

**ARABIC READING: NORMAL BEHAVIOUR AND TREATMENT  
IN PATIENTS WITH HEMIANOPIC ALEXIA**

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## Declaration

‘I, Sharifa Mohammad Alragam, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.’

## Abstract

In reading research, reading speed (single-word reading and text-reading) and eye movement efficiency is used to investigate cognitive processes during reading. Specifically, I am interested in reading speed and eye movement behaviour in Arabic-reading normal adults and patients with Hemianopic Alexia (HA) while reading Arabic text. Following a hemianopia (most commonly caused by stroke), a patient's reading ability may be affected, and this may be exacerbated depending on the visual and orthographic complexity of the language. Research on Arabic reading is scarce, and no empirical studies on Arabic readers with HA have been conducted; thus, little is known about the performance of Arabic readers with HA. Almost all of the world literature on acquired alexia (of any form) is on left-to-right-reading patients. There are 234 million Arabic readers in the Arab states (UNESCO Institute of Statistics, 2014). So, if a stroke occurs, approximately 20% of these readers with a stroke may develop HA (Isaef, Wallar, Duncan, 1974). HA has a negative impact on reading and related activities of daily living. If work heavily depends on reading, then their job may be at risk. The primary aim of my thesis was to help these patients.

By developing a novel online assessment and treatment package (an app) for Arabic readers with HA called Arabic-Read Right ([http://www.ucl.ac.uk/aphasialab/apps/arabic\\_rr.html](http://www.ucl.ac.uk/aphasialab/apps/arabic_rr.html)) I hoped to 1) develop suitable materials to aid in the clinical diagnosis of HA and 2) provide effective and empirically supported reading treatment for HA Arabic readers. I did this in a series of experiments designed to (i) contribute to our overall understanding of Arabic reader's reading speed and eye movements, (ii) expand on our understanding of oculomotor processing in Arabic, and (iii) investigate text reading and eye movements in Arabic-reading patients with HA, both before and after treatment with a developed online rehabilitation assessment and treatment package: Arabic-Read Right.

## Impact Statement

The foremost academic contribution of my thesis is the key finding that reading data from Latinate languages (English) are not easily transferrable to Semitic languages, such as Arabic. The results of my word-length effect study provide the first evidence that when healthy adults read Arabic single words morphological family size density influenced how long it took them to read words aloud. Analysis of these data indicates in Arabic there is not a simple (additive) effect of word length on reading speed, as found in English where increasing word length increases the time to read a word. This discovery means further academic research into word recognition and reading studies in Arabic are necessary to help us understand the different cognitive processes and eye movement behaviours involved in reading such a visually complex written language. The benefits of this knowledge is it helps to reconcile differences in the reading literature between Latinate and Semitic languages.

In this thesis I developed a new methodology an app (Arabic-Read Right), to address the lack of standardized assessment and treatment resources for Arabic-reading patients with HA. In the six patients who trialled it, the real life impact of the Arabic-Read Right app is to improve reading speed, such that one patient is considering returning to work, and the others reported they now enjoy reading for pleasure again thereby improving their quality of life. The benefits of this methodology and its proven efficacy means that the Arabic-Read Right app will now have important clinical translation benefits for Arabic reading HA patients. Firstly, through its comprehensive assessment package, it will aid the clinical diagnosis of HA, which will be useful for neuro-ophthalmologists and speech-language pathologists practicing in the Middle East and other Arab countries. Secondly, as the app is web-based and free, it will provide individual patients with an effective web-based treatment that they can use to improve their reading anytime

and anywhere that suits them. This represents a realistic way of delivering sufficient therapy dose to Arabic reading HA patients across the wider Arabic region, indeed internationally so that they can obtain clinically meaningful improvements. The impact of the therapy has been proven effective for individual HA patients immediately post 20 hours of training. With the App available online the wider community of Arabic patients with HA will be able to freely access ongoing training allowing them to continue to improve their reading over many years to come. The app is available to download here: <https://itunes.apple.com/app/id964478309>

To enhance the impact and disseminate the outputs of this thesis I will be publishing the results of chapters 3 and 5/6 in specialist peer reviewed academic journals. To ensure the work of this thesis benefits non-academic health service delivery practitioners, I will continue to deliver lectures/ education sessions to doctors and speech-language therapists, who will deliver treatment to HA patients in Kuwait. I have made a video to further disseminate the knowledge and App methods used in this thesis, which will be available here:

[http://www.ucl.ac.uk/aphasialab/apps/arabic\\_rr.html](http://www.ucl.ac.uk/aphasialab/apps/arabic_rr.html)

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## Chapter 1: Introduction

### 1.1 Abstract

In this introductory section I will review some of the important areas of reading research that serve as a foundation for this approach. Before investigating reading performance in Arabic reading patients with HA it is important to first understand normative eye movement reading patterns for Arabic, a non-Latinate language. Reading performance depends mainly upon number and duration of fixations, and saccadic amplitudes. Saccadic amplitude is the angular distance the eye travels towards either side (left or right) of space during reading (Rayner, 1998). To address this I provide a review of the following eye movement topics with respect to reading Arabic text as compared to Latinate languages: (a) optimal viewing position, (b) perceptual span, (c) landing positions, (d) reading speed, (e) fixations and skipping effects, (f) fixation durations, and (g) saccadic amplitudes. Then I go through the research in left-to-right readers (of English primarily) with HA including how eye movements during reading are affected by a hemianopia and how an eye movement therapy approach can improve patients' reading speed.

### 1.2 Context

Arabic is the most widely read Semitic language in the world, (Abu-Rabia, 1998) that is read and written from right to left. It consists of 28 letters; all consonants with some additionally functioning as long vowels. Short vowels are represented by adding marks or diacritics to the consonants and are not part of the Arabic alphabet. Short vowel patterns are 'rule-governed according to word meaning, inflection and function in a sentence' (Abu-Rabia, 1998, p. 106).

Classical Arabic (also called *Modern Standard Arabic*) is used in the Arab world for formal communication and writing. It is used in schools, media and formal communication, and in Arabic literature. Spoken Arabic is used informally in day-to-day situations. Spoken Arabic is

a local dialect pertaining to a specific region in the Arab world and has no written form (Abu-Rabia, 1997, 1998, 2002; Eviatar, Ganayim, & Ibrahim, 2004). The two forms of Arabic are considered related but different. This situation has been termed by many scholars as *diglossic* (Abu-Rabia, 1997, 1998, 2002; Ayari, 1996) i.e., a language has two forms, here formal literary and informal spoken. Classical Arabic is taught in the first grade, almost as a second language. Hence, children in the Arab world can face great difficulty in learning to read (Ayari, 1996).

Surprisingly few studies have examined eye movements when reading Arabic text (Farid & Grainger, 1996; Jordan, Almabruk, Gadalla, McGowan, White, Abedipour, & Paterson, 2014; Paterson, Almabruk, McGowan, White, & Jordan, 2015; Hermena, Ehab, Drieghe, Hellmuth & Liversedge, 2015; Hermena, Liversedge & Drieghe, 2017). Little empirical research has been published on Arabic reading and none on Arabic-speaking patients with HA. A search of the PubMed.gov (<http://www.ncbi.nlm.nih.gov/>) database (in 20-11-2017) revealed 281 published articles on eye movement during the reading of English text compared to only nine on eye movement during the reading of Arabic text. A review table (Table 1) summarises the existing literature on single-word eye movement processing when reading Arabic text.

Importantly, written Arabic differs fundamentally from Latinate languages on four key factors: 1) Arabic is read from right to left; 2) Arabic is written in joined script (cursive), in which spaces rarely exist between letters in words; 3) Arabic letters in many cases have extremely similar basic forms and dots are used to distinguish between them; and 4) diacritics (vowels) can be inserted so that ambiguous words can be interpreted by the reader. However, these are usually excluded from texts read by skilled readers; thus Arabic single-word reading perhaps relies more on top-down contextual processes than does English. Together these factors mean that there are significant additional visual influences on eye movement control when

reading Arabic text, as compared to Latin languages. For example, these factors may affect oculomotor processing when identifying upcoming words resulting in slower reading, more fixations and longer gaze durations. The visual appearance of the written Arabic language is discussed in detail below and the effect on the eye movements of healthy Arabic readers will then be examined.

### 1.3 Orthographical Complexity in Arabic




The complexity of Arabic orthography is due to three key characteristics associated with the written form of the Arabic language.

*(i) The first characteristic has to do with dots and diacritics.*

Dots are an essential part of the grapheme because they distinguish between different letters with an identical base. A skilled Arabic reader can differentiate between these letters based on the location and number of dots for each particular letter. For example, the following graphemes have identical bases, but are distinguished from each other based on the number and location of the dots: /b→ ب/, /t→ ت/, and /th→ ث/.

There is phoneme-grapheme correspondence in Arabic if the word is presented with a diacritic. These diacritics are marks used above or below a letter in a word, in order to deduce its meaning. Without these diacritics, readers must depend upon their literary skills, as well as on contextual meaning: for example, /كُتِبَ/ ‘to write’ and /كُتُبَ/ ‘books’. These two words are visually identical and differ only in the marks placed above the consonants, which provide them with their different meanings. Hence, reading in Arabic can be difficult, even for skilled readers, because of the visual homographic nature of its written form. Indeed, Abu-Rabia (1999) investigated the effect of Arabic diacritics on reading comprehension of second- and sixth-grade

native Arabic speakers (age range: 7 -12.5 years) and found that Arabic diacritics aided reading comprehension in both groups.

Some of the diacritics in Arabic writing are: the *fatha*, represented by a small stroke above the consonant /  /, the *kasra*, represented by a small stroke under the consonant /  /, and the *damma*, represented by a small comma above the consonant /  /. However, in most modern written and printed Arabic texts, for adult skilled readers, diacritics are not used. The reader has to infer the meaning of words from context and/or from prior knowledge.

Roman and Pavard (1987) tracked the eye movements of native Arabic-speaking adults while silently reading passages, comprised of 95 words that were either fully diacritized (vowelized) or non-diacritized (non-vowelized). They reported that in the fully diacritized condition, reading was slower, and the number of fixations and fixation durations increased. A fixation is maintaining visual gaze on a single location. That is, the “period of time when the eyes remain fairly still and new information is acquired from the visual array” (Rayner, 2009, p. 1548). Fixation duration is the length of that fixational pause during reading. They also reported that gaze duration (the sum of all fixations on a word before moving to the next word) was 75 ms longer for the fully diacritized text. Visual crowding owing to the presence of diacritics might have contributed to a delay in word identification: additional visual information (diacritics) may have interfered with the adjacent grapheme. The authors suggested that fully diacritized text created visual *perceptual noise*, which may have resulted in delayed word identification and an overall slower reading speed.

Another possible reason for this may be the nature of the materials used. Rayner (1998) claimed that number of fixations and average fixation durations are influenced by textual and typographical variables as well as by characteristics of the writing system. This was based on an

earlier study (Rayner, 1980), which found that longer passages overload the visual processing system. Therefore, more fixations are necessary for readers to process large amounts of reading information. Roman and Pavard (1987) used long passages (95 words per passage); thus their readers had more information to process, were not as efficient and made more fixations to compensate for the information overload.

Hermena, Drieghe, Hellmuth and Liversedge (2015) tracked the eye movements of native Arabic-speaking participants while silently reading either fully diacritized or non-diacritized active or passive sentences. They also found that diacritized Arabic words are more likely to be fixated upon. Additionally, diacritized full sentences resulted in a small but significant increase (7 ms) in average fixation duration. Another issue to consider is familiarity and when it is acceptable to use diacritics in the Arabic writing system. Skilled adult Arabic readers most commonly only encounter diacritics in Koranic text and poetry. Hence, the addition of diacritics in everyday written Arabic text is novel, creates visual crowding and increases visual complexity owing to the additional information (diacritics) that the skilled reader would not normally see in a natural Arabic reading session.

*(ii) The second characteristic is the letter shape depending on its placement in a word.*

In written Arabic, 22 of the 28 letters have four shapes each (word-initial, word-medial, word-final, and when they follow a non-connecting consonant). The six remaining consonants have two shapes (word-final and separate). These rules are crucial to identify and decode words (Abu-Rabia, 1997, 1998, 2002; Eviatar, Ganayim, & Ibrahim, 2004). Unlike Arabic orthography, in Hebrew the graphemes do not vary in shape according to their position in a word (Shatil, Share, & Levin, 1999). Hence, the same letters (graphemes) in the Arabic script have variable widths and shapes, and that depends on their location within words (e.g., Boudelaa & Marslen-Wilson,

2001). This characteristic increases the amount of visual information in the same space (visual crowding), in which interference of adjacent visual materials (e.g., shape of letter) within a word slows the identification of that word (Slattery & Rayner, 2013). This unique feature attributed to the Arabic script, may interfere with word identification, which may result in slower text-reading speed identified by an increase in the number and duration of fixations, and a decrease in saccadic amplitudes in skilled older Arabic readers (Jordan et al., 2015).

*(iii) The third characteristic is the manner in which the letters are connected to form a word.*

Arabic text is written in cursive script. Written words in text lack spatial segregation, which may ‘decrease their distinctiveness and introduce effects of visual crowding that impede word identification’ (Jordan et al., 2015, para. 6). In a study investigating the impact of orthographic connectivity on visual word recognition in Arabic, partially connected words yielded more accurate responses among skilled Arabic readers in a lexical decision task than connected words, further supporting the idea that visual crowding can affect word identification (Khateb, Khateb-Abdelgani, Taha, & Ibrahim 2014).

## 1.4 Morphological Complexity in Arabic

Arabic morphology follows a stringent logic. It consists primarily of consonant roots, which intertwine with patterns of vowels and affixes to form words, or word stems (Ryding, 2005; Abu-Rabia 1997). By inserting different vowels and affixes into different slots of Arabic consonant roots, different patterns are formed. For example, the consonant root morpheme /d-r-s/ → د-ر-س ‘to study’ is unconnected because vowels can be distributed between these consonants. Yet, these consonants must always be present and displayed in the same order: first /d/, then /r/, then /s/ to form different word stems with related meanings. For example, as in the word /تُدرِّسُ/ ‘tuition’ or the word /مُدرِّسٌ/ ‘teacher.’

Arabic is mostly composed of three and four consonant roots, and less frequently two and five. The root contains the lexical meaning, conveying general reference. It stands for a semantic field from which words are created. It is estimated that there are between 5,000 and 6,000 consonant roots in the Arabic language (Ryding, 2005; Abu-Rabia, 2002). The addition of patterns of vowels and affixes to the consonant roots provide a grammatical function. They categorize words into nouns, verbs, or adjectives. Ryding (2005) stated that the pattern-formation of the Arabic language includes: six vowels (three long: /aa/, /ii/, /uu/; three short: /a/, /i/, and /u/), seven consonants (ʔ, t, m, n, s, y, w), and the process of doubling a consonant.

## 1.5 Visual Word Recognition in Written Arabic Text

### 1.5.1 Optimal viewing position

During written word processing, not all letters are equally visible to the reader; the fixated letters is most visible. The foveal region spans about 1-2 degrees (about 7-8 characters) of visual angle around the reader's fixation point, which is the area of highest visual acuity. Outside the foveal region, acuity drops and the reader's ability to identify letters are not as sensitive. Visual acuity outside that area (parafoveal region) is sufficient to give information about word shape and length (Rayner, 1978; Leff et al., 2000). The visibility of the other letters depends upon several factors: the distance between the letters and the fixation location, whether the letters are outer or inner letters of the word, and whether they are located to the right or left of the fixation location (Brysbaert & Nazir, 2005). Thus, word recognition depends upon viewing position. The *optimal viewing position* for written words of five or seven letters in languages written from left-to-right is fixation between the beginning and the middle. Performance declines when fixation is on the extreme letters of words. Some authors argue that, in languages written from right-to-left, optimal viewing position depends on the morphological structure of the word (Farid & Grainger,



1996). They investigated optimal viewing position of written Arabic words. Participants' initial fixations for written Arabic prefixed words produced a leftward (word ending) preference for word identification. However, initial fixations for written Arabic suffixed words produced a rightward (word beginning) preference for word identification. This suggests that the identification of critical information for word recognition plays an important role in effecting initial fixation position. The morphological complexity of written Arabic explains this phenomenon. Different Arabic word patterns are formed when different affixes are inserted into different slots of an Arabic consonant root. Skilled readers need to identify the different affixes from the consonant root to extract the meaning of the word for word recognition.

Furthermore, Ibrahim and Eviatar (2009) suggested that there is a right visual field advantage for Arabic words when Arabic speakers performed lateralized lexical decision tasks in Arabic, Hebrew, and English. This sensitivity to the lexical status of the stimuli was significantly better for Arabic than for Hebrew and English in the right visual field, but not in the left visual field. This large effect has been attributed to the morphological complexity of Arabic.

Consistent with the Latinate literature Jordan, Almabruk, McGowan, and Paterson (2011) who investigated optimal fixation locations in five-letter Arabic words, by analysing reading reaction times for correct responses and error rates found reading performance was poorest when fixation location was either on the extreme left or right of fixation. Reaction times for correct responses were the longest for fixation locations on the extreme right and left positions, and shortest for fixation locations at the centre of the word. Additionally, error rates were the highest for fixation locations on the extreme right and left positions, and shortest for fixation locations at the centre of the word. In contrast with reading a Latinate language Arabic reading performance was only best when fixation location was at the centre of the word, not the beginning.

Adopting a different approach, using a lexical decision task, Almabruk et al. (2011) examined the recognition of five-letter Arabic words displayed in the left and right visual hemifields at locations either close to fixation and entirely in foveal vision, or further from fixation and entirely in parafoveal vision. Five-letter Arabic words in parafoveal locations were accurately recognized when displayed to the right of fixation, but this asymmetry was not recognized for foveal word recognition. This led the authors to suggest that five-letter Arabic words in the parafoveal locations were identified more accurately and quickly when displayed to the right of fixation. Thus, it seems important that we examine the benefit of parafoveal processing for reading in Arabic. Interestingly little is known about the effect of parafoveal processing of words to the left of fixation (that is, in the direction of reading) in Semitic languages.

## 1.6 Eye Movements in Reading Written Arabic Text

### 1.6.1 Perceptual span

The area at each fixational pause from which readers obtain useful information during the process of reading is known as *perceptual span*. Researchers agree that the perceptual span for skilled readers of left-to-right orthographies extends from three to four letters to the left of the fixation to 14 or 15 letters to the right of the fixation (Rayner, 1998; Rayner, Slattery, & Belanger, 2010). Conversely, the perceptual span for skilled readers of right-to-left orthographies extends from three to four letters to the right of the fixation to 14 or 15 letters to the left of the fixation (Pollatsek, Bolozky, Well, & Rayner, 1981; Jordan et al., 2014). Research by Pollatsek and colleagues (1981) demonstrated that left asymmetry in the perceptual span of left-to-right readers and right asymmetry for right-to-left readers was attributed to attentional factors related to the pattern of eye movements. In their study, native Israeli readers read Hebrew and English

text as their eye movements were monitored. A window of text moved in synchrony with their eye movements and the window was either symmetrical about the fixation point or offset to the left or right. When participants read Hebrew, perceptual span was asymmetric to the left; when they read English, it was asymmetric to the right. The authors suggested that direction of reading mainly determines the asymmetry of the perceptual span, which was evident from the results of their study. The reading performance of bilingual participants when reading English text was thus superior when perceptual span extended more to the right; reading performance when reading Hebrew text was superior when perceptual span extended to the left. A similar pattern is predicted in bilingual Arabic readers.

### 1.6.2 Landing Position

Eye movements during reading text are biased to move towards what is novel. Skilled readers of right-to-left orthographies prefer eye movements that facilitate locating the next new word, which is in their direction of reading. According to Spalek and Hammad (2005), attention is biased towards anticipating the occurrence of new information that is consistent with the direction of reading printed text. In their study, readers of English text preferred to read in a left-to-right manner, and readers of Arabic text preferred reading in the opposite direction. Skilled readers shift their attention towards the left (for English) or right (for Arabic) when reading printed text, in anticipation of finding new information. They concluded that this bias by language adapted environmentally, depending on the direction of reading to produce a more efficient tracking system for reading printed text.

### 1.6.3 Word-Length Effect

To further address the issue of landing position, Paterson et al. (2015) investigated the effect of word length on landing positions of initial fixations of target stimuli. For three-letter target

words, the average landing position was at the centre. For seven-letter target words, the average landing position was to the right of centre. For five-letter words, it was between these locations. These results are comparable to findings from studies of Hebrew (Deutsch & Rayner, 1999) but not of Latinate languages. The preferred viewing location for target (3, 5 and 7 letter) English words is to the left of centre (Rayner, 1979), consistent with the direction that language is read. These findings reveal that word length influenced the landing positions of initial fixations on single-word reading, and the location of landing positions affected both the duration of the initial fixation, and the probability of refixating the word.

In addition, Paterson et al. (2015) found that skilled readers of Arabic text were more likely to fixate and refixate longer words. Gaze durations and total reading times were the longest for seven-letter word stimuli. These findings suggest that Arabic-reading patients with HA should have a word length effect, i.e., reading will be significantly slower for seven letter words compared to three letter words.

#### 1.6.4 Text Reading Speed

Reading rates differ among individuals, as a function of reading skill (Rayner, 1998; Rayner, Slattery, & Belanger, 2010). Average total reading time for silently read English passages was 308 words per minute (wpm) in ten skilled readers with good comprehension (Rayner, 1978), with an average total reading time of 325 wpm for fast readers and 200 wpm for slow readers (Rayner et al., 2010).

Hebrew readers reading rates was 286 wpm in a group of six bilingual Israeli subjects reading Hebrew sentences (Pollatsek et al., 1981). Although Hebrew and Arabic are read in the same direction, Arabic is more linguistically complex than Hebrew. Arabic words without diacritics in isolation can have several meanings. Thus, reading in Arabic can be difficult, even

for skilled readers, because of the visually homographic nature of its written form. This homographic phenomenon is uncommon in Hebrew, rendering it easier to read (Abu-Rabia, 1996). Nevertheless, Roman and Pavard (1987) found comparable averages in Arabic reading rates across passages. Mean reading time for four Arabic passages was 268.87 wpm ( $SD = 10.98$ ) in twelve healthy Arabic readers. Their trial passages comprised 95 words per passage over four lines. In another study investigating reading rates in Arabic reading across a total of 150 trial sentences, Paterson and colleagues (2015) found a total average reading time of 249 wpm ( $SD = 69.28$ ) in 12 healthy Arabic readers. Reading rate decreases with the difficulty of the text (more complex semantics and grammar) (Rayner, 1998).

#### 1.6.5 Eye movement fixations and skipping effects

While the majority of words are fixated during reading of English texts, many words are skipped to render foveal processing of each word unnecessary. The difference between skilled and poor English readers is that poor readers consistently exhibit longer average fixation durations during reading (Rayner, 1998; Rayner et al., 2010).

In contrast skilled Arabic readers naturally fixate nearly all words within a text (Ibrahim, Eviatar, & Aharon-Peretz, 2002) and almost every word in each sentence (Paterson et al. 2015). Rayner and colleagues (2010) claimed that more fixations per word in a line of text indicated that the reader used more processing resources to encode the fixated word. This in turn would lead to a lesser supply of resources when processing information for the next fixated word. It could also explain why average reading speeds for Arabic are slower than for Latinate texts. It is proposed that the orthographic and morphological complexity of written Arabic is the most likely explanation for this.

### 1.6.6 Fixation durations

Average fixation durations last about 200 to 250 ms when silently reading English text (Rayner, 1998). In contrast, Roman and Pavard (1987) reported that fixation durations were considerably longer (342 ms) when reading comparable Arabic passages. This is perhaps unsurprising given the differences between the scripts. Arabic is written in cursive form and the majority of words are visually homographic. Hence, skilled Arabic readers may require longer fixation durations for word decoding and identification in a line of text.

### 1.6.7 Saccadic amplitudes

Saccades are rapid eye movements that are frequently made so that the eyes' visual field is placed in the area (written text) where we need to see most clearly (fovea-visual field area of optimum visual acuity). That is, the main function of a saccade is to "bring a new region of text into foveal vision for detailed analysis" (Rayner, 1998, p. 375). It is worth noting that not all saccades are made in text during reading. Saccades are also made during complex tasks such as visual search and scene perception. Saccades take time to plan and execute. Saccade latency, the time taken from the appearance of a target in the visual field to the initiation of an eye movement, usually takes about 175-200 ms. However, saccades vary as a function of the exact nature of the task. Saccade duration, the amount of time taken to move the eyes, is a function of the distance moved. For example, small-field rapid eye movements (2° saccade), typical of reading, takes about 30 ms, while a medium amplitude saccade (5° or larger), typical of visual search, usually takes around 40-50 ms. For this thesis, we are only concerned with a specific form of saccade, which is of small-field rapid eye movements typically executed during reading (Rayner, 2009). The angular distance the eye travels towards either side (left or right) of space during reading is known as saccadic amplitude (Rayner, 1978). Researchers of eye movement in

text-reading studies, agree that the saccadic amplitude for skilled readers of left-to-right orthographies is influenced by inter- and intra-word spaces (Rayner, 1975, 1998, 2009; Hautala, Hyönä & Aro, 2011). That is, the amount of physical space the word occupies (spatial extent), and its adjacent word on either side (left and/or right) determines the size of the amplitude of the saccade. Similarly, the same was found for skilled readers of right-to-left orthographies (Paterson et al., 2015; Hermena, Liversedge, Drieghe, 2017). In an eye movement experiment, Hermena and colleagues (2017) examined typographical features (wide vs. narrow word manipulations) of Arabic during sentence reading to determine the influence of word's spatial extent on saccadic amplitudes. Results showed that skilled Arabic readers made lower amplitude saccades into narrow words, relative to wider words. These findings demonstrated that saccadic amplitudes are influenced by the words' spatial extent, which replicated and expanded upon previous findings in other Latinate languages (Rayner, 2009; Hautala, Hyönä & Aro, 2011). Thus, readers make higher amplitude forward saccades into spaced words (wide, such as English type script), and lower amplitude forward saccades into unspaced words (narrow, such as Arabic cursive script).

In Arabic there are reduced spaces between words compared to Latinate languages (Hermena et al., 2017; Hermena, Drieghe, Hellmuth, & Liversedge, 2015; Alotaibi, 2007), and the cursive script limits visual acuity for words outside foveal vision. In this context the orthographic characteristics of the Arabic language reduces the ability to identify words, and increases effects of visual crowding on the perceptual abilities of skilled Arabic readers. Thus, they tend to make more fixations, longer fixation durations and lower amplitude saccades to compensate for reduced parafoveal information.

## 1.7 Normal Arabic Reading

In conclusion, written Arabic has the second most widely used alphabet in human society, after the Latin alphabet (Haywood & Nahmad, 1965; Almabruk, Paterson, McGowan, & Jordan, 2011). However despite this, research on Arabic reading remains surprisingly limited to date. To address this in my thesis, my first step was to establish normative baseline measures of reading speed and eye movement data from older healthy Arabic readers when reading Arabic single-words and texts. As highlighted in this introduction I also had to consider the influence of the visual characteristics of Arabic text. This was predicted to have not only an effect on reading speed, but also the number and duration of fixations, and amplitudes of saccades. Once I established these norms, I then focused the rest of my thesis on quantifying the eye movement behaviour of Arabic readers with HA. First, when reading static Arabic text. Then subsequently, before and after a novel therapy I developed, to improve their reading speed and increase the efficiency of their eye movement behaviours. Amazingly, there is no research on Arabic readers with HA to date. Consequently in the next section I discuss what predictions can be made about the effect of hemianopia on reading efficiency in Arabic readers with HA based on an integration of the normative data and HA patients reading Latinate languages.

## 1.8 Reading in patients with HA: predictions for Arabic

Hemianopia refers to compromised vision in one half of the visual field, in one or both eyes. HA is an acquired reading disorder related to such impairment, usually caused by stroke or head injury. During reading, the eyes move along a line of text three to four times per second in a series of eye movements called *saccades*. Reading a line of text is usually achieved by planning a series of saccades (the reading scan-path), which allow the eyes to jump from one word to another. Readers make use of peripheral visual information to the right (if reading from left to



right, e.g., in English) or to the left (if reading from right to left, e.g., in Arabic) of words, to plan their reading eye movements (Zihl, 1995; Leff, Spitsyna, & Plant, 2006; Leff & Starrfelt, 2014).

Patients with HA are deprived of this peripheral information and compensate by creating inefficient reading scan-paths with many additional saccades, resulting in accurate but slow reading. Consequently, reading ability is compromised more by right-sided HA in those who read left-to-right, and more by left-sided HA in those who read right-to-left (McDonald, Spitsyna, Shillcock, Wise, & Leff 2006). It can result in severe disability and handicap with most patients abandoning reading for pleasure altogether, and many losing their jobs because they cannot read fast enough.

Difficulties in recognizing words, and understanding the meaning of text, becomes apparent in the reading eye-movement patterns of those with HA. Zihl (1995) examined eye movement behaviour with respect to reading time in patients with either right or left-sided HA pre- and post-therapy (eye movement therapy). The results showed that reading time, and thus reading performance is dependent on the number and duration of fixations, and the number of saccades to the left. That is, the fewer the fixations, the shorter their durations, and the fewer the regressions, the faster the processing of text information (text-reading time).

With respect to the right-sided patients with HA in Zihl's study (1995), they were found to be more impaired than the left-sided patients with HA. Text-reading speed was more impaired than the left-sided patients with HA (RH: 7.3 min ( $SD = 2.1$ ), LH: 4.3 min ( $SD = 0.92$ ); average words per minute (wpm) were 53 and 76, respectively. Their eye movement pattern was characterized with a higher number of saccades to the right, more regressions, reduced saccadic amplitudes to the right, and a higher number and duration of fixations. I predict that my Arabic readers with a left-sided HA will display similar reading performance and eye movement

patterns as those with right-sided HA patients in Zihl's study. A study investigating the perceptual span of bilingual Arabic and English readers, confirmed that direction of reading determined this asymmetry (Jordan et al., 2014). Specifically, the perceptual span showed a rightward asymmetry for English printed text and a leftward asymmetry for Arabic printed text. Thus, the perceptual span is modified by overall reading direction. More importantly, this study highlighted the adverse implications of a region of text becoming obscured. Reading a line of text is usually achieved by planning a series of saccades, which allow the eyes to jump from one word to another (reading scan-path). Arabic readers use peripheral visual information to the left of the word to plan their reading eye movements. Patients with left-sided HA will be deprived of this information and may compensate by creating inefficient reading scan-paths with many additional saccades, resulting in accurate but slow reading.

Jordan and colleagues (2014) displayed Arabic and matched English sentences normally and with text falling within a limited perceptual window around the point of fixation. Reading rates for Arabic, measured in words per minute, were slowest when perceptual span was obscured leftward. Based on these findings, Arabic reading patients with left-sided HA should read more slowly when their vision is compromised on the left. More fixations were made for Arabic displays when the perceptual span was obscured leftward. In addition, Arabic-speaking participants made more regressive saccades when the perceptual span was obscured leftward. This represents a compensatory strategy for or adaptation to the visual field defect. These studies provide clear evidence that when perceptual span is obscured leftward, reading performance is compromised for languages read from right-to-left. Efficient Arabic reading benefits from an asymmetry further to the left, determined primarily by reading direction. Indeed, when this is damaged by a neurological disorder, such as a stroke (causing a hemianopia), not only slower

reading rates but also an increase in the number and durations of fixations, and decreases in saccadic amplitudes (leftward and rightward) should be observed. Reading may be difficult and laborious. The aim of any treatment for these patients is therefore to speed up reading and make it less effortful.

In the next section I discuss six fundamental studies that have influenced one of the main therapy approaches for hemianopia (moving text strategy), which is what the content and delivery of the animated laterally scrolling text (eye movement therapy) in my Arabic-Read Right app is based on.

### 1.9 Eye movement therapy

Evidence-based practice in treating HA comes from studies that retrain reading eye movements in left-to-right readers (German and English). These studies provide the most consistent and reliable evidence for improving visual function in patients with HA. This comprises repetitive practice using stimuli that induces a specific type of eye movement. This movement is called optokinetic nystagmus (OKN) in the reader and, when used as part of a rehabilitation program, has been shown to improve subsequent reading performance of static text. This type of therapy has a clear carry over effect on non-trained text (Leff, 2014). OKN is a physiological type of nystagmus that is also known as railway nystagmus. It occurs when a person is on a moving train (thus the term railway) and is tracking a stationary object that appears to be going by. The eyes slowly track the object and then quickly jerk back to start over. This type of jerk nystagmus can be induced when using laterally scrolling text (moving text) as part of therapy.

An online treatment package for English readers with HA is available and proven to be effective (Read-Right; <http://www.readright.ucl.ac.uk/>) (Ong et al., 2015). This uses laterally scrolling text to induce a form of involuntary eye movement called small field, OKN in the

reader (Zihl, 1995; Kerkhoff, Munsinger, Eberle-Strauss, & Stogerer, 1992; Spitzyna et al., 2007), with an involuntary saccade into the patient's blind field. When used as part of a rehabilitation program, with a dose of 20 hours of practice reading this scrolling text, has been shown to improve subsequent reading performance of static text (Spitzyna et al., 2007; Ong, Brown, Robinson, Plant, Husain, & Leff 2012). As no assessment or treatment resources currently exist for HA in right-to-left readers I adapted these techniques for Arabic within a novel app {Ikra litakun "read to become" اقرأ لتكون} to be used in this study.

A key study using OKN therapy to improve text reading in patients with HA comes from Spitzyna and colleagues. They compared OKN inducing reading therapy (moving text) with a sham therapy that induced non-reading eye movements in 19 English reading patients with right-sided HA (Spitzyna, Wise, McDonald, Plant, Kidd, Crewes, & Leff, 2007). This was the first study to compare OKN inducing reading therapy (moving-text) with a control or sham therapy (spot-the-difference). One group received two blocks of moving text therapy, while the second group received one block of the sham therapy before crossing over to moving text therapy for the second block. Both patient groups reading performance improved following the moving text therapy. There was no effect of the sham. Only the moving text (OKN induced therapy) resulted in improved static text reading speeds and associated eye movement behaviours. This suggested that OKN-type therapy induced involuntary saccades, which may have improved subsequent voluntary reading saccades. That is, post therapy voluntary reading saccades are influenced by the direction of the involuntary saccadic component of the OKN. Spitzyna and colleagues proposed that the brain regions that make both types of saccadic movements overlap to some degree (Spitzyna et al., 2007).

Evidence from lesion and electrical stimulation experiments suggest that cortical and subcortical brain regions involved in generating different types of saccades share interconnected neural networks, and influence one another, especially ones with similar characteristics, such as OKN type and voluntary type saccades. The dynamic properties of the quick phase (speed of motion) of OKN are similar to those of horizontal voluntary saccades (Moschovakis, Scudder & Highstein, 1996; Garbutt, Han, Kumar, Harwood, Harris, Leigh, 2003), suggesting that the OKN type of saccadic eye movement could possibly affect the horizontal voluntary type of saccades.

Training procedure for patients with HA based on moving text started in Munich, Germany in 1992 with Kerkhoff, MünBinger, Eberle-Strauss and Stögerer. A large sample of 56 patients took part (average age 46.8 years). Mean time of stroke onset was 40.2 weeks so all patients were in the chronic phase. Most presented with a right-sided homonymous hemianopia (60%), and the rest presented with either diffuse or bilateral damage (23%) or left-sided homonymous hemianopia (16%). Kerkhoff and colleagues (1992) had noted that healthy participants read moving (scrolling) text faster than static text. This type of text, also called “Times Square” presentation (Kang and Muter, 1989), induces a form of involuntary eye movement called optokinetic nystagmus (OKN) in the reader. Their aim was to use this approach therapeutically as part of a rehabilitation program, to improve subsequent reading performance of static text.

Patients were required to read moving text from right-to-left on a computer screen. That is, from the HA patients’ blind hemifield into their seeing field (Kerkhoff, 1992). Unfortunately the patients’ eye movement behaviours were not examined. Treatment sessions took place for 40 minutes once a day, five days per week. The complexity of the reading materials ranged from single words to short texts. The speed of the moving text was adapted for each patient so that

they could continuously read the text correctly within the screen. During the course of therapy the speed was increased and letter spacing was decreased to encourage the patient to read more quickly. This meant as the patient progressed, the speed and visual complexity of the text increased. Average number of sessions was 14, giving a total average dose of 9.3 therapy hours. All patients improved their reading speed and 20% of the patients ended the therapy within the normal reading speed range (Kerkhoff et al., 1992; Leff, 2014). Importantly, therapy effects remained long after training stopped.

The second study built upon Kerkhoff study (1992) by examining eye movement behaviours pre- and post-training. Eye movement data was quantitatively analyzed with respect to reading time, number and amplitudes of saccadic eye movements, number and duration of fixations, and rates and repetition of saccades and of fixations (Zihl, 1995). The first half of their study involved recording of eye movements while 50 HA patients silently read German texts consisting of 180 words arranged over 20 lines. In left-to-right readers (in this case German), reading performance (speed) is mainly dependent on the number of fixations, the number of saccades to the left, and the duration of fixations. That is, the fewer the fixations, the shorter their durations, and the fewer the regressive eye movements, the faster the processing of text information (reading). Right-sided HA patients (RH group) were more severely reading impaired than left-sided HA patients (LH group). They took longer to read: RH: 7.3 min ( $SD = 2.1$ ), LH: 4.3 min ( $SD = 0.92$ ); and a lower words per minute (wpm) reading rate 53 and 76, respectively. The RH group showed significantly longer fixation durations, a higher number of saccades and higher rate of repetitions of saccades to the right, and smaller amplitudes of saccades to the right. The LH group showed significantly more saccades to the left and used smaller amplitudes of saccades to the left (Zihl, 1995).

The second half of their study involved the effects of the therapy program on a subset of 20 patients (10 left- and 10 right-sided HAs). The method of treatment involved a reorganization of the reading eye movement pattern. Thus, patients with a left-sided HA were forced to shift their gaze to the beginning of every word in a line of text. That is, they were instructed to shift their gaze in the direction opposite to that of left-to-right readers. In contrast, patients with right-sided HA were instructed not to read a word before shifting their gaze to the end of the word. Thus, both groups were intentionally forced to perceive the whole word before reading it (Zihl, 1995). For full details of the method of treatment, see Zihl (1990) and Kerkhoff et al. (1992). The LH group completed 11 training sessions (Range: 8 - 16), whereas the RH group completed 22 sessions (Range: 9 - 29), and each session lasted 40 minutes. After the treatment both groups' reading time improved. The LH group read 113 wpm (SD = 29), and the RH group read 96 wpm (SD = 46). For comparison, their healthy control group's average reading speed for the same materials was 174 wpm (SD = 29). Both patient groups reduced the number and duration of fixations and had an increase in saccadic amplitudes following the intervention. The LH group showed a significant increase in the amplitude of their leftward saccades. The RH group displayed significantly enlarged saccades to the left and to the right. These results were the first demonstration of a clear relationship between eye movement therapy effects in HA and changes in eye movement parameters and reading speed.

The third key study in the treatment of HA came more than a decade later. Spitzyna and colleagues compared moving text therapy with a sham therapy that induced non-reading eye movements in 19 English reading patients with right-sided HA (Spitzyna, Wise, McDonald, Plant, Kidd, Crewes, & Leff, 2007). This was the first study to compare OKN inducing reading therapy (moving-text) with a control or sham therapy (spot-the-difference). The reading therapy

involved moving text (scrolling) presented via VCR tapes, and the patients were instructed to follow it; multiple copies were made when patients required new faster tapes (Spitzyna et al., 2007). Scrolling text was presented across the computer screen from right-to-left. That is, horizontal motion was from the patient's blind field into their seeing field. The sham therapy involved patients spotting as many differences as possible between two pictures. This involved patients making voluntary saccades into their blind field with a non-reading task (Spitzyna et al., 2007). One group received two blocks of moving text therapy, while the second group received one block of the sham therapy before crossing over to moving text therapy for the second block. Patients in the first group accrued a total of fifteen hours of practice with the moving text, while the patients in the second group accrued a total of eight hours of practice with the moving text.

Both patient groups reading performance improved following the moving text therapy. There was no effect of the sham. Only the moving text resulted in improved static text reading speeds and associated eye movement behaviours. Patients read quicker, made fewer fixations per word, and were less likely to make regressions within a word. After 15 hours of moving text therapy the patients' reading improved by 18%, a significant effect. This study was the first in HA patients to illustrate how treatment effects were specific, only an oculomotor task that induced reading related eye movements improved static reading abilities.

The next piece of work in the field (fourth and fifth key studies) was conducted by the same group in Germany to assess the specificity of training effects in HA (Schuett, Heywood, Kentridge, & Zihl, 2008). First, Schuett et al. (2008) varied the content of the therapy but not the type of eye movements generated. Then in their subsequent study (Schuett, Heywood, Kentridge, Dauner, & Zihl, 2012), both the content of the therapy and the type of eye movements generated were varied.



Their first study, investigated whether treatment effects associated with movement therapy critically depend on using “conventional” text material (words) or whether any other non-text material (Arabic digits) would suffice. That is, does the content of the eye movement therapy matter for inducing more efficient reading saccades in HA patients. 40 patients with left- ( $n = 16$ ) or right-sided ( $n = 24$ ) homonymous visual field defects and HA were investigated. Here text training was not based on moving text. Instead, single words of different lengths (Range: 3 – 12 letters long) were presented to patients (group A) in the centre of the screen. Patients were instructed to see the whole word before reading it aloud. Like Zihl (1995), text training consisted of forcing HA patients to shift their gaze in the direction opposite to that of reading. Throughout the training course, the length of the presented words consistently increased from three to thirteen letter words. When the patients reached 90% reading accuracy for a given length, presentation time was reduced from 1000 milliseconds to 300 milliseconds. The final stage of training consisted of the randomized presentation of words of different lengths. The authors claimed that this procedure forced patients to make quicker and more efficient saccades, as well as learned to flexibly adjust the size of the saccades according to word-length (Schuett et al., 2008). The non-text training (Arabic digits) was presented in a similar manner to the other group of patients (group B). This training induced similar saccadic movements. The only difference being it did not involve lexical-semantic linguistic processing.

The main finding was that both text training (words) and non-text training (Arabic digits) had significant therapeutic effects in HA patients. Text-reading speed for both groups significantly increased by 35 % post-training (Schuett et al., 2008). Likewise, both text and non-text training significantly improved eye movement behaviours for both groups. After training patients made significantly fewer fixations and regressions, and showed shorter fixation

durations during reading. Saccadic amplitudes increased, which led to a smaller number of rightward saccades. However, even though rightward reading saccades for both groups decreased, there was greater effect in word group versus the number group (4% difference). Leff (2014) argued that this difference, although small is relevant because “word training is more likely than training on number stimuli to help patients who make multiple fixations within words”, as patients with hemianopic alexia do. Thus, using text training helps not only identify regressive saccades (backward movement in text resulting from refixations, which depends on the reading direction), but also quantitatively measures them pre- and post-training. I further explore this in chapter 5 of this thesis.

The findings from this study are consistent with earlier studies (Kerkhoff et al., 1992, Zihl, 1995, Spitzyna et al., 2007). They confirm that the “key variable in rehabilitation for hemianopic alexia is the amplitude of the therapy saccades” (Leff, 2014, p.61). Yet, I believe that unlike Schuett et al.’s study (2008), using words as training material will be more cognitively rewarding than numbers, and may motivate the patient to continue practicing. Consistent with this view, Ong and colleagues (2012) used laterally scrolling text (from right-to-left) and found that sufficient practice (a total dose of 20 hours) with this specific eye movement therapy (moving text-training) improved patients’ reading eye movements and text reading speed when they returned to normal, static text (Spitzyna, Wise, McDonald, Plant, Crewes, & Leff, 2007).

The fifth key study, and subsequent study from the same German group investigated whether reading and visual search impairments require a specific compensatory training for their improvement or training training-related performance improvements can transfer between these two tasks (reading and visual search) (Schuett et al., 2012). Two treatments were used in a crossover design: reading therapy and visual search therapy. HA patients were randomly

assigned to one of two treatment groups. Group A first received visual search training followed by reading training; Group B did the converse. One training session lasted 45 minutes, and consisted of 10 practice blocks (30 trials each). Reading training was the same as in their previous study (Schuett et al., 2008). Visual search training consisted of “visual search displays extending 50° horizontally and 42° vertically using different target and distractor letters of varying similarity as stimuli” p. 915).

The results showed that training-related improvements in reading and visual search were task specific. That is, completing reading and visual search training led to specific improvements in performance of reading and visual search, respectively. Therapeutic effect sizes (both groups: A and B) were 0.47 for visual search and 0.28 for reading speed. That HA patients only improved reading after completing reading therapy was important in how I designed my treatment experiment. In my app-based therapy effects study (chapter 6), I added performance on a visual search task as a control. Based on Schuett’s data I predicted my moving text therapy should only improve reading, the patient’s performance on this task would remain static.

The final (sixth key paper) and most recent study utilized the Internet as a resource to deliver eye movement therapy. Like Spitzyna et al.’s study (2007), the therapy used was laterally scrolling text; but this time, the therapy was delivered (for free) via the web app: "Read Right": [www.readright.ucl.ac.uk](http://www.readright.ucl.ac.uk). The web application contained two tests: a validated automated visual field test and a standardized reading test (for test details, see Koiava, Ong, Brown, Acheson, Plant, Leff, 2012; Ong et al., 2012). Patients in this study were self-selected (they registered with a valid e-mail to log into the therapy website). Before having access to therapy, patients had to conduct baseline assessments of visual fields and text-reading speed.

Visual field tests were conducted pre- and post-therapy to observe visual field changes over time. There were none. The text reading speed test also conducted pre- and post-therapy was measured by taking an average from reading speeds over three texts. The texts were 49 words in length that spread over seven lines. Each text was followed immediately by a short yes/no comprehension question to encourage patients to read the entire text. After every five hours of therapy completed, HA patients were required to test themselves again on the visual field test and text-reading test (main outcome measure). Reading speeds for each patient ( $n = 33$ ), at each time point (5, 10, 15 and 20-hours) were analyzed to investigate the effects of therapy at all four time-points. The size of the effect increased monotonically, appearing to plateau at 20-hours. Effect sizes reported were: 5-hours (10.4%), 10-hours (19.6%), 15-hours (39.3%), and 20-hours (45.9%) (Ong et al., 2012). The implication is that sufficient practice with this specific therapy improved the patients' reading eye movements.

Importantly, the authors have shown that this therapy can be delivered successfully and effectively to English-reading HA patients via the Internet. Hence, in this thesis I wanted to examine whether an Arabic-Read Right app would produce similar therapy effects, and would also be effectively and successfully delivered to Arabic-reading HA patients via the Internet. When developing my Arabic-Read Right app, I adapted some of the core attributes of Ong and colleagues effective Read Right app for English HA readers (such as the visual field test). However, I needed to develop other components, e.g., the content and delivery of the moving text (the text needed to be Arabic and scroll from left-to-right) and the standardized Arabic reading tests (main outcome measure; see chapter 6 for details).

As there is no research currently available on Arabic readers with HA, a primary goal of my thesis was to determine the reading and eye movement performances of this patient

population. Did they behave as I predicted here based on data from the normative Arabic reading literature and HA patients who read Latinate languages.

To address this, the first part of my thesis focused on normative reading and eye movement behavior in right-to-left Arabic readers. Specifically, I investigated the impact of written Arabic text on reading speed and eye movements during healthy subjects' reading of Arabic single-words and texts (passages). The second part of my thesis centred on Arabic readers with HA. Here I investigated how text reading in Arabic was: a) affected by hemianopia; and, b) responded to moving text therapy compared (based on effect sizes) with the published data as outlined in this section from HA patients reading Latinate languages.

### 1.10 Scope and overall aims of my thesis

In the first part of this thesis, I present a series of experiments (chapters 3 and 4) designed to establish normative speed and eye movement data during single-word and passage reading from Arabic-reading healthy participants. The first study (chapter 3) investigated the effect of increasing word length on Arabic written word reading speed. The second study (chapter 4) investigated age effects on reading speed and eye movement behaviour. The two main techniques I used were single-word reading aloud (accuracy and reaction times) and eye tracking. The technical aspects of these methodologies will be dealt with in detail in the next methods chapter.

The second part of this thesis, presents a series of experiments aimed at investigating text reading and eye movement behaviour in native Arabic readers with HA, both before and after treatment. The first study (chapter 5) examined in detail two face-to-face monolingual Arabic-readers with a homonymous left-sided hemianopia on how single-word and text reading is: a) affected by hemianopia; and, b) responds to moving text therapy using my novel Arabic-Read

Right app (<https://itunes.apple.com/app/id964478309>). The second study (chapter 6) outlines my investigation of the effectiveness of my app on four (two left-sided and two right-sided homonymous hemianopic) Arabic-reading patients to see whether the same therapy effects are achievable remotely i.e., without the face-to-face interaction and support from a speech-language therapist (myself).

As with the normative studies I used eye tracking during text reading, along with behavioural measures (single-word and text reading speeds, visual search, visual neglect, and patient-reported outcome measures), visual hemifield testing and eye movement performance in both chapters 5 and 6. I discuss these measures and their application in detail in the following methods chapter.

More specifically the core aims of my thesis were to:

1. Investigate word-length effects in Arabic single-word reading aloud in Arabic-reading healthy control participants and compare it to Arabic-reading HA patients.
2. Investigate text reading speed (wpm) and eye movement patterns during passage reading from older and younger Arabic readers to establish normative measures.
3. Develop a novel standardized assessment battery of Arabic reading materials that could be used for assessment of eye movements in both healthy Arabic readers and those with alexia patients to consistently and reliably identify HA.
4. Develop an effective, novel, and empirically supported online assessment and treatment package for Arabic readers with HA {Arabic-Read Right: إقرأ لتأكّد: "read to become"}.
5. Investigate reading speed and eye movement data before and after treatment from Arabic reading stroke patients with HA to assess the efficacy of the Arabic-Read-Right App.

Table 1. Single word processing in reading

	Author (s)	Subjects	Optimum Viewing Position	Foveal	Parafoveal	Task	Results
1	Roman & Pavard (1987)	Experiment 1: 12 Arabic and 12 French readers	Not investigated	No	Yes	Short-story reading task	Gaze durations were longer per word when reading Arabic text
2	Farid & Grainger (1996)	Experiment 1 and 2: 28 Arabic-French bilinguals, 35 French monolinguals, respectively	The initial fixation position for Arabic written words is neither to the right nor to the left but depends on the morphological structure of the stimulus word	Yes	Yes	Experiment 1 and 2: Single-word reading task	Affixed Arabic word-level: identification superiority for rightward fixations with suffixed word stimuli, and for leftward fixations with prefixed word stimuli
3	Ibrahim & Eviatar (2009)	37 Trilingual native Arabic readers (Arabic, Hebrew and English)	In the right visual field, performance was better in Arabic than in Hebrew and English, while in the left visual field it was not	No	Yes	Lateralized lexical decision task	Performance was better in the right than the left visual field for the Arabic language (native)
4	Almabruk et al., (2011)	12 Arabic readers	Arabic words in parafoveal locations were recognized more accurately and quickly when displayed to the right of fixation.	Yes	Yes	Reicher-Wheeler task to assess word recognition	Written Arabic words in parafoveal locations were recognized more accurately when displayed to the right of fixation
5	Jordan et al., (2011)	18 Arabic readers	The optimum viewing position for 5-letter Arabic words was superior for fixations in central locations	Yes	Yes	Lexical decision task	Fixation location affected reaction times and error rates
6	Jordan et al., (2014)	12 Arabic readers	<i>Central perceptual span</i> for Arabic was superior when windows extended leftward	Yes	Yes	Gaze-contingent window paradigm	There is a leftward asymmetry in the <i>central perceptual span</i> when Arabic is read
7	Paterson et al., (2015)	12 Arabic readers	Preferred viewing locations: centre for 3-letters, to the right of centre for 7-letters; and between these locations for 5-letter Arabic words	No	Yes	Sentence reading task (target word-level EM)	Fixation location is at centre for short words and further to the right for longer words when reading Arabic words
8	Hermena et al., (2015)	25 Arabic readers	Arabic readers benefit from diacritics presented only on ambiguous verbs (homographs)	No	No	Sentence reading task	Diacritized Arabic words are more likely to be fixated.
9	Hermena et al., (2017)	36 Arabic readers	Preferred viewing location for written Arabic words is word centre	No	Yes	Sentence reading task (target word-level EM)	Spatial extent, not the number of letters determine landing positions; readers made lower amplitude saccades to narrow words

Note: Optimum-viewing position: eye position where reader can obtain useful information during eye fixation; Perceptual span: size of the effective visual field during reading; fovea: corresponds to the central 2 ° of the visual field; parafovea: from the foveal region up to 5° of visual angle from fixation; fixation: maintaining visual gaze on a single location; Fixation duration: length of fixational pauses during reading; Saccade: rapid eye movements between fixational pauses; Regressive saccades: backward movements in text; EM: eye movement; for more information on eye movements in reading see Rayner, 1998; Schotter, Angele, Rayner, 2012.

## Chapter 2: General Methods

### 2.1 Abstract

In this chapter I first explain eye tracking, its brief history, hardware, and its properties. I then discuss my eye tracking laboratory setup, how I measured the movements of the eye using my setup, and finally the quality of the data produced by my eye tracker. In the second part I detail the behavioural measures used in my thesis. They are tests of: reading ability (single-word and text-reading speed), visual reading, visual field, visual neglect, visual search, and patient-reported outcome measures. Then, I discuss the behavioural therapy (reading scrolling text – moving text therapy) used as the rehabilitation program to improve HA patients' reading performance on static text. In the final section I profile the research participants (healthy controls and patients), the patients' eligibility criteria, and statistical analyses I conducted on participants' data (tests and power calculations). Only the methodology used commonly in all my theses' experiments are detailed and justified in this chapter. Where applicable, specific additional methods and statistical analyses I used for each experiment are described in their respective chapters (3, 4, 5, and 6). All the experimental procedures described in this thesis were approved by the Wales Research Ethics Committee 6.



## 2.2 Eye-tracking

Eye tracking is simply the process of measuring eye movement activity. For this thesis, it is the recording of point of gaze (eye position) and eye movement on a screen based on the optical tracking of corneal reflections to test visual movement during reading. Most modern eye trackers, available on the market, use either infrared light source or a video camera to detect movements of the pupil or the cornea. The entire eye tracking data collected for this thesis was recorded using the S2 Mirametrix eye tracker.

### 2.2.1 Brief history of eye trackers

The first eye trackers were built in the late 1800s. They were difficult to build, mostly mechanical, and were very uncomfortable for the participants. For example, to ensure the participants' heads were still, Huey (1898) used a bite-bar with cooled sealing wax attached to the mouth-piece. Another example, Delabarre (1898) used a solution of two to three percent cocaine to anesthetize the eyeball. In fact, the introduction of photographing the reflection of an external light source from the fovea, was only introduced at the beginning of the twentieth century by Dodge and Cline (1901). This was less invasive and in recent years has become the leading technique for recording eye movements.

Throughout the 1950s, individual researchers developed several techniques, the most common of which are the following: lens systems with mirrors (Yarbus & Ditchburn, 1950, 1970), electromagnetic coil systems (measure the electromagnetic induction in a silicon contact lens placed on the anesthetized eye) (Collewijn, 1998), electrooculography systems (measure the electromagnetic variation when dipole of the eye ball musculature moves), and the Dual Purkinje systems from Fourward Technology (expensive, difficult to maintain, with a very small visual field recording, but precise and

accurate without having to place something directly onto the participants eye) (Deubel & Bridgeman, 1995). Indeed for most of the early twentieth century, eye movement researchers were required to build their own devices. Ready-made over-the-counter eye trackers were nonexistent; and therefore, were not a feasible alternative. This significantly slowed down their research. It made eye tracking more exclusive, and often impractical. However, these researchers were more likely to know the properties of the data and what settings are necessary for their experiments. Also, errors were easily diagnosed and maintaining the operating system (hardware) ensured that the quality of the data was not risked.

In the mid-1970s, companies were encouraged by engineers in Applied Science Laboratories to build and sell eye-tracking systems to researchers (Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & Weijer, 2011). This led to eye trackers being more accessible, which allowed new researchers to focus on their academic research and leave the technical methodological issues to the manufacturing company. However, this had its disadvantages. Foremost, it was difficult to interpret (with absolute confidence) the data output from a system, which they did not design. Also, researchers were often not trained in technical skills required to maintain the eye tracking system. Fortunately, for my contemporaries, and me many of the eye trackers manufactured today are easy to use and reliable.

### 2.2.2 Hardware and its properties

The S2 Mirametrix eye tracker (<http://www.mirametrix.com/products/>) (see Figure 1 below) is an accurate eye-tracking tool that is within 0.5 to 1-degree accuracy range. One-degree accuracy corresponds to an average error of 11 mm on a screen at a distance

of 65 cm. It takes less than five minutes to setup, it is flexible, and easily adjusts to different movements of the head and body. Its ease of movement from one clinical setting to another for testing patients made it ideal and practical for my thesis. Importantly, calibration was still possible for patients who found it difficult to fixate properly. The technical specifications for the S2 Mirametrix eye tracker are listed in Table 2 below.



*Figure 1. Mirametrix S2 eye-tracker and tripod. The rectangular device is the eye tracker, and the tripod (3 legs) is the device used to hold the eye tracker in place. The eye tracker is equipped with two cameras located on the right and left corners, and an infrared light located in the middle hidden within the device. The eye tracker was situated under the screen and slightly moved to best fit to the participant's eyes. The S2 Mirametrix eye tracker can view the participant's eye from a distance.*

Table 2. S2 Mirametrix technical specifications

Calibration Time	9 points (< 15 seconds to complete)
Gaze Accuracy	0.5 degrees
Drift	< 0.3 degrees
Data Rate (Sample Rate)	60 Hz
Freedom of Head Movement	25 x 11 x 30 cm (width x height x depth)
Binocular Tracking	Yes
Blink Tracking Recovery	Yes
Eye Tracking Technique	Bright Pupil
Infrared Intensity	< 1 mW/cm <sup>2</sup> ( <i>milliwatts per centimeter squared</i> )
Supports	Eye glasses, head tilting, head shaking, and excessive blinking
Data Server	Software based, source code included
Physical Dimensions	36 cm x 4 cm x 4 cm (width x height x depth)
Weight	0.3 KG

*Note. **Calibration Time** = Time the software configures the eye tracker to provide a result for a sample within an acceptable range; **Gaze Accuracy** = Describes the angular average distance from the actual gaze point to the one measured by the S2 Mirametrix eye tracker; **Drift** = A gradually increasing offset. Offset is the angular distance between the calculated fixation location and the location of the intended fixation target; **Data Rate** = Number of data samples per second expressed in hertz (Hz); **Head Movement Box** = Describes the maximum head movement speed allowed while maintaining robust tracking. The S2 Mirametrix eye tracker allows for head movements of 25 x 11 x 30 cm (width x height x depth) at a distance of 65 cm from the eye tracker. **Binocular Tracking** = Tracks and reports data for both left and right eye; **Blink Tracking Recovery** = Time to tracking recovery for blinks. If the pupil is occluded for only a short period (a few hundred milliseconds), the system will regain tracking immediately when the pupil becomes visible again, but only if the patient maintained approximately the same head position during the blink; **Bright Pupil** = S2 Mirametrix uses bright pupil to determine eye position. Bright pupil eye tracking technique is when an illuminator is placed close to the optical axis of the imaging device, causing the pupil to appear lit up (the same phenomenon that causes red eyes in photos); **Infrared Intensity** = Infrared spectroscopy is the interaction of infrared light with the pupil. The measurement obtained is an infrared spectrum, which is a plot of measured infrared intensity versus wavelength (or frequency) of light. The value for energy intensity is expressed in lower level output power of ultraviolet lamp as mW/cm<sup>2</sup>.*

### 2.3 Eye-tracking laboratory set up

I used quiet testing rooms with no or few windows for recording the eye tracking data. Quiet rooms minimized the risk of distracting the patients' attention from the task. It was also useful to minimize direct and ambient sunlight; that is to have few or no windows, which emits less infrared light (Holmqvist et al., 2011). However, it was important not to make the room too dark, as this makes the pupil large (and variable), affecting data quality for infrared eye trackers, such as the S2 Mirametrix (Mirametrix Inc., 2013). The S2 Mirametrix needed to be placed on a firm table standing on a level floor due to its sensitivity as a measuring instrument.

The S2 Mirametrix eye tracker can view the participant's eye from a distance. The camera and the infrared lights are hidden inside the eye tracker (see Figure 1). The stimuli (paragraphs) were always presented on a monitor, with nothing attached to the head. The S2 Mirametrix allows for head movements of 25 x 11 x 30 cm (width x height x depth) at a distance of 65 cm from the eye tracker. That is, the maximum head movement speed allowed while maintaining robust tracking (Mirametrix Inc., 2013). I placed the tracker under the monitor, without contact to the participant (see Figure 2 A). Knowing the position of the head is the key for sufficient precision and accuracy (see Figure 2 B and C). The S2 Mirametrix is easy to operate, and the participants tend to forget that the eye tracker is present. As such, it allows for the participant to behave more naturally, which should make the data more environmentally valid.

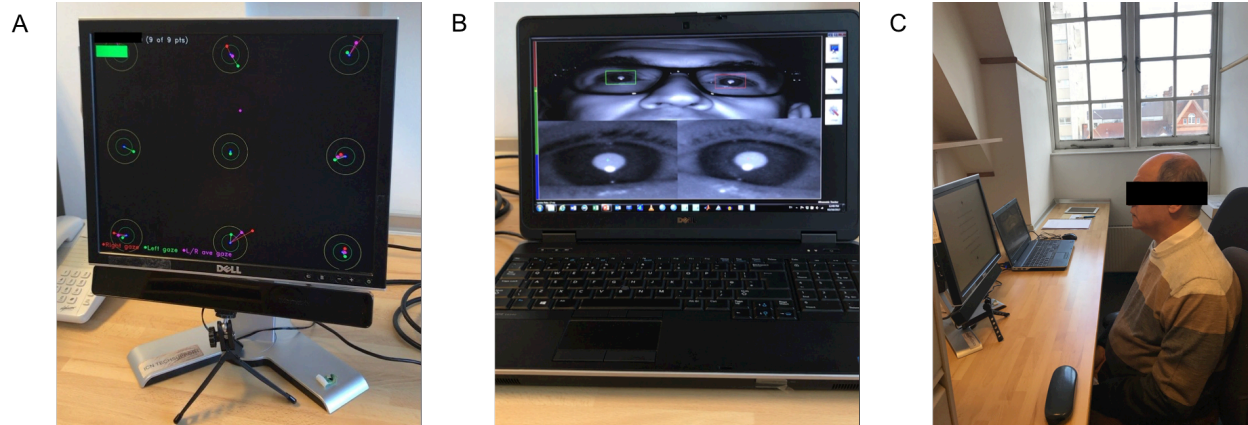


Figure 2. Eye-tracking lab setup. (A) Calibration procedure that is required for accurate eye tracking. Calibration is only required once per patient, or after the eye tracking unit or screen is moved. Calibration involved looking at a sequence of nine points on the screen; green bar on top left indicated that patient's head is in the ideal position. (B) The main window of the S2 tracker showing a real-time image from the camera, with the left and right eye identified. The left eye is outlined with a green rectangle, while the right eye is outlined with a red rectangle. Both eyes have a small cross centred on the pupil, indicating proper operation. The depth estimate bar (left corner) is also shown in the display image, where the green region (the centre) is the ideal head position. (C) The eye tracker was approximately arms-length i.e. 65 cm from the face of the patient.

## 2.4 Application of eye-tracking in reading

### 2.4.1 Measuring the movements of the eye

The human eye lets in light (the image) through the pupil. Then, it turns the image upside down in the lens, where it is projected to the back of the eyeball, the retina. The retina is filled with light-sensitive cells, called cones and rods, which transduces the incoming light into electrical signals sent through the optic nerve to the visual cortex for further processing. Cones are sensitive to visual detail, whereas rods are sensitive to light. Rods support vision under dim conditions (Holmqvist et al., 2011).

Inside the retina, there is a small area (spanning less than 2 degrees of the visual field) called the fovea. This central pit is composed of closely packed cones, which are responsible for having full acuity in this small area. To see sharply a selected object such as a word embedded in text, we need to move our eyes, so that the word image falls directly on the fovea.

Cortical magnification refers to how many neurons in an area of the visual cortex are responsible for processing a stimulus (light) of a given size, as a function of the visual field location (Hubel & Wiesel, 1974). In the fovea, a very large number of neurons process information from a small region of the visual field. If the stimulus is seen in the periphery of the visual field (i.e., away from the centre), it would be processed by a smaller number of neurons. The reduction of the number of neuron per visual field area from the foveal to the peripheral regions is achieved in several steps along the visual pathway, which originates in the retina.

For quantitative purposes, the cortical magnification factor is normally expressed in millimeters of cortical surface per degree of visual angle. The factor increases linearly with eccentricity, from about 0.15 degrees/mm cortical matter at the fovea to 1.5 degrees/mm at an eccentricity of 20 degrees (Hubel & Wiesel, 1974). Consequently, about 25 percent of visual cortex processes the central 2.5 degrees of the visual scene (De Valois & De Valois, 1980).

The S2 Mirametrix eye tracker is a video-based device. The camera focuses on both eyes (left and right) and records eye movement as the participant looks at the stimulus (passage). The S2 Mirametrix uses the centre of the pupil and infrared light to create corneal reflections to avoid all-natural light reflections, and usually illuminate the eyes with one (or more) infrared light source (Holmqvist et al., 2011). The cornea covers the outside of the eyes, and reflects light. The corneal reflection is the brightest. The vector between the centre of the pupil and the corneal reflection can be used to measure the gaze location or direction.

Human eye movements are controlled by the extraocular muscles, which are three pairs of muscles that are responsible for horizontal, vertical, and torsional (roll) eye movements. These muscles control the three-dimensional orientation of the eye inside the head (Holmqvist et al., 2011).

#### 2.4.2 Eye-movement parameters

For my experiments in this thesis, I computed and reported a series of eye movement parameters, which are listed in Table 3 below. Eye movements are usually divided into fixations and saccades, which is when the eye gaze pauses on a certain word, and when the eye moves to another position, respectively. The resulting series of fixations and saccades is called a scan path. Most information from the eye is provided during a fixation, but not during a saccade. Saccades are very fast, typically taking 30 – 80 ms to complete (Holmqvist et al., 2011).

*Table 3. Eye movement parameters measured by the S2 Mirametrix eye tracker*

Type	Definition	Measurement
Reading Speed	Total time needed to read a word or passage	Seconds (s)
Fixation	Total number of pauses, during at least 80 milliseconds, when the eye remains still over a period of time during reading	—
Fixation duration	The sum of all pauses on a word per passage during reading	Seconds (s)
Saccade	Total number of rapid eye movements between fixational pauses during reading	—
Saccadic Amplitude	Angular distance the eye travels towards either side (left or right) of space during reading	Degrees (°)
Regression	Total number of backward movement during reading (depends on reading direction)	—



### 2.4.3 Pupil and corneal reflection eye tracking

The most common method, since the 1990s, for computing the point of gaze from an image of the eye where participant looks at the stimulus, is based on pupil and corneal reflection tracking. A picture of an eye with both pupil and corneal reflection correctly identified can be seen in Figure 2 B. The corneal reflection adds an additional point of reference in the eye image to compensate for smaller head movements. This advantage has made video-based pupil and corneal reflection tracking the leading method in eye movement research, thereby providing a sensitive means of learning about cognitive and visual processing (Holmqvist et al., 2011).

The S2 Mirametrix uses the bright pupil technique to determine eye position. This means that an illuminator is placed close to the optical axis of the imaging device, causing the pupil to appear lit up (the same phenomenon that causes red eyes in photos). This technique was developed to compensate for poor contrast sensitivity in the eye camera by increasing the difference in light emission between pupil and iris (Holmqvist et al., 2011). If the pupil is large, the bright-pupil technique operates optimally, but it may falter for small pupil sizes, especially when there is a lot of ambient light. However, to my advantage, the recording software allows one to see the eye image to ensure that tracking is optimal. Access to the eye image also makes it easier to anticipate and detect potential glitches before and during data collection.

Limitations to bright pupil-corneal reflection techniques are the following: (1) disruption to the computation of pupil centre due to descending eyelid and downward pointing eye lashes (drooping), (2) extreme gaze angles often causes loss of corneal reflection, and (3) measured gaze position may be sensitive to variations in pupil dilation

(Holmqvist et al., 2011). The first limitation may cause incorrectly measured gaze positions and increased imprecision in the data in some parts of the visual field. This can easily be solved by recalibration after the tracker automatically detects the pupil and corneal reflection. The second limitation can be addressed by moving the stimulus monitor or the eye camera, and again a recalibration. A further calibration consisting of 9-points, presented in the stimulus space that are fixated and sampled one at a time, can also solve the third limitation. Each calibration is essentially giving the eye tracker some examples of how points in our tracked visual area correspond to specific pupil and corneal reflection connections (Holmqvist et al., 2011). These calibration features are built into the S2 Mirametrix eye tracker.

## 2.5 Eye tracking data quality

Here I define data quality by the property of the sequence of raw data samples produced by the S2 Mirametrix eye tracker. It results from the combined effects of the specific characteristics of the eye tracker (sampling frequency and precision) and participant-specific characteristics (glasses, mascara, and inconsistencies during calibration). Data quality is related to the speed of the eye tracker used. For my experiments in this thesis, I did not need a high-speed eye tracker. High-speed eye trackers are usually used to produce large high resolution data files. However, they are expensive, restrictive for participants (uncomfortable, fixed head positioning etc.,) and are not suitable for moving (i.e., not suitable to be ported around hospital settings, patients' homes and across countries in my case both here and in Kuwait).

### 2.5.1 Sampling Frequency

Sampling frequency refers to the speed of the eye tracker, and is measured in hertz (Hz). A high sampling frequency is required to accurately capture rapid eye movements, such as saccades (Holmqvist et al., 2011). The smaller the saccades, the higher the required sampling frequency. It is common for static eye-trackers (both infrared light and eye camera on the table, in front of the participant), such as the S2 Mirametrix, to run on 60 Hz (Holmqvist et al., 2011). This means, that for a 60 Hz system, there are 60 samples recorded per second. Even though this is considered a fairly slow system, Enright (1998) suggested that saccadic amplitude could be estimated using a 60 Hz pupil-corneal reflection eye tracker, if the saccades are larger than 10 degrees. However, Wierds, Janssen, and Kingma (2008) argued that a 50 Hz eye tracker could be used to accurately measure saccadic amplitudes if the saccades are at least five degrees. I compensated for the effect of my eye-tracker's relatively low sampling frequency by collecting multiple data samples from each participant. This is because when averaging over many eye movements, errors to a large extent decrease, i.e., the variance in sampling error decreases if the number of recorded data points is large enough (Andersson, Nyström, & Holmqvist, 2010, Holmqvist et al., 2011). As such using the S2 Mirametrix, I could still precisely measure the start and end of a fixations, and saccades. Saccadic amplitudes in my data ranged from two to ten degrees.

### 2.5.2 Accuracy and precision

Accuracy of an eye tracker is defined as the average difference between the true gaze position and the recorded gaze position, while precision is the ability of the eye tracker to reliably reproduce a measurement (Holmqvist et al., 2011). A good eye tracker should

have both high accuracy and high precision. Holmqvist et al., (2011) suggested that precision was vital for measurements of fixations and saccades, but accuracy was not of critical importance. Precision was especially important for my experiments that measured fixations and saccadic amplitudes (chapters 4 and 5). I calculated the precision measurements using the bright pupil technique from data samples recorded when the eye was fixated on a static target (passages). All precision measurements were done at 60 Hz sampling rate and a distance of 65 cm then calculated as root-mean-square (RMS) using angular distance (in degrees of visual angle) between successive data samples (Mirametrix Inc., 2013) (for details see chapter 5).

Factors that influence precision include the eye-tracking hardware and software, participant-specific characteristics, and the recording environment. I discovered in my eye recording experiments, that the exact position, movement, style of sitting of the participant affected precision. Variation in the amount of light that hit the eye also affected precision. This meant I never conducted, fixation and saccade analyses without first reviewing the raw data and removing sections with very poor data. Averaging data from the participant's two eyes helped further improve precision. This was recommended by Holmqvist et al. (2011) in their eye tracking studies that investigated factors influencing precision measurements.

Accuracy is important in all experiments that use area of interest analyses or gaze-contingency paradigms (computer screen display changes online in relation to how eyes move). That is, those studies that require knowing exactly where the participant is looking. These studies require both very high precision and a high accuracy. In my thesis, which focused on eye movements (fixations and saccades) during Arabic text reading,

accuracy was less important than precision for the calculation of stimulus-independent events such as fixations and saccades. This means, that when the eye tracking data was collected and recorded, the stimulus (passage on a monitor) display used was stationary during initial fixation, saccadic movement, and the next fixational pause. In contrast, in gaze-contingency studies, the stimulus (text on a monitor) is typically manipulated during fixations and saccades. The stimulus display has a high level of detail only directly where the participant is looking but the peripheral parts of the stimulus display are reduced in detail. The stimulus display is continuously updated as a function of the participant's current gaze position, such that the display change is completed before visual intake begins at the beginning of the next fixation (Holmqvist et al., 2011). Nevertheless I still tended to recalibrate when the screen indicated that the eye and head were not in the ideal position (see Figure 2 A and B), and continued to do so until the desired level of accuracy was reached.

### 2.5.3 Noise reduction

I aimed to remove all discrepancies in the recorded data that was not derived optimally from true eye movements. This was done offline after all data were recorded, and in preparation for subsequent data analyses. Optic artefacts that were due to erroneously detected pupil or corneal reflection appeared as sudden spikes in the data and were easily identified and removed. Another type of noise that occurred was due to eye tracker imprecision. This was difficult to detect, and that type of data was not filtered so that I did not run the risk of removing authentic eye movements. However, in my experiments with healthy controls, data that were more than two standard deviations away from the mean were excluded from the final analyses.

#### 2.5.4 Robustness

Robustness is defined as how well the eye tracker works for a large variety of participants (Holmqvist et al., 2011). Poor robustness can lead to data loss and poor data quality. S2 Mirametrix worked well with glasses, but not with contact lenses. Participants also varied in their eye physiology, such as eye colour or drooping eyelids. Fortunately, the S2 Mirametrix allowed for varying the angle of the camera to the eye. By adjusted the eye-camera angle, I solved many potential problems here. I also discovered that varying the position of the infrared lights, helped track the eyes of participants who wore glasses.

#### 2.5.5 Tracking range and headboxes

The tracking range otherwise known as the visual field recording is a measure of how far to the side a participant can look without compromising or losing data (Holmqvist et al., 2011). The headbox is the volume relative to the eye tracker, which describes the maximum head movement speed allowed while maintaining robust tracking (Holmqvist et al., 2011). The S2 Mirametrix can measure gaze on a stimulus (passages on a monitor) within a gaze span of 25 x 11 x 30 cm (width x height x depth) at a viewing distance of 65 cm from the eye tracker. The S2 eye tracker works best on 15 -22-inch monitors. If the monitor is larger, the tracker will have difficulty near the edges of the screen. To ensure optimum usage, I used a 17-inch monitor for my studies (Chapters 4 and 5).

#### 2.5.6 Monocular versus binocular eye tracking

Monocular eye trackers record from one eye only, while binocular eye trackers record data from both eyes. The S2 Mirametrix records data from both eyes. This feature was vital for my thesis to collect eye movement data from patients with hemianopia (compromised vision in one half of their visual field, in either one or both eyes). Hence,

for all participants (healthy controls and patients), I recorded both the right and left-eye gaze location every millisecond (1000 Hz). This increased the accuracy and precision of my data.

#### 2.5.7 Data samples and the frames of reference

The data files (.csv) that were generated by my S2 Mirametrix eye tracker-experimental set-up consisted of a sequence of coordinates (x and y) with time-stamps, and the coordinates corresponded to the coordinate system of the stimulus (each of the reading passages shown to my participants, see chapter 4 and 5 experiments). For example, when I show a passage, as in Figure 3, raw data (fixation identification number) with coordinates (x = 630, y = 374) always corresponded to 273 (fixation identification number) in that passage. This association between the coordinates of a raw data sample and a meaningful word made it possible to calculate each participant's total duration on a fixated word, and the total number of times he/she looked at that word. In my example, the word "يستطيع" corresponds to identification number 273 for that particular passage.

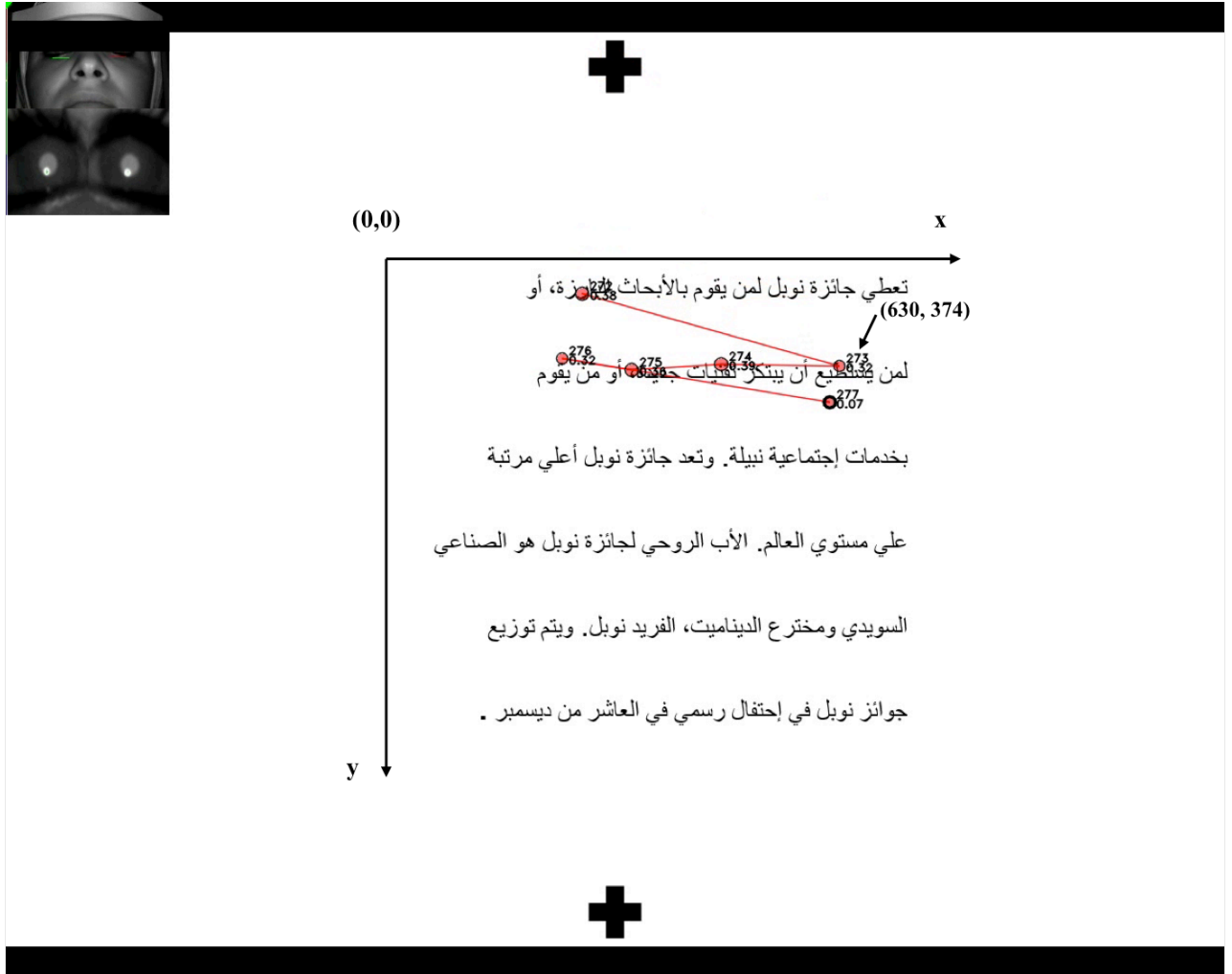


Figure 3. The coordinate system in S2 Miramatrix eye tracker has the origin ( $x = 0$ ,  $y = 0$ ) in the upper left corner. For as long as this passage is shown, the data coordinate ( $x = 630$ ,  $y = 374$ ) will be a point of gaze on a word (273). This method enabled me to have explicit links between the visual coordinates and words in the reading passages. Red dots correspond to fixations; red lines correspond to the participant's reading scan path (saccades), which depends on the reading direction of the language.

## 2.6 Tests of reading ability

### 2.6.1 Single word reading speeds

I measured naming response times and accuracy to visually-presented single Arabic written words of different letter lengths: three, five and seven-letters in both healthy controls (chapter 3) and left-sided HA patients (chapter 5). Participants were instructed to read each word aloud as quickly and accurately as possible. Single-word reading aloud



time was used because previous word recognition researchers, in languages read from left-to-right, have demonstrated that this is a sensitive measure of positive word-length effects on reading speed (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

Alternative methods previously used to examine single-word processing include: word-probability fixations during text reading (Rayner and Pollatsek, 1987; Paterson et al., 2015) and lexical decision times (Behrmann, Shomstein, Black, & Barton, 2001). Each method has its advantages and its problems. For example, investigating eye movements during text reading (sentences and paragraphs) to report on word-length effects may not accurately indicate word processing time independently of context as would single-word reading and lexical-decision time tasks. There are multiple sources of additional information available, such as syntactic, semantic constraints, and parafoveal visual input that may influence reading behaviour. Barton and colleagues (2014) agreed with this and stated that these studies are “vulnerable to top-down contextual effects from neighboring words and the rest of the sentence” (Barton, Hanif, Björnström, & Hills, 2014, p. 385). Thus, there are limits to this approach and how the data can be utilised for models of word recognition. To minimize these effects on reading, I used isolated single-word reading.

#### *2.6.1.1 Reasons behind reading aloud experimentation*

First, reading aloud was used as an overt indicator of how Arabic readers recognized or decoded single Arabic words (see chapter 3 for details). Second, previous research suggests that the time taken to initiate a response (reading aloud) is a sensitive marker for models of isolated word recognition (Grainger & Jacobs, 1996; Seidenberg & McClelland, 1989; Zorzi, Houghton, & Butterworth, 1998). Third, by utilizing this

task I was able to gain for the first time direct evidence of the relationship between word-length, eye movements and reading performance in Arabic-reading patients with HA (see chapter 5). Finally, English reading patients with HA are accurate but slower than healthy controls when reading aloud single words. There is also a word length effect with longer written words (7 letters) taking longer to read aloud compared to shorter words (both 3 letters and 5 letters) (Woodhead, Penny, Barnes, Crewes, Wise, Price, & Leff, 2013). From these data I predicted that Arabic-reading patients with HA would show similar word-length effects. That is, they should be accurate but slower than Arabic-reading healthy control on this task (see chapter 5). If correct this would be a quick, accurate and clinically useful diagnostic test for identifying HA in Arabic reading populations.

#### *2.6.1.2 Response measurement*

To measure reaction times for reading aloud (vocal responses), I devised a single-word reading aloud task and paired it with a voice key to detect voice onset. Participants were instructed to speak loudly into the microphone. Calibration of the microphone was performed at the beginning of each session to check if the voice recorded was acceptable (see chapter 3).

In developing the word lists to be read aloud I controlled across lists for the words' place, manner and voicing of articulation so that the reaction time data would not be confounded by these factors. There is substantial evidence that sounds with different manners of articulation may be realized acoustically at different points in the production process (Pisoni & Tash, 1974). For example, the production of the sound /k/ in "kit" and the sound /s/ in "sit" is not going to be the same. The sound /k/

initially involves complete obstruction of the air flow, during which time there is no acoustic energy to be perceived or measured, and only subsequent to closure release is acoustic energy emitted in the production of such a sound. In contrast, the production of the sound /s/ does not involve a complete obstruction of the air flow and as a consequence acoustic energy is emitted all the time during the production of such fricative sounds. It follows from this that even if the onset of articulation were equivalent for /kit/ and /sit/, energy may be produced and detected earlier by the measuring instrument for the fricative /s/. Even when acoustic energy is arguably present at the same time, voice keys may not detect it with equal effectiveness for all phonemes. In particular, voiced sounds, i.e., those produced with vocal fold vibration like /v/ in “vest” and /z/ in “zest”, will be of higher amplitude and arguably more easily detected by a voice key than their voiceless counterparts /f/ and /s/ for instance.

In my thesis, audio recordings for each stimulus was available for cross-validation. I conducted this manually using Audacity (a free audio software for multi-track recording and editing). I am an experienced speech-language pathologist with many years’ experience transcribing audio recordings.

### 2.6.2 Text reading speed

For the tests of text-reading speed, conducted in chapters 4, 5, and 6, twelve different Arabic passages were devised. All were chosen and modified from either the BBC Arabic current world news (<http://www.bbc.co.uk/arabic>), or the acquired alexia workbook developed by the Jeddah Institute for Speech & Hearing (Naqaweh, 2008). The passages were modified so they were matched in terms of total number of words and lines. Each passage contained 50 words spread over six lines. This was to control eye movement

behaviour rather than differences in linguistic content. They were then checked for spelling and grammar by two Arabic teachers trained in modern written Arabic linguistics. To control for potential order effects each passage was presented in a different randomized order across participants.

#### *2.6.2.1 Reasons behind text-reading speed*

Text-reading speed and eye movement behaviours were the key parameters I chose to assess the effectiveness of my Arabic-Read Right therapy program on patients reading performance. My primary outcome measure was patient's improvement in text-reading speed. A change in average fixations, durations, and saccadic amplitudes were secondary outcome measures. All HA patients entered in the rehabilitation phase of the study were tested silently reading the same twelve Arabic passages as outlined in the previous section at baseline pre-therapy. Eye movements were recorded simultaneously. Then six passages, matched on level of linguistic complexity (3 easier and 3 harder), were presented in pseudo-randomized order after patients completed 5-, 10, 15-, and 20-hours of therapy.

### *2.7 Behavioral measures using the App: Arabic-Read Right*

Although an online assessment and treatment package for HA has been developed in English (Read Right; <http://www.readright.ucl.ac.uk/>), no assessment or treatment resources currently exist for the condition in right-to-left readers. To address this I developed a novel online assessment and treatment package for Arabic readers with HA called: Arabic-Read Right (إقرأ لتأكّد: "read to become"). This app is readily available and free to download on the Apple store (see, <https://itunes.apple.com/app/id964478309>). As such, it is an ongoing live treatment and research tool currently hosted by UCL, and still collecting/ analyzing data.

My app consists of five assessments and a type of therapy in the form of animated scrolling text. As mentioned in the previous introduction chapter, this type of text, also called “Times Square presentation”, induces a form of involuntary eye movement called OKN in the reader. When used as part of therapy, in English reading HA patients it has been shown to improve their subsequent reading performance on static text (Spitzyna et al., 2007).

The app components I developed for Arabic readers will be discussed in detail below:

#### 2.7.1 Visual text-reading test (primary outcome measure)

A timed reading test was developed to evaluate the effects of scrolling text therapy. Test materials consist of six Arabic paragraphs, which contained 50 words, spread over six lines (see previous section for details). Patients initiate a countdown timer and then read the whole of the text, signaling when they have finished with a finger tap on a specific designated area, at which point the timer records their reading speed. Each passage is immediately followed by a short yes/no question. The questions vary and are related to the passages just read. They were added to encourage the patients to read the whole passage. At each point in time (baseline, five, ten, fifteen and twenty-hours of training), the patients read three passages. Their reading times are averaged to produce their reading speed (Ong, Brown, Robinson, Plant, Husain, Leff, 2012). See Figure 4A.

#### 2.7.2 Visual field test

An automated visual field test was adapted for assessing hemianopia in patients with text reading difficulties. I test six points at 1°, 2.5°, 5°, and 10° eccentricity from the fixation cross in both visual fields; four in each along the horizontal meridian, as this is key for text reading. This test has been validated by comparing it with clinical ‘gold standard’,

the Humphrey automated perimeter (both 10-2 and 24-2 protocols), and has sensitivities in the range of 0.8-1° and specificities of 0.75-1° for the affected hemifield along the horizontal meridian (Koiava, Ong, Brown, Acheson, Plant, Leff, 2012; Ong et al., 2012). See Figure 4B.

### 2.7.3 Visual neglect test

To assess visual attention to the left and right side of the patient's visual field, I developed a sensitive test of visual neglect. Using 15 target symbols and 36 distractors, patients are instructed to select all the targets across both the right and the left hemifields. They have 5 minutes to complete the task. Neglect is diagnosed if patients miss twice as many targets on one side compared with the other, or if they have a similar ratio of revisits (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain, Leff, 2015). See Figure 4C.

### 2.7.4 Visual search test (control measure)

Here I developed a reaction time-based, visual search test where patients have to search for an everyday object in a crowded desk scene. After a practice trial, 16 trials are randomly split 50:50 into target left side: target right side trials. Reaction time is taken as time from the cluttered desk to appear to correct finger tap on the item. Incorrect trials are excluded. A mean reaction time is calculated from left and right-sided trials (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain, Leff, 2015). See Figure 4D

### 2.7.5 Patient-reported outcome measures

To assess the impact of HA and the treatment program on patients' Activities of Daily Living (ADLs), I ask the patients to rate their abilities for the following six tasks: hygiene, driving, finding things, reading news, reading books, and enjoying reading on a vertically oriented visual analogue scale. The scale ranges from 0 (impossible to do) to

100 (no problem). Scores are hidden from the patients throughout, including when re-rating their ADLs at each time-point (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain, Leff, 2015). See Figure 4E.

#### 2.7.6 Arabic Moving Text Therapy

Specific eye movement therapy (practicing reading laterally scrolling text) has been shown to increase patients' reading speeds by 40% or more in left-to-right readers with HA (Ong, Brown, Robinson, Plant, Husain & Leff, 2012). Sufficient reading practice with this moving text improves patients' reading performance on normal, static text (Spitzyna, Wise, McDonald, Plant, Crewes, & Leff, 2007). Importantly, Ong and colleagues (2012) have shown that this therapy can be delivered successfully outside of controlled clinical trial conditions via a web app "Read Right": [www.readright.ucl.ac.uk](http://www.readright.ucl.ac.uk).

For this thesis, I adapted this approach for scrolling Arabic text, and tested it on Arabic-reading patients with HA. Like Ong and colleagues, I made my rehabilitation (therapy) material freely available on the Internet (via iPad Application ('app')). This would help determine the efficacy and acceptability of Internet-based reading interventions in Arabic reading HA patients. As the app remains live it continues to collect information about: 1) how much reading improvement patients can make, and 2) how much practice patients may be required to complete in order to significantly improve their reading.

The therapy consists of reading laterally scrolling Arabic text (from left-to-right). To reduce the visual complexity of the moving text, only a single line is presented at a time for reading. Patients can control the speed, colour (background and foreground) of the text. To keep the patients engaged and interested they can also choose the content of

what they read from a library of books, the Quran, and ever-changing really simple syndication (RSS) text newsfeeds from the Aljazeera website. The iOS text size is set at large (default) and dynamic. GeezaPro is the system font on iOS iPad. Patients can pause or stop therapy at any time. As long as the text is moving, a timer measures how much reading therapy is being completed. This information is feed directly to the UCL secure server. I suggest 60 min of therapy a day but patients can choose to do as much or as little as they wish. The app automatically resets to the assessment part of the rehabilitation after every five hours of therapy accrued. Thus, patients themselves determined the time period between testing points, and their own rate of practice /training. There are five testing points: at baseline, and after 5-, 10, 15-, and 20-hours of therapy (Ong et al., 2012). See Figure 4F.



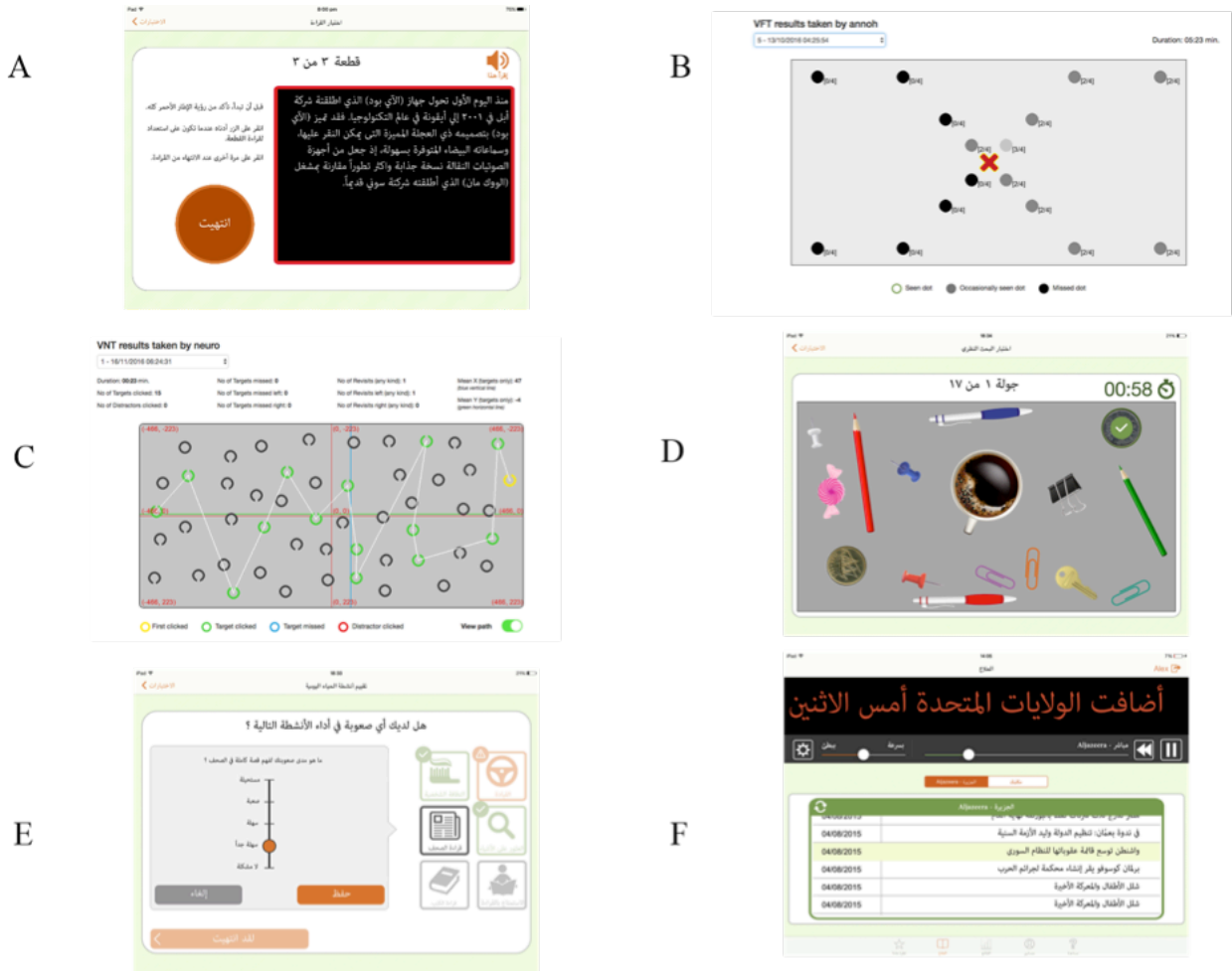


Figure 4. Screen shots from the Arabic-Read Right app showing the five cognitive test and therapy. (A) Text reading test that measures text reading speed for the main outcome measure. (B) Visual field test showing patient 1 with a left-sided homonymous hemianopia. (C) Visual neglect test, from patient 1 showing no neglect. Targets are circles with a gap at the top. Those that were correctly selected are outlined in green; selected distractors would be outlined in red; missed targets would be outlined in blue; and first target selected is outlined in yellow. Numbers within targets are revisits (abnormal). (D) Crowded desk scene for the visual search test. In this case, patient 1 correctly located the 100-fils (Kuwait currency) to the upper right of fixation. (E) Output from patient 1 ADL ratings. (F) Therapy content of laterally scrolling Arabic text (orange) against a black background. Script appears from the left side of the screen and ends at the right end of the screen.

### 2.7.7 How to videos

I developed animated explanatory videos for the Arabic-Read Right app to provide step-by-step instructions to help patients register, login, and complete each of the behavioural tests (as outlined in previous sections). Regarding the therapy section of the app, patients are provided with “how to” videos on navigating the library, choosing the color

(background and foreground), and controlling the speed of the scrolling text. Each video provided is accompanied with an audio description that narrates the instructions in case patients run into difficulty visually following the videos. The narrator spoke in standard modern Arabic, which is what is normally used in formal speech throughout the Arab region (see the supplementary material section to see examples of these explanatory videos).

## 2.8 Participants

### 2.8.1 Healthy participants

Healthy controls that took part in the experiments described in this thesis were recruited from the Cultural Office of the State of Kuwait, UCL subject databases, and social media platforms. Before any procedure took place, participants were given information sheets detailing the experimental procedures and allowed to ask questions. They then provided written informed consent.

### 2.8.2 Patients

Due to the rarity of Arabic reading patients being clinically diagnosed with HA, it was very difficult to find and recruit patients. I managed to get six Arabic reading HA patients to complete the experiments described in this thesis. Four were recruited from the hemianopia clinic at Al Bahar Ophthalmology Centre, Ibn Sina Hospital in Kuwait, one was recruited from the neurorehabilitation unit at the Wellington Hospital (North) in London, UK, and one patient was recruited from the hemianopia clinic at the National Hospital for Neurology and Neurosurgery in London, UK. In chapter 5, data was collected and analysed on two face-to-face patients. By the term “face-to-face”, I mean there was direct contact between the patient and me for all assessment time-points and

during HA moving text therapy. In chapter 6, the HA treatment was “app-based” only. There was only one encounter between the patient and me, which was during the first session. In this session, participants were given information sheets detailing the experimental procedures and allowed to ask questions. When needed, they were also provided with assistance regarding how to download and navigate the app. All patients provided written informed consent, which was collected during the first session.

#### *2.8.2.1 Inclusion criteria*

In the experiments reported in this thesis all participants were required to: (1) have had acquired brain damage due to a stroke or tumor, (> 6 months post-deficit) (2) demonstrate a fixed visual field homonymous (hemianopic visual field loss on the same side of both eyes) deficit as defined by missing one or more stimuli on the automated visual field test developed for the application, (3) have a baseline text reading speed of more than 40 words per minute, and (4) have been skilled Arabic readers premorbidly.

#### *2.8.2.2 Exclusion Criteria*

Patients were excluded if they presented with: (1) impaired speech production, speech comprehension or writing (to rule out those with central alexia and aphasia); (2) a premorbid history of neurological or psychiatric illness; and/or (3) a baseline text reading speed of less than 40 words per minute (to exclude patients with pure alexia) will be excluded from the study.

Pure alexia is a selective reading disorder commonly caused by a stroke (infarct or haemorrhage) in the posterior structure of the dominant hemisphere. It is selective because patients with pure alexia cannot read but their other language functions, such

as speech production, comprehension and writing are intact. Patients can recognize and name individual letters. As a result, the patient often engages in letter-by-letter reading since they cannot recognize words as a whole and must assemble them from their parts. Typically, these patients read slowly, and have significantly slower than normal reading times. Reading researchers use the presence of a word-length effect as part of the diagnostic criterion for Pure Alexia (Leff et al, 2001).

## 2.9 Statistical analyses of healthy participants and two HA patients eye-tracking data

Analyses of the eye-tracking data focused on investigating the text reading behaviour of HA patients compared to healthy age-matched controls. It was predicted that HA patients would due to their hemianopia fixate to the right of the preferred viewing location for words of five and seven letter lengths. Fixating to the right of the normal preferred viewing location results in less of the fixated word being processed by the language system. Ensuing fixations are likely to fall in the same region, a concept known as refixation. Refixation rate has been reported to be the main factor slowing reading time in Latinate reading HA patients. When reading passages patients are able to extract some useful visual information from text to aid in the planning of reading scan-paths but this remains slow and effortful (McDonald and Shillcock, 2005).

In this thesis the main analyses conducted are between-group statistical analyses to compare the HA patients' reading scan-paths to those generated by age-matched normal older controls reading the same Arabic passages. I compare eye movement behaviours (reading speeds, number and duration of fixations, and saccadic amplitudes) between the two groups when reading these passages. Twelve randomized passages were created. Each passage contained 50 words spread over six lines. A significance level of  $p < 0.05$  is used throughout for all reported results.

## 2.10 Statistical analysis on app-based patients

Baseline demographic and clinical information were tabulated to describe the patients in the study. Means and standard deviations were used for continuous variables and frequency counts and percentages were used for categorical variables.

For the main comparison of reading scores between individuals with HA pre and post treatment, two main analyses were conducted. First, a one-way, repeated-measures Analysis of Variance (ANOVA) was carried out in order to test the hypothesis that using the rehabilitation materials improves (static) text-reading speed. Time spent practicing the material is the independent variable. Reading speeds (the dependent variable) was entered from each time point for which the participant provides data. Subjects were entered as random factors consistent with the previous studies (Ong et al., 2012). Second, in order to investigate whether rehabilitation has a ‘dose’-related effect on reading, the relationship between percentage improvements in reading speed and amount of time spent accessing the rehabilitation materials was analysed. Linear regression analysis was employed; each subject represented a single data point. A significance level of  $p < 0.05$  is used throughout for all reported results.

In conclusion, the standard methods used in this thesis were eye tracking to measure text-reading speed and eye movement behaviours, and reading aloud to measure naming response times and accuracy to visually-presented single Arabic written words of different letter lengths: three, five and seven-letters on healthy participants and HA patients. I also developed a novel online assessment and treatment package (an app) for Arabic readers with HA called Arabic-Read Right. The app is designed to assess the following behavioural measures: reading ability (text-reading speed), visual fields, visual neglect, visual search, and patient-reported outcome measures. The therapy part of the app uses laterally scrolling text (from left-to-right) as a means

to induce therapeutic, small-field, optokinetic nystagmus. In English readers, this method (using right-to-left scrolling text) has been shown to improve reading of static text after 7 hours of practice (Zihl, 1990).

## Chapter 3: The word length effect in Arabic readers

### 3.1 Abstract

330 million people worldwide are native Semitic language speakers, Arabic being the most widely used (300 million). Reading research to date is dominated by the use of Latinate languages where word length has a dominant influence on how long readers take to read single words. Surprisingly little is known about the impact of word length on reading speed in Semitic languages where the orthographies have significantly different visual and morphological writing systems. In this study, I investigated the effect of increasing word length on naming accuracy and response times for single Arabic written words of three differing lengths: three, five and seven letters. Twenty-eight fluent native Arabic readers took part, with ages ranging from 42 to 77 years ( $M = 63$ ,  $SD = 1.56$ ). I found significantly longer response times for three letter words than five and seven letter words. Compared to data from Latinate languages, this is a “reversed” effect of word length on response time. In Latinate languages readers are fastest at reading 3 letter words. Post-hoc analyses of the data revealed a significant correlation between naming speed and word morphological density, with three letters words being the most dense. These results provide the first evidence that in Arabic, morphological family size (type frequency) influences how long adult readers take to read aloud single words of differing lengths. I discuss the implications of these findings in terms of our understanding of normal Arabic reading mechanisms.

## 3.2 Introduction

Writing systems represent spoken language in different ways. While the Arabic written language is the second most widely used alphabet after Latin (Haywood, 1965), research on Arabic reading still remains limited. Specifically, the finding that lexical access through visual processing of a single written word correlates with the number of its letters has been examined extensively in Latinate languages but less so in Semitic languages.

Both Semitic languages, Arabic and Hebrew are read from right-to-left, are alphabetic and their morphology is based on the consonantal root system. In 2005, using eye tracking methodology, Lavidor found Hebrew readers displayed similar patterns of reading fixations as English readers when reading single words. She found a word length effect when reading words presented briefly to the right but not to the left of fixation. Like English, longer words were read more slowly than shorter words. However, there are a number of important differences between the two written Semitic languages that may impact differentially on reading speed. First, Arabic is written in joined script (cursive) in which spaces rarely exist between letters in words. Hebrew letters cannot be joined. Second, unlike the Arabic orthography, in Hebrew the graphemes do not vary in shape according to their position in a word (Shatil, Share, & Levin, 1999). A minor error can lead to a mistake in decoding through confusion of letters similar in shape (Abu-Rabia, 1998). Third, Arabic is a diglossic language, Hebrew is not. Written Arabic is not the spoken Arabic language of day-to-day conversation. Written Arabic is only acquired through formal schooling.

A particular consideration for this present study is that in Latinate literature, word length has a major influence on how long readers take to read single words. Specifically, for words only fixated once, the length of this fixation is longer for longer words (Rayner, Sereno, & Raney,



1996). In Arabic, two studies have shown that there is a word-length effect consistent with the Latinate literature. Both investigated lexical access and eye-movement behaviours (eye fixations and gaze durations) for target words embedded in Arabic sentences. Firstly, Paterson and colleagues (2015) investigated effects of word-length on reading eye-movements by varying the number of letters of target words in the middle of a written sentence. They found that total gaze durations were longer for seven-letter target words than five and three-letter words. Total average reading time for target seven letter words ( $M = 610$  ms,  $SE = 47$ ) was higher than five ( $M = 519$  ms  $SE = 35$ ), and three-letter ( $M = 445$  ms,  $SE = 32$ ) words. That is, longer words within a text took more time to process and were fixated for longer. In the second study, Hermena and colleagues (2017) investigated the influence of the number of letters of a target word, also embedded centrally within a sentence and the spatial extent of the target word on eye movement control. They found that fixation duration is mainly influenced by the number of letters a word encompasses. They also found that Arabic readers made longer fixations for seven relative to five-letter words regardless of the word's spatial extent.

However, during text reading, there are multiple sources of additional information available, such as syntactic, semantic constraints, and parafoveal visual input that may influence reading behaviour. Surprisingly there is no research on naming response times and accuracy of single Arabic written words of different lengths to date. Thus, there are limits to this approach and how the data can be utilised for models of isolated word recognition. To minimise these effects on reading, researchers primarily utilise one of two task design strategies: lexical decision or naming (single word reading aloud). Indeed these two tasks have been the driving force in isolated word recognition research and the benchmark in developing computational models of lexical processing in Latinate languages (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001;

Grainger & Jacobs, 1996; Seidenberg & McClelland, 1989; Zorzi, Houghton, & Butterworth, 1998).

Using these methods to understand why lexical access through visual processing of a single word correlates with the number of its letters, some authors have argued word frequency is a key factor. For example, Cattell (1886) showed that English readers read three letter words aloud faster than single letters. The subjects (labelled as 'B' and 'C') took significantly longer to read aloud a long word (M: 10 letters) than a short word (M: 5 letters) (B: long 441 ms, short 389 ms, difference 52 ms, C: long 451 ms, short 405 ms, difference 46 ms). Further, the results showed that B and C were significantly faster at reading aloud short words than single letters (B: short 389 ms, letters 430 ms difference 41ms, C: short 405 ms, letters 461 ms, difference 56 ms). This is perhaps not surprising, since English readers are constantly reading and using words more than isolated letters (Cattell, 1886). Therefore, there is a word-length effect in English readers but it is pretty shallow because arguably English readers, through mass practice and frequency effects, read via a whole-word method. Consistent with this interpretation Weeks (1997) found word-length effects in naming latency for low frequency words and non-words but not for high frequency words. That is, naming latencies for less practiced (low frequency) or novel (non-) words were positively correlated with word length i.e. the longer the word was, the slower it was read aloud. The size of the word length effect was 11.3 ms/letter ( $SE = 3.8$ ) (Weekes, 1997).

An alternative explanation is that word neighbourhood density predicts isolated word reading performance. In both English and Dutch written languages, Frauenfelder, Baayan, Hellwig, and Schreuder (1993) found a strong relationship between word length and word neighbourhood size. In both these languages shorter written words tended to have more word

neighbours because there are a smaller number of orthographically permissible letter combinations. While longer words tended to have no or few neighbours. Orthographic neighbourhood size (Coltheart, Davelaar, Jonasson, & Besner, 1977) known as *Coltheart's N*, is defined as the number of different words created by changing a single letter of a word while maintaining letter position. Word-neighbourhood size has consistently been reported to modulate reading performance on both single word naming and lexical decisions tasks (Coltheart et al., 1977; Andrews, 1989). According to search/verification models of word recognition (Paap & Johansen, 1994), words with a large neighbourhood size will be the slowest identified i.e., reading performance will be inhibited due to increased lexical competition. However, as highlighted in the comprehensive review of the word reading literature of Latinate languages by Andrews (1997), naming latencies have been found to be facilitated by word neighbourhood size in single word studies with both more and higher frequency neighbours i.e., faster when reading words with high activation of neighbours (Andrews, 1989, Experiment 3; Andrews, 1992, Experiment 2; Sears et al., 1995, Experiment 2).

It is surprising that there have been no studies to date investigating single Arabic word reading skills. Therefore my study aimed to investigate in single written Arabic words firstly, the influence of word length on oral naming times and accuracy and secondly, the interaction between word length and orthographic neighbourhoods. As in Latinate languages, longer Arabic words have fewer neighbours than shorter words. Indeed three letter Arabic words are consonantal roots, which serve as lexical entities that can facilitate lexical access to a large cluster of words that are derived from them. That is, it stands for a lexical field from which actual words are created. If orthographic neighbourhood size is a key variable and the search/verification models of word recognition is correct for word reading, then longer Arabic

words should be read faster than shorter words because each additional grapheme reduces the number of orthographic competitors resulting in faster recognition and therefore faster reading speed. This information would not only be important for our understanding of Arabic reading processes per se but would also allow us to establish for the first time normative single-word aloud reading data, against which reading data from Arabic-speaking patients with hemianopic alexia (HA) can be compared. HA is of interest because it demonstrates how reading can be affected in patients with intact word recognition but “disruption of the visuomotor coordination of eye-movements during text reading” (Leff, Crewes, Plant, Scott, Kennard, & Wise, 2001, p. 511).

### 3. 3 Method

#### Participants

28 fluent native Arabic readers (18 females) took part in the study. Ages ranged from 42 to 77 years ( $M = 63$ ,  $SD = 1.56$ ). All were right-handed with good vision with or without correction and no reported history of neurological, psychiatric or language disorders. Arabic was their primary language, as determined by the Arabic version of the *Language Experience and Proficiency Questionnaire (LEAP-Q)* (Marian, Blumenfeld, & Kaushanskaya, 2007). Seven out of the 28 were bilingual, English being their second language. Bilingual participants were asked to fill out a questionnaire on their preferred language in terms of their exposure to its written and spoken form, age of acquisition, years spent in each language environment, and their level of proficiency. Based on their self-reported answers, these seven participants had greater Arabic to English language proficiency. Ethical approval for this study was granted by the Wales Research Ethics Committee 6.

## Stimuli

I measured naming response times and accuracy to visually presented single Arabic written words of different letter lengths: three, five and seven-letters. Words ( $n = 105$ ) were selected from the Aralex database (Boudelaa & Marslen-Wilson, 2010) with equal numbers ( $n = 35$ ) per letter length list and matched across lists for word frequency (average = 28 counts/million). Unfortunately information such as imageability and concreteness are not available in the Aralex lexical database. However frequency information is. Therefore, for this thesis, the Aralex lexical database was used to control for frequency effects. Single Arabic words were selected on the basis of precise frequency counts based on roots and word stems of the Arabic language, which underlies the distinct structural linguistic properties of the Arabic language Morphological family neighbourhood size ( $N$ ) varied across the three word groups (Westbury, Hollis, & Shaoul, 2007; Attia, Pecina, Toral, Tounsi, & Van Genabith, 2011).

I presented the Arabic words unmarked (without diacritics) consistent with normal Arabic text. Diacritics (vowels) are inserted so that ambiguous words can be interpreted while learning to read and are usually excluded from Arabic texts read by skilled readers (Frost, Forster, Deutsch, 1997; Boudelaa, Marslen-Wilson, 2015). While they provide unambiguous information that enhances word recognition and pronunciation, skilled adult readers are expected to read words and text without it almost exclusively (Abu-Rabia, 1998). Furthermore, in a study on the role of diacritics in facilitating lexical access in Arabic, it was expected that readers would benefit from diacritics disambiguating Arabic homographs and provide greater pronunciation accuracy; however, that was not the case. Ibrahim (2013) found that diacritics actually slowed total reading time and decreased accuracy when adults read three, four and five-letter words. Similarly, Yael, Tami and Tali (2015) found that typical Hebrew adult readers did not benefit

from the additional phonological information provided by diacritics. The presence of diacritics slowed single-word reading performance for normal adult Hebrew readers.

## Study Design

### Methods

The stimuli were presented using E-Prime software version 2.0 (Zuccolotto, Roush, Eschman & Schneider, 2012). Each word was displayed on a 15.6-inch Dell laptop as black text on a grey background approximately 65 cm away from the subject. The target words were presented centrally on the screen in Arabic typesetting font, size 85. The visual angle corresponded to approximately 5 degrees. Participants were instructed to read each word aloud as quickly and accurately as possible. A voice-key was used to detect voice onset latency (reaction time) and would terminate the trial. If no response was made, the target word disappeared after 3000 ms. All verbal responses were recorded. Practice trials of six items were administered before testing to allow the participants to become familiar with speaking clearly into the microphone. Each of the 105 target words was presented in a different randomized order across participants. The experimental session lasted approximately 10 minutes in total per participant.

### Analyses

To calculate accuracy, word trials read correctly scored 1, and errors or omitted words were scored 0. Reaction time analyses were conducted on correct responses only using the voice onset key data and cross validated by an expert speech-language pathologist (SAR) using the audio recordings in Audacity (<http://www.audacityteam.org/>). Homographs were removed consequently, total target

words were 96, with 31, 33, and 32 target words in each 3, 5, and 7-letter word list respectively.

Mean response times for three, five and seven-letter Arabic words were calculated using descriptive statistics in IBM SPSS version 22. Spoken word response times more than two standard deviations away from the mean were excluded (7.1% of the data). Trials affected by malfunction of the voice-key (e.g., omitting to detect valid responses) were also excluded from the analysis (1.9% of the data). ANOVAs of reaction time data determined that the target word's phoneme onset (voicing, place, and manner) was controlled and matched across all three word lists: voicing ( $F(1, 93) = .04, p = 0.85$ ), place of articulation ( $F(10, 84) = 1.33, p = 0.23$ ) and manner ( $F(5, 89) = 1.70, p = 0.14$ ) respectively.

Morphological density (orthographic neighbourhood counts) was calculated using LINGUA (Language-Independent Neighbourhood Generator of the University of Alberta <http://www.psych.ualberta.ca/~westburylab/>). Input corpus was generated from the open-source large-scale finite-state morphological processing toolkit (AraComLex) for Modern Standard Arabic distributed under GPLv3 of 1,089,111,204 words (Westbury, Hollis, & Shaoul, 2007; Attia et al., 2011). The morphological transducer is available from <http://sourceforge.net/projects/aracomlex/>.

One-way repeated measures analysis of variance (ANOVA) was used to test the data for the main factor “word length” with three levels (3, 5, and 7-letter words). To determine what additional factors might be driving any word length effects, separate two-way repeated measures ANOVAs were carried out using two between-subject factors: age, and multilingualism. Lastly, I performed another within-subject analysis with

morphological neighbourhood size (N) as an additional explanatory variable. A Pearson product-moment correlation coefficient was computed to assess the relationship between reaction times and any significant explanatory variables. The significance threshold for all reported results was set at  $p = 0.05$ .

## 3.4 Results

### Effect of Word length

Word length significantly affected reaction times ( $F(1, 27) = 4.77, p < 0.05$ ). Subjects were slower to read three-letter words than both five and seven-letter words (see Figure 5). Post-hoc paired-sample t-tests demonstrated that this effect was driven by three-letter words being read more slowly than both the five-letter ( $t(27) = 2.66, p < .05$ ) and seven-letter words ( $t(27) = 2.18, p < .05$ ). There was no significant difference in reading speeds between five and seven-letter words, ( $t(27) = 0.05, p = 0.96$ ).

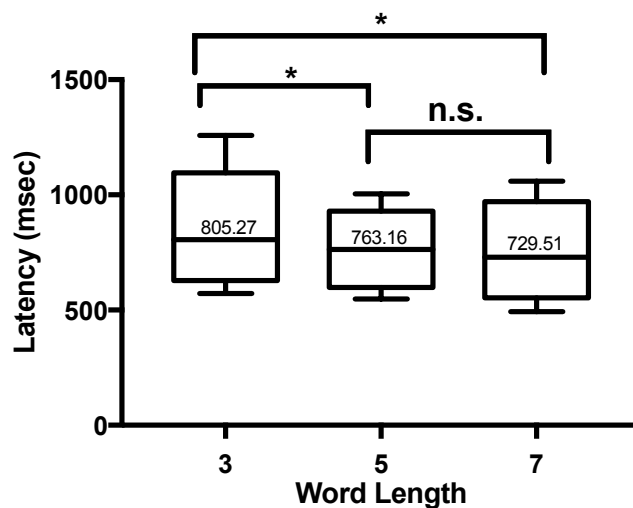


Figure 5. Word reading test oral reading latencies for 3, 5, 7 letter words in milliseconds ( $\pm 2sd.$ ) ( $N=28$  adult readers). Upper and lower error bars represent 95th and 5th percentile response latencies respectively. Upper and lower quartiles represent 75th and 25th percentile response latencies respectively. Middle quartile represents the median (average) of response latencies for each word length. Asterisks represent significant differences between word lengths at  $p < 0.05$ .



## Effect of linguistic parameters

There was a main effect of morphological neighbourhood size across the corpus ( $F(2, 93) = 71.90, p < .001$ ). Tukey post-hoc test demonstrated that shorter words ( $M = 50.65, SD = 11.83$ ) had a significantly larger ( $p < 0.05$ ) morphological neighbourhood size than both five- ( $M = 26.67, SD = 14.27$ ) and seven-letter ( $M = 16.47, SD = 7.62$ ) Arabic words. There was a strong positive correlation between response times and morphological neighbourhood size,  $r(96) = .34, p < 0.001$ . See Figure 6 below.

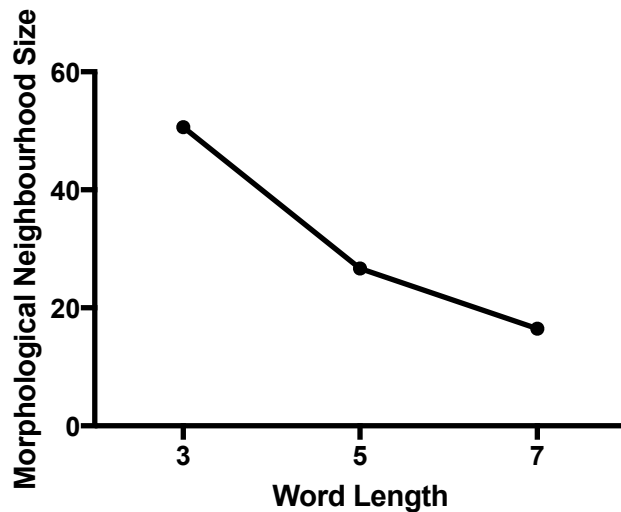


Figure 6. Relationship between mean morphological neighbourhood density and word length. Each data point represents total average of orthographic neighbourhood size for each word length. Averages for three-letter words ( $N = 31$ ) were 50.65; five-letter words ( $N = 33$ ) 26.67; and seven-letter words ( $N = 32$ ) 16.47 respectively.

## Between-subject factors

### a. Age

I performed a median split analysis to look at age effects on reading speed. There was no significant difference in response times between older ( $n=14, M = 795.33, SD = 40.53$ ) and younger participants ( $n=14, M = 747.56, SD = 40.53$ ). A two-way, repeated-measures

ANOVA showed no significant effect of age when reading Arabic words of different lengths ( $F(1, 26) = 0.70, p = 0.41$ ).

### *b. Bilingualism*

There was no significant difference in response times between monolingual ( $n = 21, M = 763.61, SD = 33.39$ ) and bilingual ( $n = 7, M = 794.93, SD = 57.83$ ) participants. A two-way repeated-measures ANOVA showed no significant effect on the knowledge and usage of one or two languages when reading aloud words of different lengths ( $F(1, 26) = 0.22, p = 0.64$ ).

## 3.5 Discussion

In this study I investigated the effect of increasing word length on Arabic written word reading speed. As predicted, the results illustrated that word length significantly affected reaction times. In direct contrast to the literature based on English readers, in Arabic shorter words were read significantly slower than longer words. This effect was not attributable to either age of the subjects or bilingualism. Analysis of linguistic parameters of the Arabic written words revealed that shorter words (three-letters) had a significantly larger morphological neighbourhood size than longer words (both five and seven-letter). There was a strong positive correlation between naming response times and morphological neighbourhood size across the whole corpus.

### Effect of word length

In English, reading latencies are positively correlated with word length i.e., the longer the word is the slower it is read aloud. This was confirmed by a study that examined the differential effects of number of letters on word and non-word naming latency. Weekes (1997) examined the effect of word length (three, four, five, and six) and item type (high-frequency words, low-frequency words, and non-words) on word reading latency and error rates. Results showed that

for low frequency words ( $M = 11.3$  ms/letter,  $SE = 3.8$ ) and non-words ( $M = 19.6$  ms/letter,  $SE = 6.4$ ), reading latencies became longer as the number of letters increased, but there was no effect of word length on response latencies for high-frequency words.

An alternative approach by Damian, Bowers, Stadthagen-Gonzalez, and Spalek (2010), examined whether the word length effect existed in word naming and/or picture naming. Results showed that a length effect emerged only in word reading but not in picture naming. The authors separated the words into two stimuli sets (monosyllabic and disyllabic). They found reading latencies were shorter for monosyllabic (three to five-letters) words than disyllabic (five to eight-letters) words with an average of 14 ms effect of syllable length when letter length was controlled for, thereby suggesting that phonologic factors may be playing a role in the task.

However, a better reading comparative language for Arabic may be Hebrew. Both require readers to read right-to-left and their orthographies share similar visual and morphological writing systems. Indeed a recent study that examined effects of diacritics and vowelization on word recognition between Hebrew typical readers and dyslexics (Yael, Tami & Tali, 2015) found in unmarked Hebrew words (1) the presence of an additional letter decreased reading response latencies and that (2) longer words were read faster than shorter words. My naming results in unmarked (without diacritics) written Arabic words are consistent with their second result.

That my data are not consistent with the oculomotor studies done on Arabic reading text where Paterson et al. (2015) found that longer words were slower to process is perhaps no surprise due to the significant differences in experimental techniques used. Their findings were based on examining word-length effects through eye-movement behaviour (fixation duration)

during sentence reading. Top-down contextual effects from neighbouring words and the rest of the sentence may have influenced their results.

Irrespective, my results may be explained by the *dual-route hypothesis* of reading aloud. Coltheart, Rastle, Perry, Langdon, and Ziegler (2001) state that Latinate written languages strongly follow sound-to-letter rules with some exceptions; this means that concatenated languages contain more consistent sound-to-letter *sub-lexical* mapping. This suggests a serial left-to-right letter processing of reading in Latinate orthographies and explains why it takes longer to read German words of increasing length (Ziegler, Perry, Jacobs, Braun, 2001). However, in non-concatenated languages such as Arabic, and Hebrew, a blend of visual/orthographic and phonological processing is required for reading. In this model of reading, a skilled reader can visually recognize whole words through the orthographic input lexicon, containing the memory of written and learned words. The words then move into a phonological output lexicon, containing the representations of spoken words and pronunciation. With this blended route, readers of Arabic can efficiently distinguish between similar words and can also locate already learnt words in their mental lexicon. The faster reading speed for longer Arabic words in my study suggests that the orthographic properties of longer words were more easily recognized than shorter words. Thus, Arabic words with more letters would be more easily recognized due to their reduced similarity in their orthographic representations.

Furthermore it can be argued that short words in Arabic are more information sparse than European words, and therefore this is why they take longer time to process. Short words in Arabic (and Hebrew) are composed mostly of three consonants, which are called roots. These roots are abstract structures and only when combined with word patterns (either a sequence of vowels or a sequence consisting of both vowels and consonants) form specific words. Although

these roots carry some meaning and syntactic information, their meaning is often obscure and changes for each root-word pattern combination (Berman, 1978; Frost, Forster, & Deutsch, 1997; Boudelaa & Marslen-Wilson, 2015). That is, there are no rules for combining roots and word pattern to generate specific word meanings.

### Effect of linguistic parameters

As previously mentioned, orthographic neighbourhood size (Coltheart, Davelaar, Jonasson, & Besner, 1977) known as Coltheart's N, is defined as the number of different words created by changing a single letter of a word while maintaining letter position. In both English and Dutch written languages, Frauenfelder, Baayan, Hellwig, and Schreuder (1993) found a strong relationship between word length and word neighbourhood size. In both these languages shorter written words tended to have more word neighbours because there are a smaller number of orthographically permissible letter combinations. While longer words tended to have no or few neighbours.

In contrast, Arabic morphology follows a different logic with the lexical space organized in a different manner than that of Latinate languages. It consists primarily of consonant roots (three/four letters), which intertwine with patterns of vowels and affixes to form words, or word stems (Ryding, 2005; Abu-Rabia 1997). By adding different vowels and affixes into different slots of Arabic consonant roots, different word patterns are formed. For example, in Latinate languages, apart from the initial and final phoneme that define the boundary of a word, all letters contained in a word are created equal for generating an orthographic code (Velan & Frost, 2011). In Arabic, the lexical space is fixed according to the consonant root morpheme. Thus, all words that contain the same root are clustered together, and the perceptual distance (or the interconnections) between two words containing different roots is uncorrelated with their overall

orthographic similarity (Velan & Frost, 2011). For example, the Arabic words /skn/ (to live) and /rkn/ (to lean on) would be considered “orthographic neighbours” in English lexical space, since they share all of their letters but one. However, in Arabic lexical space, they would not. In fact, they would be considered not related but far apart because they are two different consonant root morphemes.

In Arabic, although root words carry some meaning and syntactic information, their meaning is often obscure and changes for each root-word pattern combination (Berman, 1978; Frost, Forster, & Deutsch, 1997; Boudelaa & Marslen-Wilson, 2015). The root (three/four letter word stem) contains the lexical meaning and general word reference. It serves as a lexical entity that can facilitate lexical access to a large cluster of words (many neighbours) that are derived from it and represents a large semantic field from which further (longer) words are created. Thus, as in Latinate languages, longer Arabic words have fewer neighbours than shorter words. Analysis of my data found a significant main effect of morphological density on word length with a strong negative correlation between naming speed and morphological neighbourhood size. Consequently, Arabic readers must rely on linguistic factors for efficient word reading. Linguistic analysis of my data found a significant main effect of morphological density on word length with a strong negative correlation between naming speed and morphological neighbourhood size. These results provide the first evidence that when reading Arabic single words, morphological family size influences how long adult readers take to read aloud single words. An explanation for this effect may be that competition among co-activated lexical candidates of the target word slows down reading responses for those words with many neighbours (McClelland & Rumelhart, 1981).

Consistent with this interpretation, Yael and colleagues (Yael Tami & Tali, 2015) suggest the presence of an additional letter decreased their Hebrew readers' word response latencies. Here, the authors argued additional letters restricted the number of potential similar words in a reader's lexicon, which in turn reduced lexical competition and the amount of morphological decoding needed for word recognition. Hence word-reading performance was faster for longer words.

However, in masked-priming research in both Hebrew and Arabic, results showed that morphologically related words facilitate each other rather than compete with each other. Frost et al. (1997) found that when the prime was a Hebrew root word, lexical retrieval was speeded for the target stimuli. However, naming was not facilitated when the prime was a Hebrew word pattern. This is because many words are related, or linked to one source root word. Thus, all or most words that are obtained from a specific root would be lexically linked to it. This is because roots represent mainly a family of words that share a phonological pattern (i.e., three consonantal skeleton) and features of meaning (Frost et al., 1997; Boudelaa & Marslen-Wilson, 2015).

My hypothesis is therefore that Arabic short words (three-letters) may have been harder to read as indexed by slower reading reaction times compared to seven letter words because they were read in isolation (out of sentential context). Without contextual information these short words are more information sparse (lexically ambiguous) i.e., they represent families of words in the Arabic language with dense morphological neighbours not unique individual words. As such, slower lexical access likely accounts for why readers took longer to read these short words in isolation in my study but when primed by a sentential context in other studies were read faster.

Taken together my data illustrates how reading single Arabic words of different lengths resulted in a reversed word length effect as reported in Latinate languages. Reading speed was

correlated with a linguistic factor- word neighbourhood density size, with increasing density size slowing naming speed. Consequently, my results illustrate that reading data from Latinate languages are not easily transferrable to Semitic languages. Further studies are necessary to understand the cognitive processes and eye movement behaviour during reading of Arabic and other Semitic languages. Based on these findings, I predict that single-word reading of Semitic orthographies, when compared to Latinate orthographies will result in longer fixations and slower reading speeds.



## Chapter 4: Age effects on reading eye movements in Arabic readers

### 4.1 Abstract

Little is known about the effect of ageing on speed and eye movements during reading of non-Latin script. To address this, I compared text-reading speed and eye movement behaviours in two differently aged groups of adult Arabic readers (young:  $M = 35$ , range = 28 – 41; older:  $M = 60.28$ , range = 44 - 75). As a group my older readers read more slowly, and made more and longer fixations than the younger ones. This pattern of reading slowing with increasing age is consistent with typical findings in older readers of English (Kemper, Crow, & Kemtes, 2004; Rayner et al., 2006, 2009; Paterson et al., 2013, McGowan et al., 2014; Jordan, McGowan & Paterson, 2014). In terms of reading eye movement behaviour, my older Arabic readers made lower amplitude progressive saccades than the younger ones. This pattern is different from the findings on saccadic eye movements of older English readers where researchers have found that older readers make higher amplitude saccades than the younger readers. This is because older English readers make longer fixation durations and, make more regressive saccades per sentence (Rayner et al., 2006, 2009; Paterson et al., 2013, McGowan et al., 2014; Jordan, McGowan & Paterson, 2014). Arabic in contrast to English is deemed more challenging to read both in terms of the increased visual processing demands of the cursive Arabic script and its orthographically complex linguistic structure. This resulted in a more cautious reading strategy characterized by lower amplitude progressive saccades, and longer fixations, which was found in my older Arabic readers. In my older Arabic readers it is possible that they adopted this different reading strategy to facilitate word identification and compensate for their reduced visual acuity (less efficient processing of parafoveal information). Within these readers I examined whether age independently exerts a strong influence on reading speed and eye movement control or whether other factors equally play an important role on how long readers read, fixate and easily scan their sentences.

## 4.2 Introduction

A great deal has been learned about the effect of ageing on text-reading speed and on eye movement behaviour during reading in Latinate languages, specifically in English (Rayner, 1978; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Rayner, Castelhana & Yang, 2009; Rayner, Castelhana, & Yang, 2010; Paterson, McGowan & Jordan, 2013; McGowan, White, Jordan & Paterson, 2014; Jordan, McGowan & Paterson, 2014). However, remarkably little is known about the effect of ageing on speed and eye movements during reading of non-Latinate scripts, such as Arabic. In English older adults read more slowly, make more and longer fixations, and make larger saccades than younger readers (Kemper, Crow, & Kemtes, 2004; Rayner et al., 2006, 2009; Paterson et al., 2013, McGowan et al., 2014; Jordan, McGowan & Paterson, 2014). Given that there is a natural progressive decline in sensitivity for visual detail due to optic changes and changes in neural transmission as adults reach older age (for a review, see Owsley, 2011), Arabic readers are also predicted to have slower reading speeds with increasing age. In this study I aimed to investigate the patterns of eye movements in older compared to younger Arabic readers and if any differences between the two groups were consistent with those found in older English readers.

Written Arabic differs fundamentally from English on 5 key factors: 1) Arabic is read from right to left. 2) Arabic is only written in joined script (cursive) in which spaces rarely exist between letters in words. 3) Arabic letters in many cases have extremely similar basic forms and use dots to mark distinctions between them. 4) Diacritics (vowels) may be inserted so that readers can interpret ambiguous words. However, these are usually excluded from texts read by skilled adult readers. 5) Arabic written words in text lack spatial segregation, which may

decrease their visual detail and introduce effects of visual crowding that, may impede word identification.

Increasing the amount of visual information in the same space is referred to as *visual crowding*, in which interference of adjacent visual materials (e.g., marks (dots) and short vowels) within a word slows the identification of that word (Slattery & Rayner, 2013). In Arabic script some letters are written with one, two, or three dots (marks) above or below one letter, and when joined with other letters to create a word could increase visual crowding resulting from the presence of these distinctive marks needed for letter recognition. Likewise, the addition of diacritics (short vowels) in written Arabic text also creates visual crowding and increases visual complexity owing to the additional information (diacritics). Further, Arabic words are only written in joint script (cursive), which means that written Arabic words in text lack spatial segregation. This may ‘decrease their distinctiveness and introduce effects of visual crowding that impede word identification’ (Jordan et al., 2015, para. 6). All of these unique features attributed to the Arabic orthography, may interfere with word identification, which may result in slower text-reading speed identified by an increase in the number and duration of fixations, and a decrease in saccadic amplitudes in skilled older Arabic readers.

Of particular interest for this study, is the role of font on reading speed. Rayner et al. (2006) investigated whether font difficulty interacted with age when readers read sentences containing target words that varied in frequency and predictability in an eye movement experiment. Half of the sentences appeared in Times New Roman font, whereas, the other half of the sentences appeared in Old English font (see Figure 7). All readers found the Old English font was more difficult to read as indexed by longer reading times, longer fixation durations, more fixations, and lower saccades. Furthermore, the main slowing effect of Old English font was

significantly greater in older readers. I anticipate similar results in Arabic readers. Arabic text is written cursively, and like Old English font this may make the words in sentences more difficult to decode, especially for the older Arabic readers. Figure 7 shows examples of these different font types.

A The man drives the car.

B الرَّجُلُ يَقودُ السَّيَّارَةَ

C الرجل يقود السيارة

*Figure 7. Example sentences printed in Arabic-type and Old English fonts. (A) Example sentence in Old English font. (B) Example translated Arabic sentence with diacritics (short vowels). (C) Example translated Arabic sentence with diacritics removed.*

Building on this work McGowan et al. (2014) investigated the impact of the space between words in text on reading speed. They found that removing or replacing inter-word spaces slowed reading times for both younger and older English readers. This disruption was greater for older readers when the stimuli had no spaces between words or when the spaces were replaced with open squares between words in a given sentence. The open squares consisted of fine detail and features (horizontal and vertical lines) that are also found in letters. The authors claimed that the slowing effect was due to an increased sensitivity to visual crowding and to a decreased sensitivity to visual detail. Thus, older English readers were more cautious when reading so that they would make fewer mistakes resulting in slower reading performance. As shown in Figure 7

the visual influences of letter groupings in cursive Arabic text may further affect oculomotor processing when identifying upcoming words. In older Arabic readers the prediction is that this would result in more cautious reading and slower reading speed compared to younger Arabic readers.

How and when the eyes move during the process of reading is also important for reading efficiency, as indexed by speed. The eyes move along a line of text in a series of saccadic movements (reading scan-path) separated by brief fixational pauses, during which visual information is acquired from the page. It is well known that the *perceptual span*, the area at each fixational pause from which readers obtain useful information during reading, extends three to four letters to the left of fixation and to about 14 to 15 letters to the right of fixation for skilled English readers (Rayner, 1998; Rayner, Slattery, & Belanger, 2010). For skilled Arabic readers the converse pattern is true. Their perceptual span extends three to four letters to the right of fixation and to about 14 to 15 letters to the left of fixation (Pollatsek, Bolozky, Well, & Rayner, 1981; Jordan et al., 2014).

Rayner et al. (2009) examined in English readers whether the perceptual span size is affected by age. Using a moving window paradigm they were able to control for how much information a reader can process on each fixation (for a review, see McConkie & Rayner, 1975). Results showed that a perceptual span to the right of fixation was smaller for older readers than younger readers. That is, older readers showed no difference between two-word condition (the fixated word and the word to the right of fixation) and three-word condition (the fixated word plus the two words to the right of fixation). The younger readers in contrast showed no difference between three-word condition (the fixated word plus the two words to the right of fixation) and no-window control condition (when the sentence was presented normally), and

there was a slight increase in reading time for the two-word condition (the fixated word and the word to the right of fixation) compared with the no-window control condition. The same older readers took significantly longer (mean = 3.87 ms) to read sentences than their younger counterparts (mean = 2.66 ms). Based on these data the authors proposed that a slower reading speed in older English readers could be explained by their inability to obtain useful word or letter information beyond the word to the right of fixation.

Interestingly, they also found that their older English readers had a smaller and less asymmetric perceptual span than younger readers. That is, reading was most effective (faster) for older readers when the word to the left of fixation was available on a fixation. Given that older English readers do not process text information to the right of fixation as affectively as younger English readers, I suspect that older Arabic readers will also differ from younger readers in the amount of preview information they obtain from the word to the left of fixation (Arabic read from right-to-left). Like the older English readers, my older Arabic readers will similarly present with slower text-reading speed, and make more and longer fixations than the younger readers.

The present study expands upon these findings by examining age effects on speed and eye movements during reading of Arabic text. The purpose of this study is (1) to determine whether eye movement characteristics of older Arabic readers are the same or different from those of younger Arabic readers, and (2) whether changes in eye movements characteristic of ageing in English readers are the same or different in Arabic readers. Additionally, I wanted to examine whether age independently exerts a strong influence on reading speed and eye movement control or other factors equally play an important role on how long readers read, fixate and efficiently scan written text.

## 4.3 Method

### Participants

37 healthy fluent Arabic reading adults were recruited from the Cultural Office of the State of Kuwait (London, UK), UCL subject database, and social media platforms. 25 female and 12 male participants volunteered for the study. Two participants (one male, one female) were excluded due to slow reading speeds. The participants were divided into two groups: 17 younger adults ( $M = 35$ ,  $SD = 4.21$  years, range = 28 – 41 years) and 18 older adults ( $M = 60.28$ ,  $SD = 8.16$  years, range = 44 – 75 years). All but two were right-handed, and had adequate vision with or without correction. The two groups had similar educational backgrounds (younger adults,  $M = 18.47$ ,  $SD = 0.66$  years of education, range = 16 - 22; older adults,  $M = 16.50$ ,  $SD = 0.78$  years of education, range = 12 - 27 years;  $t(16) = 1.89$ ,  $p = 0.08$ ). Participant's education level is explained in Table 4. All participants used Arabic as their primary language, as determined by the Arabic version of the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007). Nine were bilingual, English being their second language. Bilingual participants were asked to fill out a questionnaire on their preferred language in terms of their exposure to its written and spoken form, age of acquisition, years spent in each language environment, and their level of proficiency. All nine participants reported greater Arabic to English language proficiency.

Ethical approval for this study was granted by the Wales Research Ethics Committee 6.

Table 4. Participant's education level key

Education Level	Number of Participants
1	2
2	4
3	15
4	4
5	7
6	3

*Note\* 1= HS (High School Diploma): Secondary degree; 2= AD (Associate's degree: 2 yrs. post-secondary degree; 3 = BD (Bachelor's degree): 4 yrs. post-secondary; 4 = M (Master's degree: 1 year post bachelor's degree; 5 = PHD (Doctor of Philosophy): 3 yrs. post bachelor's degree, and Master's degree; 6 = MD (Medical degree): 5 yrs. for degree, 2 yrs. for post graduate, 3-8 yrs. in specialist training e.g., neurology, emergency medicine, etc.*

## Stimuli

12 passages of Arabic text were selected and modified from the BBC Arabic current world news (<http://www.bbc.co.uk/arabic>), and from the acquired alexia workbook developed by the Jeddah Institute for Speech & Hearing (Naqaweh, 2008). To control for eye movement behaviours the passages were matched for total number of words and lines so that each contained 50 words spread over six lines. Before administering them to the participants, the 12 passages were checked for spelling and grammar by two Arabic teachers trained in modern written Arabic linguistics. Each passage was then presented in a different randomized order for each participant.

## Apparatus

### Eye Tracker

An S2 Mirametrix eye tracker (<http://www.mirametrix.com/products/>) recorded both the right and left-eye gaze location every millisecond. Each passage was displayed on a 17-inch Dell monitor as black text on a white background. The eye tracker was centred beneath the screen and as close to the lower edge of the screen as possible. The eye tracker was approximately arms-



length i.e. 65 cm from the face of the participant. A portable chin-head rest was used to prevent any head movement during the reading sessions. Prior to reading the eye tracker was calibrated once per participant and after the eye tracking unit or screen was moved. It was also checked between reading trials and the tracker recalibrated as necessary. Calibration involved looking at a sequence of nine points on the screen.

## Study Design

At the start of each reading trial, a fixation cross was presented at the top centre of the screen. Once this was fixated, participants were instructed to read the entire passage silently and at a normal pace. The passage was presented at the middle centre of the screen. Participants were then instructed to fixate a second cross that was presented at the bottom centre of the screen indicating that they finished reading the passage. This process was repeated for 12 passage trials. Each passage was presented in a different randomized order across participants. To check participants were reading accurately the passages, they were asked questions (requiring yes/no responses) about six of the passages' meaning. The experimental session lasted approximately 15-20 minutes in total.

Eye movement data collected per passage were: text-reading speed (calculated in seconds), number of fixations (the total number of these fixational pauses), average fixation durations (the average length of fixational pauses during reading in seconds), and average saccadic amplitudes (angular distance the eye travels during a movement in degrees). A saccade is defined as rapid eye movements between fixational pauses.

Text-reading speed data and eye movements were post-processed via the S2 Miramatrix Eye tracker software showing timestamps in seconds and coordinates of each fixation. This was used for the subsequent data analysis. A fixation was identified, at least five consecutive data

points, at sampling rate of 60 Hz, which is about 83 milliseconds (Mirametrix Inc., 2013). The following parameters were used to indicate eye movement components: mean size of saccades (absolute value combining X and Y coordinates); number of fixations; and mean fixation duration. Total passage reading time was determined by calculating the timestamp of each gaze point (fixation) from the first word in the first line until the last word in the sixth line of each passage (in seconds). Saccades made to proceed to the beginning of the next line in both languages (return sweeps) were discarded from the data. Then, each parameter of interest was calculated via a script developed using Matlab R 2014a (Mathworks, Natick, MA, USA) software.

### Reading speed analyses

Text-reading speed was analysed using descriptive statistics in IBM SPSS version 24 for windows. Reading speed data for each participant on all twelve passages was converting into z-scores. Scores that were more than two standard deviations away from the mean were excluded. Two participants' scores were considered as outliers and therefore removed from the analyses (5.4 % of the data). The two participants' text-reading speeds across all twelve passages were too slow and were more than two standard deviations away from the total mean reading speed. The total number of reading trials analysed were 420 passages from 35 participants.

### Between-subject effects on text-reading speed analyses

First the data were split into two age groups, identified by performing a median split analysis using SPSS v24, older adults (n=18, younger adults (n=17). Then, a series of one-way analyses of covariance (ANCOVAs) conducted in SPSS v24 was used to look in turn at the effects of age, education level, bilingualism, and gender on text-reading speed. Significance was set at  $p = 0.05$  for all reported results.

#### A. Age

Here the ANCOVA tested for age effects (two levels: young and old) on text-reading speed controlling for education level, bilingualism, and gender.

#### B. Education Level

Here the ANCOVA looked at education level effects (three levels: 1, 2, and 3) on text-reading speed controlling for age, bilingualism, and gender. Level one included secondary degree up to two years post-secondary. Level two included four to five years post-secondary. Level three included more than seven years post-secondary. Secondary school (4 years) typically follows primary school and leads into a vocational or tertiary education. In the Arab region, students are between the ages of 14-18 years.

#### C. Bilingualism

This ANCOVA looked at bilingualism effects (two levels: monolingual and bilingual) on text-reading speed controlling for age, education level, and gender.

#### D. Gender

This ANCOVA assessed gender effects (two level: female and male) on text-reading speed controlling for age, education level, and bilingualism.

### Between-subject effects on text-reading speed sub-analyses

To determine which of these independent variables: age, education level, bilingualism, and gender significantly affected reading speed; I next calculated a multiple linear regression. A Pearson product-moment correlation coefficient was also computed to assess the relationship between reading speed and any significant explanatory variables. Then I conducted a multicollinearity test to see if the explanatory variables met the assumption of collinearity.

## Mechanisms underlying text-reading speed analyses

A series of one-way between-groups analyses of variance (ANOVAs) was conducted using SPSS v24 to compare age effects (two fixed factors: young, old) on (A) number of fixations, (B) average fixation durations and (C) average saccadic amplitudes. Homogeneity of variance between groups was verified using Levene's test. Importantly, this confirmed there was no difference in variance between the young and old groups, meaning the distribution of reading behaviour was similar across all participants. Significance was set at  $p = 0.05$  for all reported results.

## 4.4 Results

Comprehension accuracy was high for all adults. There was no difference between age groups ( $t(17) = 0.291, p = 0.78$ ); younger adults ( $M = 94.22\%$   $SD = 2.67$ ), older adults ( $M = 94.50\%$ ,  $SD = 2.26$ ).

### Text-Reading Speed

The average total reading time for all passages ( $n=35$  participants) was 14.88 seconds ( $SD = 4.01$ ). The lowest and highest total reading rates for a passage were 6.94 and 22.94 seconds respectively. Mean total text-reading speed for each passage for all 35 participants are presented in Table 5. The participants read 12 passages consistently. Figure 8 illustrates consistency across the passages with the absence of any outliers. Average total reading time calculated in words per minute (wpm) was 201.61 wpm ( $SD = 16.25$ ).

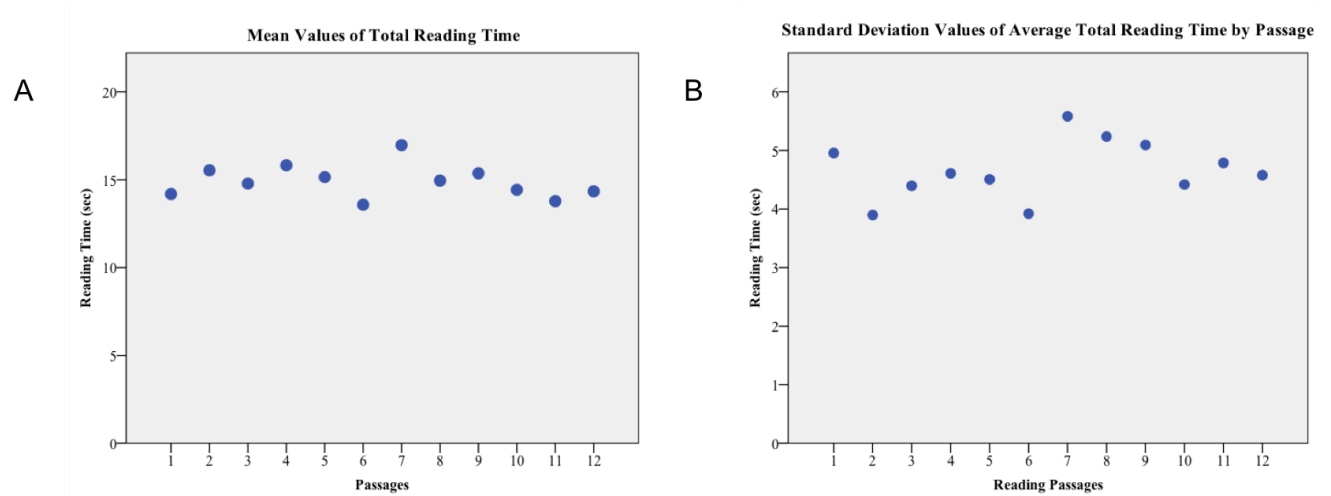


Figure 8. (A) Mean total reading speed across all passages for all 35 participants. (B) Indication of how far the values deviate from the mean total reading time across all passages for all 35 participants.

Table 5. Average total reading speed by passage

Reading Passage	Number of Participants	Range	Minimum	Maximum	Total Reading Time (sec)	
					Mean	Std. Deviation
1	35	22.80	6.55	29.36	14.19	4.96
2	35	14.73	7.63	22.36	15.54	3.90
3	35	18.34	6.69	25.03	14.78	4.40
4	35	18.83	8.02	26.85	15.82	4.61
5	35	17.25	7.26	24.51	15.15	4.51
6	35	17.20	6.23	23.42	13.58	3.92
7	35	25.94	7.58	33.51	16.97	5.58
8	35	19.49	6.95	26.44	14.95	5.24
9	35	20.49	7.27	27.76	15.37	5.09
10	35	17.73	6.46	24.18	14.43	4.42
11	35	21.42	6.31	27.73	13.78	4.79
12	35	21.32	5.90	27.22	14.34	4.58

Note\* Reading passage: Passage number ( $n = 12$ ); Range: The difference between the fastest (maximum) and slowest (minimum) text-reading speeds read per passage; Minimum: The fastest text-reading speed read per passage; Maximum: The slowest text-reading speed read per passage.

## Between-subjects effects on text-reading speed

### A. Age

There was a significant effect of age on reading speed after controlling for education level, bilingualism, and gender, ( $F(1, 30) = 8.55, p < 0.01$ ); older adults ( $M = 16.78, SE = 0.84$ ), younger adults ( $M = 12.86, SE = 0.87$ ) (see Figure 9). There was a significant positive correlation between age and reading speed,  $r(35) = 0.55, p < 0.001$  with 30% of the variance in reading speed accounted for by age (see Figure 10).

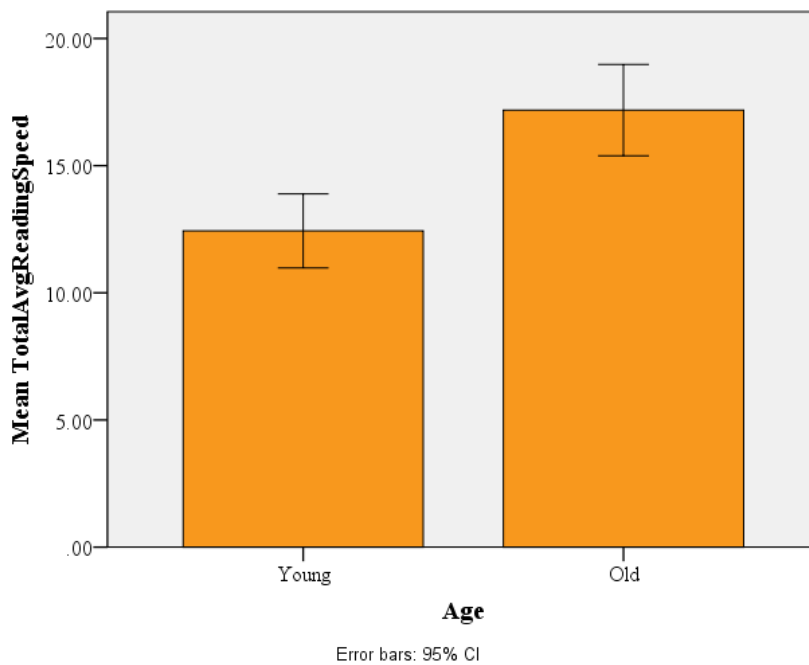


Figure 9. Mean total text-reading speed for all 12 passages for the younger ( $n=18$ ) and older ( $n=17$ ) groups. Error bars represent two standard errors of the mean.

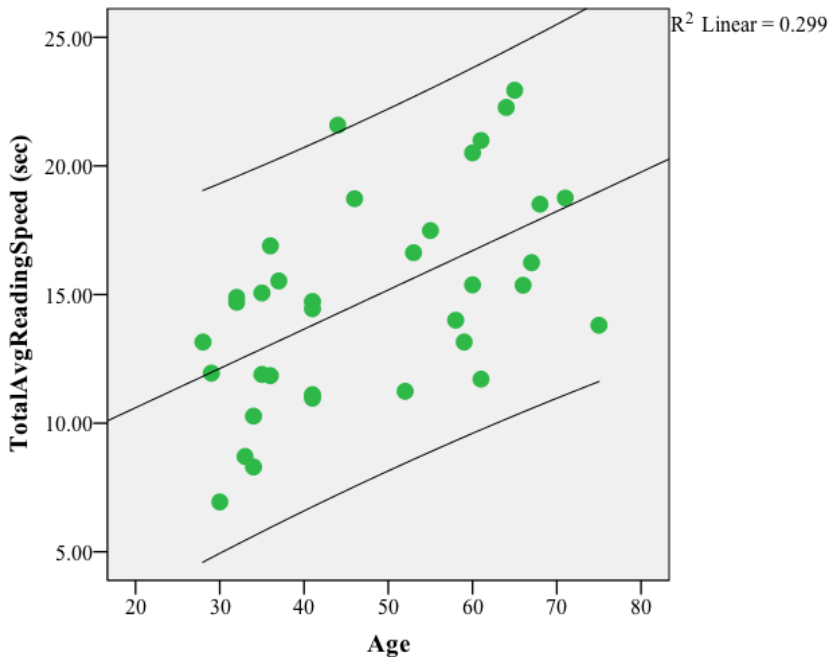


Figure 10. Scatterplot showing a positive relationship between text reading speed and age taken from 35 healthy controls. As age goes up, reading speed slows down. Pearson's  $r = 0.55$ . The middle line represents the fitted or regression line; the two lines from the data points represent the confidence intervals set to 95%, within which the true data point is expected to fall.

## B. Education Level

There was a significant effect of education level on reading speed after controlling for age, bilingualism, and gender, ( $F(2, 29) = 3.26, p = 0.05$ ), between participants in group 1 ( $n = 6, M = 16.76, SE = 1.42$ ), group 2 ( $n = 19, M = 15.53, SE = 0.75$ ), and group 3 ( $n = 10, M = 12.51, SE = 1.10$ ). There was a significant negative correlation between education level and reading speed,  $r(35) = -0.49, p < 0.01$ . Participants who had lower education levels had longer reading times. 24% of the variance in reading speed was accounted for by education level (see Figure 11). The covariate age was also significantly related to reading speed, ( $F(1, 29) = 7.33, p = 0.01$ ) and negatively correlated with education level,  $r(35) = -0.48, p < 0.01$ . That is, older adults were slower than younger adults but they also were less educated (see Figure 12).

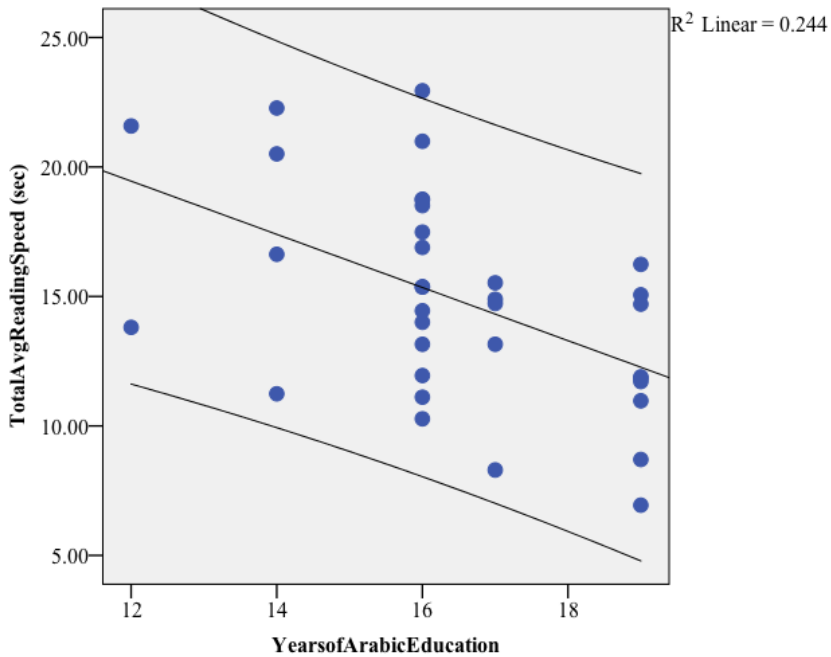


Figure 11. Scatterplot showing a negative relationship between text-reading speed and years of Arabic education taken from 35 healthy controls. Pearson's  $r = -0.49$ . The middle line represents the fitted or regression line; the two lines from the data points represent the confidence intervals set to 95%, within which the true data point is expected to fall.

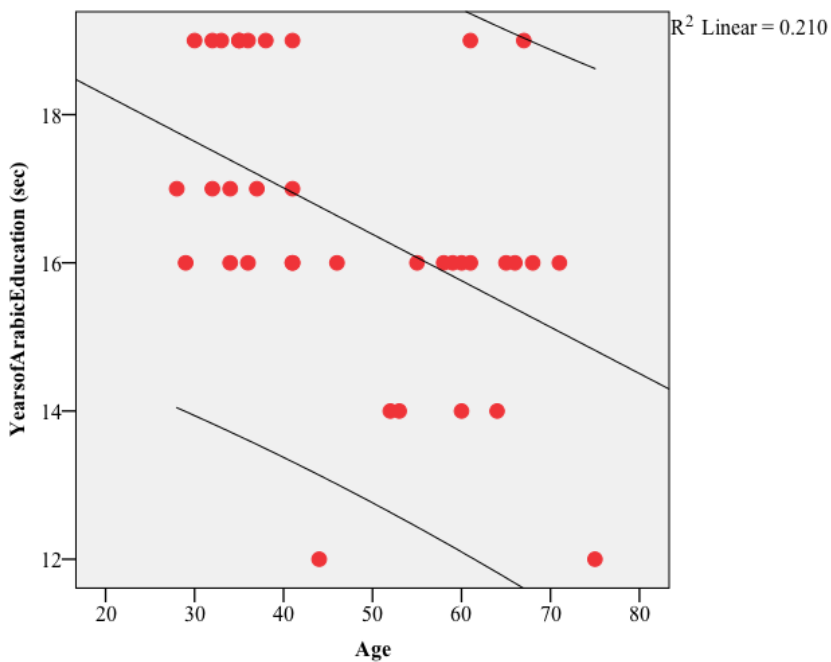


Figure 12. Scatterplot showing a negative relationship between text-reading speed and education level taken from 35 healthy controls. Education level decreased with age, and significantly negatively impacted reading speeds. Pearson's  $r = -0.46$ . The middle line represents the fitted or regression line; the two lines from the data points represent the confidence intervals set to 95%, within which the true data point is expected to fall.



### C. Bilingualism

There was no effect of the number of languages spoken on reading speed after controlling for age, education level, and gender, ( $F(1, 30) = 1, p = 0.34$ ); monolinguals' reading speed ( $n = 26, M = 14.50, SD = 4.44$ ); bilinguals' ( $n = 9, M = 14.54, SD = 2.57$ ).

### D. Gender

There was no effect of gender on reading speed after controlling for age, education level, bilingualism, ( $F(1, 30) = 0.07, p = 0.79$ ); male ( $n = 11$ ) reading speed: ( $M = 14.08, SD = 2.89$ ); female ( $n = 24$ ) ( $M = 15.24, SE = 4.44$ ).

## Between-subject effects (age and education level) on text-reading speed

A significant regression model predicted text-reading speed based on age and education level of the participants ( $F(2, 32) = 10.74, p < 0.001$ ). Together these two variables explained 40% of the variance in reading speed ( $R^2 = 0.40$ ). Age significantly predicted text-reading speed ( $\beta = 0.38, p < 0.02$ ), as did education level ( $\beta = -0.36, p < 0.03$ ). Tests to investigate if the predictor variables met the assumption of collinearity indicated that multicollinearity was not a concern (Age, *Tolerance* = 0.75, *VIF* = 1.34; Education level, *Tolerance* = 0.75, *VIF* = 1.34). As such both variables were found to be independent of each other, predicting text-reading speed in their own unique ways (see Figure 10 and 11) but with age the stronger predictive variable.

## Mechanisms Underlying Text-Reading Speed

### A. Number of Fixations

There was a significant effect of age on number of fixations, ( $F(1, 33) = 8.36, p < 0.01$ ), older group ( $M = 29, SD = 3.95$ ), younger group ( $M = 25, SD = 3.81$ ). The age variances

were not significantly different between the groups as assessed using Levene's test ( $F = 0.255, p = 0.62$ ).

#### B. Fixation Duration

The effect of age on fixation duration was not significant, ( $F(1, 33) = 3.57, p = 0.07$ ), older group ( $M = 0.45 \text{ sec.}, SD = 0.07$ ) younger group ( $M = 0.41 \text{ sec.}, SD = 0.07$ ). Levene's test found that the variances were not significantly different between the groups ( $F = 0.00, p = 0.98$ ).

#### C. Saccadic Eye Movements

The effect of age on saccadic amplitude was significant, ( $F(1, 33) = 33.29, p < 0.001$ ), older group ( $M = 2.83 \text{ degree}, SD = 0.32$ , younger group ( $M = 3.48 \text{ degree}, SD = 0.34$ ). Levene's test found that the variances were not significantly different ( $F = 0.002, p = 0.96$ ).

### 4.5 Discussion

The present study investigated the effects of age on Arabic readers' text-reading speed and whether additional factors including education level, bilingualism, and gender also influence reading speed. Age and education level both significantly influenced reading speed, and there was no effect of bilingualism or gender. When education level was controlled for, age continued to have a significant effect on reading speed independent of the older and younger groups' years of Arabic education. Older Arabic adults read more slowly than younger adults, made more fixations, and had lower amplitude forward saccades during passage reading. I discuss the text-reading speed and eye movement results in turn below.

## Text-Reading Speed

Mean reading speed was 201.61 wpm ( $SD = 4.01$ ), 14.88 seconds per passage for the 35 adult Arabic readers in this study with older Arabic adults reading more slowly (179 wpm) than younger adults (233 wpm). For both groups the wpm reading speeds are significantly slower than that found in Latinate languages. Rayner (1978) found a mean (passage) reading speed in English of 308 wpm in ten adult readers. The same author went on to find significant individual differences in English passage reading rates as a function of reading skill (Rayner, 1998; Rayner, Slattery, & Belanger, 2010) ranging from fast 325 wpm for skilled readers and slow 200 wpm for less skilled readers.

To date there have been two studies of text reading speed in Arabic readers. First, Roman and Pavard (1987) investigated passage reading speed in twelve healthy Arabic readers. Their participants read 4 Arabic passages comprised of 95 words per text spread over 4 lines. The mean reading speed was 268.87 wpm ( $SD = 10.98$ ). This is slower than reading of Latinate passages. Further analysis of their data revealed Arabic readers increase their gaze duration per word. They interpreted this as evidence that Arabic readers extract more information from every word resulting in a slower total average reading time. Interestingly it is a comparable range to that found in Hebrew readers where the average reading time was found to be 286 wpm for six bilingual Israeli participants reading Hebrew sentences (Pollatsek et al., 1981). Even though, Arabic is argued to be more complex linguistically than Hebrew (Abu-Rabia, 1996) both scripts are read in the same direction (right to left). This suggests Arabic readers are slower to read passages than readers of Latinate languages because it is a visually complex written language.

Indeed, in a second study of Arabic readers Paterson and colleagues (2015) propose that Arabic cursive script reduces visual acuity for words outside foveal vision. The mean reading

speed for their 12 healthy Arabic readers was 249 wpm ( $SD = 69.28$ ) sampled across 150 trial sentences. Each sentence was 12-17 words long and presented as a single line of text. In the context of reading Arabic text readers would make more fixations, longer fixation durations and lower amplitude saccades to compensate for reduced parafoveal information thereby slowing their reading speed. While both these studies' explanations offer an explanation as to why Arabic readers can be slower than readers of Latinate languages but do not help explain why the Arabic readers in my study (201wpm) were so much slower than both of theirs.

Perhaps it could have been the 1) nature of the materials and/ or the 2) age of subjects. (Rayner, 1998) found if the texts were more difficult (more complex semantics and grammar), then reading rate would decrease. In comparison to Roman & Pavard, and Paterson's passages, my passages had a more complex vocabulary and syntax (adapted from world news articles) that may have further contributed to a slower reading rate. Theirs focused on reading rates in Arabic reading across sentences. The participants in Roman & Pavard's study were university students with a mean age of about 25 years. In Paterson's study they ranged from 21-36 years, and all were university students as well. The mean age of participants in this study was 48 ( $SE = 2.37$ ) years. The older participants ( $M = 60.28$ ,  $SD = 8.16$  years, range = 44 – 75 years) had an average reading time of 179 wpm, ( $SE = 0.84$ ) while the younger participants ( $M = 35$ ,  $SD = 4.21$  years, range = 28 – 41 years) had an average of 233 wpm, ( $SE = 0.87$ ). As such all my participants were older than previously reported Arabic reading studies.

Relevant to my findings, Rayner and colleagues (1998) examined in an eye-tracking experiment whether elimination of spaces interfered with text-reading speed during passage reading. Results showed that there was a dramatic decrease of 44 percent in reading speed as a consequence of the removal of interword spaces. What is interesting for this study was that

forward saccade sizes were affected by the spacing manipulation. For passages, the average size of progressive saccades was 7.9 (2.6°) and 4.7 (1.57°) characters, with and without spaces, respectively. The results showed that the removal of interword spacing affected decisions on where and when to move the eyes. This is because removal of interword spacing made it difficult to determine where words begin and end. Thus, authors claimed that removal of space between words appeared to produce a different pattern of eye movements. That is, it effected landing positions (more fixations) on words, which influenced the duration of those fixations and the direction and length of the saccades that terminated those fixations (Rayner & Pollatsek, 1981). Thus, the unspaced experimental condition interfered with word identification, which led to slower reading.

Likewise, word identification difficulty in written Arabic script due to the lack of interword spacing from dots (marks), diacritics, and cursive script, can result in more and longer fixations, and lower amplitude forward saccades, with respect to reading. Reading time, and thus reading performance, is mainly dependent on number and durations of fixations, and forward saccades. These eye movements determine how readers process text information. In the case of the Arabic readers in this study, they had to make more and longer fixations and lower amplitude forward saccades (in the direction of reading) to process text information, which resulted in slower text-reading speed (Zihl, 1995). The above findings provide additional explanation as to why Arabic readers can be slower than readers of Latinate languages.

This pattern of slowing of reading speed with increasing age is consistent with that observed in young (age range: 18 – 34 years) and older (age range: 65 – 74 years) English-reading adults (e.g., Kemper, Crow, & Kemtes, 2004; Rayner et al., 2006, 2009; Paterson et al., 2013, McGowan et al., 2014; Jordan, McGowan & Paterson, 2014). Rayner and colleagues

(2006) interpreted this pattern of findings as showing older readers having greater difficulty in reading, and adopting an inefficient reading strategy. Which in turn may be affected by typical age-related changes in working memory and attention (Kemper et al., 2004; Rayner et al., 2006; Stine-Morrow et al., 2006). They called this a “risky” reading strategy to compensate for poor processing of text when attempting to decode words. Also, Rayner and colleagues (2009) found that older English readers presented with longer saccades, more skipped words, and more eye-movement regressions. They argued that older English readers may have attempted to read texts more quickly than younger readers, but in adopting this strategy (which they labelled risky), the readers had to regress to earlier portions of the text more frequently to clarify portions that were not correctly processed earlier resulting in total overall slower reading speeds. They attributed the adoption of this strategy to slower processing of foveal information, and less efficient processing of parafoveal information in older readers. However, Paterson and colleagues (2013) argued that there is very little difference in the processing of parafoveal information between younger and older English readers. In an eye movement experiment, they examined binocular eye movements (both eyes) of both younger (18-30 years) and older (65-74 years) English reading adults. They found that eye movement control during reading did not change with increasing age. These findings suggest that simple age-related visual changes and not less efficient processing of parafoveal information contributed to longer reading times.

Consistent with this, the high level of comprehension achieved by all my Arabic adult readers, irrespective of age suggests that despite reading more slowly than young adult readers, older Arabic readers utilized a reading strategy that was well-adapted to the task and allowed them to continue to read and process the information effectively. There was no evidence of age related cognitive performance deficits. As such my data may be more consistent with the

findings of McGowan and colleagues (2014) who proposed that slower, age related reading speeds in Arabic were mainly due to visual deficits that affect visual processing of text. Aging results in naturally occurring visual changes. A reduction in sensitivity to visual detail and inefficient oculomotor skills produce increased effects of visual crowding (Scialfa, Cordazzo, Bubric, & Lyon, 2013; Owsley, 2011), and slow visual processing (Solan and colleagues 1995). The impact on reading is a slower and more effortful performance. Thus, older Arabic readers most likely adopt a more cautious reading strategy (move through text more slowly), to adjust to and accommodate their increased visual processing difficulties, resulting in accurate but slower reading speeds.

That the older Arabic readers had more fixations and lower amplitude progressive saccades per passage compared to the younger readers, is consistent with this idea that they adopted a moving through text more slowly strategy. On average, they made four more fixations per passage and their progressive saccades were 0.65 degrees shorter than the younger readers. On first glance this pattern does not appear to be consistent with previous studies comparing the saccadic eye movements of older and younger English adults during text reading (Rayner et al., 2006, 2009; Paterson et al., 2013, McGowan et al., 2014; Jordan, McGowan & Paterson, 2014). These studies found, on average, progressive saccades of older readers were of greater amplitude than the saccades of younger readers. However, when spaces between words were eliminated Rayner et al., (1998) found progressive saccades of older readers were of lower amplitude ( $2.83^{\circ}$ ) than the saccades of younger readers ( $3.48^{\circ}$ ) to compensate for reduced parafoveal information. In Arabic there are reduced spaces between words compared to Latinate languages (Hermena et al., 2017; Hermena, Drieghe, Hellmuth, & Liversedge, 2015; Alotaibi, 2007), and the cursive script limits visual acuity for words outside foveal vision. In this context the

orthographic characteristics of the Arabic language reduced the ability to identify words, and increased effects of visual crowding on the perceptual abilities of older adults. Thus, it is fully consistent that older Arabic readers tended to make more fixations, longer fixation durations and lower amplitude saccades to compensate for reduced parafoveal information.

To summarize, the findings of this study revealed that older Arabic participants read text more slowly than younger Arabic readers, and also made more fixations, with longer fixation durations during passage reading. This pattern is consistent with findings from previous studies comparing the reading performance of young and older English adults. Older Arabic readers appeared to adopt a more cautious reading strategy (indexed by different eye-movement pattern- lower amplitude forward saccades, more fixations) for accurate word identification, which resulted in longer reading times.

Naturally occurring visual changes in older age lead to a reduction in sensitivity to visual detail. To adapt to these changes and adjust to the visual processing difficulties of the Arabic cursive text older Arabic readers adopt a different reading strategy. These findings outline the eye-movement mechanisms underlying older Arabic adults reading performances. These results are important for not only understanding normal ageing effects on Arabic reading but also how acquired visual impairments may impact reading and processing of text both in terms of speed and eye-movement patterns.



## Chapter 5: Therapy effects in Arabic-reading patients with left-sided hemianopia

### 5.1 Abstract

Reading is a complex skill and when it is impaired at its visual processing level, an acquired reading disorder called Hemianopic Alexia (HA) may occur. Almost all of the world literature on acquired alexia (of any form) is on languages that are written, and therefore read, from left-to-right. These patients usually have left hemisphere brain damage. In contrast, Arabic readers with HA have a left-sided hemianopia, as a consequence of right hemisphere brain injury. Specifically, I am interested in text reading speeds and eye-movement behaviours of two Arabic readers (right-to-left readers) following a right hemisphere stroke and left-sided hemianopia. This enabled me to make novel comparisons (based on effect sizes) with published data on how text reading in a non-Latinate language (Arabic) compared with Latinate language (English) is: a) affected by hemianopia; b) responds to moving text therapy. Additionally, I examine the specificity of this compensatory eye movement therapy on text-reading speed (main outcome) and visual search (control measure) to see whether training-related performance improvements can transfer between these two tasks. Despite significant impairment in visuo-spatial processing, and associated reduced visual acuity of the written Arabic language both patients responded well to the therapy resulting in significant improvements in passage reading speeds. Post therapy eye movement results revealed significant reductions in the number of fixations, regressions, and the total number of saccades to the left and right during passage reading. Furthermore, fixation duration was significantly reduced, and saccadic amplitudes were significantly increased to both the left and to the right after therapy. Thus, with respect to both spatial (saccadic amplitudes) and temporal (number and duration of fixations) measures, my right hemisphere patients, with left-sided HA showed both an increase in spatial and decrease in temporal extents in their perceptual span on text reading after therapy.

## 5.2 Introduction

Reading is a complex skill and when it is impaired at its visual processing level, different reading disorders may occur. This study focuses on a specific reading impairment hemianopic alexia-(HA) in Arabic readers. Hemianopia refers to compromised vision in one half of the visual field, affecting either one (uniocular) or both (homonymous) eyes. Hemianopic Alexia (HA) is a reading disorder related to such impairment, usually caused by stroke or head injury (Zihl, 1995; Leff, Spitzyna, Plant & Wise, 2000).

During fixation, or maintenance of visual gaze on a single word embedded in a sentence, two actions occur in parallel. Normal readers recognize a word and plan their next eye movement to the optimal viewing point of the next word imbedded in a line of text. Readers achieve this by moving their eyes along a line of text three to four times per second in a series of eye movements called *saccades* (Leff et al., 2000; Schotter, Angele, & Rayner, 2012). Reading a line of text is usually achieved by planning a series of saccades (the reading scan-path), which allow the eyes to jump from one word to another. Readers make use of peripheral visual information to the right (if reading from left to right, e.g., in English) or to the left (if reading from right to left, e.g., in Arabic) of words in order to plan their reading eye movements. Patients with HA are deprived of this peripheral information and compensate by creating inefficient reading scan-paths with many additional saccades, resulting in accurate but slow reading. Some patients abandon reading altogether, or lose their jobs because they cannot read fast enough (Leff, Spitzyna, Plant, & Wise, 2006). Consequently, the reading ability of those who read left-to-right is compromised more by right-sided HA, and in those who read right-to-left by a left-sided HA.

During reading of left-to-right texts, fixations approximately last 200 – 250 milliseconds, with intra-variability across readers (Rayner, 1998). Saccades usually last 20 – 50 milliseconds

depending on how far the eyes move (Schotter, Angele & Rayner, 2012). Experiments that manipulated viewing time in left-to-right texts, have shown that visual information necessary for reading can be acquired during the first 50 milliseconds of a fixation whereby the remainder of fixation is dedicated to cognitive processing and planning for the following saccade (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner, Liversedge, & White, 2003). Text reading performance in left-to-right reading patients with a right-sided HA is expected to be impaired in both text recognition and guidance of eye-movements since only the initial letters of a word are seen and fixations cannot be guided due to the unseen words that follow. Likewise, I expect text reading performance in right-to-left reading patients with left-sided HA to also be impaired in both text recognition and guidance of eye-movements due to disturbances in the leftward reading scan path.

Difficulties in recognizing words, and understanding the meaning of text, becomes apparent in the reading eye-movement patterns of those with HA. Zihl (1995) examined eye movement behaviour with respect to reading time in patients with either right or left-sided HA pre- and post-therapy (eye movement therapy). The results showed that reading time, and thus reading performance is dependent on the number and duration of fixations, and the number of saccades to the left. Hence, the fewer the fixations, the shorter their duration, and the fewer the regressions, the faster the processing of text information (text-reading time).

With respect to the right-sided patients with HA in Zihl's study (1995), they were found to be more impaired than the left-sided patients with HA. Text-reading speed was more impaired than the left-sided patients with HA (RH: 7.3 min ( $SD = 2.1$ ), LH: 4.3 min ( $SD = 0.92$ ); average words per minute (wpm) were 53 and 76, respectively. Their eye movement pattern was characterized with a higher number of saccades to the right, more regressions, a reduced saccadic

amplitudes to the right, and a higher number and duration of fixations. I predict that my left-sided Arabic readers with HA will display similar reading performance and eye movement patterns as those with right-sided HA patients in Zihl's study.

No empirical studies on Arabic readers with HA have been conducted; thus, little is known about the performance of Arabic readers with HA. However, in a study investigating the perceptual span of bilingual readers of Arabic and English, Jordan and colleagues (2014) found that the perceptual span showed a rightward asymmetry for English printed text and a leftward asymmetry for Arabic printed text. Thus, the perceptual span is modified by the overall direction of reading. Interestingly, they found adverse implications resulted when a region of text becomes obscured. So, when the region to the left was obscured for healthy Arabic readers, they began to display inefficient reading characterized by an increased number and duration of fixations, and regressions. This is interesting because their reading pattern was similar to English-reading HA patients who presented with a left-sided hemianopia.

Reading a line of text is usually achieved by planning a series of saccades, which allow the eyes to jump from one word to another (reading scan-path). Arabic readers use peripheral visual information to the left of the word in order to plan their reading eye movements. Thus, Arabic-reading patients with a left-sided HA are deprived of this information and compensate by creating inefficient reading scan-paths with many fixations and additional saccades, resulting in accurate but slow reading.

The findings from this study provide clear evidence that when the perceptual span is obscured leftward, reading performance is compromised for languages that are read from right-to-left. Efficient Arabic reading seems to benefit from an asymmetry further to the left, which is determined primarily by reading direction. Indeed, when this is damaged by a neurological

disorder, such as a hemianopia following stroke, I can therefore predict not only slower reading rates, but also an increase in the number and durations of fixations, regressions, and shorter saccadic amplitudes (left and right). Reading may be more difficult as well as laborious.

Reading is slow because patients with HA are trying to compensate for their parafoveal field loss and they do that mainly by changing their eye movement behaviours (Zihl, 1995; McDonald et al., 2006). Saccades are typically smaller in size, number of fixations increase, and fixation durations are longer. Therefore, Arabic readers with HA offer a unique opportunity to explore eye movement adaptation processing in text-reading. We will gain insight as to whether the eye movement therapy (laterally scrolling text from left-to-right) will improve (or not) text-reading speed and its associated eye movement behaviours in Arabic readers with HA. Also, analysis of text-reading speed before and after treatment will allow us to identify those eye movement behaviours which were changed.

Furthermore, we know that scrolling text therapy on left-to-right readers with HA only improves text-reading and not visual search performance, and vice versa (Schuett et al., 2012). Thus, in this study I also examine whether reading and visual search impairments require a specific compensatory training for their improvement or training-related performance improvements can transfer between these two tasks (reading and visual search). To do this, I use a visual search task as a control measure and I expect that eye movement therapy should not improve this.

Additionally, I will also examine speed-reading at the single-word level, because I want to analyse how Arabic readers with a left-sided HA process Arabic words. I will measure response times and accuracy to visually-presented single Arabic written words of different letter lengths: three, five and seven-letters pre- and post-therapy. In a study investigating single-word reading

in patients with HA and pure alexia, Leff and colleagues (2001) have shown that English-reading patients with a right-sided HA were slower at reading single words of differing length (three, five, seven, and nine) than those of healthy subjects and hemianopic controls. Additionally, HA patients had a greater word-length effect (short words easier to read than long words) than the normal or hemianopic controls. This suggests that Arabic-reading patients with a left-sided HA may also have a word-length effect for single-word reading. It would be interesting to find out how written Arabic words influence visual word processing. I predict that Arabic reading patients with left-sided HA may have increased reaction times for the longer words (seven-letter) because their single-word reading speed depends on the amount of parafoveal vision to the left of fixation. That is, the larger the amount of visual field sparing, the shorter the fixation durations, the faster the processing of text information (Zihl, 1995).

Moreover, it is well known that patients with right hemisphere damage, such as patient 2 in this study (parietal and occipital cortical and subcortical infarcts), may present with neglect dyslexia (Heilman, Watson, & Valenstein, 2012). Neglect dyslexia (ND) is a type of dyslexia usually seen in patients with right hemisphere damage following parietal, frontal, temporal, cortical or subcortical injury. As such, hemianopic alexia may occur along with ND or might exist alone. Visual neglect tests together with tasks requiring reading sentences and text (Schwartz and colleagues; 1997) are used to differentiate between ND and hemianopic alexia.

A patient who presents with hemianopic alexia without neglect will have difficulty seeing the things in his compromised visual field, but will not ignore the damaged side (Vallar, Burani & Arduino, 2010). These patients are aware of their reading difficulty, and report being unable to see the text on the side of the visual field loss (Warrington and Zangwill, 1957). For this reason, such a patient will often turn his head to scan the compromised side of his visual field. The core

symptom of ND is that patients make errors in the side of the stimulus (i.e., the text line or word) contralateral to the side of the lesion. However, a patient who presents with ND will make no effort to look at the contralesional side. For example, patients with ND may begin reading in the middle of the sentence and seem to completely ignore and fail to attend to the neglected side of the sentence. As such the deficit is deemed attentional rather than sensory. In addition, these patients also make errors in word reading such as letter omissions, letter substitutions, and less frequently letter additions (Galletta, Campanelli, Maul, & Barrett, 2014; Vallar, Burani & Arduino, 2010) that are rarely seen in HA.

In this study, I want to explore whether patient 2 who presents with left neglect dyslexia, would have poorer reading single-word and text-reading performance than patient 1 who presents with no neglect dyslexia. I will also explore whether Arabic-Read Right (eye movement therapy) improves (or not) her left neglect dyslexia.

Relevant to this study, Galletta and colleagues (2014) examined reading accuracy on 67 left-to-right readers with right hemisphere stroke and left neglect dyslexia on four types of text materials: words, phrases, an article, and a menu. Results showed reading performance and accuracy for functional reading materials (article, menu) were worse than reading isolated words and phrases. Estimated percentage reading accuracy were about 90% for phrase, 85% for word, 65% for menu, and 50% for article tasks. Authors suggested that reasons for poor performance on functional text materials were due to the greater need for focused attention to longer reading materials, and to the involvement of left-to-right scanning needed in order to read these longer text materials. Likewise, I predict that patient 2's accuracy and performance will be worse on passage, compared to single-word reading, and her overall performance will be worse than patient 1 and her matched controls.

The Arabic written language has the second most widely used alphabet in human societies after the Latin alphabet (Haywood & Nahmad, 1965; Almabruk, Paterson, McGowan, & Jordan, 2011). However, research on Arabic reading remains limited and, there is no research on Arabic readers with HA to date. Consequently, little is known about the performance of Arabic readers with HA on reading Arabic text and single-words of different word lengths (three, five and seven-letters). In this study I investigated reading and eye-movement performance of two Arabic readers with a left-sided HA when reading static Arabic texts. I aimed to reveal:

- 1) the effect of left-sided hemianopia,
- 2) the influence of Arabic text visual characteristics, and
- 3) the impact of laterally scrolling Arabic text (from left-to-right) when given as a treatment on their reading efficiency.

Reading efficiency was indexed by reading speeds and eye tracking measures per Arabic passage of total number of fixations, total average fixation durations and saccadic amplitudes.

An online treatment package for English readers with HA is available and proven to be effective (*Read-Right*, <http://www.readright.ucl.ac.uk/>) (Ong et al., 2015). This uses a laterally scrolling text, also called “Times Square” presentation, to induce a form of involuntary eye movement called small field, optokinetic nystagmus (OKN) in the reader (Zihl, 1995; Kerkhoff, Munsinger, Eberle-Strauss, & Stogerer, 1992; Spitzyna et al., 2007), with an involuntary saccade into the patient’s blind field. When used as part of a rehabilitation program, with a dose of 20 hours of practice reading this scrolling text, has been shown to improve subsequent reading performance of static text (Spitzyna et al., 2007; Ong, Brown, Robinson, Plant, Husain, & Leff 2012). As no assessment or treatment resources currently exist for HA in right-to-left readers I



adapted these techniques for Arabic within a novel app {Ikrā lītākūṭ:Ṣ “read to become” إقرأ (لتكون)} to be used in this study.

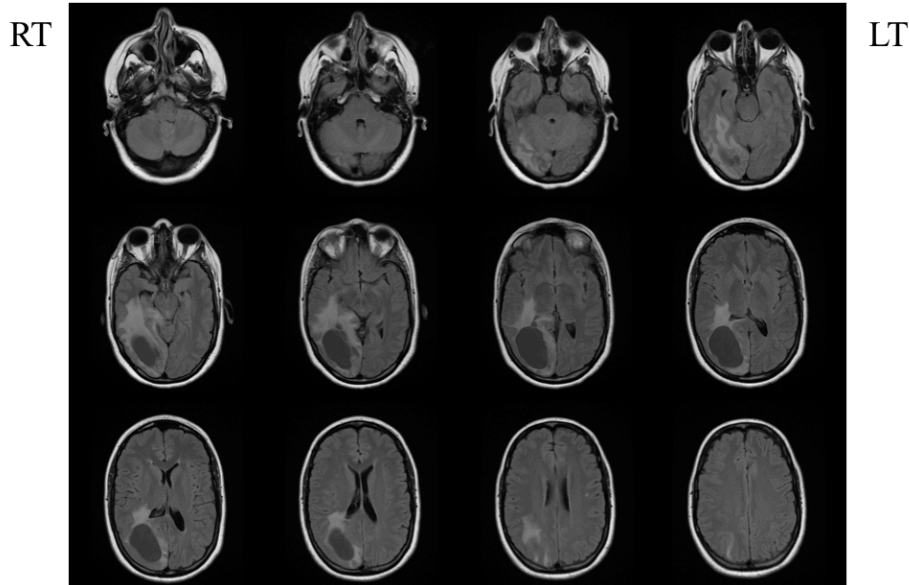
Together with eye tracking data I investigated two Arabic-reading patients’ reading speeds and eye movement behaviours during static text reading before, during and directly after a dose of laterally scrolling text therapy using my app. Consistent with Ong and colleagues’ therapy my patients were asked to read animated, laterally scrolling text (here Arabic text, moving from left-to-right) whose form and content was selected by the patients. The patients’ reading scan-paths were directly compared to those generated by healthy controls reading the same static passages. This will enable us to assess the efficacy of my newly designed treatment package Arabic-Read Right (Ikrā lītākūṭ:Ṣ “read to become”).

## 5.3 Methods

### 5.3.1 Participants – patients first then controls.

#### *Patients*

Patient 1 was a 40-year-old female with a diagnosis of right occipital arteriovenous malformation (see Figure 13 below). She is Arabic speaking and left-handed. Education was at the master’s level. Confrontational visual field test revealed a left-sided hemianopia. The patient had complete impairment of left foveal and parafoveal vision. She presented with a left hemianopic alexia. The patient was more impaired at reading text than single words.



*Figure 13. Axial T2 and Flair MRI brain scanned images showing a lesion in the right occipital lobe for patient 1.*

Patient 2 was a 53-year-old female with a diagnosis of right parietal and occipital cortical and subcortical infarcts (see Figure 14 below). She was Arabic speaking and right-handed. Education was at the secondary level. Confrontational visual field testing revealed a left-sided hemianopia. The patient had partial impairment of left foveal vision and complete impairment of left parafoveal vision. She presented with a left hemianopic alexia and left visual neglect. The patient was more impaired at reading text than single words.

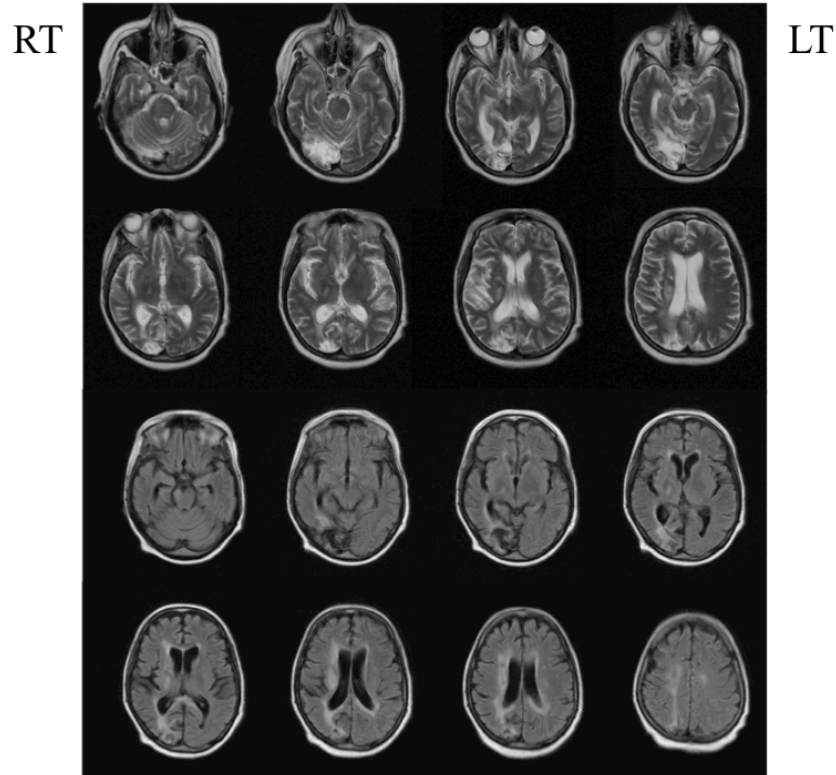


Figure 14. Axial T2 and Flair MRI brain scanned images showing a lesion in the right parietal and occipital lobe for patient 2.

Control subjects for eye movements recordings

### *Passage-reading tests*

- a. 15 healthy native Arabic reading controls (9 female) were selected for patient 1. They were matched on age (range: 35 to 61 years ( $M = 45$ ,  $SD = 10.12$ )) and education level (bachelor and master's degree). All but one were right-handed, and had normal or corrected-to-normal visual acuity and no history of neurological, psychiatric or language disorders.
- b. 5 female healthy native Arabic reading matched controls were selected for patient 2. Matching criteria were same as above. The age of participants ranged from 44 to 64 years ( $M = 55$ ,  $SD = 7.73$ ) and education level (high school diploma and

bachelor's degree). All but one were right-handed, and had normal or corrected-to-normal visual acuity and no history of neurological, psychiatric or language disorders.

### *Single-word reading tests*

28 healthy native Arabic reading matched controls (18 females) were selected for this study. Ages ranged from 42 to 77 years ( $M = 63$ ,  $SD = 1.56$ ). Education level (high school diploma and Bachelor's degree) All were right-handed with normal or corrected-to-normal visual acuity and no history of neurological, psychiatric or language disorders.

All participants gave informed consent. Ethical approval for this study was granted by the Wales Research Ethics Committee 6.

### 5.3.2 Stimuli

#### Materials

##### *A. Passage Reading Tests*

12 passages were modified from the BBC Arabic current world news (<http://www.bbc.co.uk/arabic>), and the acquired alexia workbook developed by the *Jeddah Institute for Speech & Hearing* (Naqaweh, 2008). Passages were checked for spelling and grammar by two Arabic teachers trained in modern written Arabic linguistics and matched for the total number of words and lines so that each contained 50 words spread over six lines. This is to control eye movement behaviour rather than differences in linguistic content. Each passage was then presented in a different randomized order for each participant.

For eye-tracking recordings, all HA patients entered in the rehabilitation phase of the study were tested reading twelve Arabic passages at baseline pre-therapy. Eye movements

were recorded simultaneously. Then after completing every 5 hours of reading training the patients were tested reading six passages, matched for linguistic complexity (3 easier and 3 harder). These passages were presented in pseudo-randomized order at four time-points during therapy; i.e., 5, 10, 15, and 20 hours of therapy. All 12 passages were seen 3 times only. This meant, patients' mean reading speeds were calculated from 12 static texts at baseline, and then the six static texts, at each of the four time-points during therapy measured.

For Arabic-Read Right app recordings, all HA patients entered in the rehabilitation phase of the study were tested reading six Arabic passages at baseline pre-therapy and after completing every 5 hours of reading training matched for linguistic complexity (3 easier and 3 harder). These passages were presented in pseudo-randomized order at baseline and at four time-points during therapy; i.e., 5, 10, 15, and 20 hours of therapy. On average, all 12 passages were seen 2.5 times only. This meant, patients' mean reading speeds were calculated from six static texts at baseline, and at each of the four time-points during therapy measured.

In addition, I carried out a sub-analysis for the first two baseline time-points (B1: Eye-tracking recordings, B2: Arabic-Read Right app recordings) to rule out practice effects (familiarity with the text reading stimuli). Time lapse between B1 and B2 was eight and five days for patient 1 and 2, respectively. That is, time of presentation (B1 and B2) was offset. For both patients, a paired-samples t-test will indicate whether reading speeds were significantly different between the two baselines and dose of training was not confounded with repeated presentation of passages (see Figure 15 below).

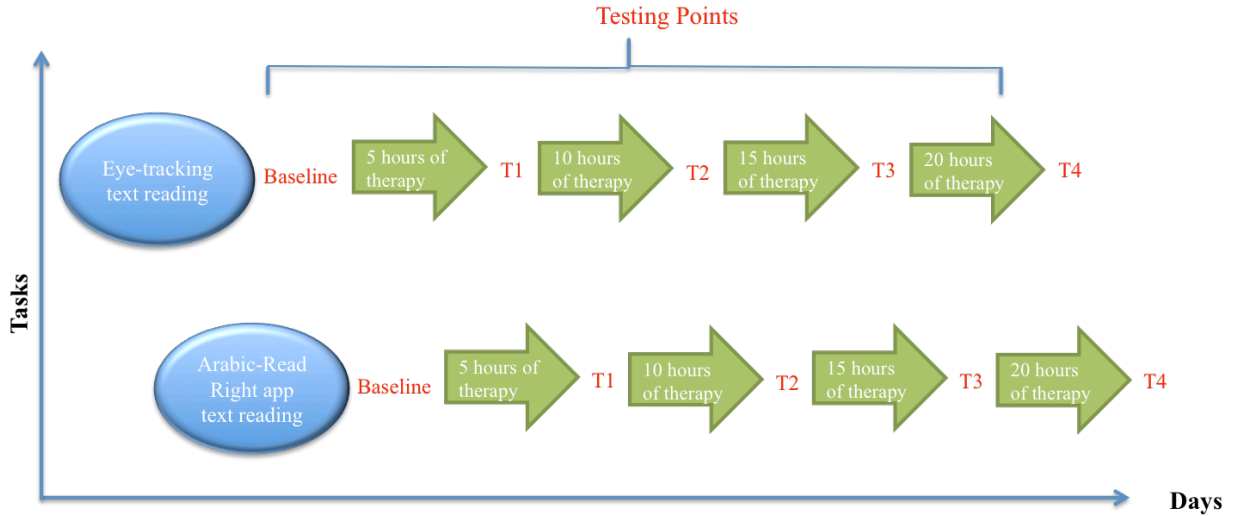


Figure 15. Schematics of Study Design with Testing Points. An illustration of passage reading testing points at each time point (baseline, and after 5, 10, 15, and 20 hours of therapy) during eye movement recordings and Arabic-Read Right app recordings. For the eye-tracking passage reading recordings, all 12 passages are seen at baseline and then 6 passages were presented in pseudo-randomized order at four time-points during therapy; i.e., 5, 10, 15, and 20 hours of therapy. This meant all 12 passages were seen twice after completing 10 hours of training, and after 20 hours, all are seen a third time. For the Arabic-Read Right app passage-reading recordings, a similar design was used. However, only 6 passages are seen at baseline and for all testing points. This meant after 20 hours of therapy, all 12 passages were seen at least twice but with 6 seen for a third time. HA patients' mean reading speeds across each time-point calculated from 12 static texts at baseline, and then 6 static texts, matched on level of difficulty (3 easy and 3 difficult), presented in pseudo randomized order on the four time-points of therapy measured with an S2 eye-tracker. Additionally, HA patients' mean reading speeds across each time-point on six static text measured with the Arabic-Read Right app. Time lapse between B1 and B2 was eight and five days for patient 1 and 2, respectively. I averaged two measurements at baseline to improve precision.

## B. Single Word Tests

I measured oral reading response times and accuracy to visually-presented single Arabic words of three different lengths: three, five and seven-letters. 96 words in total were selected from the Aralelex database (Boudelaa & Marslen-Wilson, 2010). This resulted in 31 3-letter, 33 5-letter, and 32 7-letter words in each list, matched across lists for word frequency (average = 28 counts/million). Morphological family neighbourhood size (N) varied across the three word groups (Westbury, Hollis, & Shaoul, 2007; Attia, Pecina, Toral, Tounsi, & Van Genabith, 2011).

## Apparatus

### *A. Recording of eye movements*

An S2 Mirametrix eye tracker (<http://www.mirametrix.com/products/>) recorded both the right and left-eye gaze location every millisecond (1000 Hz). Each passage was displayed on a 17-inch Dell monitor as black text on a white background. The eye tracker was centred beneath the screen and as close to the lower edge of the screen as possible. The eye tracker was approximately arms-length i.e. 65 cm from the face of the patient. Prior to reading the eye tracker was calibrated once per participant and after the eye tracking unit or screen was moved. It was also checked between reading trials and the tracker recalibrated as necessary. Calibration involved looking at a sequence of nine points on the screen.

At the start of each reading trial, a fixation cross was presented at the top centre of the screen. Once this was fixated, participants were instructed to read the entire passage silently and at a normal pace. The passage was presented at the middle centre of the screen. Participants were then instructed to fixate a second cross that was presented at the bottom centre of the screen indicating that they finished reading the passage. This process was repeated for the 12 passage trials. Each passage was presented in pseudo-randomized order across patients. The experimental session lasted approximately 15-20 minutes in total.

Parallel forms of each passage (equivalent in level of difficulty) were used to evaluate the reading speed and eye movement behaviours of both patients with left-sided HA on five testing points: at baseline, and after 5-, 10, 15-, and 20-hours of therapy. The primary outcome was to see an improvement in reading speeds. Secondary outcomes

included: changes in average number of fixations, fixation duration, and saccadic amplitude. Patient was tested on all twelve passages at baseline, and then six passages, matched on level of difficulty (3 easy and 3 difficult), were presented in pseudo-randomized order on the four time-points of therapy.

Text-reading speed data and eye movements were post-processed via the S2 Mirametrix Eye tracker software showing timestamps in seconds and coordinates of each fixation using both the right and left eye. This was used for the subsequent data analysis. A fixation was identified, at least five consecutive data points, at sampling rate of 60 Hz, which is about 83 milliseconds (Mirametrix Inc., 2013).

The following parameters were used to indicate eye movement components: number of leftward and rightward saccades in the X-axis; number of downward and upward saccades in the Y-axis; mean size of saccades (absolute value combining X and Y coordinates); number of fixations (left and right); mean fixation duration (left and right), and regressions (left and right).

Total passage reading time was determined by calculating the timestamp of each gaze point (fixation) from the first word in the first line until the last word in the sixth line of each passage (in seconds). Saccades made to proceed to the beginning of the next line (return sweeps) were discarded from the data; but regressive saccades, defined as those backward movements in the rightward direction (in Arabic) for the x axis within each line, were included in the data.



## ***B. Application-Based Assessment and Therapy***

I utilised my newly designed assessment and treatment online package modified and adapted for Arabic readers with hemianopic alexia called: Arabic Read-Right (Ikṛṭ lītākṭ: "read to become") readily available for free download on the Apple store (see, <https://itunes.apple.com/app/id964478309>). The app consists of five assessments and an Arabic reading therapy in the form of laterally scrolling text (left-to-right). The five assessments were:

- a. **Visual text-reading test** (primary outcome measure): A timed reading test was developed to evaluate the effects of scrolling text therapy. Test materials consisted of six Arabic paragraphs, which contained 50 words, spread over six lines (consistent with *passages section* above). Patients initiated a countdown timer and then read the whole of the text silently, signalling when they had finished with a screen finger tap, at which point the timer recorded their reading speed. Each passage was immediately followed by a short yes/no verification question related to the passages just read. They were added to ensure the patients read the whole passage (Ong, Brown, Robinson, Plant, Husain, Leff, 2012). At each assessment point, the patients read three passages to produce their average reading speed. Patients answered the comprehension questions with an average 93% accuracy. See Figure 4A.
- b. **Visual field test**: An automated visual field test was adapted for assessing hemianopia in patients with text reading difficulties. We tested six points at 1°, 2.5°, 5°, and 10° eccentricity from the fixation cross in both visual fields; four in each along the horizontal meridian, as this is key for text reading. This

test has been validated by comparing it with clinical ‘gold standard’, the Humphrey automated perimeter (both 10-2 and 24-2 protocols), and has sensitivities in the range of 0.8-1 and specificities of 0.75-1 for the affected hemifield along the horizontal meridian (Koiava, Ong, Brown, Acheson, Plant, Leff, 2012; Ong et al., 2012). See Figure 4B.

- c. **Visual neglect test:** Our test of visual neglect assessed attention to the left and right side of the patient’s visual field. There were 15 targets and 36 distractors in total. Patients were instructed to select all the targets across both the right and the left hemifields. They had 5 minutes to complete the task. Neglect was diagnosed if patients missed twice as many targets to one side compared with the other, or if they had a similar ratio of revisits (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain, Leff, 2015). See Figure 4C.
- d. **Visual search test (control measure):** We adapted a validated reaction time-based, visual search test where patients had to search for an everyday object in a crowded desk scene (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain, Leff, 2015). After a practice trial, 16 trials were randomly split 50:50 into target left: target right trials. Reaction time was calculated on correct trials only from the time taken from appearance of the desk scene to the subjects’ finger tap on the target item. Incorrect trials were excluded. A mean reaction time was calculated for left and right-sided trials separately. See Figure 4D
- e. **Patient-reported outcome measures:** A vertically oriented visual analogue scale was used by the patients to rate their abilities for the following six Activities of Daily Living (ADLs): hygiene, driving, finding things, reading

news, reading books, and enjoying reading. The scale ranged from 0 (impossible) to 100 (no problem) (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain, Leff, 2015). Scores were hidden from the patients when re-rating their ADLs at each time-point. See Figure 4E.

- f. **Therapy:** The therapy consisted of reading laterally scrolling text (from left-to-right). Patients could control the speed, colour (background and foreground), and content of what they read, choosing from a library of books, Quran, and ever-changing really simple syndication (RSS) text feeds from the Aljazeera website. The iOS text size is set at large (default) and dynamic. GeezaPro is the system font on iOS iPad. Patients could pause or stop therapy at any time. As long as the text was moving, a timer measured how much therapy was being delivered, feeding this information to the secure server. I suggested 60 min of therapy a day but patients could choose to do as much or as little as they wished. The app automatically resets to the assessment part of the application after every five hours of therapy accrued. Thus, the patients determined the time period between testing points. There were five testing points in total: baseline, and after 5-, 10-, 15-, and 20-hours of therapy. These interval testing points enabled me to directly compare my results with the therapy dose effects observed in the *Readright* app (Ong et al., 2012). See Figure 4F.

### *C. Single word reading speeds*

The word-reading test was presented using E-Prime software version 2.0 (Zuccolotto, Roush, Eschman & Schneider, 2012). Each word was displayed on a 15.6-inch Dell laptop as black text on a grey background approximately 65 cm away from the participant. The target words were presented centrally on the screen in Arabic typesetting font, size 85. The visual angle corresponds to about 5 degrees. At the start of each word-reading trial, instructions were presented at the centre of the screen. Patients were instructed to read each word aloud as quickly and accurately as possible. A voice-key was used to detect voice onset latency and would terminate the trial. If no response was made, the target word disappeared after 3000 ms. Practice trials of six items were administered before testing to allow the participants to become familiar with speaking clearly into the microphone. Each of the 96 target words was presented in a different randomized order across participants. The experimental session lasted approximately 10 minutes in total per participant.

## **5.3.3 Data Analyses**

### *A. Reading speed*

- a. Text-reading speed was measured using both the S2 eye-tracker and the Arabic Read-Right Application (app) at each time-point to compare text reading speed pre- and post-therapy. Text-reading speeds for each patient, at each five hour time-point, were entered into a repeated measures ANOVA using SPSS v24 to investigate the effects of therapy. I assessed therapy effects after 5, 10, 15, and 20 hours of therapy. Where the data violated sphericity assumptions, I reported Greenhouse-Geisser corrected  $p$  and  $F$  values. Significance was set at  $p = 0.05$  for all reported results. I also calculated effect sizes using standardized (*Cohen's d*) method. Partial eta squared was used in

SPSS v24 to calculate effect sizes at each five-hour time points (5, 10, 15, and 20 hours of therapy).

- b. *Single-word reading speed* for each patient was measured at two time-points only, at baseline and after 20-hours of therapy. I utilized a computer program that implements the modified t-test procedure described by Crawford and Howell (1998), which treats the control sample as statistics rather than parameters to control for Type I error rates regardless of the size of the control sample. Generally, this method is used for single-case research studies to closely match the standards demanded for group studies.

## **B. *Arabic Read-Right App Data***

- a. *Visual Search Analysis*

Visual search for each patient, at each five-hour time-point, was entered into a two-way repeated measures ANOVA using SPSS v24 to investigate reaction times for each hemifield. Factors were time (five time-points) and hemifield (left and right side).

- b. *Time by Task (Visual Text-Reading Test and Visual Search Test)*

A sub-analysis was carried out to investigate the effects of therapy on primary outcome (reading speed) and control outcome (visual search) measures. Visual search task and passage reading task for each patient, at each five-hour time-point, was entered into a two-way repeated measures ANOVA using SPSS v24. Main factors were time (five time-points) and tasks (visual search and reading speed).

### C. *Eye-movement behaviour pre-, during, and post-therapy*

A series of eye movement parameters per passage were computed: reading speed (i.e., total time – in seconds – needed to read a passage), total number of fixations (i.e., fixational pauses, during at least 80 ms) and number of fixations per hemifield (i.e., on the left and right side of the passage), total average fixations duration and average fixations duration per hemifield (in seconds), average leftward and rightward saccadic amplitudes (i.e., angular distance the eye travels towards either the left or right side of space during a movement), total number of saccades and number of saccades per hemifield (left and right), and number of regressive saccades (i.e., backward – rightward –movements while reading the text). A saccade is defined as a rapid eye movement between fixational pauses. The left and right hemifields were computed on a passage-by-passage basis with reference to the midpoint of the written text. These parameters of interest were calculated via a tailor-made script using Matlab R 2014a (Mathworks, Natick, MA, USA) software.

## 5.4 Results

### Part I.

#### A. Therapy effect on text-reading (between-group)

##### *a. Pre-therapy*

Crawford-Howell t-tests indicated a significant difference between patient 1 and matched controls in text-reading speed and the following eye-movement measures: total number of fixations, number of fixations on the left and right side of passage, and fixation durations on the left side of passage (see Table 6). There was also a significant difference between patient 2 and matched controls in text-

reading speed and all eye movement measures, except in the number of the fixations to the left side of the passage (see Table 7)

#### *b. Post-therapy*

Crawford-Howell t-tests indicated no significant difference between patient 1 and matched controls in text-reading speed and all eye-movement measures (see Table 8). However, there was a significant difference between patient 2 and matched controls in text-reading speed and the following eye movement measures: total number of fixations, the number of the fixations to the right side of the passage, mean fixation durations, and mean fixation durations to the left and right side of passage, and rightward saccadic amplitudes (see Table 9).

*Table 6. Patient 1 pre-therapy text-reading speed and eye-movement results on static text*

	Control (N = 15)				Patient	t	p	95% lower confidence limit	95% upper confidence limit
	Minimum	Maximum	Mean	SD					
Reading Speed (s)	10.97	20.99	14.86	2.84	22.98	2.76	0.01**	95.39	100
Fixations	23	35	27.34	3.01	37	3.02	0.01**	96.85	100
Fixations LT	9	18	12.56	2.62	25	4.72	0.000**	99.87	100
Fixations RT	12	17	14.78	1.70	12	-1.72	0.05*	0.48	17.33
Fixation Durations (s)	0.35	0.54	0.45	0.06	0.52	1.14	0.14	69.24	96.67
Fixation Durations LT	0.32	0.53	0.42	0.06	0.53	1.75	0.05*	83.14	99.57
Fixation Duration RT	0.37	0.55	0.48	0.06	0.52	0.68	0.25	55.09	89.71
Saccadic Amplitude (°)	2.29	3.85	3.16	0.46	2.48	-1.43	0.09	1.37	23.46
Saccadic Amplitude LT	2.30	3.88	3.15	0.45	2.48	-1.44	0.09	1.31	23.15
Saccadic Amplitude RT	2.26	4.10	3.17	0.51	2.59	-1.10	0.15	3.81	32.11

*Table 6 show mean pre-treatment reading speed and eye-movement behaviour comparisons between control group and patient 1. A single asterisk represents significant differences between patient 1 and their control group at each word length at  $p < 0.05$ . A double asterisk represents significant differences at  $p < 0.01$ . Confidence limit represents estimated percentage of normal population falling below individual score = 100%.*

Table 7. Patient 2 pre-therapy text-reading speed and eye-movement results on static text

	Control (N = 5)								
	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Reading Speed (s)	11.24	22.27	18.45	4.58	82.53	12.77	0.000**	100	100
Fixations	24	36	30.52	5.02	60	5.38	0.003**	97.32	100
Fixations LT	11	19	14.62	3.33	18	0.93	0.20	44.91	98.17
Fixations RT	13	18	15.90	1.87	42	12.76	0.000**	100	100
Fixation Durations (s)	0.40	0.64	0.51	0.08	1.07	6.12	0.002**	98.71	100
Fixation Durations LT	0.37	0.62	0.49	0.09	1.08	6.03	0.002**	98.59	100
Fixation Duration RT	0.43	0.66	0.52	0.09	1.23	7.47	0.001**	99.71	100
Saccadic Amplitude (°)	2.61	3.13	2.79	0.20	1.87	-4.07	0.01**	0.00	8.13
Saccadic Amplitude LT	2.60	3.23	2.86	0.23	1.88	-3.89	0.01**	0.00	9.38
Saccadic Amplitude RT	2.57	3.00	2.68	0.18	1.48	-6.15	0.002**	0.00	1.26

Table 7 show mean pre-treatment reading speed and eye-movement behaviour comparisons between control group and patient 2. A single asterisk represents significant differences between patient 2 and their control group at each word length at  $p < 0.05$ . A double asterisk represents significant differences at  $p < 0.01$ . Confidence limit represents estimated percentage of normal population falling below individual score = 100%.

Table 8. Patient 1 post-therapy text-reading speed and eye-movement results

	Control (N = 15)								
	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Reading Speed (s)	10.97	20.99	14.86	2.84	11.94	-0.10	0.17	4.98	35.03
Fixations	23	35	27.34	3.01	25	-0.63	0.27	11.56	46.85
Fixations LT	9	18	12.56	2.62	13	0.29	0.39	41	79.03
Fixations RT	12	17	14.78	1.70	12	-1.58	0.07	0.81	20.16
Fixation Durations (s)	0.35	0.54	0.45	0.06	0.39	-0.98	0.17	5.21	35.55
Fixation Durations LT	0.32	0.53	0.42	0.06	0.40	-0.29	0.39	20.88	58.89
Fixation Duration RT	0.37	0.55	0.48	0.06	0.38	-1.49	0.08	1.13	22.15
Saccadic Amplitude (°)	2.29	3.85	3.16	0.46	2.83	-0.70	0.25	10.06	44.54
Saccadic Amplitude LT	2.30	3.88	3.15	0.45	2.85	-0.65	0.26	10.97	45.96
Saccadic Amplitude RT	2.26	4.10	3.17	0.51	2.73	-0.83	0.21	7.42	40.04

Table 8 show mean post-treatment reading speed and eye-movement behaviour comparisons between control group and patients. Confidence limit represents estimated percentage of normal population falling below individual score = 100%.



Table 9. Patient 2 post-therapy text-reading speed and eye-movement results

	Control (N = 5)								
	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Reading Speed (s)	11.24	22.27	18.45	4.58	58.61	8.00	0.001**	99.85	100
Fixations	24	36	30.52	5.02	53	4.03	0.01**	91.57	100
Fixations LT	11	19	14.62	3.33	20	1.34	0.13	54.79	99.70
Fixations RT	13	18	15.90	1.87	33	8.44	0.001**	99.92	100
Fixation Durations (s)	0.40	0.64	0.51	0.08	0.84	3.62	0.01**	88.53	100
Fixation Durations LT	0.37	0.62	0.49	0.09	0.97	4.89	0.004**	95.82	100
Fixation Duration RT	0.43	0.66	0.52	0.09	0.80	2.88	0.02*	81.13	100
Saccadic Amplitude (°)	2.61	3.13	2.79	0.20	2.44	-1.56	0.10	0.09	40.36
Saccadic Amplitude LT	2.60	3.23	2.86	0.23	2.58	-1.11	0.16	0.87	50.51
Saccadic Amplitude RT	2.57	3.00	2.68	0.18	2.19	-2.55	0.03*	0.00	23.19

Table 9 above show mean post-treatment reading speed and eye-movement behaviour comparisons between control group and patients. Asterisk represents significant differences between groups at each word length at  $p < 0.05$ . Double asterisks represent significant differences between groups at each word length at  $p < 0.01$ . Confidence limit represents estimated percentage of normal population falling below individual score = 100%.

## B. Therapy effect on text-reading speed-silent reading (within-subject)

### a. Eye-tracker recordings

To investigate the effects of therapy on reading speeds both patients' data, at each 5-hour time-point, was entered into a repeated measures ANOVA. Patient 1's data required a Greenhouse-Geisser correction. For both patients there was a significant effect of Arabic-Read Right therapy at all four points in time, patient 1: ( $F(1.76, 3.62) = 42.39, p < 0.05, \text{partial } \eta^2 = 0.89$ ); patient 2: ( $F(4, 20) = 4.36, p < 0.05, \text{partial } \eta^2 = 0.47$ ) (see Figure 16 A, B). In patient 1 the effect sizes were large at all time points: 5-h ( $d = 1.24$ ), 10-h ( $d = 2.48$ ), 15-h ( $d = 0.83$ ), and 20-h ( $d = 2.29$ ). In patient 2 the effect sizes were as follows: 5-h ( $d = 0.50$ , medium effect), 10-h ( $d = 1.00$ , large effect), 15-h ( $d = 0.41$ , small effect), and 20-h ( $d =$

1.32, large effect). The effect sizes were found to exceed Cohen's (1988) convention for a large effect ( $d = 0.80$ ).

*b. Arabic-Read Right App recordings*

To investigate the effects of therapy reading speeds for each patient, at each 5-hour time-point, were entered into a repeated measures ANOVA. Patient 1's data required a Greenhouse-Geisser correction. For both patients there was a significant effect of Arabic-Read Right therapy at all four points in time, patient 1: ( $F(1.71, 8.56) = 124.44, p < 0.01, \text{partial } \eta^2 = 0.96$ ); patient 2: ( $F(4, 20) = 5.49, p < 0.01, \text{partial } \eta^2 = 0.52$ ) (see Figure 16 C, D). In patient 1 the effect sizes were large at all time points: 5-h ( $d = 2.07$ ), 10-h ( $d = 2.59$ ), 15-h ( $d = 2.64$ ), and 20-h ( $d = 2.54$ ). In patient 2 the effect sizes were as follows: 5-h ( $d = 1.51$ , large effect), 10-h ( $d = 1.27$ , large effect), 15-h ( $d = 1.62$ , large effect), and 20-h ( $d = 0.44$ , small effect). The effect sizes were found to exceed Cohen's (1988) convention for a large effect ( $d = 0.80$ ).

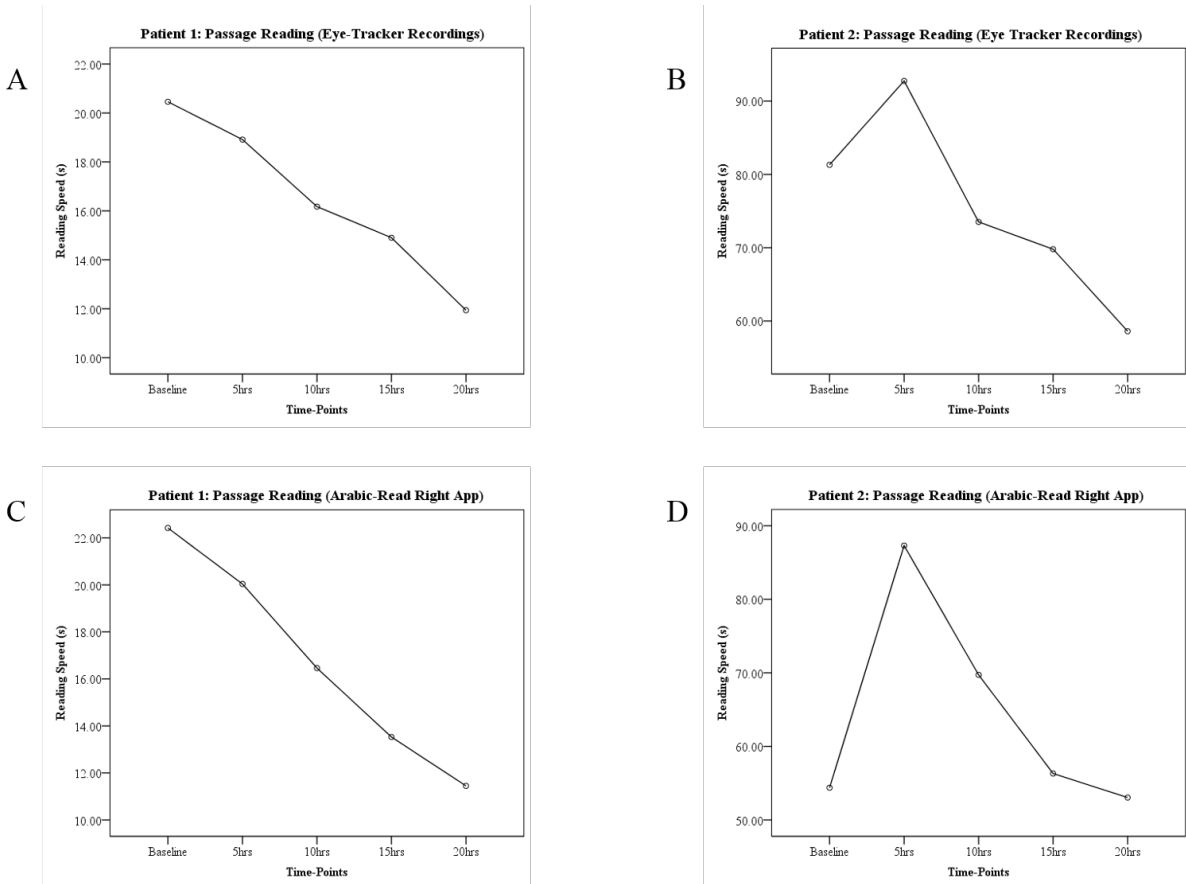


Figure 16. **Mean Text-Reading Speeds Across all Time-Points.** (A) Patient 1's mean reading speeds across each time-point calculated from 12 static texts at baseline, and then six static texts, matched on level of difficulty (3 easy and 3 difficult), presented in pseudo-randomized order on the four time-points of therapy measured with an S2 eye-tracker. (B) Patient 2's mean reading speeds across each time-point calculated from 12 static texts at baseline, and then 6 static texts, matched on level of difficulty (3 easy and 3 difficult), presented in randomized order on the four time-points of therapy measured with an S2 eye-tracker. (C) Patient 1's mean reading speeds across each time-point on six static text measured with the Arabic-Read Right app. (D) Patient 2's mean reading speeds across each time-point on six static texts measured with the Arabic-Read Right app. Reading speeds are in seconds. I averaged two measurements at baseline to improve precision.

### C. Therapy effect on text-reading speed tested on two time-points

To investigate an alternative explanation on reading speed improvement across each time-point, I carried out a sub-analysis for the first two baseline time-points (B1, B2) to rule out practice effects (familiarity with the text reading stimuli). Time lapse between B1 and B2 was eight and five days for patient 1 and 2, respectively. For both patients, a paired-samples t-test indicated that reading speeds were not significantly different between the two baselines and dose of training was not confounded with repeated

presentation of passages. Patient 1: mean: time 1 = 22.93,  $SD = 3.44$ ; time 2 = 22.42,  $SD = 0.84$ ;  $t(5) = 0.37$ ,  $p = 0.73$ . Patient 2: mean: time 1 = 80.82,  $SD = 25.65$ , time 2 = 60.35,  $SD = 25.07$ ;  $t(5) = 1.54$ ,  $p = 0.19$ . See Figure 17 below.

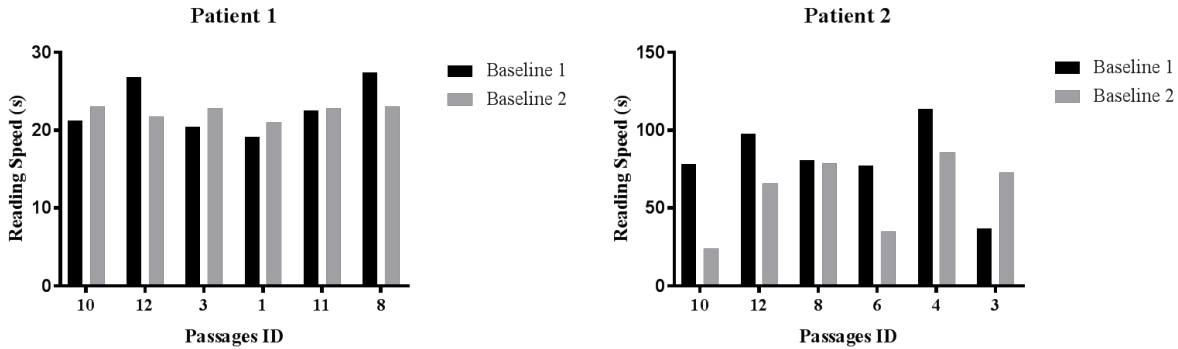


Figure 17. Patients' text-reading speeds on each passage at baseline. Numbers on the horizontal line denotes passage ID.

#### D. Therapy effects on text-reading speed (patient 2 reading aloud data)

In patient 2 to monitor her left-sided neglect across all time-points she was requested to read aloud additional passages (see Table 10). Figure 18 compares her mean text-reading speeds across all time-points with the percentage of words read aloud correctly per passage across time-points. Reading speed improved and was more accurate post-therapy.

Table 10. Patient 2 read aloud passages

ID	T	Date	TWC	TE	E-Lt	E-Rt	TWS	WS-Lt	WS-Rt	TR	Reps-Lt	Reps-Rt	RS	WPM
			(N=50)										(sec.)	
10	A	23/03/2016	32	4	2	2	2	2	0	6	4	2	84.6	35
6	A	23/03/2016	39	2	2	0	0	0	0	7	5	2	65.4	45
1	A	07/04/2016	42	3	3	0	1	1	0	0	0	0	53.92	55
3	A	07/04/2016	34	3	2	1	5	5	0	0	0	0	66.6	45
2	B	13/04/2016	45	2	2	0	0	0	0	1	1	0	70.2	43
7	B	20/04/2016	41	2	1	1	0	0	0	5	0	5	66.6	45
8	B	28/04/2016	40	4	3	1	0	0	0	2	1	1	51	58
9	A	28/04/2016	45	1	1	0	0	0	0	3	2	1	48	63

Key: ID: Passage Number; T: Type of Passage (A = Easy, B = Difficult); TWC: Total Word Correct (out of 50); TE: Total Errors; E-Lt: Errors counted on left side of passage; E-Rt: Errors counted on right; TWS: Total words missed (due to neglect) WS-Lt: Words missed on left; WS-Rt: Words missed on right; TR: Total Repetitions; Reps-Lt: Repetitions counted on left; Reps-Rt: Repetitions counted on right; RS: Reading Speed (sec.); WPM: Words per minute based on reading speeds.

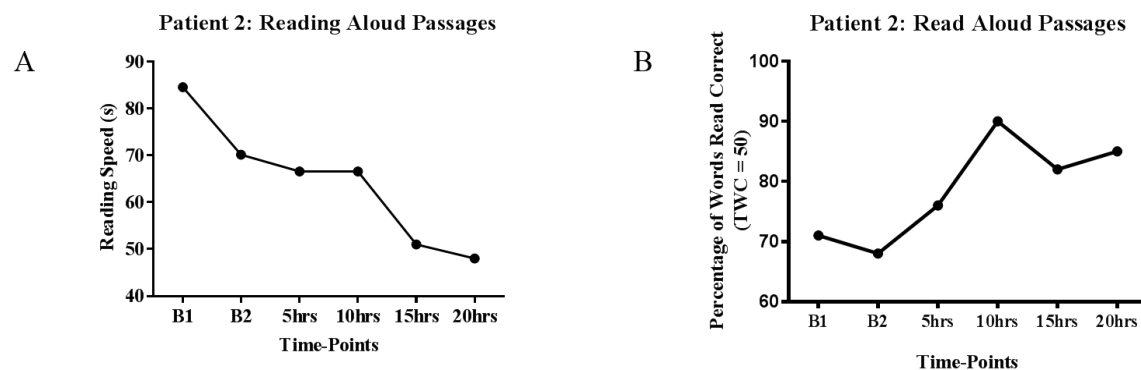


Figure 18. (A) Patient 2's mean reading aloud-speed across all time points. Mean calculated as an average of reading two passages aloud. (B) Patient 2's percentage of words read aloud correctly across all time-points. After 20-hours of therapy both reading speed and the number of words read correctly per passage improved.

#### E. Therapy effect on single-word reading speed (between group)

Single word reading speeds were measured at two time-points only, at baseline and after 20-hours of therapy for each patient and their control group. Results pre- and post-treatment for each patient are shown in Tables 11, 12, 13 and 14.

Paired-samples t-tests indicated that single word reading speeds for both patients were significantly faster post-therapy for all word-lengths (3, 5, and 7-letter words). The mean differences between patient 1's pre- and post-therapy reading speeds were: three-letter words ( $M = 153.61$ ,  $SD = 163.84$ ),  $t(30) = 5.22$ ,  $p < 0.001$ ; five-letter words ( $M = 133.52$ ,  $SD = 337.85$ ),  $t(32) = 2.27$ ,  $p < 0.05$ ; seven-letter words ( $M = 84.72$ ,  $SD = 164.24$ ),  $t(31) = 2.92$ ,  $p < 0.01$ . See Figure 19A.

The mean differences between patient 2's pre- and post-therapy reading speeds were: three-letter words ( $M = 412.43$ ,  $SD = 720.16$ ),  $t(27) = 3.03$ ,  $p < 0.01$ ; five-letter words ( $M = 423.88$ ,  $SD = 493.52$ ),  $t(25) = 4.38$ ,  $p < 0.001$ ; seven-letter words ( $M = 605.88$ ,  $SD = 784.51$ ),  $t(23) = 3.78$ ,  $p < 0.001$ . See Figure 19B.

Table 11. Patient 1 pre-treatment single word results

	Control (N = 28)								
Reaction Times (ms)	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Three-letter	571.87	1258.61	808.82	171.83	819.77	0.06	0.48	37.93	66.79
Five-letter	548.06	1004.39	754.35	136.91	780.55	0.188	0.43	42.69	71.34
Seven-letter	492.69	1059.31	751.14	165.25	715.66	-0.21	0.42	27.84	56.43

Note. Tables show reaction time comparisons between control group and patients for three, five, and seven-letter words. Confidence limit represents estimated percentage of normal population falling below individual score = 100%.

Table 12. Patient 1 post-treatment single word results

	Control (N = 28)								
Reaction Times (ms)	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Three-letter	571.87	1258.61	808.82	171.83	666.16	-0.82	0.21	10.38	34.57
Five-letter	548.06	1004.39	754.35	136.91	647.03	-0.77	0.22	11.44	36.19
Seven-letter	492.69	1059.31	751.14	165.25	630.94	-0.72	0.24	12.72	38.04

Note. Tables show reaction time comparisons between control group and patients for three, five, and seven-letter words, Confidence limit represents estimated percentage of normal population falling below individual score = 100%.

Table 13. Patient 2 pre-treatment single word results

	Control (N = 28)								
Reaction Times (ms)	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Three-letter	571.87	1258.61	808.82	171.83	1795.79	5.67	0.000**	100	100
Five-letter	548.06	1004.39	754.35	136.91	1718.54	6.92	0.000**	100	100
Seven-letter	492.69	1059.31	751.14	165.25	1876.04	6.69	0.000**	100	100

Note. Tables show reaction time comparisons between control group and patients for three, five, and seven-letter words, Asterisks represent significant differences between groups at each word length at  $p < 0.01$ . Confidence limit represents estimated percentage of normal population falling below individual score = 100%.

Table 14. Patient 2 post-treatment single word results

	Control (N = 28)								
Reaction Times (ms)	Minimum	Maximum	Mean	SD	Patient	t	p	95% lower confidence limit	95% upper confidence limit
Three-letter	571.87	1258.61	808.82	171.83	1383.36	3.30	0.001**	99.16	100
Five-letter	548.06	1004.39	754.35	136.91	1317.09	4.04	0.000**	99.84	100
Seven-letter	492.69	1059.31	751.14	165.25	1357.47	3.61	0.001**	99.56	100

Note. Tables show reaction time comparisons between control group and patients for three, five, and seven-letter words, Asterisks represent significant differences between groups at each word length at  $p < 0.01$ . Confidence limit represents estimated percentage of normal population falling below individual score = 100%.

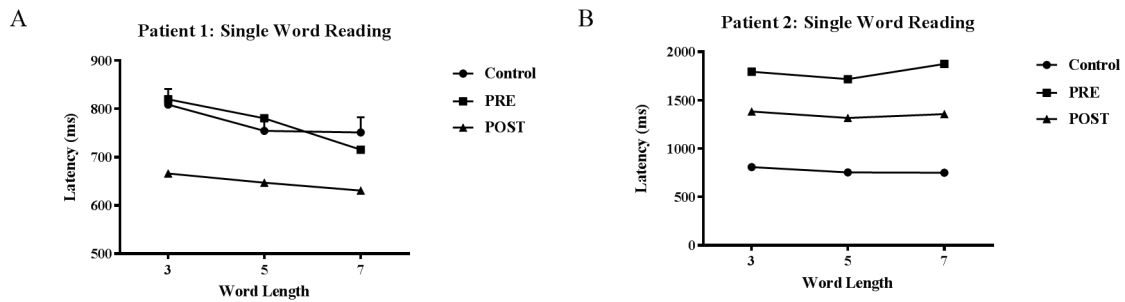


Figure 19. **Therapy Effects on Single-Word Reading.** (A) Effect of therapy on single-word reading for patient 1. (B) Effect of therapy on single-word reading for patient 2. PRE: Pre-therapy; POST: Post-therapy. Controls' results are displayed as reference.

## Part II.

### Arabic-Read Right Therapy App

#### A. Visual Text-Reading

There was a significant main effect of therapy at all time-points in both patients. Figure 20 below illustrates average passage reading speeds for both patients at each time-point.

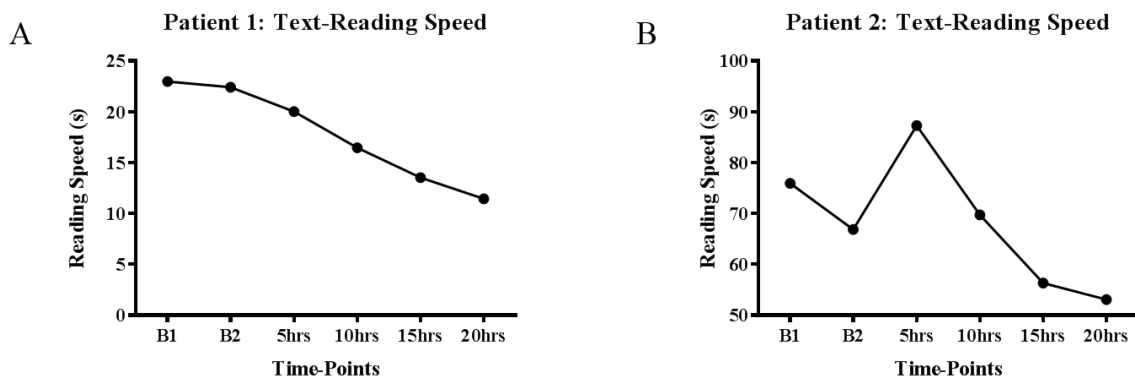


Figure 20. **Mean Text-Reading Speeds (App).** Average passage reading speeds for patient 1 and 2 across each time-point on static text. B1: Eye-tracker recordings. B2: Arabic-Read Right app recordings. Reading speeds are measured in seconds.



## B. Visual Neglect

Neglect was diagnosed if patients missed twice as many targets to one side compared with the other, or if they had a similar ratio of revisits. Numbers within targets are revisits (abnormal). Patient 1 presented with no left-sided neglect and had a mean score of 95.8% across all time-points. Patient 2 presented with moderate to severe neglect and had a mean score of 56%. As patient 2's neglect improved with therapy, her number of revisits reduced as well. Percent correct of selected targets (N = 15) for each time-point is graphed in Figure 21 for patient 1 and Figure 22 for patient 2.

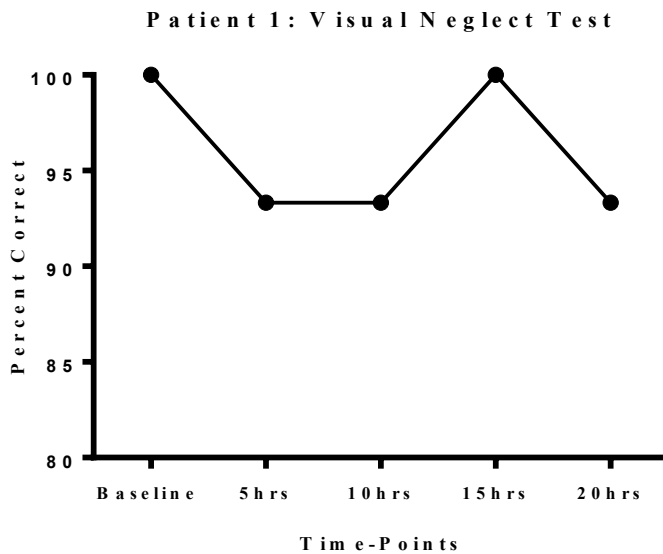


Figure 21. Patient 1's percent correct scores for each time point. Patient 1 presented with no neglect.

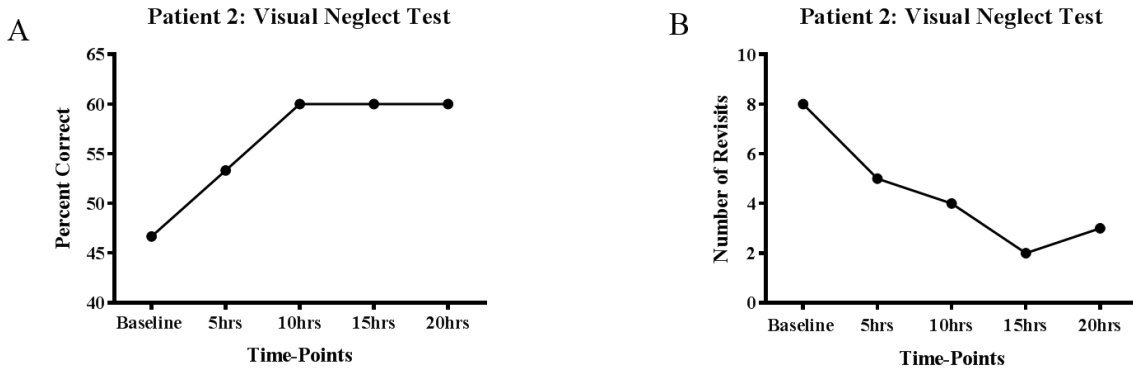
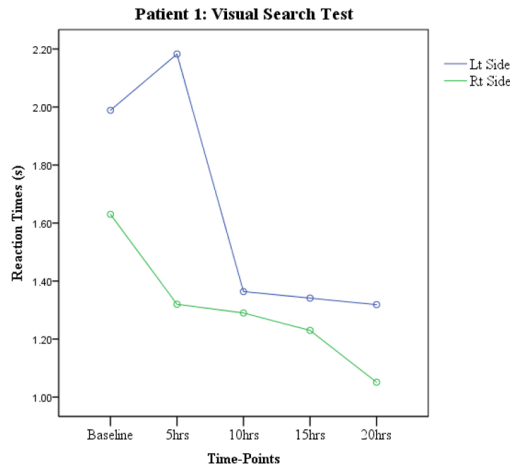


Figure 22. (A) Patient 2's percent correct scores for each time point. Patient 2 presented with left-sided neglect. (B) Patient 2's number of revisits for each time-point. Numbers within targets are revisits (abnormal). As patient 2's neglect improved with therapy, her number of revisits reduced as well.

### C. Visual Search

To investigate the effects of therapy on visual search abilities both patients' visual search reaction time data, at each 5-hour time-point, were entered into two separate (one for each patient) two-way repeated measures ANOVA. Patient 2's data required a Greenhouse-Geisser correction. In patient 1 there was a significant main effect of time, ( $F(4, 28) = 4.39, p < 0.01$ ) and a significant main effect of hemifield side (left and right), ( $F(1, 7) = 10.98, p < .01$ ). There was no significant time x hemifield interaction for all time-points, ( $F(4, 28) = 0.63, p = 0.45$ ). See Figure 23A. In patient 2 there were no significant effects of time, ( $F(1.26, 8.82) = 1.66, p = 0.19$ ), hemifield side (left and right), ( $F(1, 7) = 4.86, p = 0.06$ ), nor time x hemifield interactions, ( $F(1.25, 8.75) = 1.40, p = 0.26$ ). See Figure 23B.

A



B

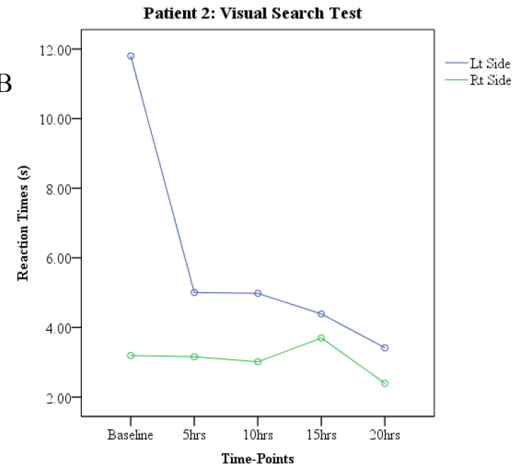
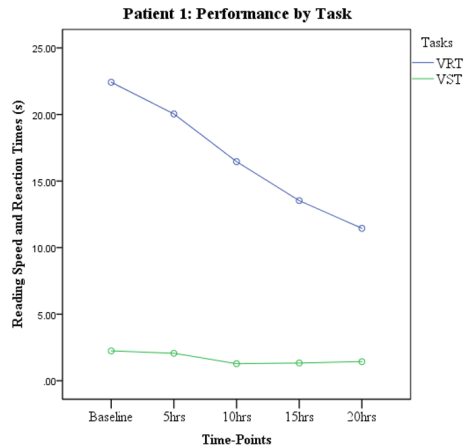


Figure 23. (A) Patient 1's average visual search reaction times across all time-points. Blue line denotes left-side of the visual field of the vertical midline, and green line denotes right-side of the visual field of the vertical midline. (B) Patient 2's average RTs across all time points.

#### D. Therapy effects by Tasks (Text-Reading and Visual Search)

To investigate the effects of therapy on Text-Reading and Visual Search performance, text reading speed and visual search data for both patients, at each 5-hour time-point, were entered into separate two-way repeated measures ANOVAs. A Greenhouse-Geisser correction was required for patient 1. For both patients there was a significant main effect of time, patient 1: ( $F(2.03, 10.13) = 83, p < 0.001$ ); patient 2: ( $F(4, 20) = 3.01, p < 0.04$ ). There was a significant main effect of task, patient 1: ( $F(1, 5) = 4848.40, p < 0.001$ ); patient 2: ( $F(1, 5) = 496.65, p < 0.001$ ). More importantly, there was a significant time x task interaction for all time-points, patient 1: ( $F(1.84, 9.19) = 74.93, p < 0.001$ ); patient 2: ( $F(4, 20) = 6.93, p < 0.001$ ). Indicating that the reading therapy significantly improved both patients' text-reading speed more than their visual search speed. See Figure 24.

A



B

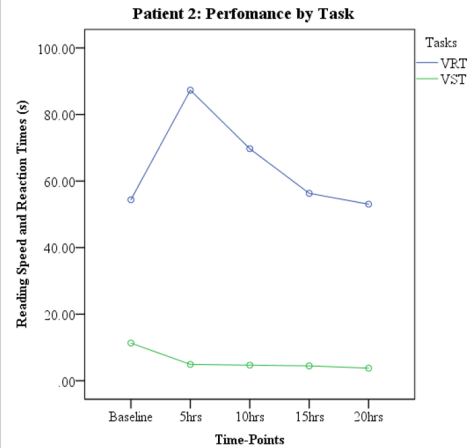


Figure 24. (A) Patient 1 average task performance across all time-points. Blue line denotes VRT (Visual Text-Reading Test) and green line denotes VST (Visual Search Test). (B) Patient 2 average task performance across all time-points.

### E. Patient-reported outcome measures (ADLs)

Results of patient-reported outcome measures are summarized for pre- and post-therapy for patient 1 in Table 15 and patient 2 in Table 16.

Table 15. Patient 1 self-reported outcome measure – activities of daily living (ADLs)

	PRE (%)	POST (%)
Hygiene	100	100
Driving	85	56
Find Things	59	100
Reading News	80	100
Reading Books	75	100
Enjoy Reading	78	100

Note. A vertically oriented visual analogue scale was used by the patients to rate their abilities for the following six Activities of Daily Living (ADLs): hygiene, driving, finding things, reading news, reading books, and enjoying reading. The scale ranged from 0 (impossible) to 100 (no problem).

Table 16. Patient 2 self-reported outcome measure (ADLs)

	PRE (%)	POST (%)
Hygiene	50	86
Driving	51	77
Find Things	100	100
Reading News	54	100
Reading Books	54	60
Enjoy Reading	54	100

Note. A vertically oriented visual analogue scale was used by the patients to rate their abilities for the following six Activities of Daily Living (ADLs): hygiene, driving, finding things, reading news, reading books, and enjoying reading. The scale ranged from 0 (impossible) to 100 (no problem).

### Part III.

#### Eye-movement behaviour across all time-points (within-subject effects)

Eye-tracking recordings of eye movement behaviour during passage reading for each time-point are shown for patient 1 in Table 17 and patient 2 in Table 18.

Table 17. Patient 1 eye movement data during passage reading

	Total Time (s)	Reading Speed (wpm)	Rt Sacc	Lt Sacc	Regressions	Total Fix	Total Fix Lt	Total Fix Rt	Total Avg Fix Dur (s)	Total Avg Fix Dur Lt	Total Avg Fix Dur Rt	Total Avg Sacc Amp (deg)	Total Avg Sacc Amp Lt	Total Avg Sacc Amp Rt
Baseline	22.98	130.53	6	28	3	29	31	27	0.49	0.50	0.48	2.36	2.45	2.27
5-hrs	18.92	158.60	6	26	3	17	18	17	0.46	0.46	0.46	2.46	2.39	2.53
10-hrs	16.17	185.47	6	23	2	15	16	14	0.45	0.41	0.48	2.60	2.51	2.70
15-hrs	14.90	201.30	6	20	1	14	14	13	0.47	0.49	0.45	2.65	2.74	2.56
20-hrs	11.94	251.26	6	19	1	13	13	12	0.39	0.40	0.38	2.83	2.87	2.80

Key: Total Time = Text reading speed in seconds; WPM = Words per minute; Fix = number of fixations; Dur = fixation duration; SaccAmp = Saccadic Amplitude; TotFix (Lt, Rt) = total number of fixations to the left or right side of the passage; AvgFixDur (Rt, Lt): Average fixation duration to the left or the right side of the passage; AvgSacAmp (Lt, Rt) = Average leftward or rightward saccades

Table 18. Patient 2 eye movement data during passage reading

	Total Time (s)	Reading Speed (wpm)	Rt Sacc	Lt Sacc	Regressions	Total Fix	Total Fix Lt	Total Fix Rt	Total Avg Fix Dur (s)	Total Avg Fix Dur Lt	Total Avg Fix Dur Rt	Total Avg Sacc Amp (deg)	Total Avg Sacc Amp Lt	Total Avg Sacc Amp Rt
Baseline	83.53	35.91	6	41	12	59	20	39	1.09	1.23	1.05	1.87	1.88	1.48
5-hrs	92.81	32.32	5	57	14	80	36	44	1.09	0.93	1.15	2.20	2.29	2.14
10-hrs	73.47	40.83	5	58	10	73	48	28	0.84	0.84	0.86	2.54	2.42	2.77
15-hrs	70.57	42.51	5	58	8	71	28	43	0.88	0.83	0.90	2.20	2.21	2.18
20-hrs	58.63	51.17	6	41	5	52	22	30	0.90	0.94	0.77	2.44	2.58	2.19

Key: Total Time = Text reading speed in seconds; WPM = Words per minute; Fix = number of fixations; Dur = fixation duration; SaccAmp = Saccadic Amplitude; TotFix (Lt, Rt) = total number of fixations to the left or right side of the passage; AvgFixDur (Rt, Lt): Average fixation duration to the left or the right side of the passage; AvgSaccAmp (Lt, Rt) = Average leftward or rightward saccades

#### A. Saccadic Amplitudes across Time-Points

To investigate the effects of therapy on angular distance saccadic amplitudes for each patient, at each 5-hour time-point, were entered into separate two-way repeated measures ANOVAs. There was a significant main effect of time for patient 1 but not patient 2, patient 1: ( $F(4, 16) = 3.63, p < 0.05$ ); patient 2: ( $F(4, 20) = 2.44, p = 0.08$ ). There was no effect of hemifield side (left and right), patient 1: ( $F(1, 4) = 0.03, p = 0.87$ ); patient 2: ( $F(1, 5) = 0.54, p = 0.50$ ) and there were no time x hemifield interactions, patient 1: ( $F(4, 16) = 0.51, p = 0.73$ ); patient 2: ( $F(4, 20) = 1.12, p = 0.38$ ). See Figure 25.

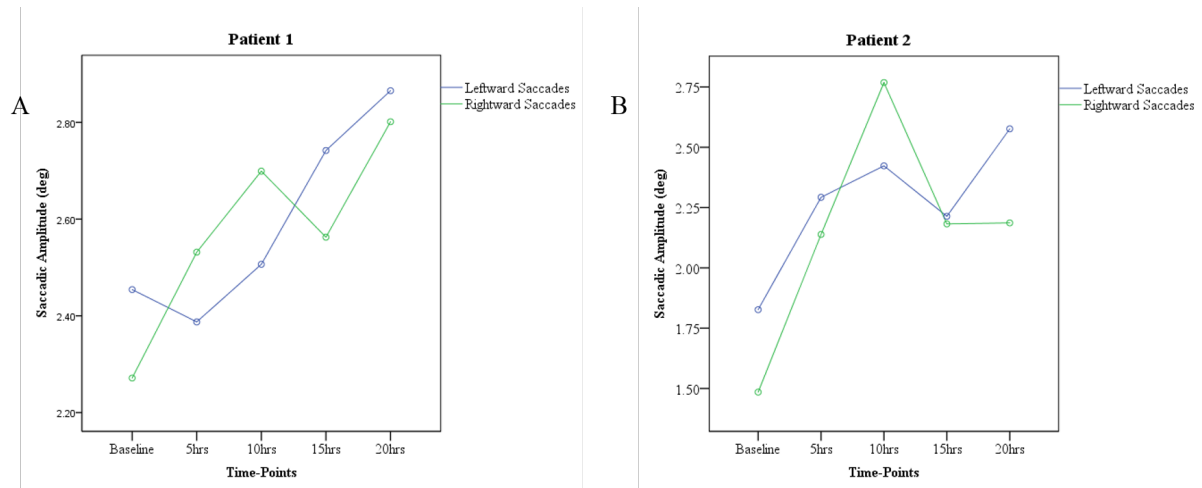
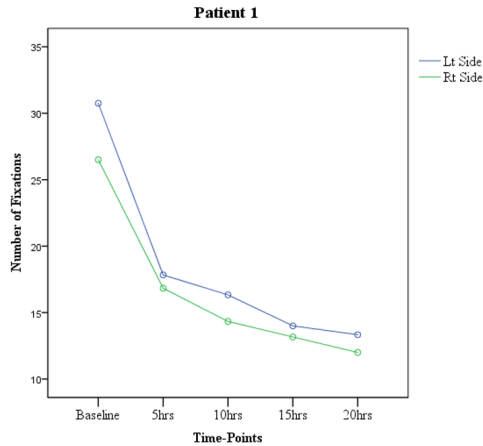


Figure 25. *Mean saccadic amplitudes across all time-points.* (A) Patient 1's both average leftward and rightward saccadic eye-movement length increased after 20 hours from 2.36 degrees pre-therapy to 2.80 degrees post-therapy. (B) Patient 2's both average leftward and rightward saccadic eye-movement length increased after 20 hours from 1.78 degrees pre-therapy to 2.44 degrees post-therapy.

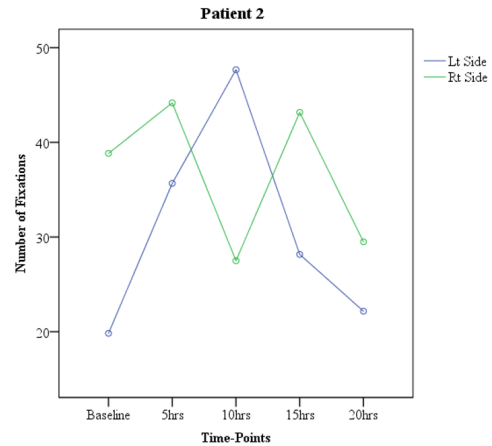
## B. Number of Fixations across Time-Points

To investigate the effects of therapy on the number of fixations both patients' number of fixations, at each 5-hour time-point, were entered into separate two-way repeated measures ANOVAs. In both patients there was a significant main effect of time, patient 1: ( $F(4, 20) = 86.60, p < .01$ ); patient 2: ( $F(1.80, 9) = 7.26, p < 0.05$ ) and a significant main effect of hemifield side (left and right), patient 1: ( $F(1, 5) = 11.22, p < 0.05$ ); patient 2: ( $F(1, 5) = 15.50, p < 0.05$ ). In patient 1 there was no significant time x hemifield interaction, ( $F(4, 20) = 1.22, p = .34$ ). See Figure 26A. In patient 2 this interaction was significant, ( $F(4, 20) = 1.22, p < 0.001$ ). See Figure 26B.

A



B



*Figure 26. Mean number of fixations across all time-points. (A) Patient 1's average number of fixations on both the left and right side decreased with therapy from 29 fixations pre-therapy to 13 fixations post-therapy. (B) Patient 2's average number of fixations on both the left and right side decreased with therapy from 80 fixations pre-therapy to 52 fixations post-therapy. Reduced number of fixations at baseline was due to the patient's left-sided neglect. That is, Patient 2 was reading fewer words per passage on the left side at baseline than after 5- and 10-hours of therapy.*

### C. Fixation Durations across Time-Points

To investigate the effects of therapy on duration time both patients' fixation durations at each 5-hour time-point, were entered into separate two-way repeated measures ANOVAs. For patient 1 there was a significant main effect of time, ( $F(4, 20) = 5.15, p < .01$ ). There was no significant main effect of hemifield side (left and right), ( $F(1, 5) = .05, p = .83$ ) nor time x hemifield interactions, ( $F(4, 20) = 2.20, p = .11$ ). See Figure 27A. For patient 2 there were no significant main effects of time, ( $F(4, 20) = 1.58, p = .22$ ), hemifield side (left and right), ( $F(1, 5) = .001, p = .97$ ) nor time x hemifield interactions, ( $F(4, 20) = 2.21, p = .10$ ). See Figure 27B.



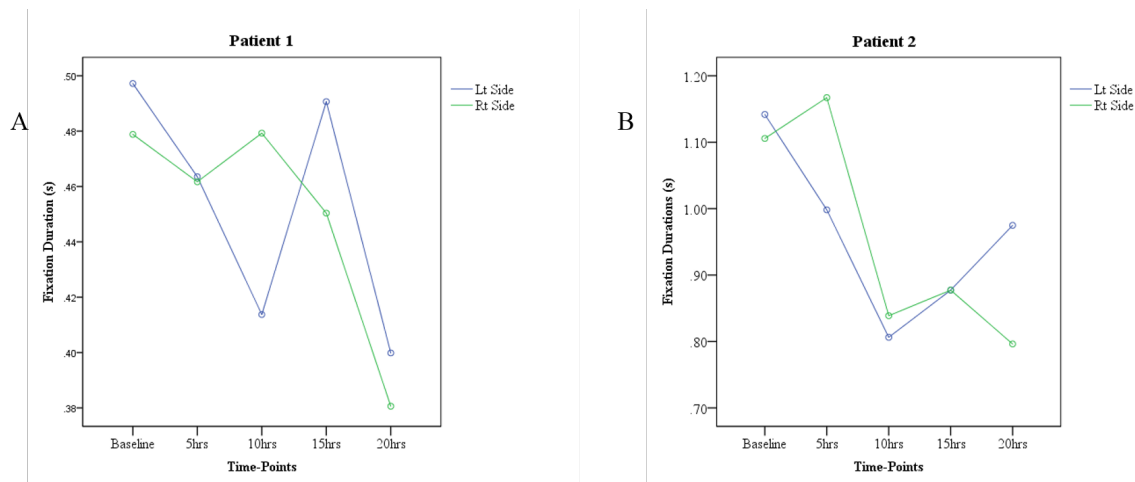


Figure 27. *Mean fixation durations across all time-points.* (A) Patient 1's average fixation duration time on both the left and right side has decreased with therapy from 0.49 seconds pre-therapy to 0.39 seconds post-therapy. (B) Patient 2's average fixation duration time on both the left and right side has decreased with therapy from 1.09 seconds pre-therapy to 0.90 seconds post-therapy, with the fastest average duration time being after 10-hours of therapy.

## 5.5 Discussion

### Part I.

#### A. Therapy effect on text-reading (between-group)

##### a. Pre-therapy

Consistent with previous reports on left-to-right readers with HA, my patients' mean reading speeds significantly differed from those of their matched normal readers (Zihl, 1995; Leff et al., 2000; Spitzyna et al., 2006). Furthermore, in terms of reading text reading speeds, and associated eye-movement behaviours patient 2 was more impaired than patient 1. Patient 1 had a mean reading time of 22.98 seconds (131 wpm) pre-therapy. Patient 2 had a mean reading time of 82.53 seconds (36 wpm) pre-therapy. Patient 1's mean reading speed pre-therapy was better than the mean reading speeds of both the right hemisphere HA group in Zihl's study (53 wpm, SD = 31) and in Spitzyna

et al.'s study (Group 1: 95 wpm, SD = 34.85; Group 2: 82 wpm, SD = 19.73). However, the right hemisphere groups in both studies were closer to patient 2's mean reading time of 82.53 seconds. It is to be expected that within group variability will occur in text reading speeds of left-to-right reading patients with HA despite visual field sparing.

#### **b. *Post-therapy***

Several studies have attempted and succeeded in treating left-to-right readers with HA (Zihl, 1995; Spitzyna et al., 2007; Schuett et al., 2008; Schuett & Zihl, 2012), but this is the first attempt to investigate the effect of therapy on mean reading speeds in right-to-left readers with HA. Both patients showed significant improvements in their reading speeds. Patient 1 had a 48% increase in mean reading speed from 131 wpm pre-therapy to 251 wpm post-therapy. In fact, patient 1's mean reading speed post-therapy was within the normal range when compared to her matched control group of 202 wpm. Patient 2 who was more severely impaired at the outset had a 29% increase in mean reading speed from 36 wpm pre-therapy to 51 wpm post-therapy. The magnitude of improvement attributable to laterally scrolling text therapy in both my patients (mean = 38.5 %) is higher than the 18% improvement found by Spitzyna et al. (2007) but comparable to the 38% reported by Zihl (1995). This may be due to methodological differences (e.g., group study analysis vs. single study analysis) or the duration of therapy, which was 20 hours for both my patients but 15 hours on average in the Spitzyna et al. study.

### **B. Therapy effect on word-reading (between-group)**

#### **a. *Pre-therapy***

In direct contrast to the literature based on left-to-right readers with HA (Leff et al., 2001), my controls read Arabic shorter words significantly more slowly than longer

words. One interpretation of this result is that the orthographic properties of longer words were more easily recognized than shorter words. Thus, Arabic words with more letters would be more easily recognized due to their reduced similarity in their orthographic representations (Farid & Grainger, 1996). Consistent with this, patient 1 exhibited the same single word-length reading pattern despite her HA. Yes, she was significantly slower at single-word reading overall compared to healthy normal controls. However, she was slower to read three-letter words than both five and seven-letter words, indeed she read seven-letter words the fastest.

Patient 2 in contrast exhibited a different pattern than normals when reading single words of different lengths. She was slower to read seven-letter words than both five and three-letter words, where five-letter words were read the fastest. In a study on left-to-right reading patients with HA, Leff et al. (2001) showed four patients with HA had a greater word-length effect than either the normal or hemianopic controls, with their hemianopia adding a word-length effect of 51-162 ms per additional letter over and above three letters. Consistent with this patient 2's hemianopia added 80.25 ms per additional letter over and above three letters. Furthermore, in this same patient there was evidence of an abnormal distribution of visual attention favouring the right rather than the left side of words likely due to her visual neglect. Most of her single-word reading errors were limited to the end of words (Arabic is read from right-to-left). This was most evident when reading five and seven-letter words. Consistent with this, a study on English-reading patients (left-to-right readers) with left-sided homonymous hemianopia, patients produced single-word reading errors that were predominately limited to the

beginning of target words (more than six letters). The last few letters of the target word were read correctly (Kinsbourne & Warrington, 1962).

#### ***b. Post-therapy***

Both patients read single words of all lengths (three, five, and seven-letters) significantly more quickly post therapy. Perhaps this could be a justification as to why their text reading speeds improved. Consistent with this is Spitzyna et al.'s study (2007), in which right-sided homonymous English-reading patients with HA, who showed significant improvement in text-reading speed post-therapy (practiced reading moving text), also read single words (three, five, seven and nine-letters) significantly quicker. In addition, patient 2 appeared to normalise her reading pattern i.e., she read three-letter words slower than both five and seven-letter words. This is the same single word-length reading pattern as exhibited by patient 1 and the normal participants. Yet, in patient 2 seven-letter words remained slower than five-letter words suggesting a word-length effect not seen in patient 1 nor the normal participants. Irrespective, her single word reading word-length effect decreased from 80.25 ms per additional letter to 25.89 ms per additional letter over and above three letters, suggesting a milder word-length effect post-therapy. Nevertheless, patient 2's single-word reading for all lengths (three, five, and seven-letters) remained inferior, even after therapy, when compared with patient 1 and matched healthy participants.

## Part II.

### Therapy effect on text reading (within-subject)

#### *A. Visual Text-Reading*

Consistent with Ong et al.'s (2012) study, there was a significant effect of the laterally scrolling text therapy (in my case in Arabic) at all four time-points post-therapy for both patients. Overall the effect sizes were found to be large for both patients. In the case of Ong et al.'s study the effect size was small and appeared to plateau at 20 hours. This is the pattern I observed in patient 2 but not in patient 1 where the effect was large irrespective of dose. In my case this may in part be due to the variation in how long each patient took to reach each five-hourly dose mark (patient 1: 17 days; patient 2: 8 days). Irrespective, my analyses revealed that therapy dose rather than simple practice effects on the assessments contributed to improvement in reading speed performance over time. Consistent with Ong and colleagues study a dose of 15 -20 hours resulted in a significant improvement of static text reading speed.

#### *B. Visual Search*

Interestingly, both patients' visual search times in left and right hemifield sides improved over time. At baseline as expected, both patients were worse on the left pre-therapy, due to their left-sided hemianopia. If their visual search improvements over time were directly due to the therapy I would predict a time by hemifield-side significant interaction. I did not find this result i.e., while patient 2's left-sided visual neglect did improve over time, there was statistically no significant side (i.e., left or right) specific effect. Irrespective, my results are consistent with studies that used similar training of compensatory eye-movement strategies on left-to-right reading patients with HA. These

studies reported training related improvements that are depicted by reduced visual search times and errors (Zihl, 1995; Schuett, 2009; Schuett, Heywood, Kentridge, Dauner, & Zihl; 2012). Perhaps visual search time improvements could be due to practice effect that is not related to the eye movement therapy (laterally scrolling text from left-to-right) used in this study. Still, the mechanism underlying these changes remains unclear and further investigation is warranted.

### *C. Therapy effects on Tasks (Visual Text-Reading Test and Visual Search Test)*

Use of the Arabic Read-Right laterally scrolling text (left-to-right eye movement therapy) showed that training-related improvements in reading and visual search were task specific. That is, completing text-reading training led to specific significant improvements in performance of reading but not in visual search, for both patients. Previous eye-movement based therapeutic studies induced compensatory eye movements via repetitive practice (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain & Leff, 2015). They then investigated if any therapeutic effects generalized to everyday activities such as patient-reported outcome measures. Visually guided tasks (e.g., reading vs. visual search) require different types of eye movements. Thus, eye-movement based therapies have been shown to be task specific (Schuett, Heywood & Kentridge, 2012). In both my patients the laterally scrolling text therapy lead to clear task specific changes (text-reading) not generalisation to other visual tasks e.g., visual search task. Despite my study using a compensatory therapy (i.e., training patients to intentionally shift their gaze into their blind visual field side), the training focused on reading text. As such my result is consistent with previous studies of left-to-right HA treatment where reading training

elicited a significant increase in reading speed but did not affect visual search times and errors (Spitzyna et al., 2007; Schuett et al., 2012).

### Part III.

#### A. Eye-movement behaviour pre-therapy

Consistent with previous reports on left-to-right readers with HA, my patients' eye movements differed from those of their matched normal readers with respect to both spatial (saccadic amplitudes) and temporal (duration of fixations) measures (Zihl, 1995; Leff et al., 2000; McDonald et al., 2006). In normal readers eye movements are guided by both foveal and parafoveal text information extraction (Rayner, McConkie & Ehrlich, 1978). My patients seemed to try to compensate for their left parafoveal field loss by changing their eye-movement behaviours. This was indexed by both smaller leftward and rightward saccades, and increased fixation durations, consistent with findings from studies of left-to-right reading right hemisphere patients with HA (Zihl, 1995; McDonald et al., 2006)

At baseline, both my patients adopted inefficient compensatory eye-movement strategies characterized by higher number of fixations, longer fixation durations, higher number of saccades to the right, increased number of regressions, and reduced leftward and rightward saccadic amplitudes. One interpretation is that this inefficient reading strategy is an attempt to compensate for the reading impairment caused by the visual field defect (McDonald et al., 2006). Consistent with my patients, Zihl's (1995) right-hemisphere patients showed more fixations and longer fixation durations and smaller amplitudes of saccades to the right when compared to normal readers. However, in contrast to Zihl's patients both my patients showed significantly smaller amplitudes of

saccades to the left. One possible explanation for this is that in Arabic the distribution of letters that convey core meaning is spread throughout words. Jordan et al. (2015) proposed that Arabic cursive script reduces visual acuity for words outside foveal vision. My patients tended to make shorter saccades in both directions to compensate for reduced parafoveal information and target specific locations in words to extract meaning.

#### B. Eye-movement behaviour post-therapy

Both my patients showed significant improvements in their reading eye-movements post therapy. After therapy the number of eye movement fixations, their regressions, fixation durations and the number of saccades to the left and to the right was significantly lower. Consistent with left-to-right readers with a right-sided HA in Zihl's (1995) study, both patients showed significantly enlarged saccades to the left and to the right after therapy.

Paired with the enhanced reading speed post therapy these data suggest reading speed and performance is dependent on the number of fixations, the number of both leftward and rightward saccades, and fixation durations. That is, visual processing of text information is faster when there are fewer number of fixations, shorter fixation durations, and fewer regressions. It is important to note however, that in my patients, improvements in eye-movement behaviours were not ascribed to left visual field improvements. I found no change in the left visual field post therapy. Despite a significant improvement in reading performance, patient 2's reading eye-movement behaviours remained impaired after therapy, as compared to patient 1 and her matched normal controls.

In conclusion, this is the first study of HA in readers of a non-Latinate script. Almost all of the world literature on acquired alexia (of any form) is on patients who have left hemisphere brain damage. Arabic readers with HA have a left-sided hemianopia, as a consequence of right



hemisphere brain injury. This study of native Arabic readers with HA enabled me to make a comparison (based on effect sizes) with published data on how text reading in a non-Latinate language (Arabic) compared with Latinate language (English): a) is affected by hemianopia; and, b) responds to moving text therapy. As such it is hoped that the results from this study will not only have an application to therapeutic rehabilitation of HA, it will also contribute to our overall understanding of Arabic reader's eye movements and expand our understanding of oculomotor processing across different languages.

There are important theoretical implications for patients with HA and a right hemisphere lesion. It is well known that right posterior brain functions are dominant for visuo-spatial processing. Despite significant impairment in visuo-spatial processing, my right hemisphere HA patients responded well to the laterally scrolling text therapy. These right hemisphere patients showed both an increase in saccadic amplitudes (spatial) and a decrease in fixation durations (temporal) after treatment. In other words, therapy influenced top-down cognitive processing by inducing involuntary saccades into the patient's blind field (Zihl, 1995; Spitzyna et al., 2007), such that the lost parafoveal field area could be successfully substituted. Regular practice of at least twenty hours reading laterally scrolling text appears to have facilitated the process of oculomotor compensation. In these two right hemisphere, left-sided Arabic reading HA patients, my Arabic-Read Right therapy app worked. Their reading speed of static text significantly improved both on formal text passage reading test, and importantly they reported this as being significantly improved in reading activities of daily living.

With respect to patient 2, who presented with left-sided neglect dyslexia as well as HA, her relatively fast text reading speed at baseline, was due to the fact that she neglected many words on the left side. As therapy progressed, her text reading speed slowed down up to a

therapy dose of five hours. Then, post-therapy (after a minimum therapy dose of twenty-hours), her text-reading speed got faster with eye movement therapy. Her increased text-reading speed was perhaps due to improved focused attention to the left side. So I suggest that perhaps her left-sided neglect improved more than her HA (see Figure 15 patient 2: passage reading). In developing my Arabic-Read Right app I aimed to provide a diagnostic and therapeutic tool that patients with HA, caregivers, and medical personnel could access remotely from anywhere in the world. This is now freely available: <https://itunes.apple.com/app/id964478309>.

## Chapter 6: Arabic-Read Right: app-delivered therapy for Arabic-reading patients with Hemianopic Alexia

### 6.1 Abstract

Arabic is one of the most widely read languages, yet no therapies exist for rehabilitation of Arabic patients with a reading disorder called Hemianopic Alexia. Hemianopic Alexia (HA) is a reading disorder related to compromised vision in one half of the visual field (hemianopia), usually caused by stroke. This study investigated the rehabilitation of HA following stroke, in Arabic readers. I developed a novel online iPad treatment package (app) for Arabic readers with HA called Arabic-Read Right ([http://www.ucl.ac.uk/aphasialab/apps/arabic\\_rr.html](http://www.ucl.ac.uk/aphasialab/apps/arabic_rr.html)). The app uses laterally scrolling text (from left-to-right) as a means to induce therapeutic, small-field, optokinetic nystagmus. In English readers, this method (using right-to-left scrolling text) has been shown to improve reading of static text after 7 hours of practice (Zihl, 1990). The aim of the Arabic-Read Right app is to improve reading speed, such that Arabic-reading HA patients can return to work, and enjoy reading for pleasure. Here I present data from 4 HA patients who used the Arabic-Read Right app, aged 57 – 68 years ( $M = 60.5$ ,  $SD = 5.07$ ). Their reading speed on static text (passages) was assessed after every five-hours of practice up till a total therapy dose of 20 hours. All patients improved their text reading speeds (pre-therapy:  $M = 28.74$  ( $SD = 8.92$ ) seconds; wpm = 103; post-therapy: 19.86 ( $SD = 5.10$ ); wpm = 152), an average unstandardized effect size of 44% at 20 hours, and reported that it significantly improved their “real-life” reading abilities. In fact, Arabic-Read Right therapy produced significant improvements in text reading speeds at all time points with a clear dose effect: 14% at 5 hours, 21% at 10 hours, 41% at 15 hours, and 52% at 20 hours. Additionally, I examine the specificity of this eye movement therapy (laterally scrolling text) on text-reading speed (main outcome) and visual search (control measure) to see whether training-related performance improvements can transfer between these two tasks. This Arabic-Read Right app is the first effective and empirically supported reading treatment for HA Arabic readers. It has two important clinical implications. Firstly, through its comprehensive assessment package, it aids the clinical diagnosis of HA,


a useful tool for neurologists, neuro-ophthalmologists and speech and language therapists. Secondly, as the app is web-based and free, it provides patients globally with an effective web-based treatment for their reading impairment anytime and anywhere that suits them. This represents a realistic way of delivering sufficient and effective therapy to Arabic reading HA patients so that they can obtain clinically meaningful improvements.

## 6.2 Introduction

Hemianopic alexia is a common acquired reading disorder. It occurs when one half of a person's visual field is damaged (a hemianopia). The commonest causes are: stroke, head injury or brain tumour (Isaef, Wallar & Duncan, 1974). For left-to-right readers (English readers) a right-sided hemianopia causes more problems with text than a left-sided hemianopia because the reader is deprived of important visual information about upcoming words (Leff, Scott, Crewes, Hodgson, Cowey, Howard, & Wise, 2000). The loss of this information slows reading speeds to around a third of normal.

Specific eye movement therapy (practicing reading laterally scrolling text) can increase patients' reading speeds by 40% or more (Ong, Brown, Robinson, Plant, Husain & Leff, 2012). When this type of text (laterally scrolling) is viewed, it induces an involuntary eye-movement called small field optokinetic nystagmus, which induces involuntary saccades into the patient's blind field. Sufficient practice with this improves patients' reading eye movements and text reading speed when they return to normal, static text (Spitzyna, Wise, McDonald, Plant, Crewes, & Leff, 2007). Importantly, Ong and colleagues (2012) have shown that this therapy can be delivered successfully via a web app "Read Right": [www.readright.ucl.ac.uk](http://www.readright.ucl.ac.uk). Until now, this therapy has only been made available for English readers. Therefore, I developed a novel online

treatment package (app) for Arabic readers with HA called Arabic-Read Right {Ikra lItakūn

“read to become” (اقرأ لتكون) Logo: .

There are 234 million Arabic readers in the Arab states (UNESCO Institute of Statistics, 2014). So, if a stroke occurs, approximately 20% of these readers with a stroke may develop HA (Isaef, Wallar, Duncan, 1974). While it has reasonably been assumed that HA therapy using laterally scrolling text should work across multiple languages, as has been shown in readers of English or German (Zihl, 1995; Ong et al., 2012) it has not been validated in readers of languages where text is written in the opposite direction from right-to-left e.g., as in Arabic or Hebrew languages.

To directly test this hypothesis I developed a new app for Arabic readers. This app included both a new comprehensive assessment package to aid the clinical diagnosis of HA in Arabic readers, as well as a novel app treatment package for Arabic reading HA patients.

This required for the assessment components adapting some of the core visual tests of the English Read Right App: <http://www.readright.ucl.ac.uk> (e.g., the visual field test,) additional tests of visual abilities e.g., visual search and visual neglect tests (Eye-Search web-based therapy App: <https://www.eyesearch.ucl.ac.uk/>), and new Arabic reading passages to be used as the primary outcome test measures of the therapy.

These tests served as both measures of the patients’ visual and reading deficits and the specificity of the therapy effects on subsequent reading performance of static text. As secondary outcome measures patients were asked to rate their abilities on activities of daily living following a hemianopia this included both reading of static text e.g., reading a newspaper or book, and non-reading tasks e.g., driving, grooming, and finding items. The therapy itself was the delivery of

scrolling Arabic text (laterally from left-to-right) to induce the involuntary eye movements called optokinetic nystagmus in the reader.

## 6.3 Method

### 6.3.1 Participants

Four chronic stroke patients took part in the study. Mean age 60.5 years (range = 57 – 68,  $SD = 5.07$ ), three males. Two presented with a fixed left visual field homonymous deficit. Mean time since stroke was 4.5 years (See Table 1). Three patients were recruited from the hemianopia clinic at Al Bahar Ophthalmology Centre, Ibn Sina Hospital in Kuwait, and one patient was recruited from the hemianopia clinic at the National Hospital for Neurology and Neurosurgery in London, UK. Initial study consultation was with an experienced speech-language therapist (SA) and all participants gave informed written consent. Ethics for the study was granted by the Wales Research Ethics Committee 6. Patients registered with a valid e-mail address, then logged into the assessment and treatment online app, which was downloaded for free from the Apple store.

Subject inclusion criteria were the following: (1) fixed visual field homonymous deficit as defined by one or more missed stimuli on the automated visual field test; (2) a baseline line text reading speed greater than 40 words per minute (no upper limit was used as all 4 patients were at least one standard deviation below the mean normal reading speed); and (3) completed more than five hours of therapy. The lower limit of reading 40 words per minute was used to exclude subjects with concomitant pure alexia.

Table 19. Demographic details for the 4 patients

Patient	Sex	Age	Cause	Side	HA Type	Onset of Stroke	Reading Speed (wpm)	Change (%) in reading speed: 10 h	Change (%) in reading speed: 20 h
1	M	57	Infarct	LH	Right Homonymous	Oct 2013	131.18	16	37
2	F	59	Infarct	RH	Left Homonymous	Dec 2006	77.49	21	50
3	M	68	Infarct	RH	Left Homonymous	Sep 2015	146.74	15	37
4	M	58	Infarct	LH	Right Homonymous	Feb 2017	91.07	5	50

*Cause: cause of stroke; Side: Side of the stroke (LH: Left hemisphere, RH: Right hemisphere; HA Type: Type of the hemianopia (left side or right side); wpm: words per minute; Percent of change in reading speed from baseline at 10 and 20 hours are presented.*

### 6.3.2 Stimuli

#### Passages

12 passages were chosen and modified from the BBC Arabic current world news

(<http://www.bbc.co.uk/arabic>), and the acquired alexia workbook developed by the *Jeddah*

*Institute for Speech & Hearing* (Naqaweh, 2008). To control for eye movement behaviour the 12

passages were matched for the total number of words ( $n= 50$ ) spread over six lines. They were

then checked for spelling and grammar by two Arabic teachers trained in modern written Arabic

linguistics before being presented in a different randomized order for each participant with HA.

### 6.3.3 Study Design

This is a dual baseline-controlled study design.

### *Application-Based Assessment and Therapy*

I developed a novel assessment and treatment online application for Arabic readers with hemianopic alexia called: Arabic Read-Right (Ikraḥ lītākūḥ: “read to become”). This is available for free download on the Apple store (<https://itunes.apple.com/app/id964478309>). The app consists of five assessments and the scrolling text therapy (from left-to-right).

### *Assessment*

First, upon enrolment with the app patients completed five assessments of visual processing and reading abilities. These were visual text-reading test (primary outcome measure), visual field test, visual neglect test, visual search test (control measure), and patient-reported outcome measures (detailed explanation of these assessments are found in chapter 5, p. 121-124).

### *Therapy*

Upon completion of these tests the patients then had access to the therapy component of the App. The therapy consisted of reading laterally scrolling text (from left-to-right). Patients could control the speed, colour (background and foreground), and content of what they read, choosing from a library of books, Quran, and ever-changing really simple syndication (RSS) text feeds from the Aljazeera website. The iOS text size is set at large (default) and dynamic. GeezaPro is the system font on iOS iPad. Patients could pause or stop therapy at any time. As long as the text was moving, a timer measured how much therapy was being delivered, feeding this information to the secure server. I suggested 60 min of therapy a day but patients could choose to do as much or as little as they wished.

After every five hours of therapy completed the app automatically re-administered the 5 assessments outlined above. Patients could only continue with the therapy upon completion of these tests. In total each patient completed five testing points: baseline, after 5-, 10-, 15-, and 20-



hours of therapy, consistent with Ong and colleagues Read Right app for treatment of HA in English readers (Ong et al., 2012).

#### 6.3.4 Data Analyses

##### *A. Text-Reading speed (main outcome)*

Reading speeds for each patient, at each five-hour time was entered into a repeated measures ANOVA using SPSS v24 to investigate the effects of therapy. I assessed therapy effects after 5, 10, 15, and 20 hours of therapy. Where the data violated sphericity assumptions, I reported Greenhouse-Geisser corrected  $p$  and  $F$  values. Significance was set at  $p = 0.05$  for all reported results. I also calculated effect sizes for text-reading speeds, at each five-hour time, using both standardized (*Cohen's d*) and effect size correlation  $r$  methods. Partial eta squared was used in SPSS v24 to calculate *Cohen's d* effect sizes at each five-hour time points (5, 10, 15, and 20 hours of therapy). Correlation coefficient  $r$  was calculated using the means and standard deviations at each time-point.

##### *B. Visual Search Analysis (control measure)*

Visual search for each patient, at each five-hour time-point, was entered into a two-way repeated measures ANOVA using SPSS v24 to investigate reaction times for each hemifield. Factors were time (five time-points) and hemifield (affected and unaffected). Reaction times for all four patients, at each 5-hour time-point, were entered into a two-way repeated measures ANOVA with a Greenhouse-Geisser correction to investigate the effects of therapy on search time.

### *C. Therapy effects by Task (Visual Reading and Visual Search)*

A sub-analysis was carried out to investigate the effects of therapy on primary outcome (reading speed) and control outcome (visual search) measures. Visual search task and passage reading task for each patient, at each five-hour time-point, was entered into a two-way repeated measures ANOVA using SPSS v24. Main factors were time (five time-points) and tasks (visual search and reading speed). Task performance (text reading speed and visual search) for all patients, at each 5-hour time-point, was entered into a two-way repeated measures ANOVA to investigate the effects of therapy on the two cognitive tests (Visual Text Reading Test and Visual Search Test).

### *D. Visual Neglect*

Neglect was diagnosed if patients missed twice as many targets to one side compared with the other, or if they had a similar ratio of revisits. No formal statistics were computed.

### *E. Patient-reported outcome measure (secondary outcome measure)*

Patient reported outcomes for each patient, at each five-hour time-point, was entered into a Friedman's two-way repeated measures ANOVA using SPSS v24 to investigate ADL ratings over time. Factors were time (five time-points) and ADL ratings (reading activities and non-reading activities). Additionally, a paired-samples Wilcoxon signed-rank test was also conducted to investigate whether patients' ratings on ADLs were different (or the same) pre- (baseline) and post-therapy (20-hours).

## 6.4 Results

### A. Text-Reading Speed

There was a significant main effect of Arabic-Read Right therapy at all four points in time, ( $F(4, 92) = 17.22, p < .01$ , partial  $\eta^2 = .43$ ). The size effect increased monotonically, reaching highest point at 20 hours. The effect sizes for this analysis were as follows: 5-h ( $d = 0.29$ , effect-size  $r = 0.14$ , small effect), 10-h ( $d = 0.44$ , effect-size  $r = 0.21$ , medium effect), 15-h ( $d = 0.90$ , effect-size  $r = 0.41$ , large effect), and 20-h ( $d = 1.22$ , effect-size  $r = 0.52$ , large effect). See Figure 28 below.

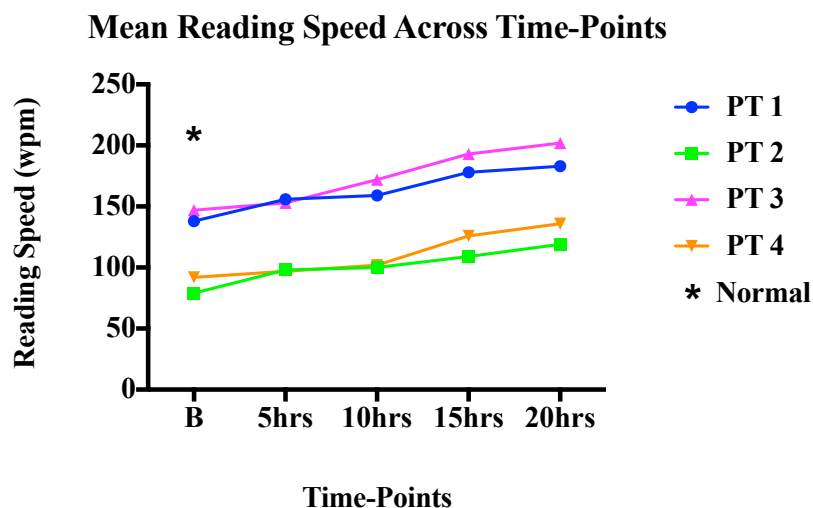


Figure 28. Patients' mean reading words per minute (wpm) across each time points on static text measured with the Arabic-Read Right app. Age-matched controls' reading speed have an average of 201.61 wpm ( $SD = 4.01$ ).

Importantly a sub-analysis for the first two baseline time-points using a paired-samples t-test indicated that reading speeds were not significantly different between the first ( $M = 28.98, SD = 7.53$ ) and second baseline ( $M = 28.51, SD = 10.46$ ),  $t(11) = 0.28, p = 0.79$ . See Figure 29 below. This indicates, it wasn't a simple effect of time but a time x treatment interaction.

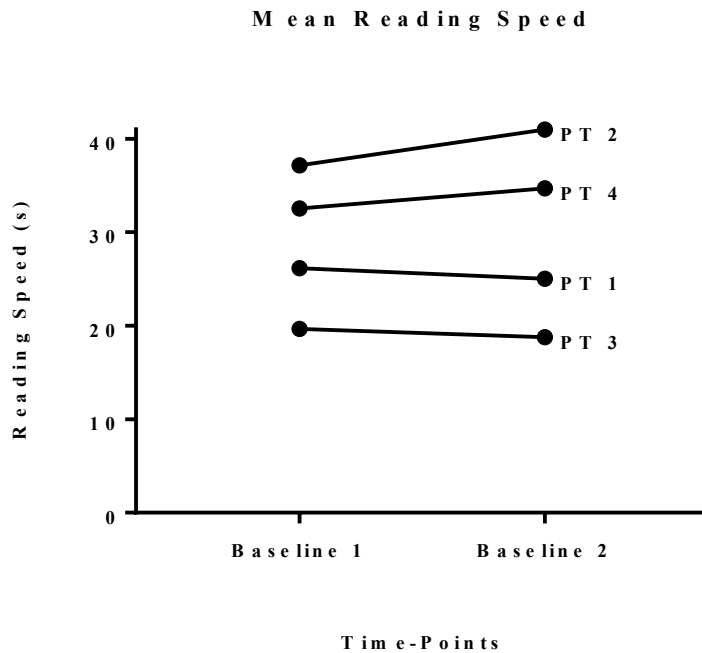


Figure 29. Line graph showing mean reading speed (in seconds) for all four patients for baseline 1 and 2. Reading speeds were not significantly different between the first ( $M = 28.98$ ,  $SD = 7.53$ ) and second baseline ( $M = 28.51$ ,  $SD = 10.46$ ),  $t(11) = 0.28$ ,  $p = 0.79$ .

### B. Visual Search

I carried out individual ANOVAs for each of the four patients and crucially, none had a significant time x hemifield interaction, patient 1: ( $F(2.57, 17.96) = 1.04$ ,  $p = .41$ ); patient 2: ( $F(1.43, 9.99) = 3.04$ ,  $p = .10$ ); patient 3: ( $F(1.27, 8.92) = 0.84$ ,  $p = .41$ ); patient 4: ( $F(6.04, 82.12) = 0.52$ ,  $p = .55$ ).

### C. Therapy Effects by Tasks (Visual Reading and Visual Search)

There was a significant main effect of time, ( $F(4, 92) = 17.16$ ,  $p < .001$ ). There was a significant main effect of task, ( $F(1, 23) = 295.56$ ,  $p < .001$ ). More importantly, there was a significant time x task interaction for all time-points, ( $F(4, 92) = 14.94$ ,  $p < .001$ ). See Figure 30 below.

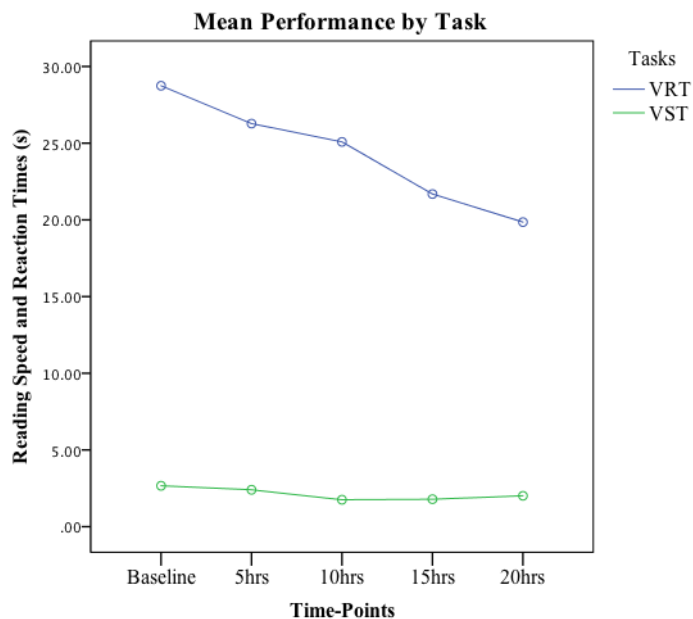


Figure 30. Patients' average task performances across all time-points. Blue line denotes VRT (text-reading speed in seconds) and green line denotes VST (visual search times in seconds) measured with the Arabic-Read Right app. Line graphs clearly show that therapy improved VRT but not VST on all time-points.

#### D. Visual Neglect

Percent correct of selected targets (N = 15) for each time-point is graphed in Figure 31 for all patients below. None of the four patients presented with visual field neglect.

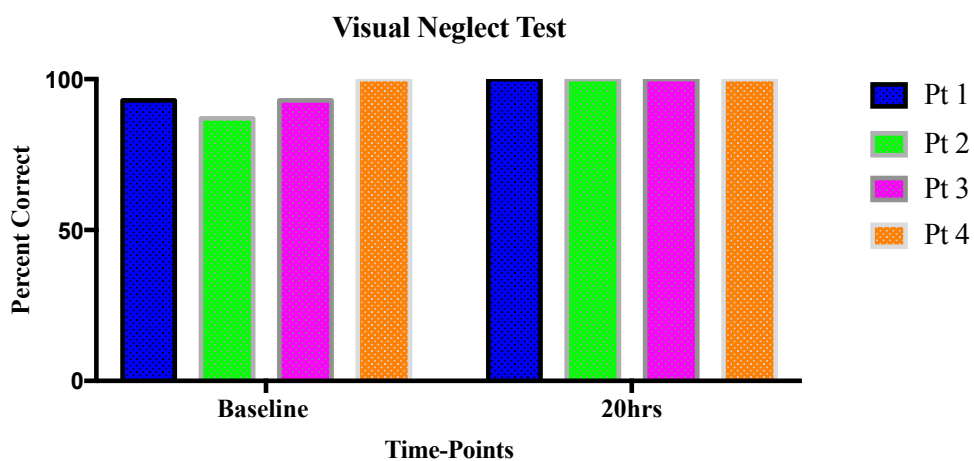


Figure 31. Graphs showing patients' percent correct scores at two time points, baseline and at 20-hours, for the visual neglect test measured with the Arabic-Read Right app.

### *E. Patient-reported outcome measures (ADLs)*

Of the six activities of daily living (ADL) ratings, four improved over time (baseline and 20-hours). These are finding things, reading news, reading books, and enjoying reading. Hygiene was not reported as problematic at baseline. Results of patient-reported outcome measures are summarized at pre- and post-therapy (baseline and 20-hours) for all four patients in figure 32 and 33 below.

Statistically, of the six ADL ratings, only the three reading-related ADLs, reading news, reading books, and enjoying reading, significantly improved over time (baseline and 20-hours). A non-parametric Friedman test of differences among repeated measures was conducted and rendered a  $\chi^2(4) = 18.62$ , which was significant ( $p < .01$ ). A Wilcoxon Signed-Ranks Test indicated that the nonrelated-reading ADLs (driving and finding things) were not significantly different at the two time-points, baseline (pre-therapy) and twenty hours (post-therapy),  $Z = -1.83$ ,  $p = .07$ .

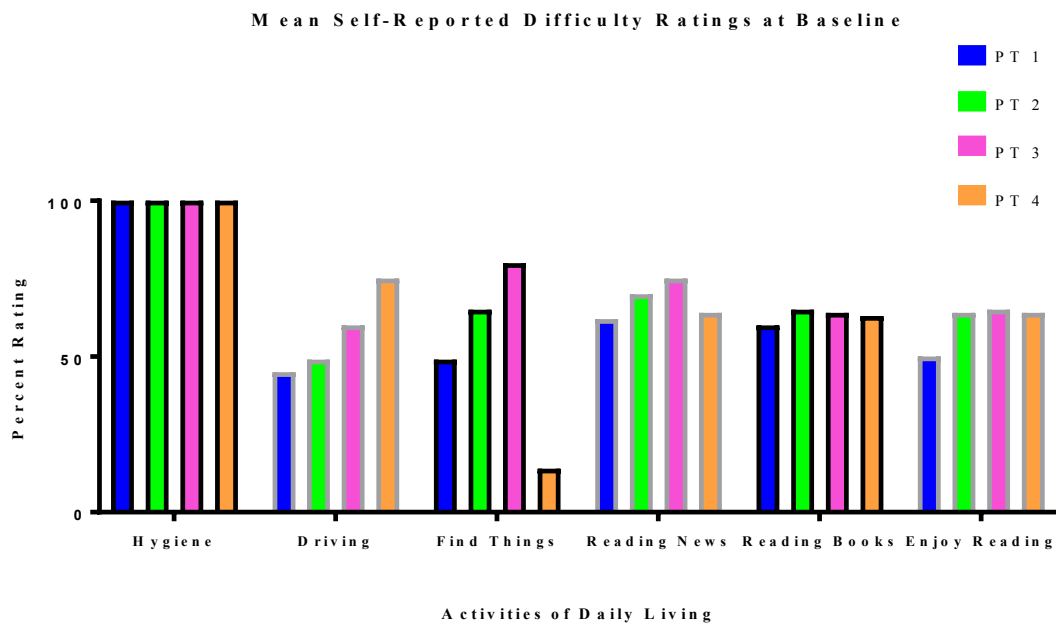


Figure 32. Graph showing average, self-reported difficulty ratings (y-axis in %) for the six activities of daily living (ADL) categories. For each category four scores are shown, one for each patient at baseline.

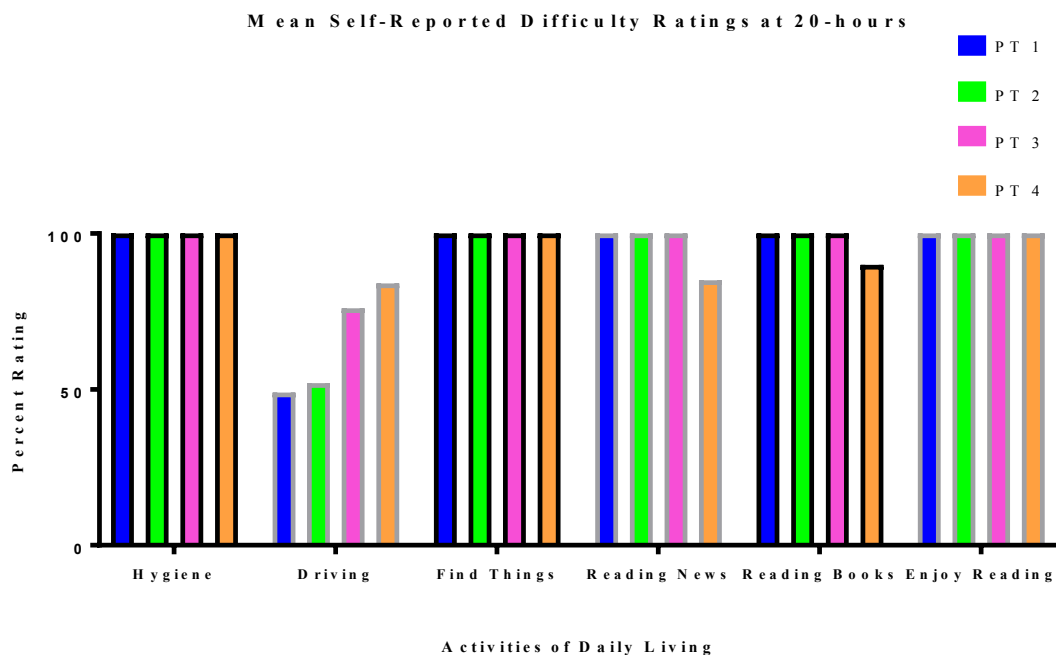



Figure 33. Graph showing average, self-reported difficulty ratings (y-axis in %) for the six activities of daily living (ADL) categories. For each category four scores are shown, one for each patient at 20-hours.

## 6.5 Discussion

The principal finding of this study is that a clinically proven eye-movement therapy (laterally scrolling text from left-to-right) can be delivered effectively to Arabic-reading patients using an app {Arabic-Read Right: Ikrā lītākūṇ “read to become” (اقرأ لتكون) Logo: }. Consistent with Ong and colleagues’ study (2012) using a similar technique in English readers with HA, I found a significant dose effect in Arabic readers with HA and my therapy effect sizes are comparable to theirs (10 % - 46%). Importantly, the therapy led to improvements in the patients’ own ratings of their ADLs that involved reading. There were no significant change in the patients’ visual field or visual search times suggesting that the therapy effects are task specific improving reading performance (speed) and compensatory as they have no effect on the damaged visual field (hemianopia).

### A. Text-Reading Speed

In line with previous eye movement therapy studies (laterally moving text) in left-to-right reading patients with HA (Kerkhoff et al., 1992, Zihl, 1995; Ong et al, 2012), my Arabic-Read Right app therapy produced significant improvements in text-reading speeds at all four time-points. My effect sizes are comparable to a previous study using the same technique for eye movement therapy (laterally scrolling text, theirs from right-to-left) in English readers with HA at all four time-points post-therapy (Ong et al, 2012). Their *Read-Right* therapy produced a clear therapy dose effect of: 10% at five hours, 20% at 10 hours, 39% at 15 hours, and 46% at 20 hours.

Additionally, sub-analysis from the first two baseline time-points suggests that my effect sizes were not due to practice effects on the testing material (passages) or to passage of time.



There was individual variability within the four patients' text-reading speeds on all four time-points. Patient 4 did not show any improvements until after a dose of 15 hours of therapy; patient 2 showed improvements after a dose of 5 hours of therapy but then remained constant until after a dose of 20 hours; whereas patients 1 and 3 showed improvements only after a dose of 5 hours of therapy. Thus, I propose that therapy dose rather than practice effects and passage of time contributed to improvement in reading speed performance over time, which was also consistent with Ong et al.'s (2012) results (see figure 28 above).

#### *B. Arabic-Read Right therapy effects on Tasks (text reading speed and visual search)*

Arabic-Read Right therapy did not lead to improvements in visual search times. The results did not show significant time by hemifield (affected and unaffected) interaction for all four patients, which were expected. Significant improvements were found only in text-reading speeds for all four patients over time. This suggests that this eye movement therapy (laterally scrolling text from left-to-right) is task specific. This is consistent with a study, which investigated the specificity of eye movement therapy in left-to-right readers with HA (Schuett et al., 2012). Specifically, they were interested in whether reading and visual search impairments require a specific compensatory training for their improvement or training-related performance improvements can transfer between these two tasks (reading and visual search) (Schuett et al., 2012).

Their results showed that training-related improvements in reading and visual search were task specific. That is, completing reading and visual search training led to specific improvements in performance of reading and visual search, respectively. Thus, in their study, when HA patients completed reading therapy, they improved only in this task. This is important because like their study, my Arabic-reading HA patients were expected to improve

only in text-reading speeds over time since they only received reading training. Visual search was added as a control measure and I expected that eye movement therapy (laterally scrolling-text from left-to-right) should not improve this. Visually guided tasks in my study (reading and visual search) require different types of eye movements as well as require specific eye-movement based therapies (Schuett et al., 2012). My study focused on reading and efficient scanning of laterally moving text.

### *C. Patient-reported outcome measures (ADLs)*

Arabic-Read Right app therapy (laterally scrolling text) led to objective improvement in reading-related (reading a book or newspaper) but not to the non-reading ADLs (finding things and driving) according to the patient's own ratings. This suggests that scrolling text therapy could generalize to related untrained activities, which involve a reading component. The other two non-reading related activities (driving and finding things) do not relate to the nature of the trained task (reading), and therefore did not significantly change. Similarly, in an eye-movement based therapeutic study, Ong and colleagues (2015) induced compensatory eye movement therapy via repetitive practice (ramp-step paradigm) to improve visual search times (main outcome). Interestingly, they found that their eye movement therapy not only improved the trained task (forced patients to make quicker and more efficient saccades) but also generalized to everyday activities such as finding things and shopping. They found that therapy effects are not limited to the trained task but can transfer to improve related "real-world" activities, which was consistent with my study (Ong, Jacquin-Courtois, Gorgoraptis, Bays, Husain & Leff, 2015). This confirms previous findings that specific moving text therapy (laterally scrolling text) can improve text reading speeds when HA patients returned to normal, static text (Spitzyna, Wise, McDonald, Plant, Crewes, & Leff, 2007).

## Conclusion

These findings show that app-based eye-movement therapy (Arabic-Read Right) can be effective. This is the first app-based standardized assessment and treatment resource for Arabic patients with HA. It has two important clinical implications. Firstly, through its comprehensive assessment package, it aids in the clinical diagnosis of HA, which will be useful for neurologists, neuro-ophthalmologists and speech and language therapists. Secondly, as the app is web-based and free, it provides patients with an effective web-based treatment for their reading impairment anytime and anywhere that suits them. This represents a realistic way of delivering sufficient therapy dose to Arabic reading HA patients across the wider Arabic region so that they can obtain clinically meaningful improvements.

## Chapter 7: Discussion

### 7.1 Abstract

In this chapter, I first give a brief synopsis of the highlights for my four data chapters (3, 4, 5, and 6) emphasising the novel contribution for each. Then, I discuss the limitations and challenges I faced with patient recruitment. Finally, I discuss my future work in research and career plan.

### 7.2 Summary of each data chapter

Chapter 3:

Here I investigated in healthy Arabic readers the effect of increasing word length (written Arabic single-words) on their reading speed. I found that in Arabic shorter words (three-letters) were read significantly slower than longer words (five and seven-letters). This is in direct contrast to the results from the literature on word-length effects in English readers where shorter words are read faster than longer words. Linguistic post-hoc analyses of the data revealed a significant negative correlation between naming speed and word morphological neighborhood size. Longer words had a smaller morphological density size than shorter words suggesting they were more easily recognized which is why they were read faster. Arabic short words (three-letters) read in isolation (out of sentential context) are more information sparse, and therefore this is why they take longer time to process. This finding showed that characteristics (word length, morphology) that have been found to affect word recognition in English do not have the same effect in Arabic. More importantly, I examined visual word recognition performance in a language (Arabic) that largely has not been examined by word recognition researchers. Indeed studies that compare

visual word recognition performance across multiple languages are very important to the understanding of the fundamental nature of word recognition processes.

#### Chapter 4:

In this chapter I examined age effects on reading speed and its associated eye movement behaviours in healthy adult Arabic readers during passage reading (50 words in length).

Results showed that older Arabic readers read more slowly than the younger adults. In terms of eye movements older Arabic readers made more and longer fixations, and made lower amplitude progressive saccades when compared to the younger Arabic readers. Naturally occurring visual changes in the older Arabic readers might have led to reduced sensitivity to visual detail. They therefore needed to adopt a different reading strategy to adapt to these changes and adjust to the visual processing difficulties of the Arabic cursive script. These findings have significantly contributed to our understanding of eye movement behaviour of older Arabic readers - reading speed and performance are dependent on the number of fixations, the number and amplitude of both leftward and rightward saccades, and fixation durations. These data were important first steps towards understanding the eye-movement mechanisms that underlie reading performance and the visual and reading impairments in Arabic reading HA patients, where processing of text and viewing conditions are less-than-ideal.

#### Chapter 5:

This chapter is an in-depth examination of reading and visual performance in two native monolingual HA Arabic readers with left-sided hemianopia. Here I investigated how their single-word and text reading performance was a) affected by their hemianopia; and, b) responded to

moving text therapy. To assess and treat these HA Arabic patients I developed a novel online

package (app) called Arabic-Read Right {Ikṛā lītākūn “read to become” (اقرأ لتكون) Logo: }.

Text-reading speed (from passages) and eye movement measures were used to assess the patients’ reading performance both before and directly after they completed 20 hours of reading practice using the Arabic-Read Right app (scrolling text). I discuss the key findings for single word processing then text reading in turn below.

Consistent with the normative data of chapter 3, I found my two left-sided HA Arabic patients read shorter words significantly slower than longer words (five and seven-letter words). At baseline (pre-therapy), both patients were slower at single-word reading of all lengths when compared to their aged-matched healthy controls. Furthermore, patient 2’s left-sided hemianopia added a word-length effect of 80.25 ms per additional letter over and above three letters. Post-therapy (dose of 20-hours training) both patients’ reading of single word (all lengths: three, five, and seven-letters) was significantly quicker. Patient 2’s word-length effect decreased to 25.89 ms per additional letter over and above three letters.

With respect to text reading both spatial (saccadic amplitudes) and temporal (number and duration of fixations) measures in the patients’ oculomotor patterns differed from those of their matched healthy controls. At baseline, this was characterized by higher number of fixations, longer fixation durations, higher number of saccades to the right, increased number of regressions, and reduced leftward and rightward saccadic amplitudes. After Arabic Read-Right therapy (20-hours), both patients’ text reading performance significantly improved. Both patient’s text-reading speed improved and the effect sizes were large. Furthermore, the number and durations of fixations and their regressions, the number of saccades to the left and to the right decreased. Both patients also showed significantly larger saccades to the left and to the right

post-therapy. I ascribe these post therapy improvements in eye-movement behaviours directly to the moving text training. I found no change in either patient's left visual field testing.

#### Chapter 6:

Observing the success of the Arabic-Read Right therapy program (app) with my first two 'face-to-face' patients, I recruited four additional patients to explore whether similar therapy effects would be obtained via the Arabic-Read Right app only. All four patients improved their text reading speed (main outcome) and reported that it significantly improved their 'real-life' reading abilities (secondary outcome).

This proves an eye-movement therapy program (practicing reading laterally scrolling text) can be delivered effectively to Arabic-reading patients with HA using an app (Arabic-Read Right) and importantly it can lead to meaningful patient reported improvements in reading-related activities (ADLs), improving their quality of life.

### 7.3 Implications

Foremost to us is the key finding that reading data from Latinate languages (English) are not easily transferrable to Semitic languages, such as Arabic. Frustratingly little empirical research has been published on Arabic reading and Arabic is a language that largely has not been investigated by word recognition researchers. The results of my first study (chapter 3) provide the first evidence that when healthy adults read Arabic single words morphological family size density influenced how long it took them to read words aloud. This means in Arabic there is not a simple (additive) effect of word length on reading speed, as found in English where increasing word length increases the time to read a word. In Arabic the effect appears to be inversed such that shorter words (3 letters) were read the slowest and seven letter words were read the fastest in

my adult readers. When looking at normal text reading performance (chapter 4) my older compared to younger Arabic readers tended to make more fixations, longer fixation durations and lower amplitude progressive saccades to adapt to the changes and adjust to the visual processing difficulties of the Arabic cursive script. This suggests to me that the orthographic characteristics of the Arabic language meant the effects of visual crowding on the reduced visual perceptual abilities of older Arabic readers were enhanced. Further reading studies in Arabic are necessary to confirm these data and help us understand the different cognitive processes and eye movement behaviours involved in such a visually complex written language.

Before the development of my app (Arabic-Read Right), there were no standardized assessment and treatment resources for Arabic-reading patients with HA. In the six patients who trialled it, the real life impact of the Arabic-Read Right app is to improve reading speed, such that one patient is considering returning to work, and the others reported they now enjoy reading for pleasure again. I hope the Arabic-Read Right app will now have important clinical translation benefits for Arabic reading HA patients. Firstly, through its comprehensive assessment package, it will aid the clinical diagnosis of HA, which will be useful for neuro-ophthalmologists and speech-language pathologists practicing in the Middle East and other Arab countries. Secondly, as the app is web-based and free, it will provide patients with an effective web-based treatment so they can improve their reading and train anytime and anywhere that suits them. This represents a realistic way of delivering sufficient therapy dose to Arabic reading HA patients across the wider Arabic region so that they can obtain clinically meaningful improvements.



## 7.4 Unanticipated Challenges: Patient recruitment

Patient recruitment for this thesis was surprisingly difficult. This was in part due to the rarity of the disorder and probably most likely due the under diagnosing of the condition in Arabic readers. I had an honorary contract for three years at the Wellington Hospital's (WH) neurorehabilitation unit, London, which is the leading UK centre for the treatment of Arabic patients from across the Arab states. During my time there I only managed to recruit one patient that fit my inclusion criteria. Dr Leff runs a national specialist Alexia clinic at the National Hospital of Neurology and Neurosurgery part of University College London Hospitals. I also only managed to recruit one patient from this clinic over the four year period. Most of the Arabic-reading patients at WH were either severely unwell or severely cognitively impaired presenting with additional aphasia or executive difficulties (head injuries). The few others who could have been good candidates were not motivated enough to take part because they felt that they were coping well enough or were no longer concerned about reading Arabic because they live in the UK. The two other Arabic-reading patients in this thesis were recruited from Kuwait. In Kuwait, patients' medical records are not managed online, especially in most government sectors. There exists no clearly defined system for filing outpatient records or of storing outdated records. So there was no historical data I could investigate and I had to recruit new / currently active patients on my collaborating neuro-ophthalmologists' caseloads.

## 7.5 Unanticipated Challenges: Patient use of the app

Surprising only a handful of HA patients have used my app and completed the rehabilitation program to date. In the following section, I will list some of the barriers that I think may have contributed to this.

### *Social networking*

The Internet penetration in the Middle East (UAE, Kuwait, Saudi Arabia, Bahrain, and Qatar) has currently reached 71%, and has become an essential requirement of an Arab's daily life (Arab Social Media Influencers Summit, 2015). More than half of the users in the Arab region use social media platforms to gain information and connect with other users (Arab Social Media Influencers Summit, 2015). Yet, despite using social media (twitter, Facebook, and Instagram) and creating a landing page ([http://www.ucl.ac.uk/aphasialab/apps/arabic\\_rr.html](http://www.ucl.ac.uk/aphasialab/apps/arabic_rr.html)), to promote the app, I found that Kuwaiti users who found the app did so via word of mouth.

In an attempt to address this issue, I created a network group of Kuwaiti, Saudi Arabian and Egyptian healthcare professionals (neurologists, neuro-ophthalmologists, and speech-language therapists) to pass information about the app to their patients and colleagues. Interactions took place via e-mails and phone conversations due to distance (being based in London) and conflicting schedules (during my study leave in the Middle East). However, I managed to get speaking opportunities in a conference at three of the major hospitals in Kuwait to showcase and create awareness about the app to healthcare providers. Unfortunately to date, this too appears to have had no effect. Instead, healthcare providers appear to prefer to interact and socialize face-to-face with colleagues and patients to create that "personal touch".

### *Cultural bias*

There is an overwhelming hierarchy in the Arab region's health care system that I was naively unaware of. Simply put, patients' status and knowledge is secondary to that of the doctor. Patients rely completely on their doctors to manage their treatment instead of initiating their own rehabilitation. Doctors are responsible for the provision of healthcare services, and as such feel the need to be in control of planning, delivering rehabilitative services to their patients. There

may also be a lack of support among some doctors and other healthcare professionals to implement a patient-centred approach in the public healthcare facilities, which emphasises listening to, and involving patients in their rehabilitation care (Almutairi & Moussa, 2014).

### *Gender bias*

I experienced a great deal of difficulty recruiting male participants, which I did not anticipate. In general, Arab male patients prefer male physicians and vice versa (Kronfol, 2012). Two of my male patients relied on their male doctor to recommend this treatment program (app), as they felt he was more knowledgeable and therefore, would be a better decision maker about his needs. Additionally, for one of my male patients, I had to make a home visit for the initial assessment. In Arab societies, women are not expected to eat or socialize in the same room as men. Taking that into consideration, I had to request a female family member to be present during my visit. Interestingly, in the Arab region, compliance with medical treatment tends to be higher and the success rate of treatment is significantly higher among females than males (Bashour & Mamaree, 2003). I speculate this is because of reduced health literacy, lack of comprehension of treatment benefits, and lack of enthusiasm/motivation among the male Arab participants. In my thesis, I found three male patients who were not interested or motivated to be part of this study, all my female patients were very motivated and the two who took part in treatment study (chapter 5) were very enthusiastic and committed especially after noticing change (from 5 hours onwards) in their text-reading speed.

### *Religious bias*

I was hesitant at the outset to include any religious reading material in my app as part of therapy (for the laterally scrolling text). Specifically, I was hesitant about including the Quran because I did not want to offend other Arabic readers from other faiths who might be interested in using

the app. However, five out of the six HA patients who have tried it to date (70%) recommend I do include the Quran as one of the choices from the library of reading materials (scrolling text therapy). Religion plays an important role in health in the Arab region (Kronfol, 2012). Most religious Arabs are convinced that the Quran has a healing power for the mind and body. By including the Quran as an option it could also help relieve some HA patients' additional anxieties. Compliance with treatment was higher; especially with one male HA patient who became motivated to continue treatment after the Quran was included.

I have learnt through the journey that was this thesis, that the idea of developing a rehabilitation app is not enough. Rehabilitation involves mass repetition training and many hours of repeating the same task is pretty boring. The product has to be culturally accessible and acceptable not only to encourage patients to complete a sufficient dose of training to see a significant improvement in their reading performance but also to make it more attractive for recruiting new users.

## 7.6 Future Work

That my eye movement therapy (practicing reading laterally scrolling text) can be delivered successfully and effectively to Arabic-reading HA patients via the Arabic-Read Right app has been a great achievement. In the future, I would like to encourage more people to use and acquire more data so I can conduct larger group studies on its clinical effectiveness for Arab readers more globally. To do this I am preparing a funding application to Kuwait Foundation for the Advancement of Sciences (KFAS) so I can employ healthcare advertising and marketing strategists who work in the Middle East. KFAS is a non-profit Kuwaiti organization that has been established by an Amiri Decree (a formal and authoritative order by a Kuwaiti ruler) since 1976. It provides sustained support to the progress and advancement of science and technology

by developing public awareness of science, and by funding scientific projects that are innovative and beneficial to the Arab society globally. Their expertise and experience working in this sector will be invaluable and hopefully it will enable more Arabic readers who have HA to find and use my app.

The second area of research that I wish to explore is the effect the app may have on reading performance across languages in bilingual HA patients. In particular I wish to explore whether training effects in a patient's dominant language (Arabic) will carry over to their second language (English) or vice versa. That is, will treatment (moving text therapy) in one language, have an impact on the other language? Also, I wish to explore whether treatment in languages that read right-to-left (Arabic) have an impact on other language that reads in the opposite and/or same direction (e.g., English and Hebrew)? That is, I want to first examine treatment effects on English text (opposite reading direction) when moving text therapy is in Arabic, then, also examine treatment effects on Hebrew text (same reading direction) when moving text therapy is in Arabic.

### 7.6.1 Multilingualism

Recently (October 2017) I collected text-reading speed and eye-movement data on one bilingual HA patient with a right-sided homonymous hemianopia. A 58-year-old man with a right-sided visual field loss presented with reading difficulties both in English (his dominant language, he lives in the UK) and in Arabic (his first language, he was born in Bagdad, Iraq). He had no impaired speech production, speech comprehension or writing as was assessed by the Comprehensive Aphasia Test (both in Arabic and English). When reading Arabic text, his right hemifield impairment meant he had difficulty perceiving the beginning of words, and for English written text, it was the exact opposite. To date, he has only completed his Arabic reading therapy

via the Arabic-Read Right app. The next step is for him to complete his English reading therapy via the Read-right app ([www.readright.ucl.ac.uk](http://www.readright.ucl.ac.uk)). In the following section I present his preliminary results.

#### *7.6.1.1 Eye-tracking data collection and analysis*

Parallel forms of each Arabic and English passage (equivalent in level of difficulty) were used to evaluate the reading speed and eye movement behaviours of the bilingual stroke patient with HA at five testing points: at baseline, and after 5-, 10, 15-, and 20-hours of therapy. The primary outcome is to see an improvement in reading speeds. A change in average fixations, durations, and saccadic amplitudes were secondary measures. Patient was tested on all twelve passages at baseline, and then six passages, matched on level of difficulty (3 easy and 3 difficult), were presented in pseudo-randomized order on the four therapy time-points (5-, 10-, 15- and 20-hours) in both Arabic and English. At each time-point, the passages were administered first in Arabic, and then followed by English.

The preliminary data collection, analyses and methods are consistent with that used in chapter 5. Text-reading speed data and eye movements were post-processed via the S2 Mirametrix Eye tracker software showing timestamps in seconds and coordinates of each fixation. This was used for the subsequent data analysis. A fixation was identified, at least five consecutive data points, at sampling rate of 60 Hz, which is about 83 milliseconds (Mirametrix Inc., 2013). The following parameters were used to indicate eye movement components: number of leftward and rightward saccades in the X-axis; number of downward and upward saccades in the Y-axis; mean size of saccades (absolute value combining X and Y coordinates); number of fixations (left and right); mean fixation duration (left and right), and regressions (left and right).

Total passage reading time was determined by calculating the timestamp of each gaze point (fixation) from the first word in the first line until the last word in the sixth line of each passage (in seconds). Saccades made to proceed to the beginning of the next line in both languages (return sweeps) were discarded from the data; but regressive saccades, defined as those backward movements in the rightward direction (in Arabic) and leftward direction (in English) for the x axis within each line, were included in the data.

#### *7.6.1.2 Preliminary summary of results and discussion*

Text-reading speed (five-time points) and language (Arabic, English) for the bilingual patient were entered into two-way repeated measures ANOVA to investigate the effects of therapy on language. There was a significant main effect of Arabic-Read Right therapy on text-reading speed at all four points in time, ( $F(4, 20) = 19.83, p < 0.001$ ). There was a significant main effect of language, ( $F(1, 5) = 90.19, p < 0.001$ ). There was no significant time by language interaction for all time-points, ( $F(4, 20) = 0.25, p = 0.91$ ).

Preliminary results showed that Arabic reading therapy (laterally scrolling text from left-to-right) via the Arabic-Read Right app, improved the patient's text reading speeds post-therapy (a minimum dose of 20 hours), in both Arabic and English static texts. Text-reading speed in Arabic improved more than the English, which is to be expected (see Figure 34). Post hoc paired t tests revealed that this was driven by reading speed improvements between the baseline and five-hour time-points for the Arabic and English languages in the bilingual patient: Arabic,  $t(5) = 4.34, p < 0.001$ , English  $t(5) = 5.87, p < 0.001$ .

Interestingly, the bilingual patient appears to have responded with improved text-reading speeds in both languages, even following just five-hours of training with the app. Calculated effect sizes using standardized (*Cohen's d*) method. In Arabic, the effect sizes were as follows:

5-h ( $d = 3.88$ , large effect), 10-h ( $d = 0.29$ , small effect), 15-h ( $d = 0.51$ , medium effect), and 20-h ( $d = 2.02$ , large effect). The effect sizes at five and 20 hours were found to exceed Cohen's (1988) convention for a large effect ( $d = 0.80$ ). In English, the effect sizes were as follows: 5-h ( $d = 5.25$ , large effect), 10-h ( $d = 0.17$ , small effect), 15-h ( $d = 0.87$ , large effect), and 20-h ( $d = 0.20$ , small effect). The effect sizes at five and 15 hours were found to exceed Cohen's (1988) convention for a large effect ( $d = 0.80$ ). These data looks promising. At least in this patient, treatment with Arabic-Read Right therapy in one language (Arabic) also improved text-reading speed in another untrained language (English), which is read in the opposite direction.

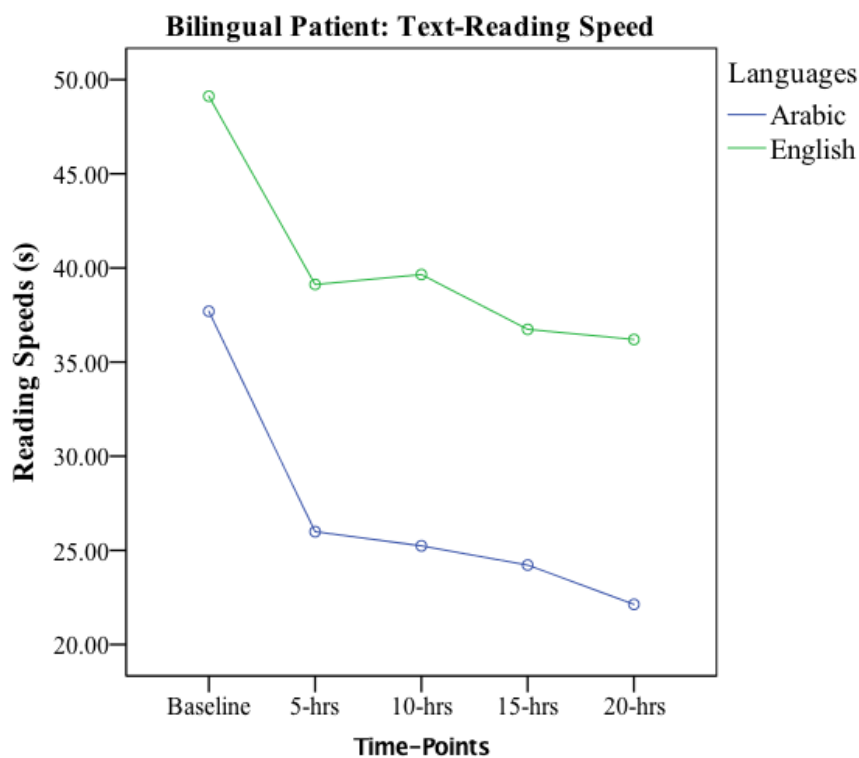


Figure 34. **Mean Text-Reading Speeds (in seconds) across all Time-Points.** Blue line represents Arabic-text reading speed. Green Line represents English text-reading speed. Patient was tested on all twelve passages at baseline, and then six passages, matched on level of difficulty (3 easy and 3 difficult), were presented in randomized order on the four time-points of therapy in both Arabic and English. At each time-point, the text-reading test was administered first in Arabic, and then followed by English.

Text-reading speed, and thus reading performance (in both Arabic and English), for this patient appears to have been mainly dependent on the number and duration of fixations, and the



number and amplitudes of leftward saccades (see Table 20). The number and duration of fixations, and the number of regressions decreased in both languages post-therapy.

Table 20. Patient eye movement data during passage reading for English and Arabic pre- and post-therapy

	Pre_Therapy (Baseline)											
	TotalTime (s)	WPM	Regressions	TotalFix	TotalFixLt	TotalFixRt	AvgFixDur (s)	AvgFixDurLt	AvgFixDurRt	AvgSaccAmp (°)	AvgSaccAmpLt	AvgSaccAmpRt
Arabic	33.59	89.30	6	44.08	19.67	24.42	0.67	0.67	0.68	1.98	2.04	1.91
English	51.35	58.42	4	63.25	35.25	28.00	0.73	0.76	0.69	1.96	1.90	2.04
	Post_Therapy (20-hours)											
	TotalTime (s)	WPM	Regressions	TotalFix	TotalFixLt	TotalFixRt	AvgFixDur (s)	AvgFixDurLt	AvgFixDurRt	AvgSaccAmp (°)	AvgSaccAmpLt	AvgSaccAmpRt
Arabic	22.13	135.54	2	33.17	15.67	17.50	0.58	0.54	0.61	2.15	2.12	2.22
English	36.20	82.88	2	49.33	25.83	23.50	0.66	0.72	0.59	1.92	1.84	1.99

Key: Total Time = Text reading speed in seconds; WPM = Words per minute; Fix = number of fixations; Dur = fixation duration; SaccAmp = Saccadic Amplitude; TotFix (Lt, Rt) = total number of fixations to the left or right side of the passage; AvgFixDur (Rt, Lt): Average fixation duration to the left or the right side of the passage; AvgSaccAmp (Lt, Rt) = Average leftward or rightward saccades

In terms of eye movement, the main effect of therapy seems to have been on reducing regressive saccades i.e., mean number of right fixations for Arabic: n=24 pre to n=17 post therapy, and mean number of left fixations for English: n= 35 pre to n=25 post therapy. This is consistent with previous eye-movement therapy studies on left-to-right reading patients with HA (Zihl, 1995; Spitzyna et al., 2007). Results also showed a language specific effect (significant interaction between language treated, which is Arabic, and time) for mean average leftward saccadic amplitudes across all time-points (see figure 35); this was not observed for mean average rightward saccadic amplitudes across all time-points.

Analysis of the effects of therapy on angular distance of leftward saccadic amplitudes for each language (Arabic and English), at each 5-hour time-point, were entered into separate two-way repeated measures ANOVAs. There was a significant main effect of time, ( $F(4, 20) = 5.20$ ,  $p < 0.001$ ), and there was a significant time by language interactions, ( $F(4, 20) = 3.74$ ,  $p < 0.05$ ).

After treatment, like all the monolingual Arabic readers with HA in this thesis (see chapters 5 and 6), the bilingual HA patient showed larger leftward saccades when reading Arabic text. However, unlike left-to-right reading patients with a right-sided HA in previous studies

(Zihl, 1995; Spitzyna et al., 2007), the bilingual patient showed slightly smaller leftward saccades when reading English text after treatment (see figure 35). Perhaps this is attributed to the direction of the eye-movement therapy received (laterally scrolling text from left-to-right). Since text-reading speed on static English text for the bilingual patient, at each time point (5, 10, 15 and 20-hours) after therapy has not been assessed yet, I cannot examine the effects of eye movement therapy in the opposite direction. The patient is undergoing this training now, I do predict however, that receiving eye-movement therapy that is typically given to English readers (laterally scrolling text from right-to-left) may increase the amplitude of his leftward saccades after treatment (Zihl, 1995, Spitzyna et al, 2007). This has yet to be determined.

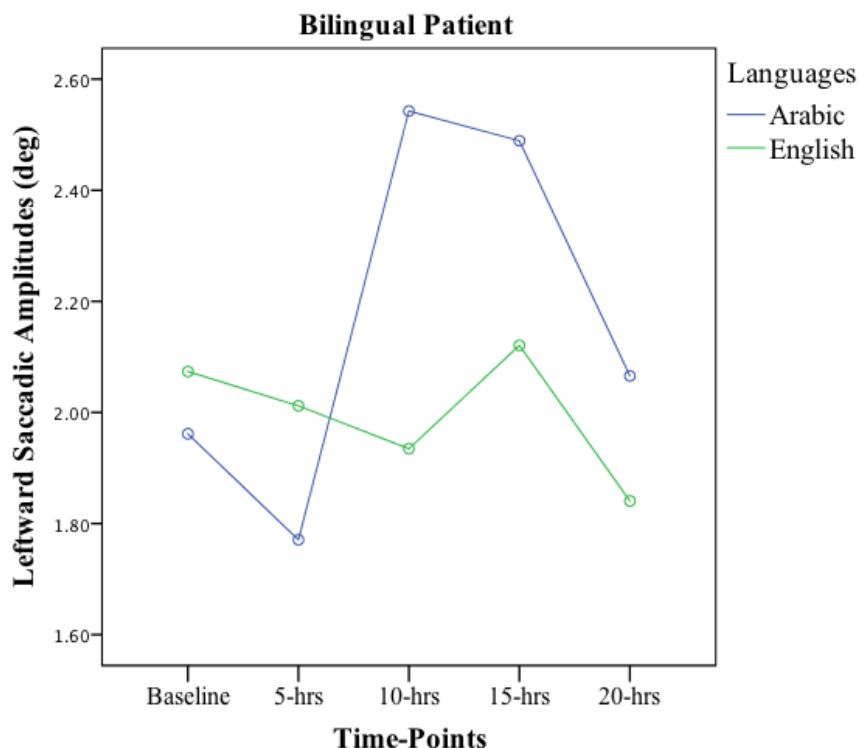


Figure 35. Mean leftward saccadic amplitudes across all time-points. Blue line denotes leftward saccadic amplitudes in Arabic, and green line denotes leftward saccadic amplitudes in English. Leftward saccades for Arabic increased after 20-hours from 2.04 pre-therapy (baseline) to 2.12 degrees post-therapy. Leftward saccades for English decreased after 20-hours from 1.90 pre-therapy (baseline) to 1.84 degrees post-therapy. There was a significant language by time interaction.

## 7.7 Concluding remarks

The data chapters (3, 4, 5, and 6) detailed in this thesis were designed to shed light on reading speed (single-word reading and text-reading) and eye movement behaviour in Arabic-reading normal adults and patients with Hemianopic Alexia (HA) while reading Arabic. Research on Arabic reading is scarce, and prior to my thesis no empirical studies on Arabic readers with HA had been conducted. By developing a novel online assessment and treatment package (an app) for Arabic readers with HA called Arabic-Read Right ([http://www.ucl.ac.uk/aphasialab/apps/arabic\\_rr.html](http://www.ucl.ac.uk/aphasialab/apps/arabic_rr.html)), I hoped to 1) develop suitable materials to aid in the clinical diagnosis of HA and 2) provide an effective and empirically supported reading treatment for HA Arabic readers.

Patient recruitment for this thesis was surprisingly difficult. This was in part due to the rarity of the disorder and probably most likely due the under diagnosing of the condition in Arabic readers. Thus, in the future, more patients need to be recruited so that I can collect more data to test the validity of the app (moving text therapy) on a larger and more global sample of HA Arabic readers. To enable more Arabic readers who have HA to find and use my app, I am applying for more funding from KFAS to employ experienced healthcare advertising and marketing strategists who work in the Middle East to help me address this both in targeting patients directly and in educating healthcare professionals.

Upon my return to Kuwait, I will resume practicing as a clinical speech and language pathologist (i.e., provide rehabilitation treatment to stroke patients and HA Arabic readers), and teach in the cognitive neuroscience department at the Public Authority for Applied Education and Training (PAAET), which is an academic institute in Kuwait. PAAET has granted me an

education scholarship. This scholarship program was implemented to recruit and train qualified applicants to work as lecturers and researchers in their newly developed cognitive neuroscience department in Kuwait. I hope to continue my research on Arabic reading (i.e., recruit more patients, collect more data from the app) and collaborate on developing more apps for language rehabilitation for Arabic populations.

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## Supplementary Material

### Videos

Video 1: Sample video clip showing eye movement therapy (laterally scrolling text from left-to-right) as well as manipulation of background and font colour, and changing of text speed on the Arabic-Read Right App.

<http://screencast.com/t/OdZAN21RsZzd>

Video 2: Sample video providing HA patients with instructions on how to login and take the five assessments on the Arabic-Read Right app. In the video, they are presented in the following order: (1) Registration and Login, (2) Visual Text-Reading Test, (3) Visual Field Test, (4) Visual Neglect Test, (5) Patient-Reported Ratings on the following six activities of daily living (ADLs): hygiene, driving, finding things, reading news, reading books, and enjoying reading, and finally, (6) Visual Search Test. Normally these how to videos are presented individually for each of the above mentioned in the app, they are just all combined in one video for viewer's convenience.

<http://screencast.com/t/mACyDQOn>

### Abstract and promotional short video

Abstract directly rising from this thesis and accepted for poster presentation is the *Effect of word lengths' morphological family size (type frequency) when reading Arabic words in adults*. The poster was presented at the eighth annual meeting of the Society of Neurobiology of Language at University College London, Institute of Education in London, UK on August 20, 2017.

Additionally, Nature Publishing Group will prepare a short video for KFAS highlighting my Arabic-Read Right app, which is scheduled to take place via Skype on January 4, 2018.

### Publications in preparation

Publications that will hopefully arise from this thesis are: (1) the normative data chapter drafted for submission on the effect of increasing word length (written Arabic single-words) on healthy normal Arabic readers (chapter 3), (2) as is the in-depth chapter examining reading and visual performance in two native monolingual HA Arabic readers with a left-sided hemianopia (chapter 5), and (3) potentially the therapy effects chapter on app-based HA patients via the Arabic-Read Right app (chapter 6) when I recruit more app patients.