the left of the centre of words. It is known that the visual information that is obtainable from a stimulus declines at an equal rate on both sides of the central fixation point, therefore, the hypothetical optimal viewing position curve must be symmetric, with its peak at the middle of the word rather than its left (Kajii & Osaka, 2000).

To deal with this matter other researchers have argued that this tendency to fixate to the left of a word's centre (OVP for English and French) might be a combination of the effects of retinal acuity and differences in the informativeness of different parts of words (Stevens & Grainger, 2003).

Stevens and Grainger (2003) looked specifically at the effects of letter visibility on the OVP effect. A brief presentation with backward masking was used. In this experiment two types of masks were employed: a small mask that covered only the stimulus word and a large mask that covered all the possible stimulus locations. To ensure accurate fixation two vertical lines were placed above and below the designated position. The results showed that there was a symmetric drop off in average letter visibility when the participant's eyes moved from the words' centre to either the right or left boundary.

The evidence shows that this tendency to fixate to the left of a word's centre might be a combination of the effects of retinal acuity and differences in the informativeness of different parts of words. Stevens and Grainger suggested that the optimal viewing position is the location where the highest quality visual information can be gathered. For example, these researchers argued that the beginning of words in English and French are most informative; therefore, readers attempt to fixate words so that this information projects to high acuity retinal locations, thus enabling better word recognition.

6.1.2   Informative Part of the Word

One of the most influential accounts of the occurrence of the OVP effect comes from the original studies by O'Regan and his colleagues (1984), in that the effect is of the *"informative part of the word"*. When we talk about Latinate languages such as English and French the informative part is very often found at the beginning of words. These languages have many suffixes (more than prefixes), which are purely to convey grammatical information, thus the important element of the word usually comes at its beginning (e.g., Bruner & O'Dowd, 1958; O'Regan et al., 1984). That might be why the OVP in these languages is shifted to the beginning of the word relative to their middle.

According to this explanation the optimal viewing position effect may be related to ongoing lexical processing (e.g., O'Regan, 1992; O'Regan & Levy-Schoen, 1987). Therefore, this effect occurs because the eye is fixated at different positions in the word and it makes a local decision. This may be affected by the informative parts of the word and this used for lexical access. For instance, the eye may make a very short fixation on a particular part of the word because this part contains little information, whereas it may linger on another part of the word that gives more information and therefore requires more processing. However, the eye movement system might be too slow to allow for such moment-to-moment control of scanning as a function of lexical information being processed. As an alternative, participants could use a pre-programmed inspection tactic, and therefore may systematically fixate at the start of the word. This strategy may not require lexical processing, so this would not affect local eye control and it would be easier to extract information from a particular part of the word. Such a strategy may perhaps still be acceptable since the beginning part of the word in many languages (e.g., English and French) is considered the most informative part (O'Regan et al, 1984).

O'Regan and his colleagues carried out another important experiment that examined whether the optimal viewing position effect is accurately associated with ongoing lexical processing (O'Regan, et al., 1984). In this experiment rare French words that have their informative part at their end rather than at the beginning were used as stimuli and compared with words that have the informative part at their beginning. The findings showed that there is an interaction between the optimal viewing position effect and the most informative part in a word, and that this is to some extent determined by ongoing lexical processing. It was also shown that the familiarity with the word has an effect on the participant's performance mainly when the eye is fixated at the informative part during the second reading.

Importantly, it could therefore be argued that if ongoing lexical processing produces the optimal viewing position effect, why is the advantage of fixating on the informative position so much smaller for the information at the end of words? One possible explanation for this is that the structure of the mental lexicon does not allow access via the end of the word, even if the ending is highly informative as determined by dictionary counts. O'Regan et al. (1984) empirically tested the possibility of this idea with an experiment that used the same word stimuli as in their previous experiment. A list of partially uncompleted (removing either the first or the last part) test words was given to the participants and they were asked to complete these words by adding at least four extra letters to create a real French word. The deleted letters were not the informative letters of either the first part or end part. The results showed that the participants took much longer to guess the word when they were shown word endings than when they were shown word beginnings.

What is important about this work is that it has provided clear strong evidence that the optimal viewing position effect in the difference between the beginning and

ending informative part of words could not have happened because of the idea of ongoing lexical processing. This can only be countered if we assume that the information contained in the end parts of words is not truly information, and the same is also true for the beginning parts of words.

An alternative explanation also considered by O'Regan et al, (1984) is that of a "dependent scanning strategy" rather than ongoing lexical processing. This means that ignoring the lexical content, the participant's eye has a tendency to automatically saccade to the beginning of the word whenever it fixates at the end part of the word. For example, in the case of the words that contain their information at the end, the associated loss in time may eliminate the advantage of lexical processing when fixating at the end. This would also merely amplify the lexical advantage of fixating the beginning part in the case of the information at the beginning.

Therefore, evidence suggests that lexical processing seems to have an effect and is at least to some extent responsible for the result found. The reason for this is that an eye-position dependent strategy cannot alone explain effects such as the action of lexical structure. Nevertheless, fixating at the beginning and the ending of the word has an asymmetrical curve of the effect. This asymmetry is consistent with both previous explanations (ongoing lexical processing and programmed strategy).

Other researchers have argued that the effect is either due to asymmetries in the perceptual span in reading(Rayner et al., 1980), or to a by-product of reading habits (Nazir, Heller, & Sussmann, 1992), and that because words are read from left-to-right in English and French, there is a bias for fixating to the left of centre of words.

6.1.3 The Perceptual Span in Reading

The perceptual span is defined as an area around the central fixation where a reader can obtain information during normal reading and facilitates where to move the reader's

eyes (e.g., McConkie & Rayner, 1975; Rayner et al., 1980). During the reading of left to right languages participants obtain more information from the right of the central fixation rather than to the left of that fixation, thus the perceptual span expands further to the right (Morrison, 1984). Therefore, readers tend to fixate on the initial part of a word since it guarantees that attention is directed to facilitate the part of the word in which the visual information that needs to be recognised is located (Deutsch & Rayner, 1999).

Another alternative account is that of *perceptual learning*. Many visual stimuli studies have revealed that the participant's capability to recognise a target stimulus can develop significantly with long-lasting training and should depend on the number of times this stimulus is repeated at one location on the retina (e.g., Nazir & O'Regan, 1990). In this area, it is useful to briefly review one study by Nazir, Ben-Boutayab, Decoppet, Deutsch and Frost (2004), which compared visual field effects across two different context conditions by presenting one stimulus either in the right or left visual field in one experiment. In another experiment the effects of the visual field were examined by presenting one stimulus so as to cover both sides of the visual field. The stimuli were five-letter strings of English and Hebrew (subtended 0.6 of visual angle). Each stimulus was shifted to straddle a central fixation point at various locations so that the participant's eyes were fixated either on the first or the last letter of the stimulus. Each critical letter was shown one time at each of the five letter positions in the two experimental conditions. The participants were presented only with their native language. An eye-tracker was used to ensure accurate fixation in this experiment. The results showed a right visual field advantage for English but not for Hebrew characters. As the participants perceived stimuli presented in both the right and left visual fields equally, researchers concluded that the different results for readers in both languages

provided no support for the perceptual learning claim.

In a follow up experiment the effects of the visual field were examined by presenting one stimulus (of nine characters) so as to cover both sides of the visual field. The nine stimuli letters were presented at the middle of the fixation point in a way that displayed each target letter individually in one of the nine possible positions. Stimuli were listed for each language and each group of participants were shown their native script. The same procedure as the previous experiment was used. The findings showed that clear visual field effects existed for both Hebrew (the right visual field was found for Hebrew) and English scripts.

In light of these findings, Nazir et al. (2004) suggested that the different results for readers in both languages provided no support for the perceptual learning claim.

6.1.4   Hemispheric Asymmetries

More recently, it has been argued that the reason why the OVP is to the left of the centre of words is due to the split foveal processing of words (the SFT will be further explored in Chapter 8) (e.g., Brysbaert & D'Ydewalle, 1990; Brysbaert, 1995; Brysbaert et al., 1996; Martin et al., 2007; Brysbaert et al., 2007). This view states that word recognition is affected fundamentally by the precise location at which a word is fixated because a precise split in hemispheric processing at the point of fixation causes all letters to the left and right of fixation to project to different, contralateral hemispheres.

According to this account, when a word is fixated it is divided in two around the point of fixation, and the two parts of the word are projected for processing in different cerebral hemispheres. Thus, if "word" was fixated between the "o" and the "r", the letters "wo" would project to the right hemisphere initially, and the letters "rd" would project to the left hemisphere, before being combined via the transmission of information across the *corpus callosum*. This account also proposes that there are

differences in the word processing capabilities of the two hemispheres, such that the left hemisphere has superior word recognition capabilities. It is therefore argued that the OVP is offset to the left of the centre of words in order to balance word processing demands across the two hemispheres. That is, according to this account word recognition is most efficient when most of the letters in a word project initially to the left hemisphere because this hemisphere has the superior word processing capabilities.

Many researchers (e.g., Brysbaert, 1994; Brysbaert et al., 1996; Hunter et al., 2007; Ellis, 2004) who have reported experimental support for the split foveal theory claim that each fovea is divided precisely at its vertical midline so information right up to fixation projects (unilaterally) to the contralateral hemisphere. For example, three experiments carried out by Brysbaert et al. (1996) examined the recognition of words using the classic OVP paradigm. Brysbaert et al. used stimuli (French and Dutch words) of three, five, and seven letters but, in line with the study by Brysbaert (1994), only three-letter stimuli were sufficiently physically small enough to always be shown entirely within foveal vision, while all other stimuli frequently exceeded this area. Stimuli were presented at different eccentricities around the point of fixation, offset to the left or right. Using a technique that involved instructing participants to fixate on the gap between two vertical lines, participants were asked to fixate the gap for 500ms. The presented word either straddled the fixation point at various locations or was entirely to the left or right of the fixation point. Participants had to make their answer by typing it at the bottom of the screen. The results showed that a word recognition advantage occurred when many or all letters were presented to the right of fixation. These effects were taken as supportive evidence for a division in hemispheric projections around the point of fixation. They claim that there are continuities between foveal and extra foveal word recognition.

In addition, an experiment carried out by Martin et al. (2007) measured the electroencephalographic activity of participants. This experiment's aim was to examine the OVP effect when presenting five-letter French words (subtended for 6.65 degrees of the visual angle) that straddled the point of fixation at different locations. A modified version of the Reicher-Wheeler paradigm was used. The result showed that the OVP lies for words near its centre when compared with the beginning or the end.

However, this view has been widely criticised. For example, Jordan, Paterson and Stachurski (2008) used fixation-contingent displays to present words precisely unilaterally to each side of fixation either entirely within foveal vision or entirely outside this area. Right-hand dominant and right-eye dominant native English speakers participated in this experiment. The task used the Reicher-Wheeler paradigm to assess each participant's performance in each location for four-letter English words. Different physical sizes of stimulus for foveal (subtended for 0.55 degrees of the visual angle and the medial edge of these stimuli was 0.15, 0.25, or 0.35 degrees from the fixation point) and extra foveal (subtended for 1.10 degrees of the visual angle and the medial edge of these stimuli was 0.15, 0.25, or 0.35 degrees from the fixation point) were used. An eye-tracker was used in this experiment to ensure fixation accuracy. The results showed that extrafoveal words displayed showed a strong hemispheric effect, as more of the participants' responses were correct when words were presented in the right visual field (72%) than to the left visual field (65%). However, for foveal presentations there was no advantage for the same words presented to the right of fixation (67 percent and 67 percent for right and left, respectively); importantly, in foveal vision words were presented slightly away from the middle point of fixation to prevent an overlap in area projection. In this experiment the presented words extended towards the boundaries of the fovea where unilateral contralateral projections were more probable to occur.

Therefore, these findings are consistent with a functional division in hemispheric projections for words presented exterior to foveal vision but show no functional division for words within foveal vision.

Indeed, many other studies, using a variety of different paradigms and procedures, have also found no evidence of split-fovea processing (e.g., Jordan & Paterson, 2009; Marzi, Mancini, Sperandio, & Savazzi, 2009). For example, Marzi et al. (2009) carried out an experiment in which they presented flashes in the right or left visual field. The participant's task was to respond as fast as they could by using their left or right hand. The results showed that the participants responded significantly more rapidly when the stimulus and the responding hand were on the same visual field compared to when they were on opposite visual fields, and this is only when the stimuli were presented in the extra visual field (6 degrees from the central fixation point), but not when the same stimuli were presented in foveal vision (1 degree from the central fixation point). These findings are consistent with a division in hemispheric projections for stimuli presented outside foveal vision but show no division for stimuli within foveal vision.

Moreover, an experiment conducted by Jordan et al. (2009) is very important in this area, since it used the Reicher-Wheeler task and an eye-tracking system linked to a computer-controlled, fixation-contingent display ensured accurate fixation when each stimulus was presented. Native English LH-dominance for language participants was used. Stimuli were English words and non-words presented (16.67 ms) at two left and right foveal locations (subtended 0.55 degrees and with medial edges 0.25 degrees from fixation) and two left and right extrafoveal (subtended 1.10 degrees with medial edges 2.20 degrees from fixation) locations of a central fixation point. In this experiment stimulus viewing was monocular and the position of the dominant eye, always the right

eye, was monitored using eye-tracking equipment. The findings showed that a functional division exists only when recognising words presented in the extrafoveal location, but there was no evidence of a division in hemispheric processing for foveal presentations. No change in non-word performance at any location was found. Jordan and his colleagues concluded that the findings from these studies are clearly problematic to accounts of word recognition based on split foveal processing.

Research on this topic using appropriate fixation and stimulus controls has so far been conducted using only Latinate languages. Consequently, much of the information acquired under properly controlled conditions about processes that underlie foveal word recognition in alphabetic languages has been derived from languages in which text is read from left to right, words have a concatenative morphology, and individual letters are typically clear and readily segregated.

6.2   The OVP in other Alphabetic Languages (e.g., Hebrew and Arabic)

Although the majority of research has looked at the effects of optimal viewing in Latinate languages such as French and English, there are a few studies that have also examined the effects in other non-Latinate alphabetic languages. One of these studies has found that the OVP for Arabic is located at the very centre of words and so differs from that of Latinate languages (Farid & Grainger, 1996; and Deutsch & Rayner, 1999, report similar findings for Hebrew). For example, Deutsch and Rayner (1999) report one experiment of OVP in Hebrew that used an eye-tracker to ensure fixation accuracy. In this experiment participants had to fixate the middle of the first letter or the final letter in each word, which was displayed in place of a fixation point at the centre of a screen; the centre of the word had to be shifted 1.2 degrees to the left or right of the fixation point, which means that the seven-letter words used in this experiment subtended more than 2.4 degrees and so would not always be presented entirely in

foveal vision. The results showed that there is a drop in performance when the fixation point was shifted horizontally from the centre of the word.

Farid and Grainger (1996) examined the OVP effect in the naming of both Arabic and French words (seven letters in length) by French-Arabic bilinguals. Every stimulus was tested with by the participants' firstly fixating at one of each letter position, so that each stimulus was fixated seven times. The participant was instructed to fixate the space between two vertical lines located just above and below the target word. These two fixation lines appeared at the central fixation point, and then a forward mask composed of sixteen hash marks covered the presentation place for 500-514ms. Following this, the stimuli was presented at a position relative to the central fixation point for 614ms followed by a backward pattern mask which remained on the screen until the next trial started. All the participants were shown stimuli in both languages, and half of them completed the Arabic stimuli first, with the other half reading the French stimuli first. The results showed that the OVP for the French stimuli was just to the left of the word's centre. However, the OVP for the Arabic stimuli was at the word's centre.

Therefore, these results appear to indicate that the OVP for Arabic is at the very centre of the word and differs from that observed during the recognition of words in Latinate languages. However, a major problem for this experiment is that despite the importance of the participants fixating a particular desired location prior to a word being displayed, no external monitoring or control of fixation accuracy was used. Instead, the experimenters relied on simply instructing the participants to fixate accurately.

6.3   Methodological Issues in OVP Research

A major concern within the literature is that the methods used to investigate the optimal viewing position (and particularly the split fovea account of this effect, the SFT will be discussed in greater detail in Chapter 8) have several methodological problems.

The importance of participants accurately fixating the designated fixation location: Obviously, it is important to the understanding of the OVP effects in word recognition that participants accurately fixate the designated fixation location when words are presented in experiments. The vast majority of experiments into the OVP and other investigations into the effects of fixation location have generally not used an eye-tracking device to control fixation location or ensured that stimuli were presented entirely within foveal vision (e.g., Farid & Grainger, 1996; Nazir, Jacob, & O'Regan, 1998, Experiment 1; Nazir, O'Regan, & Jacobs, 1991; Nazir , Heller, & Sussmann, 1992; Stevens & Grainger, 2003; O'Regan, 1981). Instead, experimenters have usually relied on simply instructing participants to fixate accurately. In particular, these previous studies used only a variety of fixation cues (accompanied by instructions to fixate these cues) to control fixation location, although it is well-established that participants have difficulty controlling their eye-movements when attempting to fixate a specified location, and accurate fixation cannot be ensured without an eye-tracking device; participants, therefore, often do not fixate accurately (e.g., Gazzaniga, 2000; Jordan, Patching, & Milner, 1998, 2000).

For example, Jordan, Patching and Milner (1998) examined the validity that instructions alone can ensure accurate participant fixation. Jordan, Patching and Milner used the traditional right visual field advantage for words and compared the instructions with eye-tracking to ensure central fixation. The results show that when only instructions were given participants did not centrally fixate on the vast majority of trails

and also even small (approximately 25 percent) shifts in fixation away from the central fixation point can produce a significant impact on visual field effects. Furthermore, Jordan, Patching and Milner (2000) found that inferences about visual fields processing are likely to be confounded if word is presented at different retinal positions in each visual field, and that just small shifts in the position of the eyes away from the central point of the visual field can produce contamination (e.g., Jordan & Patching, 2006) .

Some studies (e.g., Lavidor, Ellis, Shillcock, & Bland, 2001) have made efforts to overcome problems of fixation error by emphatically instructing participants to fixate accurately and using an intersecting stimulus (× or +) to designate the required fixation location, upon which participants were instructed to fixate. Other studies (e.g., O'Regan et al, 1984; Brysbaert et al., 1996) have used two vertical lines (¦) and instructed their participants to fixate on the centre of the inter-line gap. Other studies (e.g., Brysbaert, 1994; Hunter et al., 2007) have enhanced these instructions with an additional task involving detection of a stimulus (e.g., a digit) presented at the required fixation location. Nevertheless, because no external monitoring or control was used to determine which locations were actually fixated in any of these studies and that humans have great difficulty precisely fixating a pre-specified point without external monitoring and control, the effectiveness of these popular fixation procedures in studies of OVP is unclear (Jordan & Paterson, 2009).

Paterson, Jordan and Kurtev (2009) examined the role of fixation location by presenting words at different locations around the point of fixation while an eye-tracker recorded the fixation location of each eye. The results showed that participants did not fixate the required position in the majority of the experiment trials. Moreover, Jordan et al. (2010) carried out an experiment to evaluate the efficiency of widely-used attempts to ensure fixation accuracy by using procedures (e.g., cross (×), two vertical lines (¦),

(digit), and a dot (.)) matched to the original studies and an eye-tracker to monitor the locations actually fixated. The results show that correct fixations took place in less than 35 percent of the trials for all of the experimental conditions. The results also showed that approximately 74 percent and 68 percent of the stimuli (one letter and eight letters, respectively) were fixated between 0.25 degrees and 2 degrees away from the designated location.

The use of oversized stimuli: These problems with fixation accuracy in OVP research have been exacerbated by the use of oversized stimuli, divided foveal processing was not the focus of this work, and only a subset of fixation locations within words were investigated (e.g., O'Regan et al., 1984). These issues are not a concern for original OVP research (e.g., O'Regan, 1981; O'Regan et al., 1984; O'Regan & Jacobs, 1992; Stevens & Grainger, 2003), because these studies were not designed to examine the idea of hemispheric asymmetry as an important determinant of the OVP effect. Therefore, the hemispheric asymmetry was not a problem for those studies that motivated the SFT account of the effects of fixation location on word recognition, so that it is not well suited to evaluating the role of fixation location that SFT proposes.

Of even greater concern is that studies of within-word fixation conducted specifically in support of SFT have also not controlled stimulus size. For example, in the study by Brysbaert (1994), stimuli frequently exceeded foveal vision by extending up to 3 degrees from the designated fixation point, making it unclear how the effects of presenting information to the left and right of the fixation point reflected unilateral projections in foveal, rather than extrafoveal, vision. Similarly, Brysbaert et al. (1996) used stimuli of three, five, and seven letters but only three-letter stimuli were sufficiently physically small to always be shown entirely within foveal vision and all other stimuli frequently exceeded this area. The five-letter stimuli used by Martin et al.

(2007) subtended a horizontal visual angle of 6.65 degrees and more than 75 percent of each stimulus would have been presented in extrafoveal locations when either the first or last letter was fixated.

Van der Haegen et al. (2010) also found that naming times for words were longer when fixations were made at end letter locations rather than at other locations in words. This led van der Haegen et al. to argue that the effects provided evidence for divided hemispheric influences on the recognition of these words. However, as the words were six-letters long (and subtended 1.5 degrees or more), van der Haegen et al. conceded that this finding did not preclude the possibility that shorter words might be processed bilaterally.

Therefore, some experiments (e.g., Jordan, Paterson, Kurtev, & Xu, 2010; Jordan et al 2009; 2008) used stimuli that were made sufficiently small so that the entire word would always be perceived in foveal vision. The findings revealed that word recognition performance was equally inferior when words were shown entirely to the right or left of fixation, and performance was equally superior when fixations were made at any inter-letter locations between the beginning and middle of words. There was no evidence of the hemispheric division in word recognition predicted by the split foveal theory. Thus, it is clear that while these studies in English provide no support for the SFT account, the OVP effect is still observed in many of these studies.

The Problem with the Task: Another concern is highlighted about the findings of many studies (e.g., Brysbaert, 1994; Hunter et al., 2007; Van der Haegen et al. 2010) that used naming to assess word recognition performance. One major drawback of this approach is that speech production in the vast majority of individuals is lateralised to the left hemisphere (e.g., Banich, 2004; Zaidel, 1998). Jordan and Paterson (2009), for example, pointed out that naming can produce spurious advantages for information

projected to the left hemisphere in experiments just because this information is being sent to the hemisphere responsible for producing a response instead of because this hemisphere is better for recognizing the presented information. This will become obviously relevant with extending the stimulus size outside the fovea, but nevertheless may also occur for foveal displays if an anatomical division in process at the vertical midline exists but is nonetheless not functional for word recognition. It has been argued that in split foveal research using Latinate languages (e.g., Bryden, Mondor, Loken, & Ingleton, 1990; Faust, Kravetz, & Babkoff, 1993; Jordan et al., 2000; Jordan, Patching, & Thomas, 2003) a confound that is frequently ignored is that because of the importance of the first part of the word in these languages, participants are more able to guess a word's identity when the beginning part of it is presented near to the central fixation point. Performance in many tasks is sensitive to this problem, and naming might intensify these consequences. Therefore, tasks such as lexical decision making can be used to assess the OVP while avoiding response biases, for instance, counterbalancing the hand of response (e.g., Chiarello, Nuding, & Pollock, 1988; Jordan et al., 2009). Thus, while all the reasons for the OVP remain to be fully determined, it is clear that various factors and potentially complex interactions between factors can explain performance.

Recently, the OVP has been investigated using appropriate fixation and stimulus controls. For example, Van der Haegen et al. (2010) carried out experiments in which the OVP paradigm was used to examine fovea word recognition as a function of fixation positions. The technique used two vertical lines to ensure fixation accuracy (experiment 1), furthermore, the eyes were tracked and monocular viewing was used (experiment 2 and 3 presented the stimuli in the fovea regain). The stimuli were displayed in such a technique that ensured each letter position was fixated (in a naming

task). The naming time analysis showed there was a significant effect of condition (which was slower by 524 ms for the eye position contingent condition than for the 476 ms eye monitoring condition). There was a main effect for the fixation position with the fastest naming time at the middle letter (485 ms) and the slowest at the last letter (533 ms), and the same pattern was found when error rates were analysed.

The result also showed that from the eye fixation analysis an accurate fixation on the letter and so between the two vertical lines was 34.4 percent and 71.9 percent of the trials for eye monitoring condition and eye position contingent condition, respectively. Data in both conditions also showed bias to the left: 31.4 percent fixations on letter −1 in the eye monitoring condition and 16.4 percent in the eye position contingent condition. This showed that the participant did not constantly fixate accurately when they were told to if no eye position reliant stimulus presentation was used (Jordan et al., 2009).

Jordan et al., (2010) employed an OVP paradigm in which five-letter English words were presented for lexical decision when participants fixated the space immediately to the left or right of each stimulus or one of the four possible inter-letter spaces. Fixation location was controlled using an eye-tracker linked to a fixation-contingent display and all stimuli were presented entirely within foveal vision. The findings revealed that word recognition performance was equally poorest when words were shown entirely to the right or left of fixation, and performance was equally superior when fixations were made at any inter-letter locations between the beginning and middle of words, with no evidence of the hemispheric division in word recognition predicted by split foveal theory. Although clear effects of fixation location were obtained, no evidence to support SFT accounts of the role of fixation location in word recognition was observed.

What can be concluded about this (the OVP and the SFT) is that the same pattern of the OVP will be obtained irrespective of whether fixation location is carefully controlled. This seems to suggest that it is not the precise fixation location (as is stated in SFT) that is important, but the approximate location.

However, much of the research into the OVP effect has been conducted in Latinate languages that are read from left-to-right. Therefore, it is of considerable interest to see if similar effects are obtained in a language such as Arabic that is read from right to left. In particular, such an experiment would enable further examination of the different explanations that have been given for the OVP effect in English and French. If the offset of the OVP to the left of a word's centre is due to asymmetry in perceptual span or to reading habits for languages read from left-to-right, then it is very likely that a different OVP pattern would be observed for a language such as Arabic that is read from right to left. Moreover, if the location of the OVP is due to the split-fovea processing of words, then it seems likely that a similar OVP effect would be observed for languages read from left-to-right or right-to-left. This is because the OVP reflects the division of word processing across the two cerebral hemispheres rather than differences in the reading of words in different languages. Thus, while it is clear that fixation location influences word recognition, it appears that foveal word recognition is not affected by the precise location at which a word is fixated and does not reflect a split in hemispheric processing at the point of fixation.

One previous experiment by Farid and Grainger (1996) has examined the OVP effect in the naming of both Arabic and French words by French-Arabic bilinguals. However, a major problem for this experiment, and for the vast majority of experiments that have examined OVP effects in word recognition, is that despite the importance of participants fixating a particular desired location prior to a word being displayed, no

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external monitoring or control of fixation accuracy was used in this study. Instead, as in many other studies, the experimenters relied on simply instructing participants to fixate accurately.

The present experiment used an eye-tracker to ensure that participants were accurately fixating the desired location before a stimulus was presented. In addition, the stimuli that were used were made sufficiently small so that the entire word would always be perceived in foveal vision (this also has not been the case in many previous OVP studies), and the experiment used the lexical decision task rather than naming to investigate the effects of viewing position on the recognition of Arabic words.

In this experiment, five-letter Arabic words and legal non-words were used as stimuli and the OVP effect was tested by using an eye-tracker to ensure that participants fixated at specific locations in each word, either immediately to the left or right of the word, or at one of four inter-letter locations within words.

6.4   Summary of Chapter 6

The purpose of this chapter was to review studies of the optimal viewing position (OVP) in word recognition, which means that words were recognised most quickly when fixation was between the beginning and middle letters in word recognition experiments conducted into Latinate languages (e.g., English, French and German).

Important points can be concluded from this previous research and this is why the present experiment is concern with re-examining Arabic word recognition. For example, various attempts have been made to explain the OVP effect. In general the accounts focus on the acuity limitations of the human eye and relate this either to differences in the importance of different parts of words or to differences in the role of the two hemispheres in reading. Other research attributes the effect to perceptual learning, according to which a learned pattern of viewing words leads to systematic

effectiveness of fixating those words at particular locations. Many studies indicate that the beginnings of words (in Latinate languages), are unusually important for word recognition or due to the hemispheric asymmetry.

This is useful for the purposes of the present study, since it is clear that letters that are of special importance for word recognition are distributed throughout words in Arabic, rather than concentrated towards the beginning (as in Latinate languages). This finding is essential for the issues the current research is concerned with, since the effects of fixation location on Arabic word recognition need to be established under appropriate conditions of stimulus and fixation control. The purpose of the present research is to assess the role of fixation location in Arabic word recognition under appropriately controlled conditions.

Chapter 7 Experiment 4: the OVP Effects in Arabic Word Recognition

Research in Latinate languages discussed in the previous chapter (chapter 6) shows that there is an optimal viewing position (OVP), which means that participants have faster responses, and quicker naming times, when words are fixated just to the left of their centre. Studies of the effects of fixation location in alphabetic languages have been based on Latinate languages (e.g., English and French) in which text is read from left to right and in which individual letters are typically clear and readily segregated. Consequently, little is known about the effects of fixation location in alphabetic languages with visual properties fundamentally different from Latinate languages.

A few studies have looked at the OVP in semantic languages (e.g., Farid & Grainger, 1996; Deutsch & Rayner, 1999); one of these was a study by Farid and Grainger (1996) that looked at the OVP in Arabic. Farid and Grainger examined the OVP effect in the naming of both Arabic and French words by French-Arabic bilinguals. This study showed that the OVP for Arabic is at the centre of words. However, a major problem for this experiment was that despite the importance of participants fixating a particular desired location prior to a word being displayed, no external monitoring or control of fixation accuracy was used. Instead, the experimenters relied on simply instructing participants to fixate accurately. It is generally accepted that accurate fixation cannot be ensured without external monitoring, such as using an eye-tracking device. This is important since it is not known were participants were actually looking within the words.

As seen in the previous chapter there is considerable evidence that even when participants are instructed to look at particular location they do not do so accurately (e.g., Jordan et al., 1998; Gazzaniga, 2000; Jordan & Patching, 2006; Jordan & Paterson, 2009) . Secondly, we do not know what size of stimulus the experimenters

used, therefore it may have extended into the right visual field and into extra foveal locations, which would complicate any explanation of their findings that are based on split fovea processing. Therefore, the purpose of this study is to assess the OVP effect in Arabic in more detail. The primary reason for doing this is to determine precisely what effects take place under conditions that use appropriate control of fixation locations and properly sized stimuli. This will also allow assessment of some of the key explanations of the optimal viewing position and in particular the split fovea theory (SFT).

According to the split fovea theory word recognition is affected fundamentally by the precise location at which a word is fixated. This is because a precise split in hemispheric processing at the point of fixation causes all letters to the left and right of fixation to project to different, contralateral hemispheres. Research in this area is dominated by the use of Latinate languages (for example, English) that may induce specific effects on performance.

Nevertheless, in this experiment five-letter Arabic words (and non-words) were presented for lexical decision (the same task with exposure durations of 150ms that was used in Experiment 2, see Chapter 3 for more details) when the participants fixated immediately to the right (location 1) or left (location 6) of each stimulus, or one of the four possible inter-letter locations (locations 2-5) (see Figure 7.1 in which fixations made at each of the six locations are shown). The fixation location was controlled by using an eye-tracker linked to a fixation-contingent display, and all stimuli were presented within foveal vision to avoid confounding influences of extrafoveal projections.

(a) the locations of the 6 fixations used for each stimulus

مــعــلــمــة

6 5 4 3 2 1

(b) the displays used to achieve these fixations

Fixation Point

Location 1 مــعــلــمــة

Location 2 مــعــلــمــة

Location 3 مــعــلــمــة

Location 4 مــعــلــمــة

Location 5 مــعــلــمــة

Location 6 مــعــلــمــة
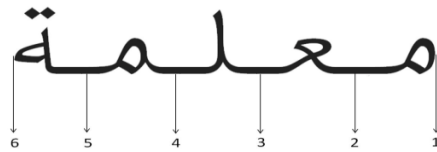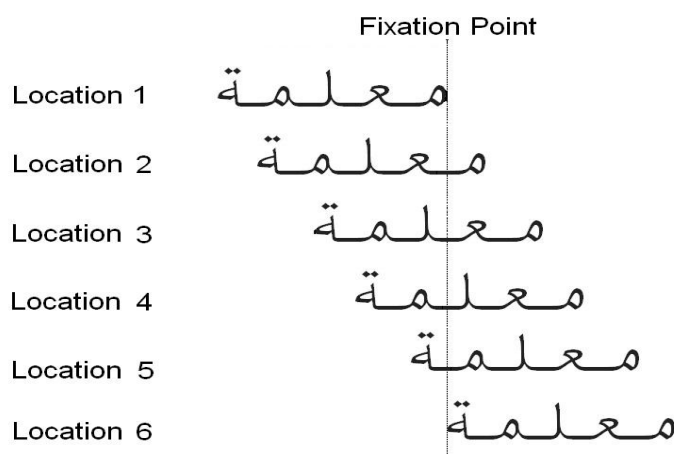
Figure 7.1. The locations of the 6 fixations used for each stimulus and the displays used to achieve these fixations

7.1 Predictions

The characteristics of Arabic differ fundamentally from those of Latinate languages. In particular, text in Arabic is read from right to left, but text in Latinate languages is read from left to right and the beginning (leftmost) letters of words are unusually important for word recognition. Moreover, there is a difference between Arabic and Latinate languages in terms of the morphological construction of words. In English, letters that are of special importance to the word are concentrated towards the word's beginning. Whereas in Arabic, letters that are of special importance for the word's (roots) recognition are distributed throughout the word. If the informative parts of words are important for determining the point of fixation, then while this effect is seen in English

we might not expect to see the bias take place in many Arabic words because most Arabic words do not have a single informative region.

If the offset of the OVP to the left of a word's centre is due to asymmetry in perceptual span or to reading habits for languages read from left-to-right, then it is very likely that a different OVP pattern would be observed for a language such as Arabic that is read from right to left. Moreover, if the location of the OVP is due to the split-fovea processing of words, then it seems likely that a similar OVP effect would be observed for languages read from left-to-right or right-to-left. This is because the OVP would reflect the division of word processing across the two cerebral hemispheres rather than differences in the reading of words in different languages. Therefore, the present experiment used an eye-tracker to ensure that the participants were accurately fixating the desired location before a stimulus was presented. In addition, the stimuli that were used were made sufficiently small so that the entire word would always be perceived in foveal vision, and the experiment used the lexical decision task rather than naming to investigate the effects of viewing position on the recognition of Arabic words.

7.2 Method

Participants: 18 native Arabic speakers from the University of Leicester took part in this experiment. All participants were assessed for normal or corrected to normal visual acuity, as determined using a Bailey-Lovie eye chart, and for right-handedness, using a revised Annett Handedness questionnaire (Annett, 1970). Since many people who are left-handed have right hemisphere dominance for language function, whereas almost all right-handed people have left-hemisphere dominance for language function, this may confound the study of word recognition (Whitehouse & Bishop, 2008). Eye dominance was also determined individually by using the Hole in the Card test for each participant

(Durand & Gonld, 1910, as cited in Shneor & Hochstein, 2006). This revealed that 13 of the participants were right-eye dominant and 5 were left-eye dominant.

Stimuli and Design: The stimuli were 120, 5-letter Arabic words and 120, 5-letter pronounceable non-words generated by rearranging the order of letters in the Arabic words. Each stimulus was presented at six different screen locations: either immediately to the right or left of the word, or at one of four inter-letter locations (see Figure 7. 1). 24 additional stimuli (12 Arabic words and 12 non-words) were used as practice items at the beginning of each session. The stimuli were presented in random order at each of six screen locations, such that the fixation point coincided with either a location immediately to the right or left of the stimulus, or one of four inter-letter locations. Stimuli were presented in six sessions (the same items were presented 6 times), with an equal number of words and non-words presented at each location and only one presentation of each stimulus in each session. Thus, there were 240 numbers of trials in each session and a total of 1,440 stimulus presentations.

Apparatus: Stimuli were presented on a high-definition display monitor. A Cambridge Research Systems VSG 2/5 card controlled the stimulus presentations and timing. Responses were collected via a Cambridge Research Systems CT3 button box. The experiment was conducted in a sound-attenuated and darkened room, and the displays were observed using a head brace and chinrest to ensure a constant viewing distance of 85cm. Stimulus viewing was monocular and the position of the dominant eye was monitored using a Skalar IRIS eye-tracking system (Cambridge Research Systems). The eye tracker was clamped firmly to each participant's head, which in turn was clamped in a rigid head brace (that incorporated the chin-rest) throughout the experiment to prevent head movements. This arrangement allowed accurate and consistent measurement of fixation location in the experiment to within five minutes of

arc (for further details, see Patching & Jordan, 1998; Jordan & Patching, 2006). The tracker's output was recorded each millisecond.

Procedure: Before the start of each session, the participants were given instructions that included emphasising the importance of accurate fixation, and the eye-tracker was calibrated for the fixation of each participant's dominant eye. Participants were instructed emphatically to fixate a point at the centre of the screen at the start of each trial. This fixation point was presented at the centre of the screen and the stimulus presentation was withheld until the accurate dominant eye fixation of this point actually occurred for 300ms. When this criterion was satisfied, the fixation point disappeared and a stimulus was presented for 150ms at one of six locations (the same display duration in Experiment 2). If fixation deviated from the fixation point before the stimulus presentation, no stimulus presentation took place until accurate fixation was re-established. Half the participants were randomly assigned to respond using their right hand and the remaining participants used their left hand. For each stimulus the participant indicated whether the stimulus was a word or a non-word by pressing one of the response keys. There were six sessions each, with lasting for 25-30 minutes.

7.3   Results

Mean error rates and reaction times for correct responses to words are shown in Figure 7.2. Reaction times for correct responses and error rates were analysed, using one-way, within-participants Analyses of Variance (ANOVA) with the variable fixation location. Preliminary analyses showed no significant effect of response hand or session, and these variables were not included in subsequent analyses.
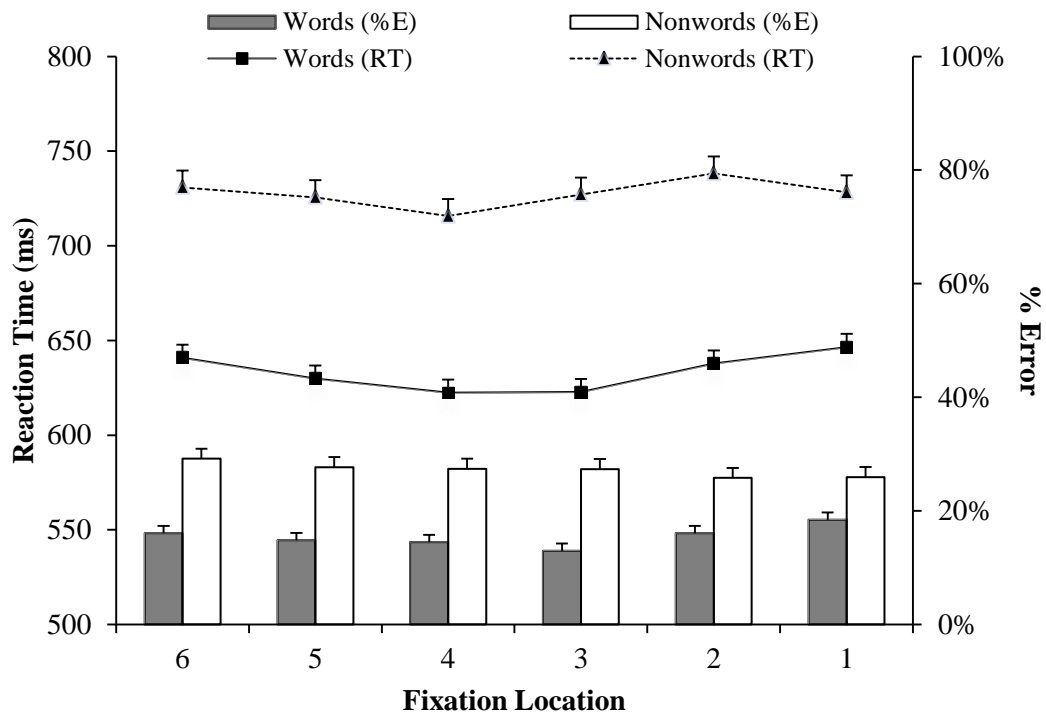
Figure 7.2. Reaction times and error rates for lexical decision for words and non-words fixated at each fixation position, with bars correspond to 95% confidence interval (e.g., Loftus and Masson, 1994)

7.3.1 Reaction Times for Words

An ANOVA revealed that the fixation location had a significant effect on reaction times for words $F(5, 85) = 3.10$, $p < .01$, $\eta_p^2 = .15$. Reaction times were shorter when participants fixated at positions 3 and 4 at the centre of words than at any other location (ps $< .01$). It was intermediate at locations 2 and 5, and longest at locations 1 and 6 (to the left and right of words). Reaction times did not differ significantly between locations 2 and 5, or between locations 1 and 6, indicating that performance did not differ when most or all letters in words were presented to either the left or right of fixation (ps $> .01$).

7.3.2 Error Rates for Words

An ANOVA revealed the significant effects of fixation location on error rates for words, $F(5,85) = 7.15$, $p < .001$, $\eta_p^2 = .15$. Specially, error rates were lowest for position

3 at the centre of words (13 percent), closely followed by position 4 (14 percent) at the centre of words. It was intermediate at locations 2 and 5, and highest at locations 1 and 6 (to the right and left of words) (all ps<.01). Error rates did not differ significantly when fixations were made at locations 2 and 5, or locations 1 and 6, indicating that accuracy for words did not differ significantly when all or most letters in words were presented to the left or right of fixation.

7.3.3   Reaction Times for Non-words

An ANOVA revealed no significant effect of fixation location on reaction times for non-words $F(5, 85) = 1.51$, $p>.05$, $\eta_p^2 = .08$.

7.3.4   Error Rates for Non-words

An ANOVA revealed no significant effect of fixation location on error rates for non-words, $F(5, 85) = 2.27$, $p>.05$, $\eta_p^2 = .21$.

7.4   Discussion

In this experiment we investigated the OVP effect in Arabic word recognition. This was achieved by using a lexical decision to assess the recognition of Arabic words (and non-words) presented entirely within foveal vision, and by ensuring precisely-determined fixations at each of six locations: the space immediately to the right (location 1) or left (location 6) of each stimulus, and four midpoints positions between the letters in each stimulus (locations 2-5). Performance with words was equally superior when fixations were at locations 3 and 4, at the centre of words, intermediate for locations 2 and 5, to the right and left of a word's centre, and equally poorest for locations 1 and 6, where words were displayed entirely to the left or right of fixation. Such findings present problems for SFT's claim that word recognition generally should be superior when most or all letters in a word are shown to the right of fixation, because these letters project

unilaterally to word recognition processes in the LH. In this experiment, this asymmetry in projection should have been greatest for fixations immediately to the left and right of words (locations 6 and 1), because, according to SFT, words in these displays would project unilaterally to the LH and RH, respectively, and so a comparison of performance for fixations at these locations provides the most straightforward test of SFT. However, near-identical levels of performance were observed, and so provided no evidence for superior word recognition when words were displayed entirely to the right of fixation.

Indeed, a further indication of the absence of asymmetry was provided by the lack of a difference in performance when fixations were made at locations 3 and 4, or locations 2 and 5, when most letters in words were presented to either the right or left of fixation (and therefore to either the LH or RH, according to SFT's claim). Moreover, the absence of a difference in performance between these locations clearly was not due to insensitivity to the effects of fixation location as, in the experiment, performance differences were clear for other fixation locations. Consequently, although a standard LH recognition advantage is found for Arabic words displayed at extra-foveal locations (e.g., Eviatar , 1999; Eviatar et al., 2004), where the existence of unilateral contralateral hemispheric projections is not contentious and is known to affect word recognition in other alphabetic languages (e.g., Gazzaniga, 2000), the present research revealed no advantage when all or most letters in words were presented to the right of fixation in foveal vision. Thus, while the findings indicate that fixation location is an important determinant of word recognition in Arabic, no evidence was found of split-foveal processing.

The results show very clearly that the OVP is at the very middle of Arabic words, as participants recognised words most accurately and with fewest errors when they fixated the middle of Arabic words as compared to the other fixation positions.

This replicates the findings reported by Farid and Grainger (1996) under conditions using the lexical decision task rather than naming, and when an eye-tracker was used to ensure fixation accuracy (e.g., Boudelaa & Marslen-Wilson, 2001, 2004, 2005). This suggests that normal processes of Arabic word recognition were being used in the experiment (Jordan et al., 2011). No such effect was observed for non-words. Precisely, neither reaction times nor error rates showed any benefit when most or all letters were presented to the right of fixation, suggesting that the OVP is specific to word recognition. The results show non-words produced overall longer reaction times and more errors than words, as is often found in lexical decision experiments (e.g., Antos, 1979; Bentin, McCarthy & Wood, 1985; Andrews, 1992).

The effect of fixation location was consistent with serial right-to-left processing of non-words, and revealed that accuracy for non-words was highest when fixations were made at locations 1 and 2, and most or all letters were displayed to the left of fixation, lower across intermediate fixation locations, and poorest for fixations at location 6, when non-words were displayed entirely to the right of fixation. A persuasive explanation of the difference between performance for words and non-words is that word recognition normally develops to accommodate a default OVP for a language. Whereas unfamiliar letter strings, such as non-words that have no stored representations, do not benefit from this default process. The absence of a 'natural' optimal viewing position for non-words may therefore result in the implementation of a serial processing strategy, from beginning letters to end letters (that is, from right to left), whereas words enjoy richer, more parallel processing (e.g., Allen & Emerson, 1991; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

The results also show that the OVP effect differs for words in Arabic and Latinate languages, as participants recognised words most quickly and most accurately

when fixating inter-letter locations at the middle of words, indicating that the OVP for Arabic word recognition is at a word's centre. It therefore appears that the OVP effect for Arabic differs from that observed in studies of word recognition in English, which have shown that words are recognised most efficiently when fixated between their beginning and middle letters. One possibility is that this is due to the different direction of reading in these languages. Moreover, there is a difference between Arabic and Latinate languages in terms of the morphological construction of these words. For example, in Latinate languages such as English and French the informative part is very often found at the beginning of the words because these languages have many suffixes (compared with prefixes which are purely grammatical information), thus the important part is usually at the beginning of words. Whereas in Arabic letters that are of special importance for a word's recognition (the word's root) are distributed throughout the word; indeed, many Arabic words do not have a single informative region (e.g., Stevens & Grainger, 2003; Farid & Grainger, 1996; Boudelaa & Marslen-Wilson, 2005). These may make the left of the centre the middle according to informativeness, because the left side is most informative (which differs from the middle according to the physical size of the OVP) in English and French. However, this is not the case for Arabic words because of the widespread distribution of informative letters across Arabic words. This makes both the physical and the informative positions in Arabic words occur at the same place (which is the word centre for the Arabic OVP).

The OVP effect for Arabic words shows a symmetrical distribution of processes across the entire Arabic word, which might help accommodate firstly, the drop-off in visual acuity that occurs with increased distance from the centre of the fovea (e.g., Olazak & Thomas, 1986). And secondly, explain the widespread allocation of morphological information across Arabic words (e.g., Farid & Grainger, 1996).

What does seem clear, however, is that the findings are problematic for the split-fovea account of the OVP, as this account would predict that a similar OVP effect would be observed for languages read from left-to-right or right-to-left because the OVP reflects the division of word processing across the two cerebral hemispheres rather than differences in the reading of words in different languages. The findings presented here and findings from other studies using Latinate languages do not support the split foveal theory's claims when using appropriate fixation and stimulus controls (e.g., Jordan et al., 2008; Jordan et al., 2009; Jordan et al., 2010). This includes research that has used the lexical decision task to investigate the effects of fixating various locations within words (and locations immediately to the left or right of words) that showed no advantage of projecting most (or all) letters in words to the right of fixation (e.g., Jordan et al, 2009, 2010), and other research that used a two-alternative forced-choice task to assess the recognition of words displayed entirely to each side of fixation at locations either close to fixation and entirely in foveal vision or further away from fixation in extra-foveal vision. Although this latter research revealed standard LH advantages for extra-foveal word displays, there was no evidence of hemispheric asymmetries in the recognition of words displayed in foveal vision.

Recent research has been conducted by supporters of the split foveal theory in response to the criticisms about the very low levels of fixation accuracy. For example, van der Haegen et al.'s (2010) findings showed the same pattern of performance when fixation accuracy was ensured or fixation location was only monitored. This led van der Haegen et al. to argue that fixation inaccuracy merely introduces an element of noise to word recognition performance (although it should be noted that this "noise" accounted for more than 65 percent of the data when fixation location was monitored). They argued that it is unnecessary to conduct OVP research with the levels of experimental

control advocated in the criticisms of split fovea research (e.g., Jordan & Paterson, 2009). However, what actually seems clear from this and other recent research (e.g., Paterson et al., 2009) is that such findings are hard to reconcile with the fundamental claim of SFT that shifts in fixation between adjacent letters in words produce major effects on word recognition (e.g., Lavidor et al., 2001; Ellis, 2004; Ellis & Brysbaert, 2010).

7.5   Summary of Chapter 7

In summary, a more general problem in interpreting the findings from previous research using the OVP paradigm is that the earlier research that provided the motivation for this approach (e.g., O'Regan, 1981; O'Regan & Jacobs, 1992; Stevens & Grainger, 2003; Vitu et al., 1990) attributed findings from this paradigm to various factors, including the drop-off in acuity that occurs with increased distance from the centre of the fovea (Olazak & Thomas, 1986), asymmetric allocation of attention and its role in letter visibility (Bouma, 1973; Rayner et al., 1980), and the informativeness of parts of words (e.g., Farid & Grainger, 1996; O'Regan et al., 1984). Thus, while all the reasons for the OVP remain to be fully determined, it should be clear that various factors and also potentially complex interactions between factors (e.g., Brysbaert & Nazir, 2005) can explain the performance in OVP research without the need for the split fovea explanation. Importantly, however, although split hemispheric processing at the fixation point is basic to the split foveal claim, studies in Arabic (this experiment) and English (e.g., Jordan et al., 2009, 2010) have shown that the effects of fixation location on word recognition examined with appropriate experimental precision provide no evidence of a functional division in hemispheric processing at the point of fixation (Jordan et al., 2011).

Chapter 8 Hemispheric Asymmetry and Word Recognition

The previous chapter included an experiment in which the OVP effect in Arabic word recognition was re-examined. Although divided hemispheric processing at the point of fixation is essential to SFT, the findings from the Arabic investigation show no evidence of a functional division in hemispheric processing at the point of fixation. However, it might be argued that the OVP paradigm may not be ideally suited for evaluating SFT. Therefore, a simple test of SFT involves using appropriate fixation and stimulus controls to assess the recognition of words presented each side of fixation at foveal and extrafoveal locations.

This chapter will focus on the roles of the hemispheres in word recognition. Hemispheric asymmetry or cerebral laterality refers to the anatomic and functional differences between the halves of the brain (Min & Oh, 1992). The hemispheric processing responsible for recognizing a word from its retinal image and a fundamental determinant of this processing is the anatomical arrangement of the human visual system, which causes information in each visual hemifield to project to the contralateral hemisphere (Jordan & Paterson, 2009).

8.1 RVF Advantage in Latinate English and French

The hemispheric split in word recognition is systematic. The fact that words are recognised better in the right visual field (RVF) than the left visual field (LVF) was first reported by Mishkin and Forgays (1952) and then Heron (1957) when they observed a right visual field advantage. In these studies English readers were presented with stimuli either to the left or to the right of the fixation point. Their findings showed that stimuli are processed more efficiently when presented at extrafoveal locations in the right visual hemifield (and so projected directly to an observer's left cerebral hemisphere, LH) than when presented at extrafoveal locations in the left visual hemifield (and so

projected directly to an observer's right cerebral hemisphere, RH; for overviews) (e.g., Bradshaw & Nettleton, 1983; Chiarello, 1988; Hellige, 1993, 2001). Further research, however, established that the series processing function is serial in the right visual field "RVF" and serially in the left visual field "LVF" (e.g., Young & Ellis 1985; Ellis, Young, & Anderson, 1988). For instance, Ellis, Young, and Anderson (1988) carried out experiments to investigate the effects of word length on participants' performance in the LVF and RVF presentation. Results showed that there was a length effect in the lexical decision task for a stimulus word displayed in the left visual field but not for a stimulus word presented in the right visual field. This study and the study by Young and Ellis (1985) found that for words shown in the left visual field, each further letter added to reaction time by about 20 ms.

Therefore, it is clear that research using lateralised visual displays has shown that the visual field is divided between the right and left sides of the brain, that visual information in one hemifield projects to the opposite side of the brain, and produces left-right differences in performance. A significant right visual field word advantage found for languages such as Hebrew and Arabic, which are read from right to left, was reported by studies such as those conducted by Faust et al. (1993) and Lavidor, Ellis and Pansk (2002). These findings showed that the right visual field advantage for words reflects privileged access to specialized LH processing.

8.2   RVF Advantage in Semantic Languages Hebrew and Arabic

Semitic languages (e.g., Hebrew, Arabic and Urdu) also produce perceptual superiority for words displayed to the right of fixation at extra-foveal locations, indicating LH dominance for processing words in this language (e.g., Ibrahim & Eviatar, 2009). For example, Eviatar (1999) conducted experiments to look at the effects of specific language features on hemispheric display performance, and presented stimuli using a

lateralized display. The results showed that Hebrew readers made more errors on the last letter in the right visual field than in the left visual field, and revealed an RVF advantage. Adamson and Hellige (2006) carried out an experiment to examine hemispheric asymmetry for native speakers of the Urdu language. The results showed that participants better identified words when they were presented to the RVF/LH than to the LVF/RH, consistent with a left-hemisphere advantage. Ibrahim and Eviatar (2009) carried out an experiment in which they presented Arabic words and non-words using a lexical decision task. The findings support the well-established view that the LH is specialised for word recognition in alphabetic languages and provides further evidence that an LH-advantage occurs for words displayed in extrafoveal locations even in languages, such as Arabic, that are read from right to left (e.g., Adamson & Hellige, 2006; Faust et al., 1993). A study by Eviatar and Ibrahim (2007) examined the effects of morphological difficulty on the hemispheric division presenting word stimuli from three different languages including Arabic, and readers showed right visual field/left hemisphere advantage.

These findings showed a clear LH advantage for words displayed at extrafoveal locations, and showed further evidence for hemispheric asymmetry in word recognition. Consequently, although a standard LH recognition advantage is found for Arabic and Hebrew words displayed at extra-foveal locations (e.g., Eviatar, 1999; Eviatar et al., 2004), the existence of unilateral contralateral hemispheric projections is not contentious and is known to affect word recognition in other alphabetic languages (e.g., Gazzaniga, 2000).

8.3   Laterality and Hemispheric Asymmetry

There is an anatomical constraint characteristic of the human brain in which certain functions (e.g., language understanding), are controlled by one side in preference to the

other. So that, the visual field is divided between the right and left sides of brain into two hemispheres which are joined together by the Corpus Callosum (e.g., Gazzaniga, 2000). For example, since the left and right cerebral hemispheres control the right and left sides of the body, respectively, visual information in one hemifield projects to the opposite side of the brain. This produces left-right differences in performance.

Laterality research has found that words displayed in the right extra foveal location are recognised more easily than those displayed in the left extra foveal location. This has been found across different languages with different directions of reading (Brysbaert et al., 1996). Previous visual laterality research has also revealed that recognition is superior if the same stimulus is presented to both visual fields at the same time. For example, Marks and Hellige (2003) carried out experiments and found that as words are bilaterally displayed, the pattern of error appeared more parallel to the right hemisphere pattern than to the left hemisphere pattern.

Three alternative explanations of the RVF advantage have been proposed in the literature (e.g., Brysbaert et al., 1996). The first explanation is that the right visual field advantage for word processing to be a result of the word beginning being more informative than the word end. In particular, in research using Latinate languages participants are more able to guess a word's identity when the highly informative beginnings of words in these languages are closer to the point of fixation (e.g., Kirsner & Schwarz, 1986; Bryden et al., 1990; Faust et al., 1993; Jordan et al., 2000; Jordan et al., 2003).

Another possible explanation for the RVF advantage are "reading habits," which means the use of languages read from left to right such as English and French, as this makes it more difficult to process a word left of the central fixation point than a word right of this point (e.g., Mishkin & Forgays, 1952). A final possible explanation for the

RVF advantage is the scanning factors, which means that the right visual field stimulus is scanned quicker than that presented in the left visual field, for the reason that the stimulus decay produces a right visual field advantage (e.g., Efron, 1990). Other studies have tried to validate the laterality account by looking at hemisphere asymmetry and running experiments with split-brain patients (e.g., Corballis & Trudel, 1993); these have claimed that difficulties in the recognition of words displayed at locations straddling a central fixation point are due to the isolated right hemisphere containing a limited capacity for word comprehension (e.g., Zaidel, 1983).

Therefore, projection of the visual field is divided between left (LH) and right (RH) hemispheres, and with typical findings indicating word advantages when projected to the LH. However, an important question concerns _what happens at the point of fixation_ or what projections exist for words around the point of fixation? There is a longstanding view that there is an area of bilateral overlap at the fovea (1-3°), where information projects bilaterally to both hemispheres. According to this view, hemispheric asymmetries in word recognition should not be observed for words displayed in foveal vision. Therefore, information in this region is projected to both hemispheres (e.g., Gazzaniga, 2000; Leventhal, Ault & Vitek, 1988; Lindell & Nicholls, 2003; Marzi, Mancini, Sperandio & Savazzi, 2009; Jordan & Paterson, 2009).

According to the bilateral theory, an area of $1\text{-}3^{\circ}$ degrees wide which is typically, 4 letters $= 1^{\circ}$, exists around fixation so foveal information on both sides projects (_bilaterally_) to both the LH and the RH, therefore information in this region is projected to _both_ hemispheres (Jordan & Paterson, 2009).

In recent years, however, some researchers have promoted the opposing view that division continues all the way up to the point of fixation because each human fovea is divided so precisely at its vertical midline that even adjacent letters in words that fall

either side of this split project (unilaterally) to a different contralateral hemisphere (e.g., Brysbaert, 2004; Marzi et al., 2009; Ellis & Brysbaert, 2010). Thus, according to this view, left-right differences in word recognition will be observed for words that are both near and far from point of fixation and all information to the left of an observer's fixation within the foveal region will project unilaterally to the opposite hemisphere; this precise division in hemispheric processing at the point of fixation is argued to have important consequences for word recognition (e.g., Br ysbaert, 2004; Ellis & Brysbaert, 2010; Shillcock & Monaghan, 2000; Shillcock & McDonald, 2005).

8.4   Split Foveal Theory (SFT)

SFT (Chapter 6 also contains detailed description of this theory as one of the OVP explanations) means that a fixated stimulus is vertically separated, with the right part being sent to the left hemisphere (LH) and the left half of the fovea being sent to the right hemisphere (RH). When applying this theory in the case of visual word recognition, it means that the word is divided into the two hemispheres (LH and RH). Whatever is presented to the right visual field projects to the left hemisphere, and whatever is presented to the left visual field projects to the right hemisphere. In order to be able to recognise the word, the information in the two halves of the brain must be recombined through the Corpus Callosum. Therefore, only once the information regarding the word in the two hemispheres is recombined can the word be identified (e.g., Shillcock & Monaghan, 2003).

According to the SFT, each fovea is divided *precisely* at its vertical midline; thus information right up to fixation projects (*unilaterally*) to the contralateral hemisphere, therefore even foveal information is projected to only *one* (the contralateral) hemisphere (Martin et al., 2007).

Evidence for SFT: Supporters of this split-fovea view have attempted to reveal evidence of split-foveal processing by observing the effect on word recognition of presenting stimuli at various eccentricities around the point of fixation (Jordan & Paterson, 2009). For example, a typical approach has been to present words at offsets to the left or right of a fixation point so that they straddle this point at various locations, and in some studies these words are also shown entirely to the right or left of this point in nearby locations (e.g., Brysbaert et al., 1996; Brysbaert, 2004; Martin et al., 2007). The findings have shown a word recognition advantage when most of the letters in a word, or words in their entirety, were shown to the right of the fixation point. Thus, according to these studies, word recognition was determined by the hemisphere to which the letters presented to the left and right of fixation were projected; a processing advantage was produced when most or all of these letters were presented to the right of the fixation point, because all letters to the right of fixation are projected to the LH.

Researchers (e.g., Brysbaert, 1994) argued that whether or not interhemispheric transfer has functional effects for word presented at foveal locations can be established by comparing two groups of participants with right or left hemisphere dominance. For example, experiments were carried out by Brysbaert (1994), and Hunter et al. (2007), who studied word recognition. Participants were either left- or right-hemisphere dominant for language processing. To ensure accurate fixation, participants had to fixate a space between two vertical lines located at the screen centre. The results showed a processing advantage when the majority or all of the letters in words were presented to the right of the central fixation point. These advantages occurred only for the left-hemisphere dominant participants. Therefore, the researchers concluded that this finding supports the split foveal theory, as word recognition was determined by the dominance of the hemisphere due to the projection of the majority of letters to the left hemisphere,

which was consistent with split foveal theory. Importantly, however, in these studies stimulus size was not adjusted to the edges of the foveal visual region, making it unclear how effects of presenting information to the left and right of the designated fixation point reflected the influence of unilateral projections in foveal, not extrafoveal, vision (Jordan & Paterson, 2009). For example, the experiment by Brysbaert (1994) presented three-, four-, five- and nine-letter words, some of them subtended up to 3° of visual angle from the designated fixation point, making the effects of presenting information to the left and right of the designated fixation point unclear.

Martin et al. (2007) also examined performance with 5-letter words that straddled a central fixation point at various locations. A modified version of the Reicher–Wheeler paradigm was used. Stimuli were presented at a distance of 60 cm, which was subtended 6.65° of the visual angle. This research focused on the electroencephalographic activity of participants and Martin et al. (2007) do not report fully the effects of fixation location on word performance. ERP results revealed that a stimulus presented around the foveal field was projected contralaterally to one hemisphere. They also concluded that the effects they observed were in favour of the split foveal claim, and argue that the effects they observed were consistent with those of Hunter et al. (2007).

Van der Haegen et al. (2010) examined the validity of the argument against the split foveal theory in their study of the left-right asymmetry between fixations on the word beginning and the word end, which has been taken as evidence for interhemispheric transfer in foveal word recognition by split foveal theory supporters (e.g., Brysbaert, 1994; Hunter et al., 2007). Using a naming task in which participants had to name Dutch six-letter words (subtended for 2.5^o of visual angle, in their first experiment, and using an eye-tracking device and stimulus subtended 1.5^o of the visual

angle, in their second and third experiments) as fast as they could. The results showed that from the eye fixation analysis an accurate fixation on the letter, and so between the two vertical lines, was 34.4% and 71.9% of the trials in the eye monitoring condition and eye position contingent condition, respectively. Thus they showed that the participants did not constantly fixate accurately to where they had been instructed to if no eye position reliant stimulus presentation was used (Jordan et al., 2009). The results also showed that naming times for words were longer when fixations were made at end letter locations than at other locations in words, and this led van der Haegen et al. (2010) to argue that the effects provided evidence for divided hemispheric influences on the recognition of these words. However, as the words were six-letters long (and subtended 1.5° or more), van der Haegen et al. (2010) conceded that this finding did not preclude the possibility that shorter words might be processed bilaterally.

Five-letter words (that subtended approximately 1.25°) were used by Jordan et al., (2010) because these provided a maximum number of fixation locations that could be present in normal-sized stimuli shown entirely within foveal vision. The experiments clearly showed no asymmetry in word recognition when all or most letters were projected to the right or left of fixation, and so it is clear that recognition of these words was not subject to divided hemispheric processes.

Van der Haegen et al.'s (2010) study used naming to assess word recognition performance. The use of this task in SFT research (e.g., Brysbaert, 1994; Hunter et al., 2007) has been criticised on the grounds that because speech production in the vast majority of individuals is lateralised to the LH (e.g., Banich, 2004; Zaidel, 1998), naming can produce spurious advantages for information projected to the LH in experiments merely because the information is projected to the hemisphere responsible for producing a response rather than because this hemisphere is superior for recognizing

that information (Jordan & Paterson, 2009). This problem of interpretation is clearly relevant when stimuli extend outside the fovea, but could also occur for stimuli presented within foveal vision if an anatomical split in foveal processing exists along the lines proposed by advocates of SFT but is nevertheless not functional for word recognition. A related task confound often overlooked in SFT research using Latinate languages is that participants in experiments are more able to guess a word's identity when the highly informative beginnings of words in these languages are closer to the point of fixation (see e.g., Bradshaw, Nettleton & Taylor, 1981; Bryden et al., 1990; Chiarello et al., 1988; Faust et al., 1993; Hellige & Sergent, 1986; Jordan et al., 2000; Jordan et al., 2003; Kirsner & Schwartz, 1986; Schwartz, Montagner, & Kirsner, 1987). Performance in various tasks is vulnerable to this confound, and naming may exacerbate this effect. Thus, although a performance advantage may be observed when most or all letters in words are presented to the right of fixation, this benefit can occur simply because the beginnings of words are more visible, and this may produce spurious indications of a LH processing advantage at the point of fixation. Crucially, given the reliance on naming as a performance measure, the van der Haegen et al. (2010) study may suffer from both these confounds.

Evidence against SFT: The split foveal theory has been criticised by research that does not support it for different reasons. For example, it is well-established that participants have considerable difficulty in fixating precisely a pre-specified fixation in studies of word recognition, and that accurate fixation cannot be ensured without external monitoring and control (e.g., Jordan & Paterson, 2009; Gazzaniga, 2000). Yet, despite emphasising the importance of accurate fixation, research providing support for SFT has not used objective methods to ensure fixation accuracy in word recognition experiments (Jordan & Paterson, 2009).

It is also well established that unilateral contralateral projections exist outside foveal vision and affect word recognition (e.g., Gazzaniga, 2000). Moreover, studies that have used appropriate fixation and stimulus controls show no evidence of any functional division in hemispheric projections for words displayed to the right and left of fixation in foveal vision even though a clear division in hemispheric projections for words displayed to the right and left of fixation in extrafoveal locations are observed in the same experiments. Consequently, to provide clear evidence that effects of fixation location on word recognition reflect unilateral contralateral projections within foveal vision (the basis of SFT), accurate fixation of the required location on each trial must be ensured and performance must not be contaminated by stimulus projections in extrafoveal locations. Earlier research that supported the split foveal theory (e.g., Ellis & Brysbaert, 2010) have claimed that difficulties in the recognition of words displayed at locations straddling a central fixation point by split-brain patients (e.g., Corballis & Trudel, 1993) provide support for SFT; this too is problematic as these studies, which were not designed to test this theory, used stimuli that exceeded foveal vision and did not monitor or control fixation location.

For example, Jordan et al. (2008) used fixation-contingent displays to present words unilaterally to each side of fixation either entirely within foveal vision or entirely outside this area. A strong LH advantage was found for words presented to the right of fixation outside foveal vision but no advantage was found for the same words presented within foveal vision (e.g., Jordan et al., 2009), indicating no evidence of split-foveal processing. Other studies (e.g., Jordan & Paterson, 2009) have also found no evidence of split-fovea processing using a variety of different paradigms and procedures. The findings from these studies are clearly problematic for accounts of word recognition based on split-foveal processing. More-recently, a study reported by Jordan et al. (2010)

investigated the fundamental claim of SFT. Stimuli were presented for lexical decision when participants fixated around the point of fixation. Fixation location was controlled using an eye-tracker linked to a fixation-contingent display and all stimuli were presented entirely within foveal vision to avoid confounding influences of extrafoveal projections. The findings of this investigation showed no evidence to support SFT accounts of the role of fixation location in word recognition.

However, research on this topic using appropriate fixation and stimulus controls has so far been conducted using only Latinate languages (e.g., English, French) in which text is read from left to right and in which individual letters are typically clear and readily segregated. There are studies that have also examined the effects in other non-Latinate alphabetic languages; these have found clear LH-superiority for word recognition in languages read from right to left, including Arabic (e.g., Adamson & Hellige, 2006; Eviatar, 1999; Eviatar et al., 2004; Faust et al., 1993). However, a major problem for these studies is that despite the importance of the participants fixating a particular desired location prior to a word being displayed, no external monitoring or control of fixation accuracy was used; these investigations were also not designed to test the split foveal theory and did not present stimuli at the foveal region.

8.5   Methodological Issues

A major concern within the literature is that the studies investigating the split fovea account have several methodological problems (for a comprehensive discussion of this see Chapter 6). Supporters of the SFT have attempted to reveal functional evidence of split-foveal processing by observing the effect on word recognition of presenting stimuli at different eccentricities in the region of the point of fixation. The fundamental logic of this approach is that if word recognition is affected by unilateral and contralateral hemispheric projections right up to the point of fixation (as the SFT claims), this precise

division in processing will be revealed by asymmetries in performance for words displayed to the left and right of fixation even when presentations are inside the foveal region and close to the central point.

There are several requirements which are fundamental to the rationale of this approach. For example, it is important that participants in experiments that examine the SFT are accurately presented with information at the correct location either side of the fixation point and therefore in the appropriate visual field. Moreover, it is crucial that stimuli are of an appropriate size to always be displayed entirely within foveal vision. Accordingly, without these controls, apparent effects of split-foveal processing can be confounded by the presence of visual information in the wrong location in each hemifield (and even in the wrong hemifield), or by the presence of visual information in extrafoveal locations where the existence of unilateral and contralateral projections is well established.

Unfortunately, the perceptual advantage for information to the right of fixation in languages read from left-to-right, like English, risks providing spurious "left-hemisphere" advantages for words displayed at foveal locations. Moreover, much of the information acquired under properly controlled conditions about processes that underlie foveal word recognition in alphabetic languages has been derived from languages in which text is read from left to right, words have a concatenative morphology, and in which individual letters are typically clear and readily segregated.

This confound may be avoided by investigating recognition of words in a language read from right-to-left (Arabic) presented at foveal and extrafoveal locations to the left and right of a central fixation point. As a result, it remains to be seen whether alphabetic languages with properties fundamentally different from Latinate languages provide evidence of unilateral hemispheric projections in foveal word recognition. In

particular, the major aim of the current research is to establish if hemispheric asymmetries in word recognition are obtained for Arabic words displayed to the right and left of fixation in extrafoveal vision, and evaluate SFT's claim that hemispheric asymmetries in word recognition will affect the recognition of words displayed at foveal locations.

8.6   Summary of Chapter 8

In summary, the current chapter discussed hemispheric asymmetries in word recognition. It is well-established that words displayed outside foveal vision project to the contralateral cerebral hemisphere. Evidence from Latinate languages (e.g., English) indicates that words projected to the left hemisphere (LH) were recognised more efficiently than words projected to the right hemisphere (RH). This has been widely taken as evidence for superior LH word recognition capabilities. Other studies have shown similar evidence of the LH advantage for words in non-Latinate alphabetic languages, such as Arabic, Hebrew (e.g., Ibrahim & Eviatar, 2009). However, what happens at the centre of vision is still a subject of considerable controversy. Some researchers argue that the division continues all the way up to the centre point of fixation. Therefore, left-right differences in word recognition will be observed for words that are both near and far from the fixation point. A major aim of the current research is to examine this possibility in Arabic, which is read from right-to-left, so reading direction is not confounded with left-right differences in word recognition. Arabic is therefore ideally-suited to testing theories of hemispheric involvement in word recognition.

Chapter 9   Experiments 5-6: Visual Field and the Word-Nonword Effect in Arabic

A major challenge for word recognition research, in the alphabetic languages discussed in the previous chapter (see Chapter 6 and Chapter 8 for more details), is to reveal how words on the page or when presented are "projected" to the two hemispheres of the brain. This is important because the two hemispheres are functionally different; the majority of people have a hemisphere that is dominant for language, usually the left hemisphere, which provides faster processing and the lexicon. Previous research has shown that there is an area approximately one to three degrees wide that exists around the fixation point, therefore foveal information on both sides projects "bilaterally" to both the left hemisphere and right hemisphere.

This chapter includes two experiments that were conducted to reassess the claim that the hemispheres affect word recognition right up to the point of fixation because each fovea is divided specifically at its vertical midline. Experiment 5 used the Reicher-Wheeler task and Experiment 6 used the lexical decision task.

The issue of how words are recognised in lateralised displays has been a major issue in word recognition and the accuracy of response in each visual field has been used as a pointer of the processing approach used by both cerebral hemispheres (e.g., Babkoff, Faust & Lavidor, 1997; Bub & Lewine, 1988; Ellis et al., 1988; Jordan et al., 2008; Young & Ellis, 1985). One of the most significant findings concerning alphabetic languages such as English and French is that when words are presented in the right extra-foveal area they are processed more efficiently than when they are presented to the left extra-foveal area (e.g., Bradshaw & Nettleton, 1983; Bryden & Allard, 1976a; Bryden & Allard, 1976b; Hellige, 1993, 2001). In particular, the right visual field advantage has been argued to be related to the left hemisphere's superiority in processing language information. Much of the research into lateralised displays, which

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controlled the visual display, has been conducted in Latinate languages that are read from left-to-right. However, it remains to be seen if processing asymmetries observed for Latinate languages are also observed for Arabic. Arabic character recognition generally involves the processing of visual properties that are fundamentally different from those in Latinate languages. For example, Arabic is formed in a cursive script in which spaces infrequently exist between letters in words, even when formally printed, and which is read from right to left thus producing different patterns of viewing positions within words compared with Latinate languages (e.g., Farid & Grainger, 1996; Elanwar et al., 2007). Therefore there is a superior opportunity to study hemispheric asymmetry, since Arabic is unaffected by the irregularity in visibility of beginning letter information. For example, in the languages that are read from left to right and words are presented in the RVF, the beginning letters have a higher probability to fall in the high visual acuity area than the letters at the end of the words. Whereas, when presenting words in the LVF, the letters at the end of the words would have a higher change of falling within the high visual acuity area (e.g., Hilz & Cavonius, 1974; Jordan, Patching, & Milner, 2000; Stevens & Grainger, 2003). Therefore, Arabic characters demand attention in laterality research, as they run from right to left rather than from left to right, and also because Arabic reading involves a scanning direction which is opposite to that found in Latinate languages (e.g., Adamson & Hellige, 2006; Ibrahim et al., 2002).

Moreover, there is a major debate concerning whether there is a split in processing at the point of fixation, such that words to the immediate left of the fixation point project to the right hemisphere initially, and words to the right of the fixation project to the left hemisphere (e.g., Brysbaert, 2004; Jordan et al., 2008, 2009).

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These kinds of studies have often been addressed by presenting stimuli at least two degrees to the left or right of a central fixation point to ensure that the presentations are safely outside the bilateral projection but projected unilaterally (e.g., Lindell & Nicholls, 2003; Jordan, Paterson, & Stachurski, 2009b). However, some researchers have argued that the visual field is divided in two around the point of fixation, and that the two parts of the field presentations are projected for processing in different cerebral hemispheres right up to the point of fixation (e.g., Brysbaert & D'Ydewalle, 1990; Brysbaert et al., 1996; Brysbaert et al., 1996; Ellis, 2004; Hunter et al., 2007; Martin et al., 2007). Thus, if "word" was presented twice, first in the right foveal field and second in the left foveal field, around the point of fixation, the first presentation "word1" would project to the left hemisphere initially, and the second presentation "word2" would project to the right hemisphere according to split foveal theory. This account also proposes that there are differences in the word processing capabilities of the two hemispheres, such that the left hemisphere has superior word recognition capabilities.

In line with these considerations, two experiments have been conducted to assess the recognition of Arabic words displayed in the left and right visual hemifields at locations either close to fixation and entirely within foveal vision or further from fixation and entirely within extrafoveal vision. Both experiments used appropriate fixation and stimulus controls (e.g., Jordan & Paterson, 2009). These experiments investigated hemispheric asymmetries in the processing of Arabic words by presenting words and pseudo-words at foveal locations (with medial edges 0.15º from the fixation point) and extra-foveal locations (with medial edges 2.00º from the fixation point) to the left and right of a central fixation point by skilled readers of Arabic using standard paradigms of the Reicher-Wheeler task (following, Reicher, 1969; Wheeler, 1970) and the lexical decision task. Presentation accuracy was controlled using an eye-tracker. An

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example of stimuli locations in either the left or the right visual field is shown in Figure 9.1.
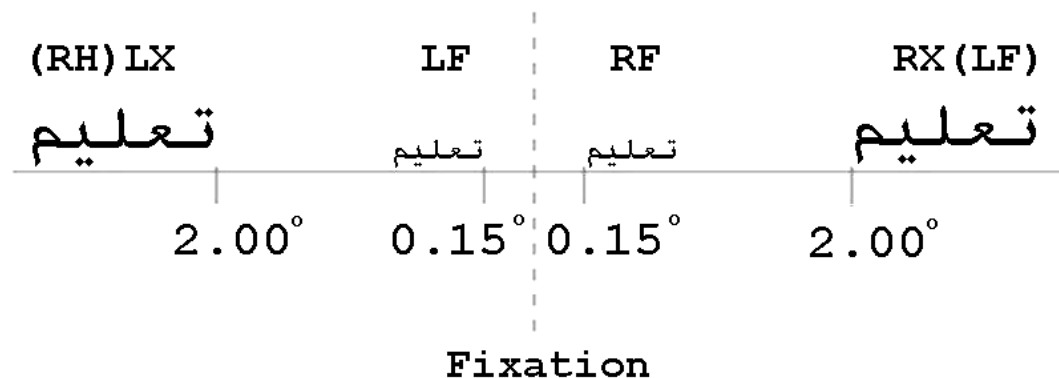
Figure 9.1. Screen locations of foveal and extrafoveal stimuli in Experiments 5 and 6

9.1 Predictions

Previous research using words presented at extrafoveal locations shows clear LH-superiority for word recognition in languages read from right to left, including Arabic (e.g., Adamson & Hellige, 2006; Eviatar, 1999; Eviatar et al., 2004; Faust et al., 1993). Consequently, if, as SFT proposes, the projection of information to the two hemispheres is split at the point of fixation, fixating so that most or all letters in foveally-presented Arabic words are to the right of fixation should produce an advantage for word recognition because these letters would project directly to the superior word recognition capabilities of the LH. Consequently, if the functional projection of information to the two hemispheres is split precisely such that hemispheric asymmetries in word recognition occur right up to fixation, an LH advantage should be observed for Arabic words displayed at extrafoveal *and* foveal locations. However, if split-fovea processing has no functional influence on word recognition, even under the experimental conditions afforded by Arabic stimuli, an LH advantage should be observed for words displayed only at extrafoveal locations, and no such advantage should be observed for words displayed each side of fixation within foveal vision.

9.2   Experiment 5: The Reicher-Wheeler Task

In this procedure, brief displays of words are followed by a forced choice between two alternatives that differ by one (critical) letter. For example, if "word" was displayed as the target, "word" and "work" may then be displayed as alternatives and participants would be required to indicate which alternative had been displayed as the target. Across the experiment, all letter positions are tested and all alternatives are presented as targets. The primary benefit of the Reicher-Wheeler task is that it reveals processes of word recognition while suppressing influences of artefactual bias based on partial word information; this is because the correct response containing the critical letter (in this case "word") cannot be deduced from other parts of the stimulus (w-o-r) (e.g., Jordan, Patching & Thomas, 2003; Jordan, Patching & Milner, 1998). Thus, and in line with the concerns raised earlier (see chapter 1 and 2 for more details), while participants may be more able to guess a word's identity when it is presented to one side of fixation simply because parts of the word can be seen more readily, the Reicher-Wheeler task will suppresses left-right imbalances in the informativeness of partial word information and, when combined with the benefits of using Arabic stimuli, will provide a particularly powerful technique for assessing word recognition in the left and right hemifields.

9.3   Method

Participants: Twelve native Arabic speakers took part. All had normal or corrected to normal visual acuity, determined using a Bailey-Lovie eye chart, and were right-handed, determined by a revised Annett Handedness questionnaire (Annett, 2003). Eye dominance was determined individually using the hole in the card test (Durand & Gould, 1910; see also Shneor & Hochstein, 2006).

Stimuli: 120 five-letter Arabic words, comprising 60 pairs of five-letter taken from the Arelex database (Boudelaa & Marslen-Wilson, 2001) and 120 matched five-

letter Arabic pseudo-words were used. Following the requirements of the Reicher–Wheeler task, words were selected to form matched pairs in which the members of each pair differed by just one letter (e.g., the Arabic words تعليم and تعليق, which differ at only the final, i.e., leftmost, letter position) and these differences occurred equally often at each of the five letter positions across all stimuli. Pseudo-word stimuli were constructed for each pair by re-arranging the four non-critical letters (the same letters differ for both words and non-words) in each word to form pronounceable non-words. An additional six pairs of five-letter words and six pairs of five-letter pseudo-words were constructed to provide 24 practice stimuli at the beginning of each session.

Stimuli were presented in standard cursive Arabic script as black text on a white background at foveal and extrafoveal locations to the left and right of a central fixation point. The physical size of the stimuli presented at foveal and extrafoveal locations was adjusted to avoid the confounding effects of visibility on overall levels of performance (e.g., Drasdo, 1977; Jordan et al., 2008, 2009) and to ensure that stimuli were shown entirely in either foveal or extrafoveal locations. Accordingly, foveal stimuli subtended approximately 1º horizontally, and the inner edges of these stimuli were 0.15º from fixation. Extrafoveal stimuli subtended approximately 2º horizontally, and the inner edges of these stimuli were 2º from fixation. Preliminary testing established that these sizes and eccentricities produced similar levels of overall performance for foveal and extrafoveal displays.

Apparatus: Stimuli were presented on a high-definition 21 inch ViewSonic G220F display monitor. A Cambridge Research Systems VSG 2/5 card controlled stimuli presentations and timing. Responses were collected via a Cambridge Research Systems CT3 button box. The experiment was conducted in a sound-attenuated and darkened room and displays were observed at a constant viewing distance of 85 cm.

Stimulus viewing was monocular via each participant's dominant eye to eliminate the confounding effects of binocular fixation disparity (e.g., Liversedge, Rayner, White, Findlay & McSorley, 2006; Blythe, Holliman, Jainta, Tbaily, & Liversedge, 2012) and dominant eye fixations were monitored using a Skalar IRIS eye-tracking system (Cambridge Research Systems). The eye tracker was clamped to each participant's head, which in turn was clamped in a head brace and chin-rest throughout the experiment to prevent head movements. This arrangement allowed accurate and consistent measurement of fixation location to within five minutes of arc (for further details, see Jordan, Patching, & Milner, 1998; Jordan & Patching, 2006). The output of the tracker was recorded through the ADC input of the Cambridge Research Systems VSG 2/5 card, which also controlled the visual display (for further details, see Jordan, Patching, & Milner, 1998, 2000; Jordan, Paterson, & Stachurski, 2009).

Design: Participants took part in three sessions, one on each of three different days. For each session, experimental words and pseudo-words were selected pseudo-randomly and assigned pseudo-randomly to the four stimulus locations so that 320 presentations took place in each session. Across all sessions, each participant was shown 960 presentations so that each experimental word and pseudo-word was shown once in each stimulus location.

Procedure: At the start of each session, participants were given instructions describing the forced-choice task and emphasising the importance of accuracy when responding. The eye-tracker was then calibrated. At the start of each trial, a single but clearly visible pixel (the fixation point) was presented at the centre of the screen. Participants were required to fixate this point and stimulus display was prevented until accurate fixation occurred continuously for 300ms. Once this criterion was satisfied, a stimulus was presented for 33ms (the display durations were increased from 17ms as in

"Experiment 2 Chapter 3" in order to reach a sufficient level of accuracy), at one of the four stimulus locations. If fixation deviated from the fixation point before stimulus presentation, stimulus presentation was immediately prevented and continued to be prevented until accurate fixation occurred again for at least 300ms (Jordan & Patching, 2006). Immediately following each display, the target stimulus and its matched pair-mate were displayed one above the other, in random order, and participants indicated which string had been shown by pressing the appropriate key on the button box. The fixation point then reappeared for the next target display. Forced-choice alternatives were presented in a size intermediate between the two sizes used for target presentations, at the bottom of the screen well away from the locations at which targets were presented, and were displayed until a response was made. Hand of response was counterbalanced across participants, so that half of the participants responded with their right hand and half responded with their left hand.

9.4   Results and Discussion

A straightforward way to investigate SFT would be to examine the LH advantage for stimuli presented to the left and right of fixation but using stimuli either entirely within foveal or extrafoveal locations. Therefore, the physical size of stimuli presented at foveal and extrafoveal locations in the experiment was adjusted to avoid the confounding effects of visibility on overall levels of performance (e.g., Drasdo, 1977), and to ensure that the stimuli were shown entirely in either foveal or extrafoveal locations (e.g., Jordan, Paterson & Stoyan, 2009; Jordan et al., 2011). Overall levels of performance were matched for foveal and extra-foveal stimuli (words and non-words) displays, (67% vs. 67%, preliminary analyses showed no significant effect of eccentricity (foveal, extrafoveal) or interaction with other factors, and these variables were not included in subsequent analyses), demonstrating that the size manipulations

used in the experiment effectively matched visibility across foveal and extra-foveal locations.

Consequently, a 2 (lexicality: words vs. pseudowords) x 2 (hemisphere: left vs. right) repeated measures ANOVA was performed on responses to stimuli separately for foveal and extrafoveal locations. Mean identification accuracy for words and pseudowords displayed at foveal and extrafoveal locations are shown in Figure 9.2.

Accuracy for foveal displays: There was a main effect of lexicality (words = 73%, pseudowords = 60%), $F(1,11) = 19.78$, $p = .001$, $\eta_p^2 = .64$, but no effect of hemisphere ($F < 1.5$) or interaction between these factors ($F < 1.3$). Indeed, there was no indication at all of a division in hemispheric processing for stimuli displayed in foveal vision (words, 73% vs. 73%; pseudowords, 61% vs. 60%).

Accuracy for extrafoveal displays: Main effects were found for lexicality (words = 72%, pseudowords = 62%), $F(1,11) = 22.50$, $p = .001$, $\eta_p^2 = .67$, and hemisphere (RH = 63%, LH = 71%), $F(1,11) = 16.33$, $p < .01$, $\eta_p^2 = .60$, with no interaction between these factors ($F < 1.5$), indicating an LH advantage for both words and pseudowords (words, 67% vs. 76%; pseudowords, 60% vs. 65%). Consequently, in contrast to the findings obtained for foveal presentations, performance showed substantial LH superiority for stimuli presented in extrafoveal locations.
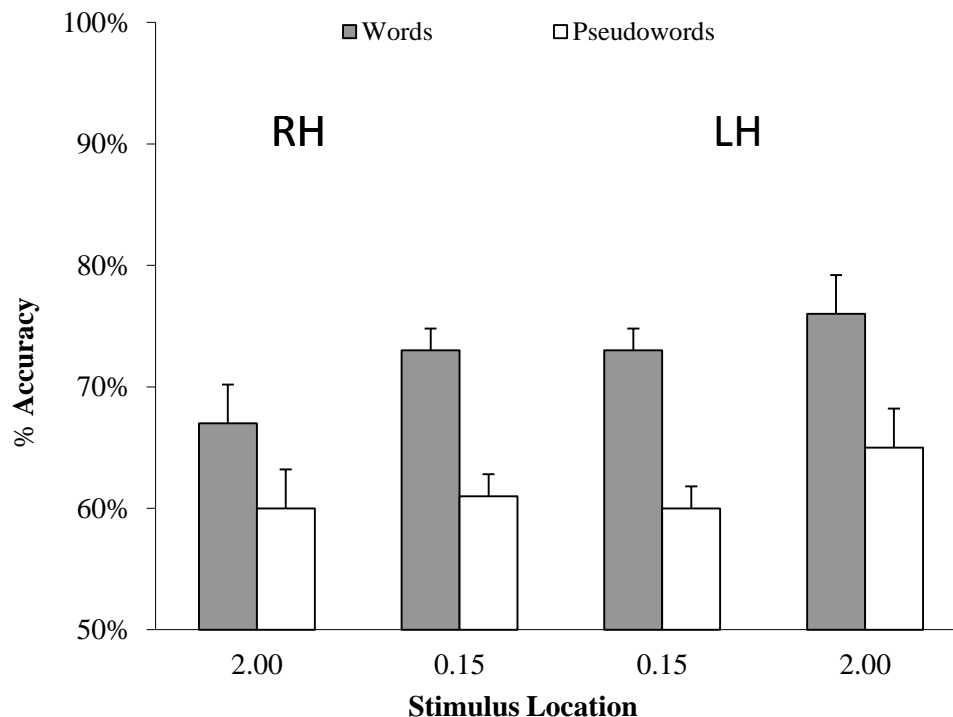
Figure 9.2. Mean identification accuracy for words and pseudo-words displayed at foveal and extrafoveal locations

Bars indicate the 95% confidence interval for each mean based on the within subjects mean square error (e.g., Loftus & Masson, 1994). The terms RH and LH refer to the hemisphere contralateral to the hemifield in which stimuli were presented.

The objective of this experiment was to investigate hemispheric asymmetries in the processing of Arabic words by presenting words and pseudo-words at foveal and extra-foveal locations to the left and right of a central fixation point, by skilled readers of Arabic using standard experimental paradigms of the Reicher-Wheeler task (e.g., Reicher, 1969; Wheeler, 1970; Reuter-Lorenz & Baynes, 1992; Jordan et al., 1998, 2000; Jordan, Thomas, & Patching, 2003) to suppress influences of guesswork (e.g., Johnston, 1978). Presentation accuracy was controlled using an eye-tracker.

The results show very clearly that there was right visual field advantage, as participants recognised stimuli more accurately when stimuli were presented in the right-extra-foveal area, than when stimuli were presented in the left-extra-foveal area;

the same stimuli presented within foveal vision showed the same levels of accuracy in both sides of the foveal fixations. These findings further support the idea that the effect of hemispheric asymmetry was completely absent for foveal presentations and that the information projected to both hemispheres (e.g., Jordan & Paterson, 2009; Paterson et al., 2009). However, this study has been unable to demonstrate that the visual field is split precisely into two sides at the point of fixation or that there is a difference in processing between the two hemispheres at this point (e.g., Brysbaert, 2004; Ellis, 2004).

9.5   Experiment 6: The Lexical Decision Task

The previous experiment revealed that the right visual field advantage is involved in the recognition of Arabic words as it is in recognition of words in Latinate languages, despite the very different characteristics of Arabic, but provided no evidence of a distribution (lateralization) in hemispheric processing for foveal presentations.

Advocates of the split-fovea account have criticised previous research that used the Reicher-Wheeler task and which found no evidence of an effect of split-foveal processing on word recognition by suggesting that it is an off-line task that does not provide reaction time measures of performance, and so may not be sensitive to small effects associated with split-foveal processing of words (e.g., Ellis & Brysbaert, 2010; van der Haegen et al., 2010). However, the task is clearly sensitive to the left-right divisions in hemispheric processing of word perception when these divisions occur (i.e., for extrafoveal locations) but provides no evidence at all for split-foveal processing, as both the present experiment and previous research have demonstrated (e.g., Jordan et al., 2008, 2009). The Reicher-Wheeler task has the particular advantage of being specifically designed to suppress influences of bias that might otherwise create spurious indications of the influence of hemispheric asymmetries on word recognition (e.g.,

Jordan et al., 2003; Reuter-Lorenz & Baynes, 1992). However, other techniques can be used to assess influences of hemispheric asymmetries on word recognition if they are selected carefully and conducted appropriately. Some researchers have used overt naming to assess word recognition performance in studies of hemispheric asymmetry using Latinate languages (e.g., Brysbaert, 1994; Hunter et al., 2007). Unfortunately, overt naming is problematic because speech production in the vast majority of individuals is lateralised to the LH and so naming can produce a spurious advantage for information projected to the LH because this information is projected to the hemisphere responsible for producing a response rather than because this hemisphere is superior for recognizing that information. However, not all tasks suffer from this problem, and one paradigm that has been used widely in word recognition research is the lexical decision task, which requires stimuli to be identified as either words or non-words as quickly and as accurately as possible. Although this task may not provide the stringent controls offered by the Reicher-Wheeler task and may not be exclusively sensitive to processes of perception (see e.g., Balota & Chumbley, 1984), it nevertheless has been shown to be sufficiently sensitive to reveal hemispheric asymmetries in word recognition when hand of response is appropriately counterbalanced to avoid hemispheric confounds in responding (e.g., Chiarello et al., 1988).

Therefore, in order to extend the findings of Experiment 5 by using a different paradigm, Experiment 6 assessed the influence of hemispheric asymmetries on perception of Arabic words and pseudo-words in foveal and extrafoveal locations using a lexical decision task, which provides a measure of reaction times for word recognition, with appropriate stimulus and fixation controls and counterbalanced hand of response.

9.5.1 Predictions

As in Experiment 5, the predictions are straightforward: if a functional division in hemispheric processing of words exists right up to fixation, performance should be superior for words displayed to the right of fixation in both foveal and extrafoveal locations. If, however, a functional division in hemispheric processing of words occurs only outside the fovea, performance should be superior for words displayed to the right of fixation in extrafoveal locations but no left-right superiority should be observed for foveal locations.

9.5.2 Method

Participants: Twelve native Arabic speakers took part. Participants had normal or corrected to normal vision, determined using a Bailey-Lovie eye chart, and were right-handed, determined by a revised Annett Handedness questionnaire (Annett, 2003), and had not taken part in Experiment 5. Eye dominance was determined individually using the hole in the card test (e.g., Durand & Gould, 1910; see also Shneor & Hochstein, 2006).

Stimuli: Stimuli comprised 120 real Arabic words and 120 Arabic pseudo-words created by re-ordering letters in Arabic words. These stimuli were drawn from the stimuli used in Experiment 1. 24 additional stimuli (12 words and 12 pseudo-words) were used as practice items at the beginning of each session. In this experiment Arabic words and pseudo-words were presented in the right visual field (RVF), left visual field (LVF) and central visual field (CVF). Participants took part in one day of each three sessions. The numbers of stimuli were equal in each session and each one appeared one time. (e.g., Jordan et al., 1998; Jordan et al., 2008). Stimuli were presented in three sessions, with an equal number of words and pseudo-words presented at each location and only one presentation of each stimulus in each session. Thus, there were 320 trials

in each session (one on each of three different days) and a total of 960 stimulus presentations.

Apparatus: Stimuli were presented on a high-definition 21-inch ViewSonic G220F display monitor. A Cambridge Research Systems VSG 2/5 card controlled stimulus presentations and timing. Responses were collected via a Cambridge Research Systems CT3 button box. The experiment was conducted in a sound-attenuated and darkened room and displays were observed at a constant viewing distance of 85 cm. Stimulus viewing was monocular via each participant's dominant eye to eliminate the confounding effects of binocular fixation disparity (e.g., Liversedge, Rayner, White, Findlay & McSorley, 2006; Blythe, Holliman, Jainta, Tbaily & Liversedge, 2012) and dominant eye fixations were monitored using a Skalar IRIS eye-tracking system (Cambridge Research Systems). The eye tracker was clamped to each participant's head, which in turn was clamped in a head brace and chin-rest throughout the experiment to prevent head movements. This arrangement allowed accurate and consistent measurement of fixation location to within five minutes of arc (for further details, see Jordan et al., 1998; Jordan & Patching, 2006). The output of the tracker was recorded through the ADC input of the Cambridge Research Systems VSG 2/5 card, which also controlled the visual display (Jordan et al., 2009b).

Design: Participants took part in three sessions, one on each of three different days. For each session, experimental words and pseudo-words were selected pseudo-randomly and assigned pseudo-randomly to the four stimulus locations so that 320 presentations took place in each session. Across all sessions, each participant was shown 960 presentations so that each experimental word and pseudo-word was shown once in each stimulus location.

Procedure: At the start of each session, participants were given instructions

describing the lexical decision task and emphasising the importance of speed and accuracy when responding. On each trial, a target word or pseudo-word was shown for 150 ms at one of the four stimulus locations. Participants were required to decide whether the stimulus was a word or pseudo-word and press the appropriate key on the button box, one marked "word" and the other marked "pseudo-word". Hand of response was counterbalanced across participants, so that half of the participants responded with their right hand and half responded with their left hand, and all used their index finger to make responses.

9.5.3 Results and Discussion

Mean error rates and reaction times for correct responses in lexical decision for words and pseudo-words fixated at each of the four foveal and extra-foveal locations are shown in Figure 9.3. The physical size of stimuli presented at foveal and extrafoveal locations was adjusted to avoid the confounding effects of visibility on overall levels of performance, and so comparisons of performance across foveal and extrafoveal locations were not of theoretical interest (see Experiment 5 for more details). Consequently, a 2 (lexicality: words vs. pseudo-words) x 2 (hemisphere: left vs. right) repeated measures ANOVA was performed on reaction times and error rates separately for foveal and extrafoveal locations.

Reaction times for foveal displays: There was a main effect of lexicality (words = 572 ms, pseudo-words = 609 ms), $F(1,11) = 10.13$, $p< .01$, $\eta_p^2 = .48$, but no main effect of hemisphere or an interaction (Fs < 1). Consequently, there was no indication of a division in hemispheric processing for stimuli displayed in foveal vision (words, RH = 573 ms, LH = 570 ms; pseudo-words, RH = 608 ms, LH = 610 ms).

Error rates for foveal display: There was no main effect of lexicality, $F(1,11) = 3.60$, $p = .09$, $\eta_p^2 = .25$, hemisphere, $F(1,11) = 1.81$, $p = .21$, $\eta_p^2 = .14$, or an interaction

between these factors ($F < 1.5$), and so no indication of a division in hemispheric processing for stimuli displayed in foveal vision (words, RH = 16%, LH = 16%; pseudowords, RH = 23%, LH = 21%).

Reaction times for extrafoveal display: There were main effects of lexicality (words = 582 ms, pseudo-words = 628 ms), $F(1,11) = 40.49$, $p < .001$, $\eta_p^2 = .79$, and hemisphere (LH = 599 ms, RH = 611 ms), $F(1,11) = 4.72$, $p = .05$, $\eta_p^2 = .30$, and an interaction between these factors, $F(1,11) = 15.52$, $p < .01$, $\eta_p^2 = .59$. A strong LH advantage was observed for words (602 ms vs. 563 ms, $p < .01$) but not for pseudo-words (621 ms vs. 635 ms, $p > .05$).

Error rates for extrafoveal display: There was a main effect of lexicality (words = 16%, pseudowords = 29%), $F(1,11) = 22.88$, $p = .001$, $\eta_p^2 = .68$, but no main effect of hemisphere ($F < 1.5$). However, there was an interaction between these factors, $F(1,11) = 17.57$, $p < .01$, $\eta_p^2 = .30$. A strong LH advantage was observed for words (20% vs. 11%, $p < .01$) and a similar pattern was found for pseudo-words, although this was not significant (30% vs. 27%, $p > .05$).
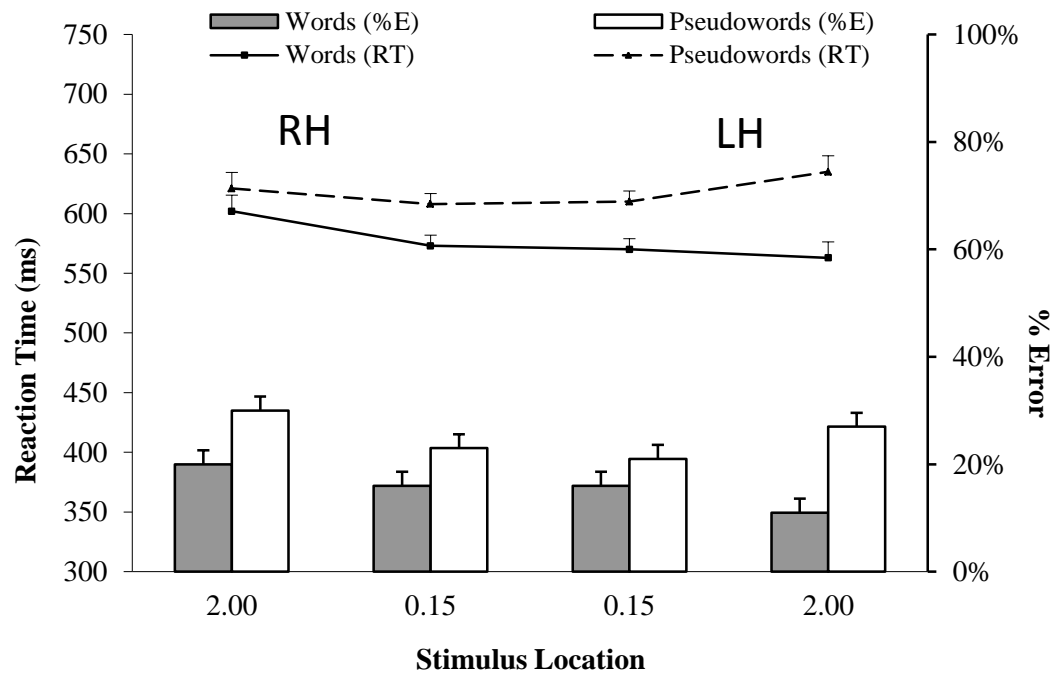
Figure 9.3. Mean error rates and reaction times for correct responses in lexical decision for words and pseudo-words fixated at each of the four foveal and extra-foveal locations

Bars correspond to 95% confidence interval (Loftus & Masson, 1994). The terms RH and LH refer to the hemisphere contralateral to the hemifield in which stimuli were presented.

This experiment was conducted as a further investigation of the hemispheric asymmetries in the processing of Arabic words that used the lexical decision task. The findings show superior right hemifield for Arabic words displayed outside the fovea, as participants recognised the words presented at the right visual field with less errors and faster reaction times than those presented at the left visual field, but this provides no evidence in support of hemifield superiority for words displayed within foveal vision, as the participants recognised the words equally well on each side of foveal fixation (e.g., Jordan et al., 2009).

9.6   General Discussion

The aim of these two experiments was to investigate hemispheric asymmetries in the processing of Arabic words by presenting words and pseudo-words displayed to the left and right of fixation, either close to fixation and entirely within foveal vision, or further

from fixation and entirely within extrafoveal vision, by skilled readers of Arabic using two standard paradigms, the Reicher-Wheeler task and the lexical decision task.

Presentation accuracy was controlled using an eye-tracker and the stimulus size. In addition, stimulus viewing was monocular to avoid the confounding influences of fixation disparity (e.g., Paterson et al., 2009; Jordan & Paterson, 2009; Liversedge et al., 2006). The main point to appear from the results of these experiments is the superior right visual field/left hemisphere recognition for words presented at extra-fovea and the appearance of no asymmetries for words presented within foveal vision in the Reicher-Wheeler task. Furthermore, using the lexical decision task showed that Arabic words were recognised quicker and more accurately when they were presented at the right-visual-field than at the left-visual-field, for extra fovea presentation. Pseudo-words also showed an LH advantage for extrafoveal displays in Experiment 5, and no hemispheric advantage for foveal displays in either experiment.

These findings support the well-established view that the LH is specialised for word recognition in alphabetic languages and provides further evidence that an LH-advantage occurs for words displayed in extrafoveal locations even in languages, such as Arabic, that are read from right to left (e.g., Adamson & Hellige, 2006; Faust et al., 1993; Ibrahim & Eviatar, 2009). These two experiments reveal clear hemispheric asymmetries in the recognition of Arabic words displayed at extrafoveal locations when accurate fixation is ensured.

However, these findings provide no evidence for a corresponding asymmetry in recognition of foveal word displays to the right and left of fixation under conditions of fixation accuracy, even when using measures of reaction times for words. Thus, the findings provide no evidence of a functional influence of split-foveal processing on word recognition and are more consistent with the view that foveal word recognition in

both non-Latinate and Latinate alphabetic languages reflects functions of bilateral hemispheric processing (e.g., Jordan et al., 2008, 2009; Jordan & Paterson, 2009).

It is important to note that the findings reported here for Arabic were obtained by using tasks other than two-alternative forced-choice, indicating the problems for SFT are not task specific. Researcher (e.g., Jordan et al., 2008, 2009, 2010; Paterson et al, 2009, for words in English), has revealed an absence of hemispheric asymmetries in the recognition of words displayed entirely to the left or right of fixation in foveal vision in a task that involves the measurement of reaction times to word stimuli, and so provides exactly the sort of evidence against SFT stated by its supporters (e.g., Ellis & Brysbaert, 2010).

The implications of a foveal division in hemispheric projections for Arabic word recognition may also impact on even the basic processing of Arabic words. Many studies indicate that the right hemispheric is particularly poor at identifying Arabic letters (e.g., Eviatar & Ibrahim, 2004; Eviatar et al., 2004; Ibrahim & Eviatar, 2009), and this may be exacerbated by the poorer discriminability of individual letters in words and additional crowding (e.g., Pelli et al., 2007) introduced by the cursive nature of Arabic script (e.g., Ibrahim & Eviatar, 2009; Jordan et al., 2011). The explanation given for this deficiency is that the right hemispheric may have a specific difficulty with Arabic letters, due to letters sharing the same basic form and the extensive use of dots to mark distinctions between letters in Arabic script. For example, Arabic letters representing /t/ and /n/ (ت & ن) become the graphemes that represent /th/ and /b/ (ث & ب) respectively, simply by adding or changing the number or location of small dots within the word, and also some Arabic letters have the same basic form without dots, such as the letter /ḥāʾ/ (ح) , while when it is written with dots it become the graphemes that represent two letters /jīm/ (ج) and /khāʾ/ (خ).

Split-foveal accounts require that asymmetries in hemispheric processing of words extend right up to the point of fixation, and so this particular RH deficiency in Arabic processing should affect recognition of Arabic words to the left of fixation in foveal and extrafoveal vision (and, indeed, recognition of those parts of fixated Arabic words that fall to the left of fixation). However, from the experiments reported here, recognition of Arabic words is not affected by such a catastrophic division in foveal processing. In particular, both experiments showed no evidence of this asymmetry in performance for Arabic words displayed in foveal locations but clear asymmetries when these words were presented in extrafoveal locations. The indications are, therefore, that a division in projection to impoverished RH letter processing occurred for extrafoveal locations but not for foveal word recognition. Bilateral projections may also benefit foveal word recognition in Arabic, and other languages that are read from right to left. Split-foveal processing in these languages would not produce the paradox of projecting beginning letter information to the RH because, when a word is fixated, beginning letters would now fall to the right of fixation, and so project to the LH (if the split-fovea view were correct). However, because of the different morphological construction of words in these languages compared to Latinate languages, the important consideration for word recognition in Arabic (and other Semitic languages) is the efficient identification of a word's morphological root (e.g., Ibrahim & Eviatar, 2009; Farid & Grainger, 1996; Deutsch & Rayner, 1999; Velan & Frost, 2009; Perea, Abu Mallouh & Carreiras, 2010; Bick, Frost & Goelman, 2010, 2011).

In particular, the vast majority of words in Semitic languages such as Arabic (and Hebrew) are created from triliteral roots that comprise a sequence of three consonants that express the general meaning of a word and combine with other letters (which form the word pattern) to create different inflections of meaning. For example,

the Arabic root comprising the consonants h-s-l (حصل) has the basic meaning of "to receive" or "to achieve", and combines with other letters to form words such as محصول ("mahsul" meaning "crop" or "product") and تحصيل ("tehsil" meaning "achievement"). In Latinate languages, morphological composition is achieved by affixation, whereby adding a morpheme as the prefix or suffix of a word creates the desired inflectional meaning (e.g., affixing "-ed" to "achieve" produces "achieved"). However, Semitic languages have a nonconcatenative morphology in which the root and word pattern do not combine via affixation, and the letters of these two components intermingle to form a word. For example, in the word تحصيل ("tehsil"), the root consonants appear as the second, third, and final letters and are combined with other letters that form the word pattern. Consequently, the root is not identifiable as a contiguous sequence of letters, and must be identified from a sequence of consonants spread throughout the word (see, e.g., Boudelaa & Marslen-Wilson, 2005), and this may have important consequences for word recognition (e.g., Velan & Frost, 2007, 2009; Perea et al., 2010). Indeed, it is of particular relevance to the present research that when a word in Arabic (or Hebrew) is fixated, consonants that form the root are unlikely to project to retinal locations on the same side of fixation. Consequently, if hemispheric processing is divided at the point of fixation, these consonants will often project to different hemispheres and recognition of the root may be delayed until the letters are recombined via interhemispheric transfer. By comparison, bilateral foveal processing of words in these languages has the capacity to achieve greater efficiency in word recognition by ensuring that letter information needed to identify the root is made available rapidly to each hemisphere regardless of which side of the foveal midline this information may occur.

Finally, what does seem clear, however, is that the findings are problematic for the split-fovea account; as this account would predict that the projection of visual

information from each fovea is divided precisely at the vertical midline. Thus, each fixated word is effectively split in two so that all letters on each side of fixation project unilaterally to the contralateral hemisphere, with considerable implications for word recognition that should occur irrespective of the reading direction for a language. Clearly, however, these findings show that effects of "left-hemisphere" advantages for words displayed at foveal locations were entirely absent (Jordan et al., 2008).

9.7   Summary of Chapter 9

In summary, the current chapter discussed two experiments that were conducted to investigate hemispheric asymmetries in the processing of Arabic words by presenting words and pseudo-words at foveal and extra-foveal locations to the left and right of a central fixation point by skilled readers of Arabic using two standard paradigms, the Reicher-Wheeler task and the lexical decision task. Presentation accuracy was controlled using an eye-tracker and the stimulus size. In addition, stimulus viewing was monocular to avoid the confounding influences of fixation disparity.

The main point to appear from the results of these experiments is the superior right visual field/left hemisphere recognition for words presented at the extra-fovea, and the absence of asymmetries for words presented within foveal vision. No advantages for words presented within foveal region were found. The results demonstrate that the effects of left-hemisphere advantages for words displayed at foveal locations were entirely absent. The present research shows clear evidence of a division in hemispheric processing for extrafoveal word recognition, and the influence that these asymmetries have on the processing of words in locations outside the fovea to the right and left of fixation during reading in Arabic (see Chapter 5) was determined; this shows the benefits of parafoveal processing for reading in Arabic. It is also well established in Hebrew and Latinate languages that information about the next word or words in a

sentence is acquired during reading, and that this information is used to programme eye movements as well as to begin pre-processing the identity of these words (e.g., Deutsch, Frost, Pelleg, & Rayner, 2003; Deutsch, Frost, Pollatsek & Rayner, 2005; Rayner, 2009). However, the precise influence of hemispheric projections in parafoveal processing of words in textual reading in any language is unknown (e.g., Baccino & Manunta, 2005; Barber, Donamayor, Kutas, & Munte, 2010). One likely possibility is that the nature of the parafoveal processing that takes place will reflect the language processing abilities of the hemisphere to which this information projects. Consequently, for most readers in Latinate languages, parafoveal processing of words to the right of fixation (that is, in the direction of reading), will take advantage of the superior word recognition capabilities of the LH to which these words would unilaterally project. In contrast, qualitatively different effects may be observed in reading Arabic, where parafoveal processing of words to the left of fixation (that is, in the direction of reading) would involve unilateral projections to the inferior language processing capabilities of the RH. The effects of these differences in hemispheric projection on reading efficiency have yet to be revealed.

Chapter 10 General Discussion

The fundamental issue of whether word recognition and reading in Arabic has the same basic process as in Latinate languages, such as English and French, is of key importance for research in the field of word recognition. This is mainly due to the nature of language transactions in the two languages we are concerned with in this research project. Therefore, the aim of the present research was to examine word recognition processes by skilled readers of Arabic using a range of standard paradigms. Several areas of inconsistency in the previous (corpus) body of research were investigated, including: (1) whether Arabic (with visual properties fundamentally different from Latinate languages) produces word superiority effects; (2), to retest the Optimal Viewing Position (OVP) effect in Arabic word recognition and whether this is similar to the OVP found in Latinate languages such as English and French or to the findings reported by Farid and Grainger (1996) when they presented Arabic words more freely; (3), to investigate the influence of word length in eye movement behaviour and how the visual characteristics of Arabic words influence eye movement behaviour during the reading of Arabic text; and lastly (4) to re-assess the claim that a vertical division in the human fovea has consequences for word recognition.

This chapter begins with a review of the main findings obtained from each of the six reported experiments, and as to how these findings can be explained in terms of the current hypothesis of word recognition, and finally some promising future directions in the line of current research will be pointed out and discussed briefly.

10.1 The Main Findings: A Summary

The first two experiments were conducted to determine whether the word superiority effect (which has been shown robustly for Latinate languages) exists for Arabic word recognition. Experiment 1 used the Reicher-Wheeler task in which participants were

presented with brief displays of words followed by a forced choice between two equally valid alternatives that differ by only one letter. The participants' task was to indicate which of the two alternatives had already been shown. The findings showed that there were advantages for words over pseudo-words and non-words, and also for pseudo-words over non-words.

Having established the existence of the word superiority effect in Arabic word recognition using the Reicher-Wheeler task, Experiment 2 tested whether this effect could be replicated by using the lexical decision task, in which measuring of how quickly people classify stimuli as words or non-words is provided, in order to determine if an Arabic WSE is also observed when using this technique. In this experiment the participants' task was to decide as fast as possible whether a presented stimulus was a word or non-word. Importantly, Experiment 2 found the same pattern of findings as Experiment 1, and the Arabic readers that participated in this experiment showed a similarly strong word superiority effect. Thus, it was clear that the effects obtained in experiment 1were replicated in such a task that measured the reaction time; this shows that these findings are not task specific, since they were obtained using the two very different paradigms provided by those two tasks.

This finding provides an important basis for more research in Arabic word recognition and contributes in several ways to our understanding of Arabic word recognition. This demonstrates that the WSE and PSE reported in studies that used Latinate languages are also found in Arabic. One possibility is that similar processes are involved in the recognition of Arabic words as are used to recognise words in Latinate languages, despite the very different characteristics of Arabic.

Experiment 3 went a step further and directly examined eye movement behaviour during the reading of Arabic text. The task of the participants was to read

single line sentences including critical words that were three-, five- or seven-characters long. Initial sentence frames were identical across the three conditions. Word frequency and predictability were carefully controlled. The results showed that in contrast to the reading of left-to-right languages, and similar to the reading of right-to-left Hebrew text, the preferred viewing location is to the right of the centre of words in Arabic (at least for five- and seven-letter words), for three-letter words saccade seem to land in the centre rather than right of centre. The results indicate that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic. The initial reading times are also influenced by word length.

Experiment 4 made an effort to retest the optimal viewing position effect by using an eye-tracker to ensure that the participants fixated at specific locations in each word, either immediately to the left or right of the word, or at one of four inter-letter locations within words. Thus, a key question addressed in this experiment was to examine the different explanations that have been given for the optimal viewing position effect in English and French. If the offset of the OVP to the left of a word's centre is due to asymmetry in perceptual span or to reading habits for languages read from left-to-right, then it is very likely that a different OVP pattern would be observed for a language such as Arabic that is read from right to left. Moreover, if the location of the OVP is due to the split-fovea processing of words, then it seems likely that a similar OVP effect would be observed for languages read from left-to-right or right-to-left because the OVP reflects the division of word processing across the two cerebral hemispheres rather than differences in the reading of words in different languages. The findings showed that performance with words was equally superior when fixations were at locations three and four, at the centre of words, intermediate for locations two and five, to the right and left of a word's centre, and equally poorest for locations one and

six, where words were displayed entirely to the left or right of fixation; this shows very clearly that the OVP is at the very middle of Arabic words. Therefore, the results indicate that the OVP for Arabic is different from that observed during the recognition of words in Latinate languages. One possibility is that this is due to the widespread distribution of morphological information across Arabic words. No OVP effect was observed for non-words, suggesting that the OVP is specific to word recognition. Findings demonstrate that an area exists around the point of fixation within which information is not divided between the two hemispheres but is processed bilaterally (e.g., Gazzaniga, 2000; Jordan & Paterson, 2009).

Experiments 5 and 6 were conducted to investigate hemispheric asymmetries in the processing of Arabic words by presenting words and pseudo-words at foveal and extra-foveal locations to the left and right of a central fixation point by skilled readers of Arabic using two standard paradigms. Experiment 5 used the Reicher-Wheeler task while Experiment 6 used the lexical decision task. Thus, an important prediction that was tested in these experiments is that well-established asymmetries in word recognition in extrafoveal locations should also be observed for words presented in foveal locations and, indeed, that the influence of these hemispheric asymmetries should be observed unchanged right up to the point of fixation. Arabic word recognition was assessed using appropriate control of fixation location and stimulus size, and monocular viewing to avoid confounding influences of fixation disparity. The findings revealed left-right differences for words shown at locations far from the point of fixation, but no difference for words near the point of fixation, in both tasks. The findings demonstrate that there are left-right brain differences in recognition of words displayed outside of foveal vision, and evidence that the left and right sides of the brain collaborate when recognising words in foveal vision.

10.2   The Implications of the Main Experimental Findings

The experiments reported here examined Arabic word recognition processes employed by native readers of Arabic, whose writing-systems are cursive, with most of the letters within a word and the word being read from right to left. This is one of the first studies to deal with word recognition for Arabic readers and examine if the finding observed for Latinate languages (e.g., English and French) would be true for Arabic as well.

Studying reading in Arabic provides important insights into the effects of the direction of reading (unlike English, Arabic is read from right to left), the form of the script (Arabic is a cursive language, i.e., the letters in words are naturally interlinked, much like handwritten English), and the construction of the language (Semitic languages such as Arabic and Hebrew have a non-connective derivational morphology that is based on the interweaving/intermixing of roots and word patterns, which differs fundamentally from the morphological construction of words in Latinate languages like English and French). This research is one of the first to examine the cognitive and physiological processes underlying word recognition and reading in Arabic, despite the fact that Arabic has the second-most widely used alphabet of any alphabetic language; thus the results of these experiments provide valuable information about the processes involved in the understanding of normal Arabic reading processes that will be of considerable interest to the research community worldwide.

A series of very carefully designed experiments have revealed some of the fundamentals of reading in Arabic. For example, the differences in left and right brain function influence the recognition of words each side of where a reader is looking on a page, but only when these words are outside of central vision. This reveals both left/right brain specialisation for reading and evidence that the two halves of the brain collaborate when making sense of words in central vision, and that native Arabic

readers recognise Arabic words most efficiently when they fixate these words at their very centre. This shows that where we look in a word is very important for reading, as well as that the findings for Arabic are different from the findings for English and other western languages, which are read most efficiently by looking at a location between the beginning and middle of the word.

These findings obtained with Arabic stimuli add to those from English (e.g., Jordan et al., 2008, 2009) to provide a persuasive indication through fundamentally different alphabetic language systems that effects of fixation location on word recognition do not reflect a functional division in hemispheric processing at the point of fixation. It seems likely that true functional divisions in hemispheric projections occur for information further away from fixation and that an area exists around the point of fixation within which information is not divided between the two hemispheres but is processed bilaterally (e.g., Gazzaniga, 2000; Jordan & Paterson, 2009).

The preferred viewing position tended to be at the word centre or just right of the word centre, demonstrating that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic. According to Rayner et al. (1982), parafoveal word recognition plays a role in text reading in English (e.g., Rayner, 1998). One of the important findings in the current study and also in other studies that examined languages read from right to left (e.g., Faust et al., 1993; Ibrahim & Eviatar, 2009; Lavidor et al., 2002) was the existence of RVF word advantage. Arabic readers require more information from the upcoming words in parafoveal vision in the left visual filed (project to left hemisphere). Interestingly, in reading the Arabic language participants tend to skip much less and the average saccade length was shorter when compared to English (e.g., Pollatsek et al., 1981). Therefore, during reading of Latinate languages, partial pre-processing of words to the right extra visual field may provide

some pre-activation of LH processing. However, this is not the case when Arabic words are read, because the eyes are directed to the left visual field and therefore pre-activation would be very difficult.

10.3 Possible Explanations for WSE in Arabic

Previous research that has investigated the WSE effects has shown that people are more accurate in identifying a letter within a word than when it is presented in isolation, or when it is presented within a non-word (e.g., Cattell, 1886; Reicher, 1969; Wheeler, 1970). For instance, Reicher (1969) investigated the WSE and excluded factors such as memory and guessing work by asking participants immediately after the display about one letter only and using a two-alternative forced-choice task where both alternatives would make real words. The findings of this showed that these were advantages in recognising single letters from real words compared to non-words (WSE).

This effect has shown to be an essential finding for word recognition models, and particularly is supported by the work of McClelland and Rumelhart (1981); precisely they asked how does the knowledge that we already have interact with the input? McClelland and Rumelhart proposed the interactive activation model (IAM) of word recognition that suggested both bottom-up and top-down processing. The IAM begins by feature detection, so according to this model when a particular feature is detected, activation is forwarded to all letters containing that feature but inhibition is forwarded to all the other letters not having these features. In a similar way, the process happens also at the level of word, so that letters send off activation to any words that contains these letters but is inhibited in any other words that do not have these letters. The WSE and PSE can be explained by the interactive activation model (McClelland & Rumelhart, 1981; McClelland et al., 1988) in terms of the activation of nodes at the word levels. Accordingly, when a reader is presented with a word, activation of the

corresponding word unit will provide activation to appropriate letter units and this will aid performance in the task. By contrast, presentation of an illegal non-word will not produce activation of word units and so will not facilitate performance in the task. The pseudo-word advantage results from the activation of word units that share letters with the pseudo-word and hence provide feedback activation to shared letter units. Accordingly, pseudo-words are likely to activate more units at the word level than illegal non-words do. For example, people are better at perceiving the letter G in a pseudo-word context such as POG than in a non-word context (e.g., BNG), since POG partially overlaps with a number of other words (e.g., FOG and DOG) (Lete & Ducrot, 2008). Although the IAM of word recognition is rather dated, it has some attractive features that many newer models have adopted (e.g., Whitney's SERIOL model, 2001; Davis's spatial coding model, 2010). For example, the occurrence of the word superiority effect in Arabic involves sorts of entry or encoding advantages, which real words have but non-words do not have. Therefore, words were recognised better than non-words because they may directly activate lexical entries. Pseudo-words partially activated lexical entries; however, non-words did not activate the lexical entries.

What was the aim of the current experiments? The first two experiments were carried out to assess and verify the WSE of Arabic word recognition, and to find an explanation of these effects. These experiments have found evidence for the word superiority effect in Arabic. Particularly, these experiments' findings demonstrate that, while superiority effects seem to reflect the efficiency by means of which visually presented words are processed, it appears even when languages do not facilitate the ready isolation of individual letters. Therefore, even when very short presentation conditions (e.g., the Reicher-Wheeler task presented for 17ms and the lexical decision task presented for 150ms) are used to reveal word superiority effects, the features (e.g.,

cursive and the reading direction) of Arabic stimuli do not prevent the exciting relative efficiency of visual word perception. This might provide a further indication that perceptual superiority of words in Arabic (and perhaps other languages too) rely on characteristics that are greater than single letters, originated from supra-letter or configural analyses of letter groups and whole words (e.g., Allen et al., 2009; Jordan, 1990; Patching & Jordan, 2005). Indeed, from the findings of many studies (e.g., Pillsbury, 1897; Woodworth, 1938; Allen et al., 1995; Jordan et al., 1999) , the recognition of words can be completed without perception of their component letters and as complete units. This means that word recognition can be completed on the basis of something other than precise visual form (Jordan et al., 1999).

In general, the revealing of the WSE and PSE in Arabic show that these perceptual phenomena characterize a global feature of human alphabetic language perception that occurs even in a language such as Arabic which differs significantly from that of ubiquitous Latinate languages. For example, the reader has to read Arabic words as only one cursive shape and Arabic offers a breakdown in PAW (Part of Arabic Word; PAWs could be compared to Latin syllables written separately). PAW introduces that breaks in Arabic writing have an influence on the recognition process. It also simplifies character apprehension and eases linear recognition. Sub-words in Arabic may consist of one character (e.g., /Saad/ ص) or multiple characters (e.g., /Mar'haba/ / مرحبا means hello (*informal*)) (El rube, El Sonni & Saleh, 2010).

It is believed that the cursive nature of Arabic decreases the distinctiveness of individual letters in words and introduces additional crowding (e.g., Pelli, Tillman, Freeman, Su, Berger & Majaj, 2007) that might decrease letter resolution (e.g., Eviatar et al., 2004; Ibrahim et al., 2002). As Arabic writing is generally described as more complex than Latinate languages, it appears clear that a letter segmentation/part cannot

be an sufficient explanation of these effects (e.g., Elanwar et al., 2007; Belaid & Choisy, 2009).

10.4 Possible Explanations for PVL in Arabic

Landing position distributions indicate the PVL is to the right of centre of words in Arabic (at least for five- and seven-letter words), for three-letter words saccades seem to land in the centre rather than right of centre. In this respect, the findings for Arabic are similar to those for Hebrew. Consistent with previous studies the mean landing position was further into the word as word length increased (e.g., Rayner, 1979; Deutsch & Rayner, 1999; Rayner et al., 2001). This demonstrates that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic. The possible explanation for this is that since word units in Arabic play the most important role in saccadic programming, the accessibility of visually distinct word edges in peripheral vision facilitates the reader to make a decision where to move in a text and assists reading (e.g., Rayner, 1998; Rayner et al., 1998; Kajii et al., 2001). This indicates that in Arabic (and perhaps in Hebrew) the morphological previews, which have roots distributed throughout the word, relate to the processing of landing position (e.g., Deutsch et al., 2002).

With regard to the models of reading and eye movements, the results indicate that, similar to other languages, parafoveal word length information is used to guide saccade targeting in Arabic (e.g., Juhasz et al., 2008; Rayner et al., 1982 ;), and as the E-Z Reader predicts, to the left in Arabic (consistent with the reading direction in this language, e.g., Reichle et al., 1998).

The low re-fixation probabilities for end of words are unexpected and may possibly be linked to the distribution of information within Arabic words or other language-specific factors. However, re-fixation rates in Rayner et al. (1996) were

attenuated for fixations at end letters in English words, so it remains unclear if re-fixation effects reflect hemispheric asymmetries in word processing.

10.5 Possible Explanations for OVP Effect in Arabic

As it was described in Chapter 6, the widely-reported advantage for word recognition of fixating a specific location in words is referred to as the optimal viewing location, or OVP, which for Latinate languages such as English appears to be located just to the left of the centre of words (e.g., O'Regan et al., 1984; O'Regan & Jacobs, 1992). The general technique that was used in these studies has involved instructing participants to fixate the gap between two vertical lines and then presenting stimuli at different offsets around this location so that a different letter in a word coincides with this gap. Participants must then respond to these words, which in some experiments has involved making a lexical decision for the presented stimuli and in other experiments has involved reading the words aloud. The basic finding is that participants have faster responses, and quicker naming times, when words are fixated just to the left of their centre.

Various explanations of this basic effect have been put forward in the literature. O'Regan and his colleagues (e.g., O'Regan, 1981; O'Regan, 1984) explain the effect in terms of the visibility of word information in foveal vision. They noted that there is a steep drop-off in retinal acuity with increased distance from the centre of the fovea (Hilz & Cavonius, 1974), and argued that words should therefore be recognised most efficiently when fixated near their centre. However, this does not explain why the OVP in English and French is to the left of the centre of words. Other researchers have argued that this tendency to fixate to the left of a word's centre might be a combination of the effects of retinal acuity and of differences in the informativeness of different parts of words (Stevens & Grainger, 2003). For example, these researchers argue that the

beginning parts of words in English and French are most informative, therefore readers attempt to fixate words so that this information projects to high acuity retinal locations. However, with a highly accurate eye-tracking system, these findings could not be replicated as no differences in landing position were observed as a function of word informative parts was found (e.g., Rayner & Morris, 1992).

Other researchers have argued that the effect is either due to asymmetries in the perceptual span in reading (Rayner et al., 1980), or to a by-product of reading habits (Nazir et al., 1992), and that because words are read from left to right in English and French, there is a bias for fixating to the left of centre of words. More recently, however, it has been argued that the reason why the OVP is to the left of the centre of words is due to the split foveal processing of words (e.g., Brysbaert & D'Ydewalle, 1990; Brysbaert, 1995; Brysbaert et al., 1996; Ellis, 2004; Hunter et al., 2007; Martin et al., 2007). According to this account, when a word is fixated it is divided in two around the point of fixation, and the two parts of the word are projected for processing in different cerebral hemispheres. Thus, if "word" was fixated between the "o" and the "r", the letters "wo" would project to the right hemisphere initially, and the letter "rd" would project to the left hemisphere, before being combined via the transmission of information across the corpus callosum. This account also proposes that there are differences in the word processing capabilities of the two hemispheres, such that the left hemisphere has superior word recognition capabilities. It is therefore argued that the OVP is offset to the left of the centre of words in order to balance word processing demands across the two hemispheres. That is, according to this account word recognition, most efficient when the majority of the letters in a word project initially to the left hemisphere because this hemisphere has the superior word processing capabilities.

Much of the research into the OVP effect has been conducted in Latinate languages that are read from left to right. Therefore, Experiment 3 evaluated the OVP effect in Arabic word recognition by presenting Arabic words for lexical decision task. Participants fixated immediately to the right or left of each stimulus, or one of the four possible inter-letter locations. Fixation location was controlled using an eye-tracker linked to a fixation-contingent display and all stimuli were presented within foveal vision to avoid confounding influences of extrafoveal projections.

The findings showed that word recognition was better for fixations in central locations (e.g., the OVP was at the very middle of Arabic words) and this superiority decreased symmetrically either side of this region. It is clear therefore that there is a drop-off in visual acuity (e.g., Olazak & Thomas, 1986) and that information is spread across Arabic words. For example, Arabic words have prefixes, suffixes and also infixes so that their informativeness (and perhaps the roots) are more distributed throughout the word (e.g., Boudelaa & Marslen-Wilson, 2005); these explanations account for the significant effects observed in the current experiments. The findings are also largely consistent with the findings reported by Farid and Grainger (1996) when they presented Arabic words more freely, indicating that normal processes of Arabic word recognition were being used in the experiment.

The question which needs to be answered is why is the OVP in Arabic different from that in English? The explanation of why the OVP in English and French is to the left of the centre of words. The left of the centre is the middle according to informativeness, because the left side is most informative (differing from the middle according to physical size). This is not the case for Arabic words, as the widespread distribution of informative letters (roots) across Arabic words (e.g., Boudelaa &

Marslen-Wilson, 2005; Farid & Grainger, 1996) this makes both the physical and the informative positions at the same place (which is the word centre for Arabic).

In Latinate languages, morphological composition is achieved by affixation, whereby adding a morpheme as the prefix or suffix of a word creates the desired inflectional meaning (e.g., affixing "-ed" to "achieve" produces "achieved"). However, Arabic words have a prefix and suffix, and also infixes in which the root and word pattern do not combine via affixation, and the letters of these two components intermingle to form a word so that their informativeness (and perhaps the roots) are more distributed throughout the word such as: تحصيل =حصل second; third and the final قصيدة = قصد, first; second and third سلطات = سلط, first; second and fourth سفينة = سفن, second and fourth and تعبير = عبر second; third and the final. The roots in Arabic words are combined with other letters that form the word pattern. Thus, the root is not identifiable as a contiguous sequence of letters, and must be identified from a sequence of consonants spread throughout the word (e.g., Boudelaa & Marslen-Wilson, 2005), and this may make the OVP in Arabic different from that in English. The absence of a 'natural' optimal viewing position for non-words may therefore result in the implementation of a serial processing strategy, from beginning letters to end letters (and therefore from right to left in Arabic), whereas words enjoy richer, more parallel processing (e.g., Allen & Emerson, 1991; Ans, Carbonnel, & Valdois, 1998; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

10.6 Hemispheric Asymmetry in Arabic Word Recognition

The hemispheric projection of words presented about the point of fixation is a matter of considerable importance (e.g., Jordan & Paterson, 2009, 2010). According to one view, the projection of visual information from each fovea is divided precisely at the vertical midline (e.g., Brysbaert, 2004; Ellis & Brysbaert, 2010). As a consequence, each fixated

word is effectively split in two so that all letters on each side of fixation project unilaterally to the contralateral hemisphere, with considerable implications for word recognition. Unfortunately, a perceptual advantage for information to the right of fixation in languages read from left-to-right, like English, risks providing spurious "left-hemisphere" advantages for words displayed at foveal locations. This confound was avoided by investigating recognition of words in a language read from right-to-left (Arabic) presented at foveal and extrafoveal locations to the left and right of a central fixation point, and also it remains to be seen whether alphabetic languages with properties fundamentally different from Latinate languages provide evidence of unilateral hemispheric projections in foveal word recognition.

Therefore, two experiments were conducted to investigate hemispheric asymmetries in the processing of Arabic words by presenting words and non-words at foveal and extra-foveal locations to the left and right of a central fixation point to skilled readers of Arabic using two standard paradigms, the Reicher-Wheeler task and the lexical decision task. Word recognition was assessed using appropriate control of fixation location and stimulus size, and monocular viewing to avoid the confounding influences of fixation disparity (Jordan & Paterson, 2009). The findings revealed superior right hemifield/left hemisphere recognition for words displayed outside the fovea and no asymmetries for words displayed within foveal vision.

What are the implications of these findings in the processing of Arabic words? Further studies (e.g., Eviatar & Ibrahim, 2004; Eviatar et al., 2004; Ibrahim & Eviatar, 2009) have shown that the right hemisphere is principally poor at recognizing Arabic letters. This might be exaggerated by the cursive nature of Arabic which decreases the distinctiveness of individual letters in words and introduces additional crowding (e.g., Pelli et al., 2007; Elbeheri, Everatt, Mahfoudhi, Al-Diyar, & Taibah, 2011). The

explanation given for this deficiency is that the RH may have a specific difficulty with Arabic letters, due to letters sharing the same basic form and the extensive use of dots to mark distinctions between letters in Arabic script. For instance, the Arabic letter /th/ and /t/ (ث & ت) become the graphemes that represent the letter /b/ (ب) just by changing the location and reducing the numbers of the dots within the words. Therefore, these features of Arabic might inadvertently affect participants' performance. For example, in the study of Jordan, Fuggetta, Paterson, Kurtev and Xu (2011), the average reaction times were around 100ms faster than in the current study in Arabic, and this in line with the evidence of increased difficu`lty of the perception of Arabic scripts, due to the reasons mentioned above.

Another question is what are the reasons for the direction of reading and the hemispherical asymmetry? According to split-foveal theory each fovea is divided *precisely* at its vertical midline so information right up to fixation projects (*unilaterally*) to the contralateral hemisphere, so this account requires that asymmetries in hemispheric processing of words extend right up to the point of fixation. Thus this particular RH deficiency in Arabic processing should affect recognition of Arabic words to the left of fixation in foveal and extrafoveal vision (and, indeed, recognition of those parts of fixated Arabic words that fall to the left of fixation). However, from the experiments reported here, recognition of Arabic words is not affected by such a catastrophic division in foveal processing. In particular, these two experiments reveal clear hemispheric asymmetries in the recognition of Arabic words displayed at extrafoveal locations when accurate fixation is ensured. There is no evidence for a corresponding asymmetry in recognition of foveal word displays to the right and left of fixation under conditions of fixation accuracy, even when using measures of reaction

times for words. This thesis shows no evidence of a functional influence of split-foveal processing on word recognition.

The results showed that the reaction times for Arabic words and pseudo-words are nearly the same in the left extra foveal location. This suggests that the right hemisphere is not capable of processing visual linguistic information (or is very poor at doing so), to the effect that the performance for words is nearly the same as for pseudo-words.

10.7 Future Directions

This study has been one of the first attempts to thoroughly examine word recognition and reading in Arabic. The current research has provided important information about how Arabic readers recognise words that has implications for researchers interested in the cognitive and physiological processes underlying word recognition and reading. Nevertheless, some issues need to be assessed in future research.

The current research has shown advantages for the recognition of words over pseudo-words and illegal non-words and for pseudo-words over illegal non-words, thereby demonstrating that the superiority effects that have been reported for Latinate languages including English exist in Arabic as well, and that participants recognised words most quickly and most accurately when fixating inter-letter locations at the middle of words, indicating that the OVP for Arabic word recognition is at a word's centre. The findings also revealed the superiority of the right visual field for words displayed outside the fovea, and no asymmetries for words displayed within foveal vision. One experiment of my study investigated the landing position effects for three-, five-, and seven-letter words in Arabic, and found that the PVL is to the right of centre of words in Arabic (at least for five- and seven-letter words), for three-letter words saccade seem to land in the centre rather than the right of centre. Thus far the research

has made an important advance on our understanding of processes involved in Arabic word recognition by revealing that word superiority and pseudo-word superiority effects similar to those reported in Latinate languages are also observed in Arabic, and that the OVP effect in Arabic differs from that found in English.

It is important to mention here that the OVP in Latinate languages is between the beginning and middle letters (e.g., O'Regan et al., 1984), whereas it is at the centre of words in Arabic (e.g., current study and Farid & Grainger, 1996). The inverted OVP is similar for Latinate languages and Arabic, with fixation durations being longest at the centre of words, and shorter at the beginning and end of words (e.g., Vitu et al., 1990 and the current study).

A further study that will employ a wider range of stimuli and participants than those investigated in the current research could be informative for understanding the processing of Arabic word recognition. For instance, a future study could compare the OVP effects of two groups of participants: monolingual and bilingual Arabic speakers. Such a study will provide more direct information on how the pattern of effects in this experiment was affected by participants' knowledge of English (e.g., Farid & Grainger, 1996; Ibrahim, Eviatar, & Aharon-Peretz, 2007). Moreover, in many cases, pairs of Arabic letters differ from each other only in terms of the addition, number, or location of small dots that are placed above or below the main body of the letter. This suggests that Arabic word recognition depends on detecting subtle differences between the letters in words (e.g., Eviatar & Ibrahim, 2004; Eviatar et al., 2004; Ibrahim & Eviatar, 2009). This experiment will investigate whether native Arabic speakers are thus skilled at recognising the differences between letters in words, and whether they can discriminate between properly spelled words and words that are misspelled by either omitting dots or placing dots in an incorrect location.

Another important issue that has not been addressed yet by currents studies is how to incorporate models of words recognition with models of eye movement control in such a way that they can work together. For example, in the E-Z Reader model where we have a word identification system, ideally accompanying it with models of word recognition would provide an explanation to this.

At the moment these models of eye movement control are sufficiently explaining how we read as our eyes move forward in a text. However, in actual fact when we start to attempt to explain eye movement control in circumstances of careful reading, these models are currently insufficient. For example, we understand how a sentence is read in experimental conditions, but we do not know what is happening when eyes are moved back, when reading in different circumstances, or when skimming and scanning texts. It would be very interesting to understand how these models are adapted to explain these different kinds of circumstances (e.g., Grainger, 2003).

Overall, this sort of research provide a better understanding of the nature of saccade targeting during reading across languages, and also whether the mechanisms predicted by current models (for both word recognition and eye movement models), hold for Arabic. In other words, this kind of study may provide broader implications for understanding which mechanisms are universal and which are language-specific.

Finally, from the results of these experiments, it could be concluded that the different characteristics of Arabic have consequences for the reading of Arabic, and it is fairly clear that the direction of reading is very important. The cursive nature of the text and form of the individual letters are also important. However, further experiments are needed because this is still a new area of research. For example, further research (e.g., McConkie & Rayner, 1976; Rayner, 1975) shows that the perceptual span for skilled readers of English is asymmetrical around the point of fixation, and readers require

three to four characters to the left of fixation and up to 15 characters to the right of fixation to read normally. In view of the fact that the direction of reading determines the asymmetric nature of the perceptual span, this suggests that linguistic processing affects eye movements. As noted previously, it is well established in Hebrew and Latinate languages that information about the next word or words in a sentence is acquired during reading, and that this information is used to programme eye movements as well as to begin pre-processing of the identity of these words (e.g., Deutsch et al., 2003, 2005; Rayner, 2009). However, the precise influence of hemispheric projections in parafoveal processing of words in textual reading in any language is unknown (e.g., Baccino & Manunta, 2005; Barber et al., 2010). One likely possibility is that the nature of the parafoveal processing that takes place will reflect the language processing abilities of the hemisphere to which this information projects. Consequently, for most readers in Latinate languages, parafoveal processing of words to the right of fixation (that is, in the direction of reading), will take advantage of the superior word recognition capabilities of the LH to which these words would unilaterally project. In contrast, qualitatively different effects may be observed in reading Arabic, where parafoveal processing of words to the left of fixation (that is, in the direction of reading) would involve unilateral projections to the inferior language processing capabilities of the RH. The effects of these differences in hemispheric projection on reading efficiency have yet to be revealed.

10.8 Conclusions

The present study was the first attempt to thoroughly examine the cognitive and physiological processes underlying word recognition and reading in Arabic, providing important insight into the effects of direction of reading, the form of the script, and the construction of the language.

Chapter 10 General Discussion

Firstly, it was clearly shown that there exist advantages for the recognition of words over pseudo-words and illegal non-words and for pseudo-words over illegal non-words. The research therefore demonstrates that the superiority effects that have been reported for Latinate languages, including English, exist for Arabic as well. Thus, even under very brief viewing conditions, these characteristics of Arabic do not thwart the relative efficiency of word perception and suggest that the perceptual superiority of words in Arabic (and perhaps other languages too) may rely on features that are greater than individual letters, derived from supra-letter or configural analyses of letter groups and whole words (e.g., Jordan, 1990, 1995; Patching & Jordan, 2003; Allen et al., 2009). Secondly, the optimal viewing position for Arabic word recognition is at a word's centre. This is a critical finding which clearly shows the differences between the OVP observed in studies of word recognition in English, which have shown that words are recognised most efficiently when fixated between their beginning and middle letters, and Arabic. These findings are consistent with both the drop-off in acuity that occurs with increased distance from the centre of the fovea (Olazak and Thomas, 1986) and the widespread distribution of morphological information across Arabic words (e.g., Boudelaa & Marslen-Wilson, 2005; Farid & Grainger, 1996). Thirdly, the landing position distributions indicate that the PVL is to the right of centre of words in Arabic (at least for five- and seven-letter words), for three-letter words saccade seem to land in the centre rather than the right of centre, possibly to the highest acuity retinal regions during reading. Finally, left-right differences have been seen for words shown at locations far from the point of fixation, but there was no difference for words near the point of fixation, indicating left-right brain differences in the recognition of words displayed outside of foveal vision, and that the left and right sides of the brain collaborate when recognising words in foveal vision.

The present research has aimed to provide an insight into a very interesting area that unfortunately has not been extensively investigated by researchers. As it has become clear from the current thesis, Arabic has some unique features with properties that fundamentally differ from the Latinate languages that have been the focus of previous word recognition research into alphabetic languages. These features of Arabic may have made Arabic better suited to the study of visual word recognition. For example, Arabic is read from right to left, and this gives it the capacity to help disentangle the effects on foveal word recognition caused by division in hemispheric processing rather than direction of reading (e.g., Farid & Grainger, 1996). Moreover, Arabic is formed in cursive script in which spaces seldom exist between letters in words, even when formally printed, which decreases the distinctiveness of individual letters in words and may present problems for efficient language perception (e.g., Elanwar et al., 2007). Unlike English, letter shapes in the Arabic written system are context dependent, and reading and eye movements depend on learnt characteristics of the writing system (e.g., Nazir et al., 2004), so these features of Arabic may have an effect on the role of fixation location in word recognition and reading. Another aspect is that the letters that are of special importance for word recognition are distributed throughout words in Arabic, rather than concentrated towards the beginning (as in Latinate languages). Consequently, Arabic may provide a particularly transparent indication of a functional division in hemispheric processing when words are fixated. Thus, future research should be aimed at examining this area in more detail, since only by this way would it be possible to obtain a more detailed picture of the strategies that readers employ when processing the Arabic language. This study can provide support for or against the IAM, which relies on activations at the level of individual letters, so

that when a participant/reader is shown a word, each letter in parallel will either stimulate or inhibit different feature detectors (McClelland & Rumelhart, 1981).

APPENDICES

Appendix 1:

Conference and Publication Papers Based on the Thesis

Poster Given

Abubaker, A.A.A., McGowan, V. A., White, S.J., Jordan, T.R., & Paterson, K.B. (2011). Reading Arabic text: Effects of word length on landing positions and fixation durations. Poster presented at ECEM, Marseille, 21-25 August.

Abubaker, A.A.A. (2011). How the Brain Recognizes Words: Evidence from Arabic. Poster presented at Festival of Science, Leicester, 16 June.

Almabruk, A. A. A., Paterson, K. B., & Jordan, T. R. (2010). Hemispheric asymmetries in word recognition: Evidence from Arabic. Paper presented at EPS meeting. Manchester, July 7-9 July.

Publication Papers

Almabruk, A. A., Paterson, K. B., McGowan, V., & Jordan, T. R. (2011). Evaluating effects of divided hemispheric processing on word recognition in foveal and extrafoveal displays: the evidence from Arabic. *PLoS One, 6*(4), e18131. doi: 10.1371/journal.pone.0018131

Jordan, T. R., Almabruk, A. A., McGowan, V. A., & Paterson, K. B. (2011). Evaluating hemispheric divisions in processing fixated words: the evidence from Arabic. [Research Support, Non-U.S. Gov't]. *Cortex, 47*(8), 992-997. doi: 10.1016/j.cortex.2011.02.012

Jordan, T. R., Paterson, K. B., & Almabruk, A. A. (2010). Revealing the superior perceptibility of words in Arabic. *Perception, 39*(3), 426-428.

Appendix 2:

Ethics Statement

This research was conducted with the ethical approval of the School of Psychology Ethics Committee at the University of Leicester, and in accordance with the ethical guidelines of the British Psychological Society. All participants gave informed consent in writing.

Consent Statement

- I understand that my participation is voluntary and that I may withdraw from the research at any time, without giving any reason.

- I am aware of what my participation will involve.

- I understand that there are no risks involved in the participation of this study.

- All questions that I have about the research have been satisfactorily answered.

- I agree to participate.

- Participant's signature: _____

- Participant's name (please print): _____

- Tick this box if you would like to receive a summary of the results by e-mail.

- E-mail: _____ Date: -----------------------------

If you have any questions about the ethical conduct of this research please contact the Departmental Ethics Officer, using the contact detail at the top of this letter.

Thank you very much for participating,

Appendix 3:

Examples of Stimuli used in the study

<u>Examples of experimental sentence frames used in Experiment 2 and critical words. The critical words are shown in red</u>

◄·· Reading Direction

3-Letters شارك المؤلف برواية تحت عنوان شهد الحروف وعرضها بمعرض الكتاب
5-Letters شارك المؤلف برواية تحت عنوان أمنية صغيرة و يبعت بالمعرض
7-Letters شارك المؤلف برواية تحت عنوان استعادة النظام وتم عرضها بالمعرض

<u>Word and Non-word Stimuli used in Experiments 1, 2, 4, 5 and 6</u>

Stimulus Condition Experiment 1			
Words	Pseudo-words	Illegal Non-words	Inverted words
تعليق	يعلتق	ليتعق	(inverted word)

<u>Example of words stimuli used in the two-alternative Reicher-Wheeler task</u>

The Arabic words تعليم and تعليق, which differ at only the final, i.e., leftmost, letter position

Examples of Arabic words used in experiments

حديقة	(hadiqa)	"garden"
أَشْجَار	(ashJaR)	"trees"
تعليم	(tahleam)	"education"
مكاتب	(makatib)	"desks" or "offices"
عاصمة	(asema)	"capital"
تعليق	(tahleak)	"comment"
معرفة	(Marifat)	"Knowledge"

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REFERENCES

Abu-Rabia, S. (1998). Reading Arabic texts: Effects of text type, reader type and vowelization. *Reading and Writing, 10*(2), 105-119. doi: 10.1023/a:1007906222227

Abu-Rabia, S., & Awwad, J. (2004). Morphological structures in visual word recognition: The case of Arabic. *Journal of Research in Reading, 27*(3), 321-336. doi: 10.1111/j.1467-9817.2004.00235.x

Adamson, M. M., & Hellige, J. B. (2006). Hemispheric differences for identification of words and nonwords in urdu-English bilinguals. *Neuropsychology, 20*(2), 232-248. doi: 10.1037/0894-4105.20.2.232

Allen, P. A., & Emerson, P. L. (1991). Holism revisited: Evidence for parallel independent word-level and letter-level processors during word recognition: Correction. *Journal of Experimental Psychology: Human Perception and Performance, 17*(4). doi: 10.1037/0096-1523.17.4.985

Allen, P. A., Smith, A. F., Lien, M. C., Kaut, K. P., & Canfield, A. (2009). A multistream model of visual word recognition. *Atten. Percept. Psychophys., 71*, 281-296.

Ament, P. A., & Bazin, B. (2001). The effect of unreported visual deficits on the processing of brief visual stimuli. *Journal of Behavioral Optometry, 11*, 11-16.

Annett, M. (2003). Do the French and the English differ for hand skill asymmetry? Handedness subgroups in the sample of Doyen and Carlier (2002) and in English schools and universities. *Laterality: Asymmetries of Body, Brain and Cognition, 8*(3), 233-245. doi: 10.1080/13576500342000031

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist multiple trace memory model for polysyllabic word reading. *Psychological Review*, *105*, 678–723.

Antos, S. J. (1979). Processing facilitation in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance, 5*(3), 527-545. doi: 10.1037/0096-1523.5.3.527

Baccino, T., & Manunta, Y. (2005). Eye-Fixation-Related potentials: Insight into parafoveal processing. *Journal of Psychophysiology, 19*(3), 204-215. doi: 10.1027/0269-8803.19.3.204

Bai. X, Yan. G, Liversedge. S, Zang. C, & Rayner, K. (2008). Reading spaced and unspaced Chinese text: Evidence from eye movements. Journal of Experimental Psychology: Human Perception and Performance, 34, (5), 1277-1287.

Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 340-357.

Barber, H. A., Donamayor, N., Kutas, M., & Munte, T. (2010). Parafoveal N400 effect during sentence reading. *Neurosci Lett, 479*(2), 152-156. doi: 10.1016/j.neulet.2010.05.053

Baron, J., & Thurston, I. (1973). An analysis of the word-superiority effect. *Cognitive Psychology, 4*(2), 207-228. doi: 10.1016/0010-0285(73)90012-1

Behrmann, M., Shomstein, S. S., Black, S. E., & Barton, J. J. (2001). The eye movements of pure alexic patients during reading and nonreading tasks. *Neuropsychologia, 39*(9), 983-1002.

Bela, A., & Choisy, C. (2008). *Human reading based strategies for off-line Arabic word recognition*. Paper Presented at the Proceedings of the 2006 Conference on Arabic and Chinese Handwriting Recognition, College Park, MD, USA.

Bentin, S., McCarthy, G., & Wood, C. C. (1985). Event-related potentials, lexical decision and semantic priming. *Electroencephalogr Clin Neurophysiol, 60*(4), 343-355.

Benuck, M. B., & Peverly, S. T. (2004). The effect of orthographic depth on reliance upon semantic context for oral reading in English and Hebrew. *Journal of Research in Reading, 27*(3), 281-299. doi: 10.1111/j.1467-9817.2004.00232.x

Besner, D., & Johnston, J. C. (1989). Reading and the mental lexicon: On the uptake of visual information. In W. M. Wilson (Ed.), *Lexical representation and process* (pp. 291-316). *Cambridge, MA, US: the MIT Press*, vii, 576 pp.

Besner, T., Waller, G., & Mackinnon, G. (1985). *Reading research : Advances in theory and practice* (Vol. 5): *Academic Press*.

Bick, A. S., Frost, R., & Goelman, G. (2010). Imaging implicit morphological processing: Evidence from Hebrew. *J Cogn Neurosci, 22*(9), 1955-1969. doi: 10.1162/jocn.2009.21357

Blythe, H. I., Holliman, N. S., Jainta, S., Tbaily, L., & Liversedge, S. P. (2012). Binocular coordination in response to two-dimensional, three-dimensional and stereoscopic visual stimuli. *Ophthalmic and Physiological Optics*, 32, 397–411. doi:10.1111/j.1475-1313.2012.00926.x

Blythe, H. I., Liversedge, S. P., Joseph, H. S., White, S. J., & Rayner, K. (2009). Visual information capture during fixations in reading for children and adults. *Vision Res, 49*(12), 1583-1591. doi: 10.1016/j.visres.2009.03.015

Blythe, H. I., Liang, F., Zang, C., Wang, J., Yan, G., Bai, X., and Liversedge, S. P. (2012). Inserting spaces into Chinese text helps readers to learn new words: an eye movement study. Journal of Memory and Language, 67, (2), 241-254. (doi:10.1016/j.jml.2012.05.004).

Boudelaa, S., & Marslen-Wilson, W. D. (2001). Morphological units in the Arabic mental lexicon. *Cognition, 81*(1), 65-92. doi: 10.1016/s0010-0277(01)00119-6

Boudelaa, S., & Marslen-Wilson, W. D. (2005). Discontinuous morphology in time: Incremental masked priming in Arabic. *Language and Cognitive Processes, 20*(1), 207-260. doi: 10.1080/01690960444000106

Boudelaa, S., & Marslen-Wilson, W. D. (2010). Aralex: A lexical database for Modern Standard Arabic. *Behavior Research Methods, 42*(2), 481-487. doi: 10.3758/brm.42.2.481

Bowers, J. S. (1996). Different perceptual codes support priming for words and pseudowords: Was Morton right all along? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(6), 1336-1353. doi: 10.1037/0278-7393.22.6.1336

Bradshaw, J. L., & Nettleton, N. C. (1983). Hemispheric specialization: Return to a house divided. *Behavioral and Brain Sciences, 6*(03), 528-533. doi: doi:10.1017/S0140525X00073775

Bryden, M. P., & Allard, F. (1976). Visual hemifield differences depend on typeface. *Brain and Language, 3*(2), 191-200. doi: 10.1016/0093-934x(76)90016-x

Bryden, M. P., Mondor, T. A., Loken, M., & Ingleton, M. A. (1990). Locus of information in words and the right visual field effect. *Brain and Cognition, 14*(1), 44-58. doi: 10.1016/0278-2626(90)90059-w

Brysbaert, M. (2004). The importance of interhemispheric transfer for foveal vision: A factor that has been overlooked in theories of visual word recognition and object perception. *Brain and Language, 88*(3), 259-267. doi: 10.1016/s0093-934x(03)00279-7

Brysbaert, M., & D'Ydewalle, G. R. (1990). Tachistoscopic presentation of visual stimuli for assessing cerebral dominance: Reliability data and some practical recommendations. *Neuropsychologia, 28*(5), 443-455. doi: 10.1016/0028-3932(90)90071-u

Brysbaert, M., & Vitu, F. (1998). Word skipping: Implications for theories of eye movement control in reading. In G. Underwood (Ed.), *Eye guidance in reading and scene perception.* (pp. 125-147). Oxford England: Elsevier Science Ltd.

Brysbaert, M., Vitu, F., & Schroyens, W. (1996). The right visual field advantage and the optimal viewing position effect: On the relation between foveal and parafoveal word recognition. *Neuropsychology, 10*(3), 385-395. doi: 10.1037/0894-4105.10.3.385

Carr, E. G., Binkoff, J. A., Kologinsky, E., & Eddy, M. (1978). Acquisition of sign language by autistic children. I: Expressive labelling. *J Appl Behav Anal, 11*(4), 489-501. doi: 10.1901/jaba.1978.11-489

Cattell, J. M. (1886). The time taken up by cerebral operations. *Mind, 11*, 220-242.

Catlin, J. (1969). On the word-frequency effect. Psychological Review, 1969, 76, 504-506.

Chase, C. H., & Tallal, P. (1990). A developmental, interactive activation model of the word superiority effect. *Journal of Experimental Child Psychology, 49*(3), 448-487. doi: 10.1016/0022-0965(90)90069-k

Chiarello, C., Nuding, S., & Pollock, A. (1988). Lexical decision and naming asymmetries: influence of response selection and response bias. *Brain Lang, 34*(2), 302-314.

Coch, D., & Mitra, P. (2010). Word and pseudoword superiority effects reflected in the ERP waveform. *Brain Research, 1329,* 159-174. doi: 10.1016/j.brainres.2010.02.084

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychol Rev, 108*(1), 204-256.

Corballis, M. C., & Trudel, C. I. (1993). Role of the forebrain commissures in interhemispheric integration. *Neuropsychology, 7*(3), 306-324. doi: 10.1037/0894-4105.7.3.306

Davis, C. J. (2001). *The self-organising lexical acquisition and recognition (SOLAR) model of visual word recognition.* (62), ProQuest Information & Learning, US. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2001-95014-128&site=ehost-live Available from EBSCOhost psyh database.

Davis, C. J. (2010). SOLAR versus SERIOL revisited. *European Journal of Cognitive Psychology, 22*(5), 695-724. doi: 10.1080/09541440903155682

Davis, C. J. (2010). The spatial coding model of visual word identification. *Psychological Review,* 117, 713-758. doi: 2010-14834-00110.1037/a0019738. 10.1037/a0019738 .

Deutsch, A., & Rayner, K. (1999). Initial fixation location effects in reading Hebrew words. *Language and Cognitive Processes, 14*(4), 393-421. doi: 10.1080/016909699386284

Deutsch, A., Frost, R., Pelleg, S., Pollatsek, A., & Rayner, K. (2003). Early morphological effects in reading: Evidence from parafoveal preview benefit in Hebrew. *Psychonomic Bulletin & Review, 10*(2), 415-422. doi: 10.3758/bf03196500

Deutsch, A., Frost, R., Pollatsek, A., & Rayner, K. (2005). Morphological parafoveal preview benefit effects in reading: Evidence from Hebrew. *Language and Cognitive Processes, 20*(1), 341-371. doi: 10.1080/01690960444000115

Drasdo, N. (1977). The neural representation of visual space. *Nature, 266*(5602), 554-556.

Drieghe, D., Rayner, K., & Pollatsek, A. (2005). Eye movements and word skipping during reading revisited. *J Exp Psychol Hum Percept Perform, 31*(5), 954-959. doi: 10.1037/0096-1523.31.5.954

Driver, J., Baylis, G. C., Goodrich, S. J., & Rafal, R. D. (1994). Axis-based neglect of visual shapes. *Neuropsychologia, 32*(11), 1353-1365.

Dunn-Rankin, P. (1978). The visual characteristics of words. *Sci Am, 238*(1), 122-130.

Egeth, H., & Blecker, D. (1971). Differential effects of familiarity on judgments of sameness and difference. *Percept Psychophys, 9*(4), 321-326. doi: 10.3758/bf03208686

Elanwar, R. I., Rashwan, M. A., & Mashali, S. A. (2007). Simultaneous segmentation and recognition of Arabic characters in an unconstrained on-line cursive handwritten document. In C. Ardil (Ed.), *Proceedings of World Academy of Science, Engineering and Technology,* (Vol. 23, pp. 288-291). Canakkale: World Acad Sci, Eng & Tech-Waset.

Elbeheri, G., Everatt, J., Mahfoudhi, A., Al-Diyar, M. A., & Taibah, N. (2011). Orthographic processing and reading comprehension among Arabic speaking mainstream and LD children. *Dyslexia: An International Journal of Research and Practice, 17*(2), 123-142. doi: 10.1002/dys.430

Ellis, A. W. (2004). Length, formats, neighbours, hemispheres, and the processing of words presented laterally or at fixation. *Brain and Language, 88*(3), 355-366. doi: 10.1016/s0093-934x(03)00166-4

Ellis, A. W., & Brysbaert, M. (2010). Divided opinions on the split fovea. *Neuropsychologia, 48*(9), 2784-2785. doi: 10.1016/j.neuropsychologia.2010.04.030

Ellis, A. W., Young, A. W., & Anderson, C. (1988). Modes of word recognition in the left and right cerebral hemispheres. *Brain Lang, 35*(2), 254-273.

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Research*, 42, 621-636.

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychol Rev, 112*(4), 777-813. doi: 10.1037/0033-295X.112.4.777

Eviatar, Z. (1999). Cross-language tests of hemispheric strategies in reading nonwords. *Neuropsychology, 13*(4), 498-515. doi: 10.1037/0894-4105.13.4.498

Eviatar, Z., Ibrahim, R., & Ganayim, D. (2004). Orthography and the hemispheres: Visual and inguistic aspects of letter processing. *Neuropsychology, 18*(1), 174-184. doi: 10.1037/0894-4105.18.1.174

Farid, M., & Grainger, J. (1996). How initial fixation position influences visual word recognition: A comparison of French and Arabic. *Brain and Language, 53*(3), 351-368. doi: 10.1006/brln.1996.0053

Faust, M., Kravetz, S., & Babkoff, H. (1993). Hemispheric specialization or reading habits: Evidence from lexical decision research with Hebrew words and sentences. *Brain Lang, 44*(3), 254-263. doi: 10.1006/brln.1993.1017

Ferrand, L. & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked nonword priming. *Quarterly Journal of Experimental Psychology, 45A*, 353-372.

Frost, R., Kugler, T., & Forster, K.I. (2005). Orthographic structure versus morphological structure: principles of lexical organization in a given language. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 31, 1293-1326.

Gazzaniga, M. S. (2000). Cerebral specialization and interhemispheric communication: Does the corpus callosum enable the human condition? *Brain: A Journal of Neurology, 123*(7), 1293-1326. doi: 10.1093/brain/123.7.1293

Gilmore, G. C., & Egeth, H. E. (1976). When are nonwords easy to see? *Mem Cognit, 4*(5), 519-524. doi: 10.3758/bf03213213

Gomez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review*, 115, 577-600.

Grainger, J. (2003). Moving eyes and reading words: How can a computational model combine the two? In J. Hyönä, R. Radach, & H. Deubel (Eds.), the mind's eye: Cognitive and applied aspects of eye movement research (pp. 457-470). *Amsterdam, the Netherlands: Elsevier*.

Grainger, J. (2008). Cracking the orthographic code: An introduction. *Language and Cognitive Processes, 23*(1), 1-35. doi: 10.1080/01690960701578013

Grainger, J., & Jacobs, A. M. (1994). A dual read-out model of word context effects in letter perception: Further investigations of the word superiority effect. *Journal of Experimental Psychology: Human Perception and Performance, 20*(6), 1158-1176. doi: 10.1037/0096-1523.20.6.1158

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*(3), 518-565. doi: 10.1037/0033-295x.103.3.518

Grainger, J., & Jacobs, A. M. (2005). Pseudoword context effects on letter perception: The role of word misperception. *European Journal of Cognitive Psychology, 17*(3), 289-318. doi: 10.1080/9541440440000131

Grainger, J., & Whitney, C. (2004). Does the huamn mnid raed wrods as a wlohe? *Trends in Cognitive Sciences, 8*(2), 58-59. doi: 10.1016/j.tics.2003.11.006

Grainger, J., Bouttevin, S. B., Truc, C., Bastien, M., & Ziegler, J. (2003). Word superiority, pseudoword superiority, and learning to read: A comparison of dyslexic and normal readers. *Brain and Language, 87*(3), 432-440. doi: 10.1016/s0093-934x(03)00145-7

Grossi, G., Murphy, J., & Boggan, J. (2009). Word and pseudoword superiority effects in Italian-English bilinguals. *Bilingualism: Language and Cognition, 12*(1), 113-120. doi: 10.1017/s1366728908003891

Haikio, T., Bertram, R., Hyona, J., & Niemi, P. (2009). Development of the letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of Exp Child Psycholology, 102*(2), 167-181. doi: 10.1016/j.jecp.2008.04.002

Hellige, J. B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA US: Harvard University Press.

Hellige, J. B. (2001). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA US: Harvard University Press.

Hellige, J. B., & Yamauchi, M. (1999). Quantitative and qualitative hemispheric asymmetry for procesing Japanese Kana. *Brain and Cognition, 40*(3), 453-463. doi: 10.1006/brcg.1999.1074

Heron, W. (1957). Perception as a function of retinal locus and attention. *Am J Psychol, 70*(1), 38-48.

Hildebrandt, N., Caplan, D., Sokol, S., & Torreano, L. (1995). Lexical factors in the word-superiority effect. *Memory & Cognition, 23*(1), 23-33.

Hilz, R., & Cavonius, C. R. (1974). Functional organization of the peripheral retina: Sensitivity to periodic stimuli. *Vision Research, 14*(12), 1333-1337. doi: 10.1016/0042-6989(74)90006-6

Humphreys, G. W., & Mayall, K. (2001). A peripheral reading deficit under conditions of diffuse visual attention. *Cogn Neuropsychol, 18*(6), 551-576. doi: 10.1080/02643290042000242

Hunter, Z. R., Brysbaert, M., & Knecht, S. (2007). Foveal word reading requires interhemispheric communication. *J Cogn Neurosci, 19*(8), 1373-1387. doi: 10.1162/jocn.2007.19.8.1373

Hutzler, F., Braun, M., & Jacobs, A. M. (2008). On the specificities of the inverted-optimal viewing position effect and their implications on models of eye movement control during reading. *Brain Res, 1239*, 152-161. doi: 10.1016/j.brainres.2008.08.065

Hyona, J. (1995). An eye movement analysis of topic-shift effect during repeated reading. *J Exp Psychol Learn Mem Cogn, 21*(5), 1365-1373.

Hyona, J., & Bertram, R. (2011). Optimal viewing position effects in reading Finnish. *Vision Res, 51*(11), 1279-1287. doi: 10.1016/j.visres.2011.04.004

Ibrahim A. El rube', M. T. E. S., Soha S. (2010). Printed Arabic sub-word recognition using moments. *International Conference on Computer, Electrical, and Systems Science, and Engineering, Paris, France.*

Ibrahim, R., & Eviatar, Z. (2009). Language status and hemispheric involvement in reading: Evidence from trilingual Arabic speakers tested in Arabic, Hebrew, and English. *Neuropsychology, 23*(2), 240-254. doi: 10.1037/a0014193

Ibrahim, R., & Eviatar, Z. (2012). The contribution of the two hemispheres to lexical decision in different languages. *Behav Brain Funct, 8*, 3. doi: 10.1186/1744-9081-8-3

Ibrahim, R., Eviatar, Z., & Aharon-Peretz, J. (2002). The characteristics of Arabic orthography slow its processing. *Neuropsychology, 16*(3), 322-326. doi: 10.1037/0894-4105.16.3.322

Ibrahim, R., Eviatar, Z., & Aharon-Peretz, J. (2007). Metalinguistic awareness and reading performance: A cross language comparison. *Journal of Psycholinguistic Research, 36*(4), 297-317. doi: 10.1007/s10936-006-9046-3

Johnston, J. C. (1978). A test of the sophisticated guessing theory of word perception. *Cognitive Psychology, 10*(2), 123-153. doi: 10.1016/0010-0285(78)90011-7

Johnston, J. C., & McClelland, J. L. (1973). Visual factors in word perception. *Perception & Psychophysics, 14*(2), 365-370.

Jordan, T. R. (1990). Presenting words without interior letters: Superiority over single letters and influence of postmask boundaries. *Journal of Experimental Psychology: Human Perception & Performance, 16*, 893-909.

Jordan, T. R. (1995). Perceiving exterior letters of words: Differential influences of letter-fragment and non-letter-fragment masks. *J Exp Psychol Hum Percept Perform, 21*(3), 512-530.

Jordan, T. R., & Patching, G. R. (2006). Assessing effects of fixation demands on perception of lateralized words: A visual window technique for studying hemispheric asymmetry. *Neuropsychologia, 44*(5), 686-692. doi: 10.1016/j.neuropsychologia.2005.08.008

Jordan, T. R., & Paterson, K. B. (2009). Re-evaluating split-fovea processing in word recognition: A critical assessment of recent research. *Neuropsychologia, 47*(12), 2341-2353. doi: 10.1016/j.neuropsychologia.2008.07.020

Jordan, T. R., Almabruk, A. A. A., McGowan, V. A., & Paterson, K. B. (2011). Evaluating hemispheric divisions in processing fixated words: The evidence from Arabic. *Cortex,* doi: 10.1016/j.cortex.2011.02.012

Jordan, T. R., Fuggetta, G., Paterson, K. B., Kurtev, S., & Xu, M. (2011). An ERP assessment of hemispheric projections in foveal and extrafoveal word recognition. *PLoS One, 6*(9), e23957. doi: 10.1371/journal.pone.0023957

Jordan, T. R., McGowan, V. A., & Paterson, K. B. (2011). Out of sight, out of mind. The rarity of assessing and reporting participants' visual abilities when studying perception of linguistic stimuli. *Perception, 40*(7), 873-876. doi: 10.1068/p6940

Jordan, T. R., Patching, G. R., & Milner, A. D. (1998). Central fixations are inadequately controlled by instructions alone: Implications for studying cerebral

asymmetry. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 51*(2), 371-391. doi: 10.1080/027249898391675

Jordan, T. R., Patching, G. R., & Milner, A. D. (2000). Lateralized word recognition: Assessing the role of hemispheric specialization, modes of lexical access, and perceptual asymmetry. *Journal of Experimental Psychology: Human Perception and Performance, 26*(3), 1192-1208. doi: 10.1037/0096-1523.26.3.1192

Jordan, T. R., Paterson, K. B., & Kurtev, S. (2009). Reevaluating split-fovea processing in word recognition: Hemispheric dominance, retinal location, and the word-nonword effect. *Cognitive, Affective & Behavioral Neuroscience, 9*(1), 113-121. doi: 10.3758/cabn.9.1.113

Jordan, T. R., Paterson, K. B., & Stachurski, M. (2008). Re-evaluating split-fovea processing in word recognition: Effects of retinal eccentricity on hemispheric dominance. *Neuropsychology, 22*(6), 738-745. doi: 10.1037/a0013140

Jordan, T. R., Paterson, K. B., & Stachurski, M. (2009). Re-evaluating split-fovea processing in word recognition: Effects of word length. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 45*(4), 495-505. doi: 10.1016/j.cortex.2007.07.007

Jordan, T. R., Paterson, K. B., Kurtev, S., & Xu, M. (2010). Re-evaluating split-fovea processing in word recognition: effects of fixation location within words. *Cortex, 46*(3), 298-309. doi: 10.1016/j.cortex.2009.01.008

Jordan, T. R., Thomas, S. M., & Scott-Brown, K. C. (1999). The illusory-letters phenomenon: An illustration of graphemic restoration in visual word recognition. *Perception, 28*(11), 1413-1416. doi: 10.1068/p2919

Jordan, T. R., Thomas, S. M., Patching, G. R., & Scott-Brown, K. C. (2003). Assessing the importance of letter pairs in initial, exterior, and interior positions in reading. *J Exp Psychol Learn Mem Cogn, 29*(5), 883-893. doi: 10.1037/0278-7393.29.5.883

Joseph, H. S. S. L., Liversedge, S. P., Blythe, H. I., White, S. J., & Rayner, K. (2009). Word length and landing position effects during reading in children and adults. *Vision Research, 49*(16), 2078-2086.

Juhasz, B. J., Liversedge, S. P., White, S. J., & Rayner, K. (2006). Binocular coordination of the eyes during reading: Word frequency and case alternation affect fixation duration but not fixation disparity. *Q J Exp Psychol (Hove), 59*(9), 1614-1625. doi: 10.1080/17470210500497722.

Just, M. A., & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychol Rev, 87*(4), 329-354.

Kajii, N., & Osaka, N. (2000). Optimal viewing position in vertically and horizontally presented Japanese words. *Perception and Psychophysics, 62*(8), 1634-1644.

Kajii, N., Nazir, T. A., & Osaka, N. (2001). Eye movement control in reading unspaced text: The case of the Japanese script. *Vision Research, 41*(19), 2503-2510. doi: 10.1016/s0042-6989(01)00132-8

Kirsner, K., & Schwartz, S. (1986). Words and hemifields: Do the hemispheres enjoy equal opportunity? *Brain and Cognition, 5*(3), 354-361. doi: 10.1016/0278-2626(86)90036-9

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology, 16*(1-2), 262-284. doi: 10.1080/09541440340000213

Lavidor, M., Ellis, A. W., & Pansky, A. (2002). Case alternation and length effects in lateralized word recognition: Studies of English and Hebrew. *Brain Cogn, 50*(2), 257-271.

Lavidor, M., Ellis, A., Shillcock, R., & Bland, T. (2001). Evaluating a split processing model of visual work recognition: Effects of word length. *Cognitive Brain Research, 12*(2), 265-272. doi: 10.1016/s0926-6410(01)00056-8

Lete, B., & Ducrot, S. P. (2008). Visuo-attentional processing by dyslexic readers on the Reicher-Wheeler task. *Current Psychology Letters: Behaviour, Brain & Cognition, 24*(1), 25-39.

Leventhal, A. G., Schall, J. D., & Ault, S. J. (1988). Extrinsic determinants of retinal ganglion cell structure in the cat. *J Neurosci, 8*(6), 2028-2038.

Li, X., Liu, P., & Rayner, K. (2011). Eye movement guidance in Chinese reading: Is there a preferred viewing location? *Vision Research, 51*(10), 1146-1156. doi: 10.1016/j.visres.2011.03.004

Lindell, A. K., & Nicholls, M. E. R. (2003). Cortical representation of the fovea: Implications for visual half field research. *Cortex, 39*(1), 111-117. doi: 10.1016/s0010-9452(08)70079-0

Liversedge, S. P., Rayner, K., White, S., Vergilino-Perez, D., Findlay, J. M., & Kentridge, R. (2004). Eye movements when reading disappearing text: Is there a gap effect in reading? Vision Research, 44, (10), 1013-1024.

Liversedge, S. P., White, S. J., Findlay, J. M., & Rayner, K. (2006). Binocular coordination of eye movements during reading. *Vision Res, 46*(15), 2363-2374. doi: 10.1016/j.visres.2006.01.013

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review, 1*(4), 476-490.

Lukatela, G., Lorenc, B., Ognjenovic, P., & Turvey, M. T. (1981). A word superiority effect in a phonetically precise orthography. *Language and Speech, 24*(2), 173-183.

Lyddy, F., & Roche-Dwyer, C. (2008). A bilingual word superiority effect in Irish speakers. *Written Language and Literacy, 11*(1), 1-14. doi: 10.1075/wll.11.1.02lyd

Marks, N. L., & Hellige, J. B. (2003). Interhemispheric interaction in bilateral redundancy gain: Effects of stimulus format. *Neuropsychology, 17*(4), 578-593. doi: 10.1037/0894-4105.17.4.578

Martin, C. D., Thierry, G., Demonet, J. F., Roberts, M., & Nazir, T. (2007). ERP evidence for the split fovea theory. *Brain Res, 1185*, 212-220. doi: S0006-8993(07)02210-X, 10.1016/j.brainres.2007.09.049

Martin, C. D., Nazir, T., Thierry, G., Paulignan, Y., & Demonet, J. F. (2006). Perceptual and lexical effects in letter identification: An eventrelated potential study of the word superiority. *Brain Research, 1098*, 153-160.

Marzi, C. A., Mancini, F., Sperandio, I., & Savazzi, S. (2009). Evidence of midline retinal nasotemporal overlap in healthy humans: A model for foveal sparing in hemianopia? *Neuropsychologia, 47*(13), 3007-3011. doi: 10.1016/j.neuropsychologia.2009.05.007

McClelland, J. L., & Johnston, J. C. (1977). The role of familiar units in perception of words and nonwords. *Percept Psychophys, 22*(3), 249-261.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88*(5), 375-407. doi: 10.1037/0033-295x.88.5.375

McClelland, J. L., Rumelhart, D. E., Collins, A. M., & Smith, E. E. (1988). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. In A. M. Collins & E. E. Smith (Eds.), *Readings in cognitive science: A perspective from psychology and artificial intelligence.* (pp. 580-596). San Mateo, CA US: Morgan Kaufmann.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics, 17*(6), 578-586.

McConkie, G. W., & Rayner, K. (1976). Asymmetry of the perceptual span in reading. *Bulletin of the Psychonomic Society, 8*(5), 365-368.

McConkie, G. W., Kerr, P. W., Reddix, M. D., & Zola, D. (1988). Eye movement control during reading: I. The location of initial eye fixations on words. *Vision Res, 28*(10), 1107-1118.

McConkie, G. W., Reddix, M. D., & Zola, D. (1985). Chronometric analysis of language processing during eye fixations in reading. *Bulletin of the Psychonomic Society, 23*(4), 297-298.

McDonald, S. A., & Shillcock, R. C. (2003). Eye movements reveal the on-line computation of lexical probabilities during reading. *Psychol Sci, 14*(6), 648-652.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*(2), 227-234. doi: 10.1037/h0031564

Miller, N. K. (1988). Mens reading, womens writing - gender and the rise of the novel. *Yale French Studies*(75), 40-55.

Min, S. K., & Oh, B. H. (1992). Hemispheric asymmetry in visual recognition of words and motor response in schizophrenic and depressive patients. *Biological Psychiatry, 31*(3), 255-262. doi: 10.1016/0006-3223(92)90048-5

Mishkin, M., & Forgays, D. G. (1952). Word recognition as a function of retinal locus. *Journal of Experimental Psychology, 43*(1), 43-48. doi: 10.1037/h0061361

Monaghan, P., & Shillcock, R. (2003). Connectionist modelling of the separable processing of consonants and vowels. *Brain Lang, 86*(1), 83-98.

Morris, R. K., Rayner, K., & Pollatsek, A. (1990). Eye movement guidance in reading: The role of parafoveal letter and space information. *Journal of Experimental Psychology: Human Perception and Performance, 16*(2), 268-281. doi: 10.1037/0096-1523.16.2.268

Morrison, R. E. (1984). Manipulation of stimulus onset delay in reading: Evidence for parallel programming of saccades. *J Exp Psychol Hum Percept Perform, 10*(5), 667-682.

Morrison, R. E., & Rayner, K. (1981). Saccade size in reading depends upon character spaces and not visual angle. *Percept Psychophys, 30*(4), 395-396.

Nazir, T. A., & O'Regan, J. K. (1990). Some results on translation invariance in the human visual system. *Spat Vis, 5*(2), 81-100.

Nazir, T. A., Ben-Boutayab, N., Decoppet, N., Deutsch, A., & Frost, R. (2004). Reading habits, perceptual learning, and recognition of printed words. *Brain and Language, 88*(3), 294-311. doi: 10.1016/s0093-934x(03)00168-8

Nazir, T. A., Heller, D., & Sussmann, C. (1992). Letter visibility and word recognition: The optimal viewing position in printed words. *Perception & Psychophysics, 52*(3), 315-328.

Neisser, U. (1967). *Cognitive psychology*. New York: Appleton-Century-Crofts.

Norris, D. (2006). The Bayesian reader: Explaining word recognition as an optimal Bayesian decision process, *Psychological Review113*, 327-357.2006-04733-00510.1037/0033-295X.113.2.327. 10.1037/0033-295X.113.2.327 .

Norris, D. (2009). Putting it all together: A unified account of word recognition and reaction-time distributions, *Psychological Review116*, 207-219.2009-00258-00710.1037/a0014259. 10.1037/a0014259.

Nuthmann, A., Engbert, R., & Kliegl, R. (2005). Mislocated fixations during reading and the inverted optimal viewing position effect. *Vision Res, 45*(17), 2201-2217. doi: 10.1016/j.visres.2005.02.014

Olzak, L. A., & Thomas, L. P. (1986). Seeing spatial patterns. In K. R. Boff, L. Kaufman & J. P.Thomas (Eds.), *Handbook of Perception and Human Performance* (Vol. II, pp. 7.1-7.56).

O'Regan, J. K. (1981). The 'convenient viewing position' hypothesis. In D. F. Fisher, R. A. Monty, & J. W. Senders, *Eye movements*: *Cognition and visual perception* (pp. 289–298). Hillsdale, NJ: Erlbaum.

O'Regan, J. K. (1984a). How the eye scans isolated words. *Advances in Psychology* (Vol. 22, pp. 159-168).

O'Regan, J. K. (1984b). Retinal versus extraretinal influences in flash localization during saccadic eye movements in the presence of a visible background. *Perception and Psychophysics, 36*(1), 1-14.

O'Regan, J. K. (1990). Eye movements and reading. [Review]. *Rev Oculomot Res, 4*, 395-453.

O'Regan, J. K., & Jacobs, A. M. (1992). Optimal viewing position effect in word recognition: A challenge to current theory. *Journal of Experimental Psychology: Human Perception and Performance, 18*(1), 185-197. doi: 10.1037/0096-1523.18.1.185

O'Regan, J. K., & Levy-Schoen, A. (1987). *Eye movements: From physiology to cognition*. New York, NY US: Elsevier Science.

O'Regan, J. K., Levy-Schoen, A., Pynte, J., & BrugaiU, B. (1984). Convenient fixation location within isolated words of different length and structure. *Journal of*

Experimental Psychology: Human Perception and Performance, 10(2), 250-257. doi: 10.1037/0096-1523.10.2.250

Paap, K. R., Newsome, S. L., McDonald, J. E., & Schvaneveldt, R. W. (1982). An activation verification model for letter and word recognition: The word-superiority effect. *Psychological Review, 89*(5), 573-594. doi: 10.1037/0033-295x.89.5.573

Patching, G. R., & Jordan, T. R. (1998). Increasing the benefits of eye-tracking devices in divided visual field studies of cerebral asymmetry. *Behavior Research Methods, Instruments & Computers, 30*(4), 643-650.

Patching, G. R., & Jordan, T. R. (2005). Assessing the role of different spatial frequencies in word perception by good and poor readers. *Mem Cognit, 33*, 961-971.

Paterson, K. B., & Jordan, T. R. (2010). Effects of increased letter spacing on word identification and eye guidance during reading. *Memory & Cognition, 38*(4), 502-512. doi: 10.3758/mc.38.4.502

Paterson, K. B., Alcock, A., & Liversedge, S. P. (2011). Morphological priming during reading: Evidence from eye movements. *Language and Cognitive Processes, 26*(4-6), 600-623. doi: 10.1080/01690965.2010.485392

Paterson, K. B., Jordan, T. R., & Kurtev, S. (2009). Binocular fixation disparity in single word displays. *J Exp Psychol Hum Percept Perform, 35*(6), 1961-1968. doi: 10.1037/a0016889

Pelli, D. G., Tillman, K. A., Freeman, J., Su, M., Berger, T. D., & Majaj, N. J. (2007). Crowding and eccentricity determine reading rate. *J Vis, 7*(2), 20 21-36. doi: 10.1167/7.2.20

Perea, M., Abu Mallouh, R., & Carreiras, M. (2010). The search for an input-coding scheme: Transposed-letter priming in Arabic. *Psychonomic Bulletin & Review, 17*(3), 375-380. doi: 10.3758/pbr.17.3.375

Pillsbury, W. B. (1897). A study in apperception. *American Journal of Psychology, 8*(3), 315-393. doi: 10.2307/1411485

Plummer, P., & Rayner, K. (2012). Effects of parafoveal word length and orthographic features on initial fixation landing positions in reading. *Attention, Perception & Psychophysics,* 950-963.

Pollatsek, A., Reichle, E. D., & Rayner, K. (2006a). Attention to one word at a time in reading is still a viable hypothesis: Rejoinder to Inhoff, Radach, and Eiter

(2006). *J Exp Psychol Hum Percept Perform, 32*(6), 1496-1500. doi: 10.1037/0096-1523.32.6.1496

Pollatsek, A., Reichle, E. D., & Rayner, K. (2006b). Serial processing is consistent with the time course of linguistic information extraction from consecutive words during eye fixations in reading: A response to Inhoff, Eiter, and Radach (2005). *J Exp Psychol Hum Percept Perform, 32*(6), 1485-1489. doi: 10.1037/0096-1523.32.6.1485

Pollatsek, A., Reichle, E. D., & Rayner, K. (2006c). Tests of the E-Z Reader model: Exploring the interface between cognition and eye-movement control. *Cogn Psychol, 52*(1), 1-56. doi: 10.1016/j.cogpsych.2005.06.001

Pring, L. (1981). Phonological codes and functional spelling units: Reality and implications. *Percept Psychophys, 30*(6), 573-578.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*(1), 65-81. doi: 10.1016/0010-0285(75)90005-5

Rayner, K. (1978). Eye movements in reading and information processing. *Psychol Bull, 85*(3), 618-660.

Rayner, K. (1979). Eye guidance in reading: Fixation locations within words. *Perception, 8*(1), 21-30.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *J Exp Child Psychol, 41*(2), 211-236.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372–422.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *The Quarterly Journal of Experimental Psychology, 62*(8), 1457-1506. doi: 10.1080/17470210902816461

Rayner, K., & Bertera, J. H. (1979). Reading without a fovea. *Science, 206*(4417), 468-469.

Rayner, K., & Clifton, C., Jr. (2002). Language processing. In D. Medin (Volume Editor) Stevens Handbook of Experimental Psychology, 3rd: Volume 2, Memory and Cognitive Processes (pp 261-316). New York: John Wiley and Sons, Inc.

Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation times in reading: effects of word frequency, verb complexity, and lexical ambiguity. *Mem Cognit, 14*(3), 191-201.

Rayner, K., & Fischer, M. H. (1996). Mindless reading revisited: Eye movements during reading and scanning are different. *Percept Psychophys, 58*(5), 734-747.

Rayner, K., & Morris, R. K. (1992). Eye movement control in reading: Evidence against semantic preprocessing. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 163-172.

Rayner, K., & Pollarsek, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice Hall.

Rayner, K., & Pollatsek, A. (1996). Reading unspaced text is not easy: Comments on the implications of Epelboim et al.'s (1994) study for models of eye movement control in reading. *Vision Research, 36*(3), 461-465. doi: 10.1016/0042-6989(95)00132-8

Rayner, K., Ashby, J., Pollatsek, A., & Reichle, E. D. (2004). The effects of frequency and predictability on eye fixations in reading: implications for the E-Z Reader model. *J Exp Psychol Hum Percept Perform, 30*(4), 720-732. doi: 10.1037/0096-1523.30.4.720

Rayner, K., Binder, K. S., Ashby, J., & Pollatsek, A. (2001). Eye movement control in reading: word predictability has little influence on initial landing positions in words. *Vision Research, 41*(7), 943-954.

Rayner, K., Castelhano, M.S., & Yang, J. (2009). Eyemovements and the perceptual span in older and younger readers. *Psychology and Aging*, 24, 755-760.

Rayner, K., Fischer, M. H., & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. *Vision Res, 38*(8), 1129-1144.

Rayner, K., Inhoff, A. W., Morrison, R. E., Slowiaczek, M. L., & Bertera, J. H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *J Exp Psychol Hum Percept Perform, 7*(1), 167-179.

Rayner, K., Pollatsek, A., Ashby, J., & Clifton, C., Jr. (2012). *Psychology of reading (2nd ed.)*. New York, NY US: Psychology Press.

Rayner, K., Sereno, S. C., & Raney, G. E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance, 22*(5), 1188-1200. doi: 10.1037/0096-1523.22.5.1188

Rayner, K., Slattery, T. J., & Belanger, N. N. (2010). Eye movements, the perceptual span, and reading speed. *Psychon Bull Rev, 17*(6), 834-839. doi: 10.3758/PBR.17.6.834

Rayner, K., Slattery, T. J., Drieghe, D., & Liversedge, S. P. (2011). Eye movements and word skipping during reading: Effects of word length and predictability. *J Exp Psychol Hum Percept Perform, 37*(2), 514-528. doi: 10.1037/a0020990

Rayner, K., Well, A. D., & Pollatsek, A. (1980). Asymmetry of the effective visual field in reading. *Perception & Psychophysics, 27*(6), 537-544.

Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Percept Psychophys, 31*(6), 537-550.

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology, 81*(2), 275-280. doi: 10.1037/h0027768

Reichle, E. (2011). Serial attention models of reading. In Liversedge S. P., Gilchrist I. D. & Everling, S. (Eds.), *Oxford handbook on eye movements* (pp. 767-786). Oxford, UK: Oxford University Press.2011-23569-042.

Reichle, E. D., & Laurent, P. A. (2006). Using reinforcement learning to understand the emergence of "intelligent" eye-movement behavior during reading. *Psychol Rev, 113*(2), 390-408. doi: 10.1037/0033-295X.113.2.390

Reichle, E. D., Pollatsek, A., & Rayner, K. (2007). Modeling the effects of lexical ambiguity on eye movements during reading. In R. P. G. van Gompel, M. H. Fischer, W. S. Murray & R. L. Hill (Eds.), *Eye movements: A window on mind and brain.* (pp. 271-292). Amsterdam Netherlands: Elsevier.

Reichle, E. D., Pollatsek, A., & Rayner, K. (2012). Using E-Z Reader to simulate eye movements in nonreading tasks: A unified framework for understanding the eye–mind link. *Psychological Review, 119*(1), 155-185. doi: 10.1037/a0026473 10.1037/a0026473.supp (Supplemental)

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychol Rev, 105*(1), 125-157.

Reichle, E. D., Rayner, K., & Pollatsek, A. (1999). Eye movement control in reading: Accounting for initial fixation locations and refixations within the E-Z Reader model. *Vision Res, 39*(26), 4403-4411. doi: 10.1016/s0042-6989(99)00152-2

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z reader model of eye-movement control in reading: Comparisons to other models. *Behav Brain Sci, 26*(4), 445-476; discussion 477-526.

Reichle, E. D., Tokowicz, N., Liu, Y., & Perfetti, C. A. (2011). Testing an assumption of the E-Z Reader model of eye-movement control during reading: Using event-

related potentials to examine the familiarity check. *Psychophysiology, 48*(7), 993-1003. doi: 10.1111/j.1469-8986.2011.01169.x

Reichle, E. D., Warren, T., & McConnell, K. (2009). Using E-Z Reader to model the effects of higher level language processing on eye movements during reading. *Psychon Bull Rev, 16*(1), 1-21. doi: 10.3758/PBR.16.1.1

Reilly, R. G., & Radach, R. (2006). Some empirical tests of an interactive activation model of eye movement control in reading. *Cognitive Systems Research, 7*(1), 34-55. doi: 10.1016/j.cogsys.2005.07.006

Reuter-Lorenz, P. A., & Baynes, K. (1992). Modes of lexical access in the callosotomized brain. *J Cogn Neurosci, 4*(2), 155-164. doi: 10.1162/jocn.1992.4.2.155

Richter, E. M., Engbert, R., & Kliegl, R. (2006). Current advances in SWIFT. *Cognitive Systems Research, 7*(1), 23-33. doi: 10.1016/j.cogsys.2005.07.003

Rizzolatti, G., Gentilucci, M., Fogassi, L., Luppino, G., Matelli, M., & Ponzoni-Maggi, S. (1987). Neurons related to goal-directed motor acts in inferior area 6 of the macaque monkey. *Exp Brain Res, 67*(1), 220-224.

Roy-Charland, A., Saint-Aubin, J., Klein, R. M., MacLean, G. H., Lalande, A., & Bélanger, A. (2012). Eye movements when reading: The importance of the word to the left of fixation. *Visual Cognition, 20*(3), 328-355. doi: 10.1080/13506285.2012.667457

Rumelhart, D. E., & Siple, P. (1974). Process of recognizing tachistoscopically presented words. *Psychol Rev, 81*(2), 99-118.

Sainio, M., Hyona, J., Bingushi, K., & Bertram, R. (2007). The role of interword spacing in reading Japanese: An eye movement study. *Vision Res, 47*(20), 2575-2584. doi: 10.1016/j.visres.2007.05.017

Schiepers, C. (1980). Response latency and accuracy in visual word recognition. *Percept Psychophys, 27*(1), 71-81.

Schotter, E. R., Angele, B., & Rayner, K. (2012). Parafoveal processing in reading. *Attention, Perception, & Psychophysics, 74*(1), 5-35. doi: 10.3758/s13414-011-0219-2

Schwartz, S., Montagner, S., & Kirsner, K. (1987). Are there different methods of lexical access for words presented in the left and right visual fields? *Brain Lang, 31*(2), 301-307.

Shen, D., Liversedge, S. P., Tian, J., Zang, C., Cui, L, Bai, X., Yan, G., & Rayner, K. (2011). Eye movements of second language learners when reading spaced and unspaced Chinese text. Journal of Experimental Psychology, 18(2):192-202.

Shillcock, R. C., & McDonald, S. A. (2005). Hemispheric division of labour in reading. *Journal of Research in Reading, 28*(3), 244-257. doi: 10.1111/j.1467-9817.2005.00268.x

Shillcock, R., Ellison, T. M., & Monaghan, P. (2000). Eye-fixation behavior, lexical storage, and visual word recognition in a split processing model. *Psychol Rev, 107*(4), 824-851.

Shneor, E., & Hochstein, S. (2006). Eye dominance effects in feature search. *Vision Research, 46*(25), 4258-4269. doi: 10.1016/j.visres.2006.08.006

Slattery, T. J., Staub, A., & Rayner, K. (2012). Saccade launch site as a predictor of fixation durations in reading: Comments on Hand, Miellet, O'Donnell, and Sereno (2010). *J Exp Psychol Hum Percept Perform, 38*(1), 251-261. doi: 10.1037/a0025980

Staub, A. (2011b). Word recognition and syntactic attachment in reading: Evidence for a staged architecture. *Journal of Experimental Psychology*, 140, 407-433.

Stevens, M. l., & Grainger, J. (2003). Letter visibility an the viewing position effect in visual word recognition. *Perception & Psychophysics, 65*(1), 133-151.

Van der Haegen, L., Drieghe, D., & Brysbaert, M. (2010). The split fovea theory and the leicester critique: What do the data say? *Neuropsychologia, 48*(1), 96-106. doi: 10.1016/j.neuropsychologia.2009.08.014

Velan, H., & Frost, R. (2009). Letter-transposition effects are not universal: The impact of transposing letters in Hebrew. *Journal of Memory and Language, 61*(3), 285-302. doi: 10.1016/j.jml.2009.05.003

Vitu, F. O., McConkie, G. W., Kerr, P., & O'Regan, J. K. (2001). Fixation location effects on fixation durations during reading: An inverted optimal viewing position effect. *Vision Research, 41*(25), 3513-3533. doi: 10.1016/s0042-6989(01)00166-3

Vitu, F., O'Regan, J. K., & Mittau, M. (1990). Optimal landing position in reading isolated words and continuous text. *Perception & Psychophysics, 47*(6), 583-600.

Vitu, F., O'Regan, J. K., Inhoff, A. W., & Topolski, R. (1995). Mindless reading: Eye-movement characteristics are similar in scanning letter strings and reading texts. *Percept Psychophys, 57*(3), 352-364.

Wheeler, D. D. (1970). Processes in word recognition. *Cognitive Psychology, 1*(1), 59-85. doi: 10.1016/0010-0285(70)90005-8

White, S. J. (2008). Eye movement control during reading: Effects of word frequency and orthographic familiarity. *Journal of Experimental Psychology: Human Perception and Performance, 34*(1), 205-223. doi: 10.1037/0096-1523.34.1.205

White, S. J., & Liversedge, S. P. (2006). Linguistic and nonlinguistic influences on the eyes' landing positions during reading. *The Quarterly Journal of Experimental Psychology, 59*(4), 760-782.

White, S. J., Hirotani, M., & Liversedge, S. P. (2011). Eye movement behaviour during reading of Japanese sentences: Effects of word length and visual complexity. *Reading and Writing*, 1-26.

Whitehouse, A. J. O., & Bishop, D. V. M. (2008). Cerebral dominance for language function in adults with specific language impairment or autism. *Brain: A Journal of Neurology, 131*(12), 3193-3200. doi: 10.1093/brain/awn266

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: the SERIOL model and selective literature review. [Review]. *Psychon Bull Rev, 8*(2), 221-243.

Whitney, C., & Cornelissen, P. (2008). SERIOL Reading. *Language and Cognitive Processes, 23*(1), 143-164. doi: 10.1080/01690960701579771

Whittaker, S. G., & Lovie-Kitchin, J. (1993). Visual requirements for reading. *Optometry and Vision Science, 70*, 54-65.

Winskel, H., & Luksaneeyanawin, S. (2009). Obligatory grammatical categories and the expression of temporal events. [Comparative Study]. *J Child Lang, 36*(2), 355-380. doi: 10.1017/S0305000908008970

Woodworth, R. S. (1938). *Experimental psychology*. New York: H. Holt and company.

Yan, M., Kliegl, R., Richter, E. M., Nuthmann, A., & Shu, H. (2010). Flexible saccade-target selection in Chinese reading. *Quarterly Journal of Experimental Psychology, 63*(4), 705-725.

Young, A. W., & Ellis, A. W. (1985). Different methods of lexical access for words presented in the left and right visual hemifields. *Brain Lang, 24*(2), 326-358.

Zaidel, E. (1998). Stereognosis in the chronic split brain: Hemispheric differences, ipsilateral control and sensory integration across the midline. *Neuropsychologia, 36*(10), 1033-1047.

Zang, C., Liversedge, S. P., Liang, F., Bai, X., & Yan, G. (2012). Interword spacing and landing position effects during Chinese reading in children and adults. *Journal of Experimental Psychology: Human Perception and Performance*, 18(2), 192-202.