Visual Word Processing of Non-Arabic-speaking Qur'anic Memorisers

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Abstract

Visual word processing typically involves the interplay between orthographic, phonological, morphological, and semantic knowledge. However, there are atypical learning situations where the input of one of the above is limited, such as rote memorisation of the Qur'an with little semantic input. This is common in non-Arabic-speaking countries where speakers from Muslim communities learn how to read the Qur'an without understanding what it means. Despite this unique and pervasive phenomenon, little work has been carried out in this area.

The goal of this dissertation is to investigate the visual word processing of non-Arabic-speaking Qur'an memorisers at three levels of processing—lexical, sublexical, and morphological. It also aimed to investigate individual differences through examining potential interactions of effects with Qur'an vocabulary knowledge and amount of Qur'an memorised, thereby informing us of the roles of semantics and print exposure to the language in visual word processing.

Using stimuli constructed from the Qur'an Lexicon Project, a series of psycholinguistic experiments were conducted with non-Arabic-speaking Qur'an readers and memorisers from Singapore. Participants were given two visual lexical decision tasks (one with morphological priming and one without) and a speeded pronunciation task. A standardised Qur'an Vocabulary Test was also given to measure their vocabulary knowledge and self-reports of Qur'anic memorisation scores were elicited to measure the amount and fluency of Qur'anic memorisation.

Findings from these experiments provide insight into the factors influencing the visual word processing of non-Arabic-speaking Qur'an memorisers and demonstrate that the influence of these factors can vary differentially depending on one's vocabulary knowledge and amount of Qur'an memorised, given several significant three-way interactions. The findings broadly suggest the implicit learning of lexical and sublexical features of a writing system through exposure to its orthography and phonology, despite limited exposure to semantics, with vocabulary knowledge and statistical exposure to the language playing different but interdependent roles in strengthening the quality of lexical and sublexical representations. However, for morphological processing, findings suggest that vocabulary knowledge plays a more important role alongside statistical exposure in the implicit learning of roots whereas statistical exposure is more important than vocabulary knowledge in the implicit learning of word patterns, which is consistent with the view that roots and word patterns represent distinct structural characteristics in Semitic languages.

Keywords: visual word processing; visual word recognition; semantic knowledge; print exposure; statistical learning.

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Chapter 1. Introduction

Visual word processing typically involves the interplay between orthographic, phonological, morphological, and semantic knowledge (e.g. Baayen, Feldman, & Schreuder, 2006; Boudelaa & Marslen-Wilson, 2015; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Dilkina, McClelland, & Plaut, 2010; Frost, 1998; Frost & Katz, 1992; Grainger & Holcomb, 2009; Henderson, 1982; Hudson & Bergman, 1985; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Rastle, Davis, & New, 2004). For example, lexicality effects typically show that words elicit faster responses than pseudowords as repeated exposure to an item may lead to the development of its lexical representation through its orthographic, phonological, and semantic representations, thus facilitating lexical access (Coltheart et al., 1993). However, in atypical learning situations such as rote memorisation of a language, it is arguable how much input from the last three is available to learners. One such situation which exemplifies this is that of rote Qur'an memorisation by non-Arabic-speaking Muslim populations in Southeast Asia and the Indian sub-continent. Speakers from these communities learn how to read the Qur'an but usually learn very little Qur'anic Arabic in the process. This raises the question of what, if any, higher levels of the grammar of the language these speakers manage to encode in the process of the memorisation, and how fluent reading develops potentially without the support of vocabulary or meaningful word segmentation.

1.1 Visual Word Recognition

One of the key research areas in the field of visual word processing is visual word recognition, which seeks to answer the question of how people recognise or identify visually presented words, a task that is central to reading and literacy. For decades now, numerous studies have characterised the effects of various psycholinguistic variables such as frequency, length, and neighbourhood density on visual word recognition using a wide variety of paradigms; two of the more popular ones which help to provide converging evidence on these effects are lexical decision and speeded pronunciation (see

Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Balota, Yap, & Cortese, 2006; Yap & Balota, 2009). Findings from studies in this area have greatly contributed to visual word recognition research not only in terms of helping us understand how people process and recognise words, but also in terms of informing current models and theories of visual word recognition that need to be constrained by these effects.

However, given the diversity of a particular population in terms of age, reading ability, and linguistic experience (amongst many other things), current models and theories of visual word recognition need to move beyond describing the characteristics of the average "prototypical" adult reader (usually an undergraduate) and account for individual differences in visual word recognition processes (see Davies, Arnell, Birchenough, Grimmond, & Houlson, 2017; Yap, Balota, Sibley, & Ratcliff, 2012). Not only that, given that the majority of reading research has been on English and/or with populations for whom the script being read reflects their first language, there is also a call for more research on much understudied populations to contribute to cross-linguistic comparisons, and thus, inform us with regards to the generalisability or universality of current models and theories of reading (Share, 2008).

1.2 Non-Arabic-speaking Qur'anic Memorisers

One unique yet much understudied population is that of non-Arabic-speaking Qur'anic memorisers. In many non-Arabic-speaking Muslim communities, Qur'anic reading, recitation, and memorisation constitute a major component in the religious education of children, to the extent that parents send their children to special schools and classes for the sole purpose of learning to read, recite, and/or memorise the Qur'an (Boyle, 2006; Raja Yusof, Zainuddin, & Haji Mohd Yusoff, 2011). The rote memorisation of the Qur'an is a massive task as it requires the memorisation of 77,430 words; to make the task even more difficult, it often occurs with a limited understanding of the meaning of these words for non-Arabic-speakers who undertake the task. Despite this fascinating phenomenon and the widespread use of the Qur'an, little is known regarding how Qur'anic Arabic is processed by children and adults, and even less so for non-

Arabic-speakers. To date, there have only been two published studies that have looked at the effects of Qur'anic memorisation on serial memory skills (Wagner & Spratt, 1987) and on the statistical learning of grammar (Zuhurudeen & Huang, 2016).

Studying the visual word processing of this unique population would not only help to provide an insight into visual word processing with limited semantics, but also contribute to the study of individual differences in visual word processing by allowing us to examine two constructs (vocabulary knowledge and print exposure) simultaneously while teasing apart their roles in visual word processing. Studies on individual differences in word processing have typically used populations in which print exposure has a reciprocal relationship with vocabulary knowledge (see Cunningham & Stanovich, 1998) and significant correlations exist between the two (e.g. all *r*s > .50 in Lewellen, Goldinger, Pisoni, & Greene, 1993), to the extent that these terms are often used together to denote effects of 'reading ability' in modulating effects of lexical variables on visual word recognition (e.g. Yap et al., 2012). With the benefit of a unique population that has large variability in print exposure through rote memorisation as well as in vocabulary knowledge, the current work can help to address the gap in the literature with regards to disambiguating the roles of vocabulary knowledge and print exposure in the effects of lexical variables on visual word processing.

1.3 Qur'anic Arabic

Although Qur'anic Arabic is a transparent orthography with consistent grapheme-to-phoneme correspondences, it has a non-concatenative morphology in which word formation involves non-linear combinations of roots and word patterns. Frost et al. (2005) argued that visual processing of words is first determined by morphological characteristics and that Semitic words are lexically organised by non-concatenative morphological principles of roots and word patterns instead of orthographic similarity such as orthographic N like in English. A question that one can then ask is whether the visual word processing of our non-Arabic-speaking Qur'anic memorisers is determined by orthographic characteristics (as shown by extant findings for alphabetic orthographies) or morphological characteristics as Frost et al. (2005) argued. This provides the motivation to consider morphological variables such as root variables and contrast their effects with measures of orthographic similarity such as neighbourhood density when examining the visual word processing of non-Arabic-speaking Qur'anic memorisers. Another way to answer the above question would be through examining the visual word processing of non-Arabic-speaking Qur'anic memorisers at the morphological level, testing for root and word pattern priming effects.

1.4 Overview of the Current Work

The goals of the current work are two-fold: First, to characterise the effects of psycholinguistic variables on the visual word processing of non-Arabic-speaking Qur'anic memorisers through three tasks (lexical decision, speeded pronunciation, and lexical decision with unmasked morphological priming); second, to examine individual-differences in the effects of these variables on the visual word processing of non-Arabic-speaking Qur'anic memorisers through two- and three-way interactions between amount of memorisation, vocabulary knowledge, and the effect.

1.4.1 Contributions

The current work breaks ground in numerous ways. Not only is it the first study on visual word processing in Qur'anic Arabic, it is also the first study to look at the visual word processing of non-Arabic-speaking Qur'anic memorisers, a unique population that engages in rote memorisation of a text with limited semantic knowledge, thereby providing a natural window into the disambiguation of the roles of vocabulary knowledge and print exposure in influencing the effects of various psycholinguistic variables on visual word processing. Furthermore, it is currently the only study of visual word processing in vowelled Arabic that utilizes a comprehensive array of traditional and novel lexical variables, and it is the only study of visual word processing in a transparent orthography that have examined individual differences in the effects of those predictors. Last, given the non-linear morphology of Qur'anic Arabic, this is the first study to be able to investigate within the same population whether lexical organisation arises from a language's morphological principles or from how the individual himself acquires the language.

1.4.2 Research Questions

The current work seeks to answer the following research questions:

a) What are the factors influencing the visual word processing of non-Arabic-speaking Qur'anic memorisers?
    a. How are the effects of these factors modulated by amount of memorisation and vocabulary knowledge?

b) Do morphological variables such as root and word pattern influence the visual word processing of non-Arabic-speaking Qur'anic memorisers?
    a. How are the effects of these variables modulated by amount of memorisation and vocabulary knowledge?

1.5 Organisation of the Dissertation

This dissertation comprises 8 chapters and is organised as follows: After the introduction in Chapter 1, Chapter 2 provides the background to the current study by introducing the unique population of non-Arabic-speaking Qur'anic readers and memorisers, the psycholinguistic characteristics of the language to which they are exposed, as well as the linguistic (orthographic, phonetic, and semantic) inputs they receive through their rote memorisation process. The large variability in their linguistic inputs provides the case for exploring individual differences in the current study.

Chapters 3 and 4 describe the development of item-level variables and individual-level measures respectively for the experiments conducted for this dissertation. Chapter 3 presents the Qur'an Lexicon Project, the first psycholinguistic database for Qur'anic Arabic containing various lexical characteristics calculated for 18,994 orthographic types and 19,286 contextually transcribed phonetic types. These lexical characteristics include measures of frequency, length, orthographic and phonological similarity, phonotactic probabilities, and root. The effects of these measures on the visual word processing of non-Arabic-speaking Qur'anic memorisers were examined in the experiments conducted in Chapter 5 to 7. In chapter 4, a review of the literature with regards to individual differences in the effects of these measures on visual word processing is presented, focusing on individual differences in vocabulary knowledge and print exposure, two theoretically different constructs whose roles in visual word processing have yet to be teased apart. Measures for Qur'an vocabulary knowledge (Qur'an Vocabulary Test: QVT) and print exposure (amount and fluency of Qur'an memorisation: MemScore) are then developed and validated for their use in the experiments in this dissertation.

Chapter 5 describes a study that examined the effects of various underlying lexical dimensions (i.e., principal components of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root) as well as lexicality on the visual word processing of non-Arabic-speaking Qur'anic memorisers via a lexical decision task. Individual differences in the effects of these variables were also examined through two- and three-way interactions of each effect with Qur'an vocabulary knowledge and amount of Qur'an memorisation.

Chapter 6 describes a study that examined the effects of various underlying lexical dimensions (i.e., principal components of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root) on the visual word processing of non-Arabic-speaking Qur'anic memorisers via a speeded pronunciation task. Individual differences in the effects of these variables were also examined through two- and three-way interactions of each effect with Qur'an vocabulary knowledge and amount of Qur'an memorisation.

Chapter 7 describes a study that examined the visual word processing of non-Arabic-speaking Qur'anic memorisers at the morphological level via a lexical decision task with unmasked morphological priming. A selective review of the literature on Arabic morphological processing provided the case to test for priming effects of root and word pattern, therefore indirectly testing whether implicit learning of non-concatenative morphemes can take place despite limited semantic knowledge. Individual differences in the priming effects of root and word pattern were also examined through two- and three-way interactions of each priming effect with Qur'an vocabulary knowledge and amount of Qur'an memorisation

Chapter 8 presents the general discussion of the findings across all three studies, highlighting the theoretical implications of selected findings. The final part of this chapter presents the limitations of the current work, future directions, and the overall conclusions.

Chapter 2. Background

2.1 Introduction

In this chapter, the background to the study is provided by describing the importance of Qur'anic reading and memorisation, the psycholinguistic characteristics of Qur'anic Arabic, as well as the characteristics of the population of interest (Singaporean Muslims), which include a description of their Qur'anic memorisation process and linguistic input.

2.2 Importance of Qur'anic Reading and Memorisation

The Qur'an, written solely in Arabic, is the religious text of around 1.6 billion Muslims all over the world, of which a large proportion are non-Arabic speakers (Pew-Research-Center, 2011). Qur'anic verses are not only recited during special religious occasions, but also by practising Muslims in their daily ritual prayers. For many non-Arabic-speaking Muslims, the first (and often only) exposure to the Arabic script and language is through the Qur'an. Despite the widespread use of the Qur'an, little is known regarding how Qur'anic Arabic is processed by children and adults, and even less for non-Arabic-speakers.

In many non-Arabic-speaking Muslim communities, especially in the Indo-Pak and Southeast Asian regions, Qur'anic reading, recitation, and memorisation constitute a major component in the religious education of children, to the extent that parents send their children to special schools and classes for the sole purpose of learning to read, recite, and/or memorise the Qur'an (Boyle, 2006; Raja Yusof et al., 2011). Here, it is important to differentiate between *madrasahs* (Islamic schools that provide a comprehensive religious education curriculum covering various subjects, which may include Arabic) and *tahfiẓ/hifẓ* schools/programmes which only focus on the memorisation of the Qur'an. *Tahfiẓ/hifẓ* schools/programmes may either be full-time (in which students formally dedicate at least few hours a day to Qur'an memorisation) or part-time (in which students are typically given verses to memorise as homework during the week and get tested on their memorisation over the weekend). This phenomenon of rote Qur'an memorisation has become so pervasive that *tahfiẓ* programmes have been founded in North America and Europe to cater to mostly immigrant Muslim communities; a simple Google search turned up more than 10 such programmes in the US and UK each, and this excluded online programmes where individuals could sign up to undertake Qur'an memorisation on their own and have their memorisation checked by a Qur'an teacher.

As the children (and sometimes adults) in these *tahfiẓ* schools/programmes are usually non-Arabic speakers, this rote memorisation often occurs with a limited understanding of the 77 430 words (of which approximately 19 000 are orthographically unique) in the Qur'an. To many it might seem inconceivable to undertake a massive rote memorisation task with limited understanding of what it is being memorised, especially for children with immature attention and memory skills. However, various religious and socio-cultural beliefs have likely motivated the existence of this phenomenon in non-Arabic-speaking Muslim communities, especially in the Indo-Pak and Southeast Asian regions:

1) The belief that memorising the Qur'an would provide immense rewards in the afterlife not only to the memoriser but also to his/her parents. Depending on one's interpretation of various religious evidences, these rewards may include having special intercession on the Day of Judgement, being assigned to higher (and thus, better) levels of heaven, amongst others.
2) The belief that reciting (and thus, memorising) even just one letter of the Qur'an would provide immense rewards, with those who find the task more difficult getting double the reward.
3) The high status that a *hafiẓ* (m.)/*hafiẓah* (f.) (someone who has memorised the entire Qur'an) may hold in certain communities, which in turn, is a source of pride for his/her parents. In these communities, a *hafiẓ*/*hafiẓah* is typically given important leadership roles such as leading special congregational prayers during the fasting month (*Ramadhan*).
4) The belief that familiarising children with the Qur'an in an intensive manner and a controlled environment would provide numerous benefits such as moulding good character and behaviour.

Given such beliefs, it is unsurprising that many parents enrol their children in dedicated *tahfiẓ* schools or programmes to provide them with a fast route to become a *hafiẓ*/*hafiẓah*, in which they typically take several years to memorise the entire Qur'an. This is perceived to be faster than learning Arabic as a third or fourth language[1] as well as spending time to learn and understand the contextual meaning of the words of the Qur'an before memorising the Qur'an, which may take decades instead.

However, it is important to note that in many of these *tahfiẓ* programmes, children (or adults) must already be fluent in reading and reciting the Qur'an with proper *tajweed* (elocution) before they can fully embark on Qur'an memorisation; they will not be admitted into these programmes otherwise. *Tajweed* is defined as "the proper articulation and reading of the Qur'an" as received from the Prophet (peace be upon him), describing in detail how consonants and vowels are to be articulated singly and consecutively, amongst other things (Haleem, 1994, p. 173). To achieve proper *tajweed,* the Qur'anic text which learners read is an exacting system of orthographic representation; it not only encodes the phones but also additional cues such as consonant assimilation, emphasis, pausing, and more (see Czerepinski & Swayd, 2006; Haleem, 1994; Leong, 1998). Therefore, reading with proper *tajweed* not only means fluently articulating the Qur'anic Arabic letters or phones, but also means being able to follow fully specified recitation rules with regards to the text. To better understand the linguistic input that non-Arabic-speaking Qur'anic readers receive, the next section will describe the psycholinguistic characteristics of Qur'anic Arabic, namely its orthography and phonology.

2.3 Psycholinguistic Characteristics of Qur'anic Arabic

It is crucial to keep in mind that Qur'anic Arabic has similarities and differences when compared to Modern Standard Arabic (MSA), which will be covered below. This means that one may not necessarily generalise the findings from word recognition studies that have been completed in MSA (and using native

[1] Many non-Arabic-speaking Muslims typically formally learn English and their native language in school, thus making Arabic a third or even a fourth language for them should they start learning it.

Arabic speakers) to those in the population of interest in the current study: non-Arabic-speaking Qur'anic readers and memorisers.

2.3.1 Orthography

Qur'anic Arabic orthography was developed to be the written representation of how the Prophet (peace be upon him) would recite the Qur'an himself, and therefore, requires more precise levels of representation than in ordinary Arabic orthography (Haleem, 1994). As mentioned earlier, to achieve proper *tajweed*, the Qur'anic text which learners read is an exacting system of orthographic representation; it not only encodes the phones but also additional cues such as consonant assimilation, emphasis, pausing, and more (see Czerepinski & Swayd, 2006; Haleem, 1994; Leong, 1998). In this section, characteristics such as script and diacritization are described.

Like MSA, Qur'anic Arabic is written from right to left in a cursive script. Although the Qur'an can be written in various styles of Arabic script, this dissertation will focus on the *Uthmani* script as it originated from Saudi Arabia and is the most popular script used globally. More importantly, it is the script most commonly used by our population of interest (Singaporean Muslims) to read the Qur'an.

Due to the nature of the cursive script, letters can be written in up to four different forms, depending on whether the letters are isolated or contextualised in the initial, medial, or final position (see Table 2-1) (Abu-Rabia, Share, & Mansour, 2003; Abu–Rabia, 2002). Diacritics in the form of consonant pointing or 'dots' were developed to distinguish between letters with identical shapes, such as ب /ت /ث or س/ش (see Haleem, 1994; Saiegh-Haddad & Henkin-Roitfarb, 2014). This similarity in shapes and dots in the script can have implications on orthographic processing; a minor error can lead to a mistake in decoding through confusion of letters of the same shape (Abu-Rabia, 1998). The overall visual complexity of Arabic orthography has been found to increase its perceptual load, thus slowing word identification even for university students whose first language is Arabic (Ibrahim, Eviatar, & Aharon-Peretz, 2002). However, how the visual complexity of the script can affect orthographic processing remains an empirical question for non-Arabic-speaking Qur'anic readers and memorisers.

Table 2-1. The Qur'anic alphabet with letter names, transliteration used by the Qur'anic Arabic Corpus (Dukes, 2009) based on Arabic through the Qur'an (Jones, 2005), basic IPA transcription, as well as its isolated and contextual forms in the Arabic script. Vowels are written in red, though و and ي are also consonants. (NB. *alif maqṣūrah and tā marbūṭah are not part of the alphabet but are contextual variants and appear quite frequently in the text.)

			Arabic	Contextual Forms		
Letter Name	**Transliteration**	**IPA**	**Isolated**	**Final**	**Medial**	**Initial**
alif	ā	aː	ا	ـا		ا
bā	b	b	ب	ـب	ـبـ	بـ
tā	t	t	ت	ـت	ـتـ	تـ
thā	th	θ	ث	ـث	ـثـ	ثـ
jīm	j	dʒ	ج	ـج	ـجـ	جـ
ḥā	ḥ	ħ	ح	ـح	ـحـ	حـ
khā	kh	x	خ	ـخ	ـخـ	خـ
dāl	d	d	د	ـد		د
dhāl	dh	ð	ذ	ـذ		ذ
rā	r	r	ر	ـر		ر
zāy	z	z	ز	ـز		ز
sīn	s	s	س	ـس	ـسـ	سـ
shīn	sh	ʃ	ش	ـش	ـشـ	شـ
ṣād	ṣ	sˤ	ص	ـص	ـصـ	صـ
ḍād	ḍ	dˤ	ض	ـض	ـضـ	ضـ
ṭā	ṭ	tˤ	ط	ـط	ـطـ	طـ
ẓā	ẓ	ðˤ	ظ	ـظ	ـظـ	ظـ

			Arabic	Contextual Forms		
Letter Name	**Transliteration**	**IPA**	**Isolated**	**Final**	**Medial**	**Initial**
ʿayn	ʿ	ʕ	ع	ـع	ـعـ	عـ
ghayn	gh	ɣ	غ	ـغ	ـغـ	غـ
fā	f	f	ف	ـف	ـفـ	فـ
qāf	q	q	ق	ـق	ـقـ	قـ
kāf	k	k	ك	ـك	ـكـ	كـ
lām	l	l	ل	ـل	ـلـ	لـ
mīm	m	m	م	ـم	ـمـ	مـ
nūn	n	n	ن	ـن	ـنـ	نـ
wāw	w or ū	w or u:	و	ـو		و
hā	h	h	ه	ـه	ـهـ	هـ
hamza	'	ʔ	ء		ء	
yā	y or ī	j or i:	ي	ـي	ـيـ	يـ
**alif maqṣūrah*	ā	a:	ى	ـى	n.a.	
**tā marbūṭah*	t or h	t or h	ة	ـة	n.a.	

In terms of vowelisation, which is the addition of information regarding vowels in text, MSA script is mostly unvowelled; vowelisation only occurs in religious text, children's books, or sporadically in ordinary texts when an ambiguity of pronunciation might arise (Abu-Rabia, 2012; Saiegh-Haddad & Henkin-Roitfarb, 2014). However, Qur'anic Arabic is fully vowelled and marked with various diacritics not only to indicate short vowels and gemination but also vowel lengthening, consonant assimilation, nasalisation, and more (see Appendix A for a full list of diacritics in the Qur'an). This is to ensure accurate and precise pronunciation in the reading and recitation of the Qur'an that is as close as possible to that of the Prophet (peace be upon him) (Haleem, 1994; Leong, 1998).

The transparent nature of Qur'anic Arabic orthography brought about by diacritics and contextual recitation rules means that once these rules are learned, decoding, and thus, reading aloud is relatively error-free; the one-to-one orthography-to-phonology mapping means that a string of graphemes in a particular context will only have one pronunciation. However, even for beginning native Arabic readers, reading a fully vowelled text is likely to be cognitively demanding, as the reader has to process many rules simultaneously to extract meaning from print or to read aloud accurately (Abu-Rabia et al., 2003). The implications of a possibly cognitively demanding transparent Qur'anic Arabic orthography on predictions for word recognition processes in non-Arabic-speaking Qur'anic readers will be discussed in Chapters 5 and 6.

2.3.2 Phonology

Qur'anic Arabic phonology comes in several forms depending on the style of recitation (*qira'at*). There are ten recognised styles and the most popular one (*Ḥafs*) is described here and applied throughout the dissertation (see Chapter 3 on the use of *Ḥafs* to phonetically contextually transcribe Qur'anic Arabic items for the Qur'anic Lexicon Project). The term 'phone' instead of 'phoneme' will be used throughout the dissertation as no assumptions are made with regards to the phonological representation of non-Arabic-speaking Qur'anic Arabic readers and memorisers.

Like MSA, Qur'anic Arabic has a rich consonantal inventory comprising 28 phones that correspond to the consonant letters in the alphabet (see Saiegh-Haddad & Henkin-Roitfarb, 2014, for a description of the phonetics in MSA; see Watson, 2002, for a detailed description of the phoneme system in Classical Arabic). Gemination occurs when marked by ‹ ّ › on the consonant, indicating to the reader that the consonant is doubled, i.e., lengthened. For example, ‹كَفَّرَ› is read as /kaffara/. Gemination can occur for all consonants except /ɣ/.

MSA has a vocalic inventory that consists of 6 vowel phones (short vowels: /a/, /i/, /u/; long vowels: /aː/, /iː/, /uː/). Qur'anic Arabic has the same vocalic inventory but also "longer" vowels of four to six beats marked by the diacritic ‹~›.

Short vowels are recited one beat “long” and long vowels are recited two beats “long”, whereas in ‹سَابِقُوٓاْ›, which has the diacritic ‹ ~ › on the letter ‘waw’ ‹ و › indicating vowel lengthening, the /uː/ in /saːbiquː/ is recited four to six beats long; six beats if it is at the end of a sentence (see Leong, 1998; Yeou, 2003). Qur’anic Arabic also contains two diphthongs, /aw/ and /aj/.

Syllables in Qur’anic Arabic have simple structures with very few consonantal clusters only occurring at the end of sentences that may require final syllable reduction. Their syllable structure includes VC, CV, and CVC (or CVCC at the end of the abovementioned sentences), which makes it easy to decode in reading aloud. Syllable segmentation is facilitated even further with a script that is heavily based on consonants and vowelisation that is typically marked by diacritics either above or below the consonant, e.g., ‹ شَهِدَ › can be easily segmented into three syllables in oral reading as /ʃa.hi.da/. However, the syllable segmentation (and thus, phonological representation) of geminated consonants and assimilated consonants across words in Qur’anic Arabic as well as other varieties of Arabic remains an interesting empirical question for researchers to study in the future. For example, /mm/ can either be segmented as /m.m/ or /mm./ and thus represented as either /CVC.CVC/ or /CVCC.VC/. The implications of consonant assimilation across words on the contextual phonetic transcription of the Qur’an are further discussed in Chapter 3. The implications of Qur’anic Arabic’s simple syllabic structure on word recognition processes will be discussed in Chapters 5 and 6.

As mentioned in the previous section, Qur’anic Arabic has very high feedforward consistency, with one-to-one orthography-to-phonology mapping and well-specified contextual recitation rules. Unfortunately, the same cannot be said for its feedback consistency from phonology to orthography where similar to MSA, a string of phones in Qur’anic Arabic can be spelled in more than one way. For example, /h/ at the end of a sentence can be spelled either as ‹ ه › or ‹ ة ›. Phonological assimilation across words is also a source of opacity and may affect the development of phono-lexical representations of words. This feedback inconsistency, or opacity, can have implications for researchers who are interested in Qur'anic Arabic orthographic encoding, or spelling, but for now, the focus of this dissertation will be on Qur'anic Arabic reading, in which the feedback inconsistency is hypothesised to have less importance.

Overall, the transparency of the orthography and simple syllabic structure of Qur'anic Arabic should not detract from the impressive feat it is for non-Arabic-speakers to achieve fluency in reading the Qur'an (and then to fully memorise it), given the visual complexity of the script, numerous contextual recitation rules, and the number of its verses (6236). This feat is even more impressive given that most non-Arabic-speakers are not exposed to the Arabic script or to the Arabic language other than through the Qur'an. To understand the population of interest in this study it is important to consider how a non-Arabic-speaking Qur'anic reader learns to read and achieve fluency (and progress to memorisation). The next section therefore aims to describe this learning and memorisation process for the population of interest (Singaporean Muslims).

2.4 Qur'anic Reading and Memorisation in Singapore

To appreciate the unique characteristics of this population, one must compare them to other L2 or native-Arabic-speaking populations and consider the nature of the linguistic input as well as learning and memorisation processes for Qur'anic Arabic. The current population of interest comes from predominantly non-native-Arabic-speaking Muslim communities such as the ones in the Indo-Pak and South-east Asian regions. According to the Singapore Census in 2010, the Muslim community in Singapore make up approximately 15% of the local population aged 15 and above, of which 84% are ethnically Malay and 13% are ethnically Indian; their language backgrounds are mostly bilingual (English and ethnic language) (Wong, 2011), thus making it an ideal sampling location.

Although the Muslim community in Singapore is that of a minority, it has a strong social presence with 70 mosques (Majlis-Ugama-Islam-Singapura, 2017), its own religious council, a *Shari'ah* (Islamic Law) court, six full-time *madrasahs* (religious Islamic schools), and numerous part-time/weekend *madrasahs*. Religious identity of Muslims in Singapore was also reported to be the strongest compared to other faiths, with 67.6% of Muslim respondents reporting that religion was very important to their identity compared to 44.1% of Protestants and 26.9% of Roman Catholics (Mathews, Bin Khidzer, & Teo, 2014). Daily prayers and Qur'an recitation form the main religious practices of Muslims, thus Qur'anic recitation and memorisation constitute a major component in the formal and informal religious education of children. For example, in the aLIVE programme implemented by the Islamic Religious Council of Singapore (MUIS) through part-time/weekend *madrasahs* via mosques, the Qur'anic Literacy and Understanding component of the curriculum begins at five years of age (Majlis-Ugama-Islam-Singapura, 2018). Here, enrolled children are introduced to the Qur'anic Arabic alphabet and *Iqra'* (a phonics system of learning to read the Qur'an), as well as learning how to recite and understand four very short *surahs* (chapters) of the Qur'an, while formal memorisation of Qur'anic *surahs* begins at nine years of age (Majlis-Ugama-Islam-Singapura, 2018). It is worth noting that according to their website, "more emphasis is placed on Qur'anic Literacy in the Kids and Tweens aLIVE programmes" as compared to other aspects of the curriculum (Majlis-Ugama-Islam-Singapura, 2018), which further re-iterates the perceived importance of learning how to read the Qur'an.

Despite this perceived importance, there is surprisingly no existing formal literature on Qur'anic reading and memorisation in Singapore. Therefore, to provide a holistic picture of the Qur'anic reading and memorisation practices amongst Singaporean Muslims, it was necessary to collect new background data to inform the study methods and interpretation. The following sections summarise findings based on data collected through the following methods:

a) In-depth interviews with 12 *huffaẓ* (people who have fully memorised the entire Qur'an); $M_{\text{Age}} = 28.46$, $SD_{\text{Age}} = 5.11$. These were recruited through word-of-mouth, friends or colleagues.
b) Classroom observations at six *tahfiẓ* (memorising) schools and centres recruited through email invitations.
c) An online Qur'anic reading and memorisation questionnaire that was given to 362 participants (230 females, $M_{\text{Age}} = 20.22$, $SD_{\text{Age}} = 7.36$). To get a wide range of responses, a link to the online questionnaire was shared in Facebook and WhatsApp groups for Singaporean Muslims.

Participants were also sampled from full-time and part-time *madrasahs* as well as full-time and part-time Qur'an *tahfiẓ* schools and centres, some of which were the same ones as mentioned in (b). The questionnaire is provided in Appendix C.

Given the psycholinguistic focus of the current study, the following sections will focus on the description of the various linguistic inputs received by the non-Arabic-speaking Qur'anic reader, i.e., orthographic, phonetic, and semantic.

2.4.1 Orthographic Input

Singapore has four official languages: English, Malay, Mandarin, and Tamil; most public signs are written in English and another language, or all four. Most Singaporean Muslims learn at least two languages formally in school, English and their ethnic language, which is typically Malay. Both English and Malay use the same Latin alphabetic script, while Mandarin uses a logographic script and Tamil uses an abugida script. This means that unlike native Arabic speakers, for many Singaporean Muslims, the only exposure to the Arabic script is either through attending an Islamic school, reading the Qur'an, or formal Arabic language classes. Perhaps due to this limited exposure and given the importance placed on Qur'anic reading, many parents start their children young when it comes to learning how to read the Qur'an; when online respondents were asked at what age they started to read the Qur'an, the average age reported was 6.86 years (*SD* = 3.36).

When learning how to read the Qur'an, children are first introduced to the Qur'anic Arabic alphabet with the letters in isolated form (see Table 2-1). As mentioned earlier, the Islamic Religious Council of Singapore (MUIS) uses a phonics system called Iqra' to teach the children in their aLIVE programme how to read the Qur'an; Iqra' is also widely used in the Singaporean Muslim community by parents and Qur'anic teachers to teach children how to read the Qur'an in one-on-one settings at home or in classes. Indeed, 91.71% of online respondents said yes when asked if they had used "a special book" to learn how to read the Qur'an, of which 84.59% of online respondents reported having used Iqra' when asked what book was used. Although there are other similar learning aids that may be used when learning how to read the Qur'an (e.g., Muqaddam, Qiraati, etc.), this section will focus on describing in detail the learning process using the most popular aid, Iqra'.

Iqra' (Humam, 1990) is a six-volume book that uses a phonics system to teach the learner *tajweed* (elocution) rules comprising the grapheme-to-phoneme correspondences in Qur'anic Arabic in tandem with contextual pronunciation rules such as phonetic assimilation, nasalisation, pauses, amongst many others. Progress is tied to the individual's ability to master a stage and pass its assessment before moving on to the next stage (volume). Online respondents reported taking 2.65 years (*SD* = 2.15) on average to complete the entire course.

In the initial stages, learners begin with individual graphemes and short vowel diacritics, immediately pronouncing them as syllables. In the first volume, learners master decoding all combinations of consonant + ◌َ (a short vowel diacritic, /a/). For example, learners master reading ‹ أَ › and ‹ بَ › as /ʔa/ and /ba/ respectively through various permutations of the two syllables, reading the second row from right to left, /ba/ /ʔa/ /ba/ and /ʔa/ /ba/ /ʔa/ (Humam, 1990, p. 1, Vol. 1). They are also guided to pay careful attention in distinguishing between consonants that look similar, such as ‹ سَ › /sa/ vs. ‹ شَ › /ʃa/, or sound similar, such as ‹ حَ › /ħa/ vs. ‹ هَ › /ha/. In the later volumes, learners then progress to connected letter forms as well as decoding disyllables and multisyllables (see Humam, 1990, p. 1, Vol. 2). They are also taught to distinguish between short and long vowel pronunciation (see Humam, 1990, p. 2, Vol. 3) and introduced to diacritics that lengthen vowels (see Humam, 1990, p. 19, Vol. 3). Finally, they move on to decoding short and long sentences in which the end of a sentence is marked by a white circle; learners are expected to know rules relating to stopping at the end of a sentence, such as deletion of the final vowel (see Humam, 1990, p. 26, Vol. 5). In the final volume, learners progress to reading even longer sentences without pausing for breath, unless there are pause or stop marks (see Humam, 1990, p. 30, Vol. 6). At the end of this learning process, learners are expected to be able to read the Qur'an (see Figure 2-1) fluently with proper *tajweed*.

When online respondents were asked to rate their fluency in reading the Qur'an with proper *tajweed* on a scale of 1 to 9 (1 = "Not fluent at all", 9 = "Very fluent"), their rating was 6.55 on average (*SD* = 1.77). Furthermore, Qur'an memorising schools and centres do expect their students to be fluent Qur'an readers by the time they begin memorising, so one can expect that this non-Arabic-speaking population of Qur'anic memorisers should be able to read Qur'anic Arabic words rather accurately and to do reasonably well in visual word processing tasks that biases sublexical decoding such as speeded pronunciation, notwithstanding individual differences in performance.

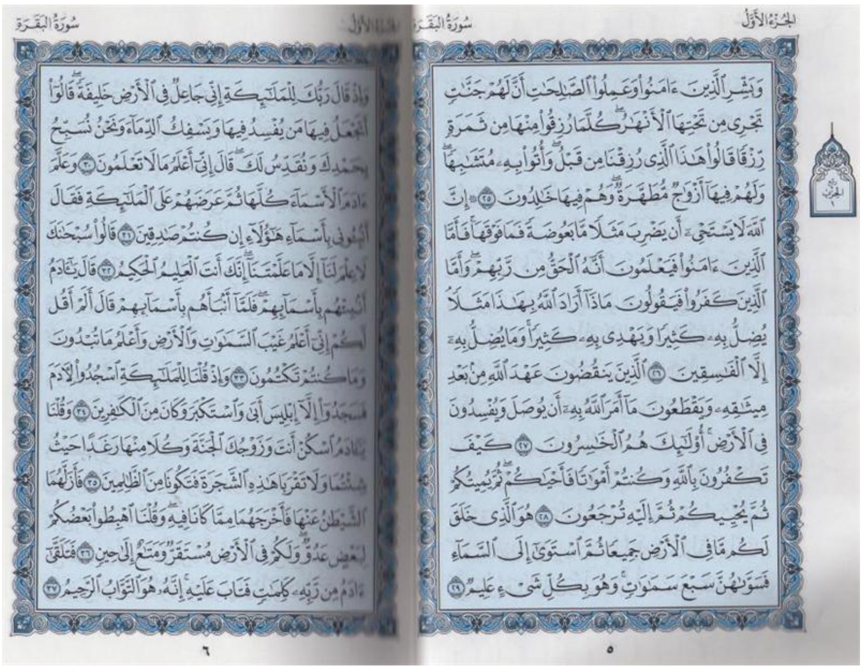

Figure 2-1. Pages from the Qur'an (2nd Chapter: Al-Baqarah). From "Mus'haf al-Madinah: Ḥafs Edition" by King Fahd Complex for the Printing of the Holy Quran, 1986, p.5-6. Copyright 1986 by King Fahd Complex for the Printing of the Holy Quran. Reprinted with permission.

What makes this population unique (and different from other L2 populations) is the extensive amount of consistent exposure to the orthography in a corpus for the non-Arabic-speaking Qur'anic reader. 90.61% of the online respondents reported reading the Qur'an at least daily or weekly (see Table 2-2). 69.34% of online respondents also reported having done a *khatam* (completed the reading of the entire Qur'an) at least once; this is typically a special event for Muslims and parents would celebrate this occasion by giving away sweets.

This consistent exposure to the orthography is even more so for the non-Arabic-speaking Qur'anic memoriser than for the non-Arabic-speaking Qur'anic reader. This is because the memorisation process typically involves a lot of reading and repetition of what is being memorised. When online respondents were asked about their Qur'anic memorisation methods, the majority of online respondents (85.91%) reported memorising by reading the Qur'an and repeating the sentence or verse they are memorising multiple times. One respondent reported that he/she repeated a sentence 15 times before moving on to the next sentence. This reading-repetition-rehearsal method holds true for all the *huffadẓ* interviewed and in all the Qur'an memorising classes observed. 22.38% of online respondents reported supplementing this method by writing out the verses that they are memorising, which possibly aids in further consolidating their orthographic knowledge.

Qur'an memorisation starts at a young age for this population; online respondents reported starting to memorise the Qur'an at 8.55 years on average (SD = 5.29). However, it is worth noting that there is greater variability in the frequency of Qur'an memorisation; only 68.27% of online respondents reported practising their Qur'an memorisation at least daily or weekly and 21.25% of online respondents reported rarely practising their Qur'an memorisation (see Table 2-2). The ones who practise daily or weekly are typically students in Qur'an memorising schools or centres. In Qur'an memorising schools, students spend at least four hours every day practising their memorisation and having it checked by the teacher individually. In all classroom observations of a Qur'an memorising class with older students (teenage and adult), while waiting for their turn to be checked, students would practise their memorisation on their own, either using the Qur'an to check their own memorisation or asking a classmate to help them to do so. Furthermore, this variability in Qur'an memorisation is also demonstrated in another way: only 6.55% of online respondents (N = 22) reported having memorised the entire Qur'an.

Table 2-2. Proportion of online respondents choosing a particular option when answering the questions "How often do you read the Qur'an?" and "How often do you practise memorising the Qur'an?".

Option	Frequency of reading the Qur'an	Frequency of practising Qur'an memorisation
Daily	53.04%	31.44%
Weekly	37.57%	36.83%
Monthly	3.59%	10.48%
Rarely	5.80%	21.25%

In summary, the orthographic input for non-Arabic-speaking Qur'anic readers and memorisers is similar to that of an L2 beginner reader of a transparent orthography in that it begins at the level of the grapheme and emphasis is placed on decoding consistent grapheme-to-phoneme correspondences. However, unlike L2 readers, there is extensive consistent exposure to the orthography and the corpus given the high frequency of Qur'anic reading and memorisation. More importantly, unlike L2 readers, there is no direct instruction on the meaning of the words being read or any attempt to use the words creatively for communication. This makes the population an excellent case study to investigate the role of statistical exposure to orthography in visual word processing, specifically whether implicit statistical learning can help in forming orthographic lexical representations despite limited semantic input. This will be discussed further in Chapter 4. Qur'anic memorisers do rely on the Qur'an to start off their memorisation and to check their memorisation, but it remains to be seen whether the orthographic input is encoded into long-term memory like their phonetic input, and whether the orthographic input and learning processes facilitated by the use of Iqra' is sufficient in helping them identify word boundaries and segments despite the small whitespace of the script as seen in Figure 2-1. Furthermore, the variability in Qur'an memorisation allows for the investigation of the effect of individual differences in statistical exposure to orthography on visual word processing. The implications of both on predictions for visual word recognition processes will be discussed in Chapters 5 and 6.

2.4.2 Phonetic Input

Upon mastering Iqra', non-Arabic-speaking Qur'anic learners would have not only acquired the impressive phonetic inventory of Qur'anic Arabic, but also the extensive bank of contextual recitation rules. Learners in this population may receive this phonetic input through various ways: their Qur'an teacher during the early stages of reading as well as during correction of recitation errors, themselves while reciting the Qur'an, or listening to professional Qur'an recitation (i.e., the best possible phonetic input).

Qur'anic recitation differs from normal speech given the extensive contextual co-articulation rules and that it is akin to singing; one is trained in breath control to be able to recite a very long sentence (e.g. 30 syllables or more) in one breath without breaking it up with pauses like normal speech (see al Faruqi, 1987). It is this phonetic input that Qur'anic readers and memorisers are consistently exposed to, similar to their exposure to the orthography, given the frequency of their Qur'anic reading and memorisation. As mentioned earlier, students in Qur'an memorising schools are expected to memorise several pages of the Qur'an and to practise their past memorisation each day; they mostly do so through pure repetition and rehearsal. This provides them with an enormous amount of exposure to such phonetic input regularly (daily to weekly). However, similar to their individual differences in exposure to the orthography, there are also individual differences in the frequency of exposure to such phonetic input.

Looking at exposure to the best possible phonetic input (i.e., professional Qur'anic recitation), 92.88% of online respondents reported listening to professional Qur'an recitation, with the most popular methods being via a Qur'an app on a tablet or smartphone (68.42%), via YouTube videos (65.02%), and MP3 files (31.27%). However, most online respondents prefer to read the Qur'an silently or recite the Qur'an themselves instead of listening to professional Qur'an recitation to accompany their Qur'anic reading, with 88.86% of online respondents reporting only listening to professional Qur'an recitation to accompany their Qur'anic reading sometimes or less often (see Table 2-3). Furthermore, only 43.37% of online respondents reported supplementing their Qur'anic memorisation with the listening of professional Qur'an recitation. These two findings reflect the possible variability in the quality of phonetic input received by non-Arabic-speaking Qur'anic readers and memorisers.

Table 2-3. Proportion of online respondents choosing a particular option when answering the question "How often do you listen to Qur'an recitation while reading the Qur'an"?

Option	% of Online Respondents
Never	27.11%
Rarely (while reading the Qur'an)	28.01%
Sometimes (while reading the Qur'an)	33.73%
Most of the time (while reading the Qur'an)	9.34%
All the time (while reading the Qur'an)	1.81%

2.4.3 Semantic Input

As mentioned earlier, the fundamental goal of learning to read and memorise the Qur'an is to be able to recite accurately and fluently the verses from memory. Classes that teach how to read and/or memorise the Qur'an do not include the teaching of the meaning of the words and the verses, therefore learners and memorisers receive very limited semantic input in their reading and memorisation. To quote one of the *huffaẓ* who was interviewed, "…it was like memorising a song in a foreign language".

It is thus unsurprising that the majority of online respondents (83.43%) reported that they only understand some of the Arabic or less while reading the Qur'an (see Table 2-4). Similarly, the majority of online respondents (78.19%) reported that they only understand some of the Arabic or less while memorising the Qur'an (see Table 2-4). When asked how they memorised verses of the Qur'an, only five of the 362 online respondents wrote in their free response option that they tried to find out the meaning of the words or the verses that they were memorising to help their memorisation.

Table 2-4. Proportion of online respondents choosing a particular option when answering the questions "How much of the Arabic do you understand while reading the Qur'an?" and "How much of the Arabic do you understand while memorising the Qur'an?".

Option	Understand the Arabic while **reading** the Qur'an	Understand the Arabic while **memorising** the Qur'an
None at all	3.87%	2.27%
A little of it	29.56%	29.18%
Some of it	50.00%	46.74%
Most of it	15.75%	19.83%
All of it	.83%	1.98%

In summary, semantic input for non-Arabic-speaking Qur'anic readers and memorisers is typically very limited but largely differs based on the individual. Not only does this make an interesting case for investigating how this population processes words visually with limited semantic knowledge, but also for investigating the effect of individual differences in semantic knowledge on visual word processing. The implications of both on predictions for visual word recognition processes will be discussed in Chapters 5 and 6.

2.5 Summary

This chapter provided the background of the current study by introducing the unique population of non-Arabic-speaking Qur'anic readers and memorisers, the psycholinguistic characteristics of the language to which they are exposed, as well as the linguistic (orthographic, phonetic, and semantic) inputs they receive. In summary, what makes this population unique is that it engages in a rote memorisation exercise rather frequently despite self-reported limited understanding of what is being memorised. This makes it different from a native-Arabic-speaking population, an L2 population, or typically developing children who are acquiring language with semantic and contextual cues and whose goal is word and grammar learning. Studying the visual word processing of this unique population may have important theoretical implications on existing theories and models of word processing that the previous rather Anglocentric body of evidence have not uncovered (see Share, 2008).

Furthermore, the current study offers an excellent opportunity to investigate the role of implicit statistical learning in visual word processing via a naturalistic experiment. In artificial language experiments using laboratory learning paradigms, participants typically receive short term exposure to linguistic input and statistics manipulated over a small set of items (Apfelbaum, Hazeltine, & McMurray, 2013). However, the amount of exposure to linguistic input (years) in our population is so much longer and cover a range of statistics over a much wider range of items, thus making it more ecologically valid. Based on the large variability in exposure to the abovementioned linguistic inputs, there is also a case to explore individual differences in the current study. One can surmise two important individual-level variables: amount of Qur'an memorisation and vocabulary knowledge. These variables and their measures will be further discussed in Chapter 4.

Chapter 3. The Qur’an Lexicon Project: A Psycholinguistic Database for Qur’anic Arabic

3.1 Introduction

Despite the Qur’an’s large user base, there has not been a single study on the psycholinguistic processing of Qur’anic Arabic. A major impediment to the development of such research has been the lack of data regarding the lexical characteristics of Qur’anic Arabic necessary to develop stimuli for empirical psycholinguistic studies, such as word frequency, neighbourhood density and so on. To date, databases of lexical statistics exist for numerous languages, which are important in the study of the effects of various psycholinguistic variables on visual word recognition across languages. These include the English Lexicon Project (Balota et al., 2007), French Lexicon Project (Ferrand et al., 2010), Malay Lexicon Project (Yap, Liow, Jalil, & Faizal, 2010), Chinese Lexicon Project (Sze, Liow, & Yap, 2014), and Aralex (Boudelaa & Marslen-Wilson, 2010) for Modern Standard Arabic, but none for Qur’anic Arabic.

To overcome the above limitation and develop a better understanding of the statistical patterns in the language one is exposed to via Qur’anic recitation and/or memorisation, we developed the Qur’an Lexicon Project, a database of lexical variables for 19,286 types in the Qur’an corpus that had been contextually and phonetically transcribed based on Qur’anic recitation. This is the first lexical database for Qur’anic Arabic, building on and extending past Qur’anic projects such as the Tanzil project (Zarrabi-Zadeh, 2008), the Qur’anic Arabic Corpus (Dukes, 2009), and Quranic Corpus (Zeroual & Lakhouaja, 2016), which served to provide a verified Qur’an text and annotated Qur’an resources with morphosyntactic information respectively. The resulting database will be made open-source with the aim of providing a resource for researchers studying Qur’anic Arabic lexical and phonological processing as well as for making systematic cross-linguistic comparisons that allow for a better delineation of language-specific and language-general processes in language processing.

3.2 Development of the Qur'an Lexicon

The initial stages of development and content of the Qur'an Lexicon Project were presented in a conference paper by Binte Faizal and colleagues (2015). More variables and further refinements have since been completed and the following sections describe the complete and final method together with results characterizing the nature of the corpus with respect to the lexical and morphological variables calculated.

3.2.1 Corpus

We started by using the Qur'anic Arabic Corpus (Dukes, 2009) that was built on the verified Arabic text of the Qur'an distributed by the Tanzil project (Zarrabi-Zadeh, 2008). In this corpus, 77,430 orthographic tokens had already been segmented according to the whitespaces between them in the text. The corpus also had the position of each token in the text annotated by its *surah* (chapter) number, sentence number, and word position in the sentence. Each token also had its own Buckwalter transliteration (Buckwalter, 2002) that uses American Standard Code for Information Interchange (ASCII) characters to represent Arabic orthography.

3.2.2 Transcription

To construct stimuli with specific orthographic and phonological properties for the psycholinguistic experiments in this dissertation and to calculate characteristics such as phone frequency, it was necessary to transcribe phonetically each item in the Qur'an corpus. However, it is important to note that the Qur'an corpus is unique in that all the words appear in a certain order and are recited in that order. Due to strict rules of recitation, or *tajweed*, the pronunciation of a word depends on the position of the word in a sentence as well as the word that precedes or follows it; context thus plays a huge role in the pronunciation of a word (see Czerepinski & Swayd, 2006; Leong, 1998). Not only does this make the Qur'an Lexicon different from other lexicons that were created from corpora with words in isolation, this also speaks to possible theoretical implications for future studies that look into a better delineation of orthographic versus phonological processes in language processing.

For the Qur'an Lexicon, special rules were scripted to convert each token's Buckwalter transliteration into a contextual broad phonetic transcription that considered co-articulatory effects in continuous Qur'anic recitation marked orthographically in the script. Pauses in the Qur'anic recitation are reflected in sentence endings and compulsory pause markers, which the transcription also took into account.

This means that the phonetic transcription in this corpus is not necessarily how one would read the word in isolation but is based on how one would recite the word, taking into account the *tajweed* rules of recitation. For example, at the end of words, a long vowel ending is shortened when it is assimilated with a *sukun* (ْ) in the next word. Table 3-1 presents an example of فَلَا that is followed by ٱقْتَحَمَ. Such contextual transcription ensures that the Qur'an corpus accurately reflects the characteristics of items as they are recited or heard by Qur'an users, thus increasing the validity of the phonological characteristics calculated in the Qur'an Lexicon such as phonotactic probability. A list of the contextual transcription rules based on *tajweed* can be found in Appendix B.

Table 3-1. Example of a tajweed rule in which a long vowel ending is shortened when it is assimilated with a *sukun* (ْ) in the next word.

	First word	Second word
	فَلَا	ٱقْتَحَمَ
Buckwalter transliteration	falaA	{qotaHama
Phonemic transcription	fa.laa	ʔɪq.ta.ħa.ma
Contextual phonetic transcription	fa.la	q.ta.ħa.ma

Each token's contextual phonetic transcription was manually cross-checked with a professional *qari* (Qur'an reciter) recitation and verified by a proficient Qur'anic Arabic reader. Approximately 10% of the corpus was also manually checked and verified by a *hafiẓ* (someone who has memorised the entire Qur'an).

The final corpus had 77,430 tokens, with 18,994 unique orthographic representations and 19,286 unique phonetic representations. It was these orthographic and phonetic representations that were used to calculate all the lexical and phonotactic probability characteristics instead of more traditional definitions of phonological representations of words in isolation that do not take into account co-articulatory effects in recitation. This is because we did not seek to make any assumptions about the Qur'anic reciters' or memorisers' phonological representations, but rather planned to investigate the nature of these representations in future work, such as whether فَلَا is phonologically represented as /fa.laa/ as it is pronounced in isolation or /fa.la/ as it is pronounced contextually. Following traditional definitions of phonological representations would bring certain assumptions to calculations of lexical and phonotactic probability characteristics such as phonological neighbourhood density, thus it would be best to remain atheoretical for now.

In the following sections, we describe the various lexical and phonotactic probability characteristics that were computed for the Qur'an Lexicon Project, as informed by previous work completed in lexical databases of other languages such as English, Arabic, and Malay, as well as anticipating specific research questions in this dissertation. Table 3-2 presents the descriptive statistics of these characteristics.

Table 3-2. Descriptive item statistics and phonotactic probabilities in the Qur'an Lexicon

	M	*SD*	Min	Max
Orthographic Item Frequency	4.08	22.81	1.00	1098
Log(Orthographic Item Frequency)	.46	.29	.30	3.04
Phonetic Item Frequency	4.02	23.66	1.00	1264.00
Log(Phonetic Item Frequency)	.45	.29	.30	3.10
Syllable Count	3.41	1.00	1.00	8.00
Phone Count	7.71	2.04	2.00	17.00
Character Count	5.27	1.45	1.00	11.00
Orthographic Levenshtein Distance (OLD20)	2.77	1.11	1.00	9.40
Phonological Levenshtein Distance (PLD20)	2.37	.91	1.00	10.00
Orthographic Neighbourhood Density (ON)	.66	1.03	.00	8.00
Phonological Neighbourhood Density (PN)	1.13	1.59	.00	18.00
Lexical Uniqueness Point	6.28	1.84	2.00	15.00
Positional Segment Average (PosSegAv)	.12	.04	.00	.35
Positional Segment (PosSegSum)	.90	.41	.01	3.18
Biphone Average (BiPhonAv)	.02	.01	.00	.09
Biphone Sum (BiPhonSum)	.12	.10	.00	1.45
Root Length	3.02	.13	3.00	4.00
Root Frequency	30.41	113.23	1.00	2851
Log(Root Frequency)	.92	.61	.30	3.46
Root Family Size	8.35	9.81	1.00	84

3.3 Database Descriptives

The following describes the lexical and phonological characteristics calculated in the Qur'an Lexicon Project, special considerations, methods for calculation or development, and their summary data to provide the reader with a description of the available data.

3.3.1 Pronunciation

Both isolated and contextual IPA transcriptions of each item are provided.

3.3.2 Length

Linguistic databases for alphabetic writing systems such as English and Malay typically define length variables as the number of characters or letters, syllables, and phonemes in a word (e.g. Balota et al., 2007; Yap et al., 2010). Length variables are included as they are useful for measuring length effects in visual word recognition tasks; inhibitory length effects on lexical decision and speeded pronunciation latencies are well-documented in numerous studies across alphabetic writing systems (see Chapters 5 and 6 for a review). Furthermore, this also means that stimuli for psycholinguistic tasks often need to be matched for length, making such information important for researchers.

For length measures in the Qur'an Lexicon, number of characters, syllables, and phones are provided for each item. Although there are debates in Arabic on the segmental representation of diphthongs (e.g. Watson, 2002) and geminates (e.g. Al-Tamimi & Khattab, 2011; S. Davis, 2011; S. Davis & Ragheb, 2014; Khattab, 2007), they were treated here as singular phones for phone counts so as to be consistent with other psycholinguistic databases such as in English or Malay. For example, بَيْتٌ (house: /bajtun/) has three characters: ب, ي, ت; five phones: /b/ /aj/ /t/ /u/ /n/; and two syllables: /baj/-/tun/. In the Qur'an Lexicon, the average Qur'anic Arabic item was about five characters long with eight phones and three syllables (see Table 3-2).

3.3.3 Frequency

Frequency is defined as the number of times a word (or other sublexical units) occurs in a corpus. Linguistic databases for alphabetic writing systems such as English, Malay, and Arabic typically collate frequency counts of words from a variety of corpora such as newspapers and film subtitles (e.g. Balota et al., 2007; Boudelaa & Marslen-Wilson, 2010; Yap et al., 2010). However, the Qur'an corpus is limited to the text in the Qur'an itself (as readers only use one book for recitation), therefore frequency counts in the Qur'an Lexicon are limited to the Qur'an corpus with 77,430 tokens.

Frequency variables are included as they are useful for measuring frequency effects in visual word recognition tasks; facilitatory frequency effects on lexical decision and speeded pronunciation latencies are well-documented in numerous studies across alphabetic writing systems (see Chapters 5 and 6 for a review). Furthermore, this also means that stimuli for psycholinguistic tasks often need to be matched for frequency, making such information important for researchers.

An N-gram extraction tool (Zhang, n.d.) was used to compute the following frequency counts in the Qur’an corpus: *item (orthographic and phonetic), syllable, biphone*, and *phone*. For *item frequency*, both raw and log-transformed counts were provided. For *syllable, biphone*, and *phone frequencies*, both overall and position-specific counts were provided. Figure 3-1 and Figure 3-2 present the type and token counts for items grouped by number of phones and number of syllables respectively. On average, an item occurs in the Qur’an corpus about four times, both orthographically and phonetically (see Table 3-2).

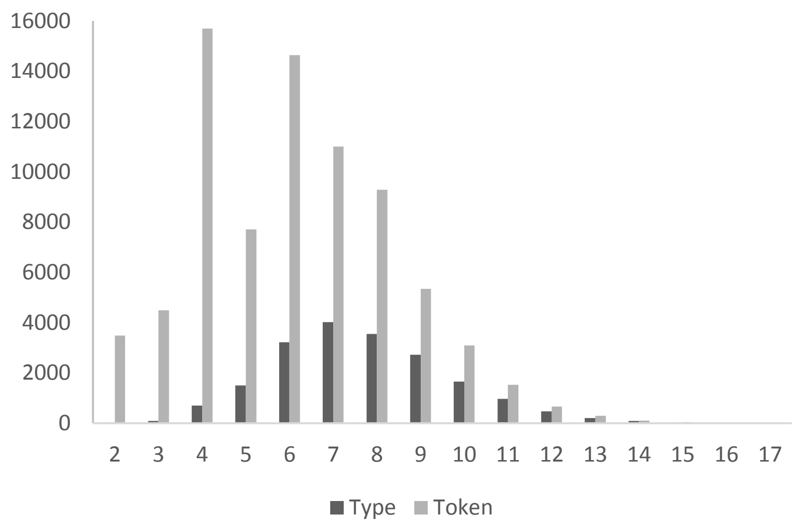

Figure 3-1. Type and token counts for items grouped by number of phones in the Qur’an Lexicon

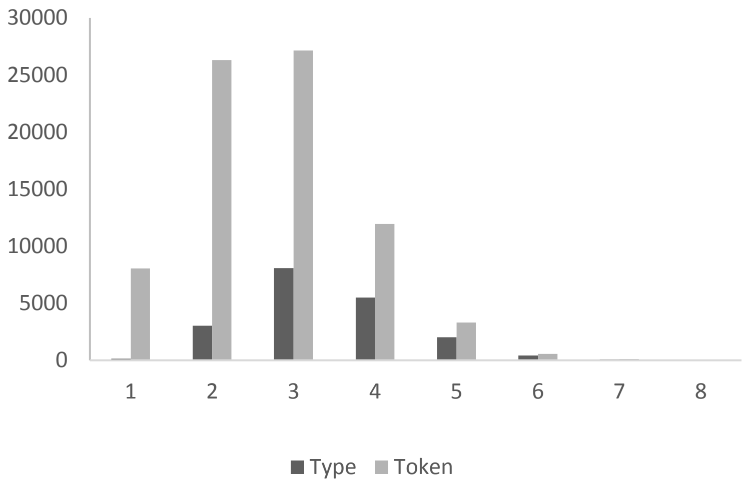

Figure 3-2. Type and token counts for items grouped by number of syllables in the Qur'an Lexicon

3.3.4 Lexical Uniqueness Point

Lexical uniqueness point is defined as the point at which a set of phonemes or graphemes is no longer a subset of some other set of phonemes or graphemes in a word (Francom, Woudstra, & Ussishkin, 2009). This variable is included as they may be useful for researchers who are interested in looking at uniqueness point effects in word recognition as documented in various studies (e.g. Lindell, Nicholls, & Castles, 2003; Luce, 1986; Radeau, Morais, Mousty, & Bertelson, 2000; Radeau, Mousty, & Bertelson, 1989) or would like to control for lexical uniqueness point in their stimuli, as advised by Goldinger (1996).

The code for the lexical uniqueness point calculator used in the web resource for Hebrew spoken word recognition (Francom et al., 2009) was adapted to suit the Arabic script and the special characters used in our phonetic transcription. The lexical uniqueness point was then calculated for each item both phonetically and orthographically. This calculator searches the Qur'an Lexicon database for the desired string and then compares the string to each entry that overlaps with the desired string. It then provides an index of the point at which the desired string no longer overlaps with other entries, i.e., the lexical uniqueness point. On average, the lexical uniqueness point of an item in the Qur'an Lexicon coincided with the sixth phone, which means that the average item is rather phonologically similar with other items up to the sixth phone (see Table 3-2), which may have implications on word processing.

3.3.5 Neighbourhood Size

Linguistic databases for alphabetic writing systems such as English and Malay traditionally define neighbourhood size using Coltheart's definition: the number of words that can be obtained by changing a single character in the target word, while holding the identity and positions of the other characters constant (e.g. Balota et al., 2007; Yap et al., 2010). Neighbourhood size variables are included as they are useful for measuring neighbourhood effects in visual word recognition tasks; facilitatory effects of neighbourhood size on lexical decision and speeded pronunciation latencies are well-documented in numerous studies across alphabetic writing systems (see Chapters 5 and 6 for a review). Furthermore, this also means that stimuli for psycholinguistic tasks often need to be matched for neighbourhood size, making such information important for researchers.

To the best of our knowledge, there is no consensus about what should constitute a neighbour in Arabic (see Alsari, 2015; Perea, 2015, for discussions), and therefore, Qur'anic Arabic. Given the lack of agreement and that the significance of orthographic or phonological similarity in the psycholinguistic processing of Qur'anic Arabic is an empirical issue that still needs to be addressed, we thus decided to include classical neighbourhood size measures (number of lexical items differing by one character or phoneme through addition, substitution or deletion) in the Qur'an Lexicon as was calculated in other lexical databases such as English and Malay (e.g. Balota et al., 2007; Yap et al., 2010). Maintaining consistency with other databases will also allow researchers to make cross-linguistic comparisons of neighbourhood size measures should the need arises.

Neighbourhood size measures were computed using LINGUA (Westbury, Hollis, & Shaoul, 2007). Orthographic neighbourhood density (ON) is a measure of orthographic similarity referring to the number of words that can be obtained by changing a single character in the target word, while holding the identity and positions of the other characters constant (Coltheart, Davelaar, Jonasson, & Besner, 1977; C. J. Davis, 2005). Here, supplementary diacritics or *tashkīl* are treated as separate characters from consonants and computed into the neighbourhood density calculation. For example, the orthographic neighbours of وَلَدَ (he begot: /walada/) include وَرَدَ (he came: /warada/), وَلَدٌ (child: /waladun/), وَعَدَ (had promised: /waʕada/), and وَلَكَ (and for you: /walaka/). On average, an item in the Qur'an Lexicon has .66 orthographic neighbours (*SD* = 1.03), with a range of zero to eight orthographic neighbours.

Phonological neighbourhood density (PN) is the phonological analogue of orthographic neighbourhood density and reflects the number of words that can be obtained by changing a single phoneme in the target word while holding the other phonemes constant and preserving the identity and positions of the other phonemes (Yates, 2005; Yates, Locker, & Simpson, 2004). PN was computed using Qur'anic Arabic contextual phonetic transcription. For example, the phonological neighbours of عَقِيمٍ (barren: /ʕaqi:m/) are عَلِيمٌ (All-Knowing: /ʕali:m/), سَقِيمٌ (ill: /saqi:m/), and عَظِيمٌ (great: /ʕaðˤi:m/). On average, an item in the Qur'an Lexicon has 1.13 phonological neighbours (*SD* = 1.59), with a range of zero to 18 phonological neighbours (see Table 3-2).

3.3.6 Levenshtein Distance

Levenshtein distance was developed from a standard computer science metric of string similarity and has been calculated in English and Malay lexical databases (e.g. Balota et al., 2007; Yap et al., 2010). This was defined as the number of insertions, deletions, and substitutions needed to generate a string of elements, such as letters or phonemes, from another (Yarkoni, Balota, & Yap, 2008). This differs from classical neighbourhood measures such as Coltheart's N, which limit themselves to a difference of one insertion, deletion, or substitution (Coltheart et al., 1977).

As mentioned in the previous section, there is still a need to determine empirically the best approach of measuring orthographic and phonological similarity in Qur'anic Arabic. Including Levenshtein distance measures in the Qur'an Lexicon would allow researchers to compare these measures with classical neighbourhood size measures and test the validity and predictive power of these measures. The Levenshtein measures have been shown by Yarkoni and colleagues (2008) to circumvent many limitations that are linked to traditional neighbourhood measures such as orthographic N, to the extent of being more powerful predictors of word recognition performance in English (see Yap & Balota, 2009; Yarkoni et al., 2008) and in Malay (Yap et al., 2010). For instance, the utility of OLD20 and PLD20 as a measure of similarity or distinctiveness extends to words of all lengths and especially to long words, wherein the utility of orthographic N and phonological N is limited, as most long words (e.g. television, intermission) have few or no orthographic and phonological neighbours. This is especially significant in Arabic, which is an agglutinative language, and thus, has naturally longer words than English (see Figure 3-3 and Figure 3-4).

To create usable metrics of orthographic and phonological similarity, orthographic and phonological Levenshtein distances were first calculated between every item and every other item in the Qur'an Lexicon. OLD20 and PLD20 represent the mean orthographic and phonological Levenshtein distances, respectively, from an item to its 20 closest neighbours. Like phonological N, PLD20 was computed using Qur'anic Arabic contextual phonetic transcription. Figure 3-3 presents the mean OLD20 and ON as a function of item length while Figure 3-4 presents the mean PLD20 and PN as a function of item length. On average, an item in the Qur'an Lexicon has an OLD20 of 2.77 (*SD* = 1.11) and a PLD20 of 2.37 (*SD* = .91) (see Table 3-2).

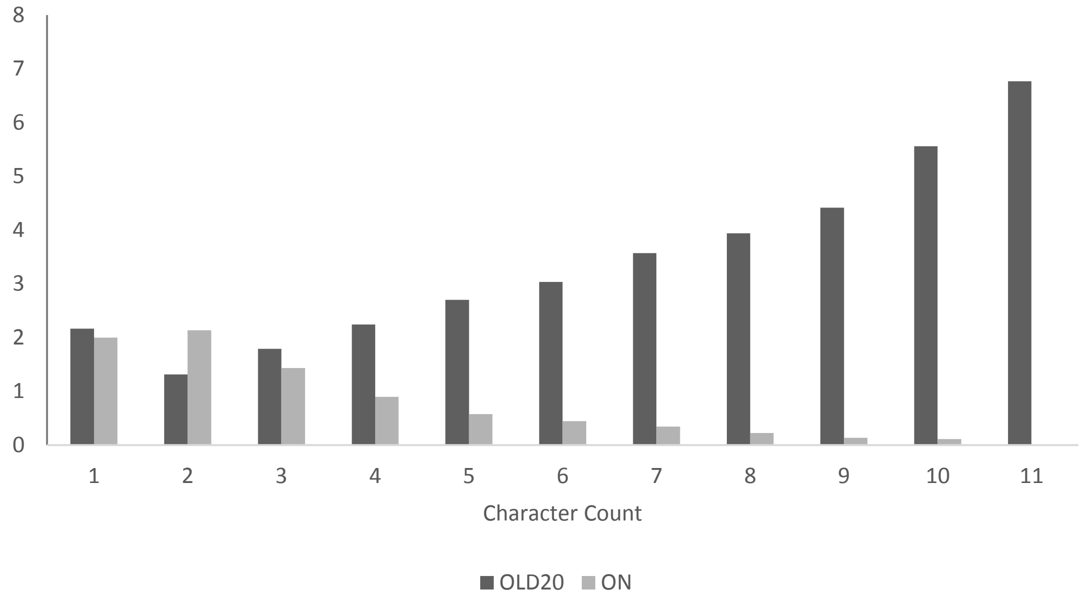

Figure 3-3. Mean orthographic Levenshtein distance (OLD20) and orthographic N (ON) as a function of length.

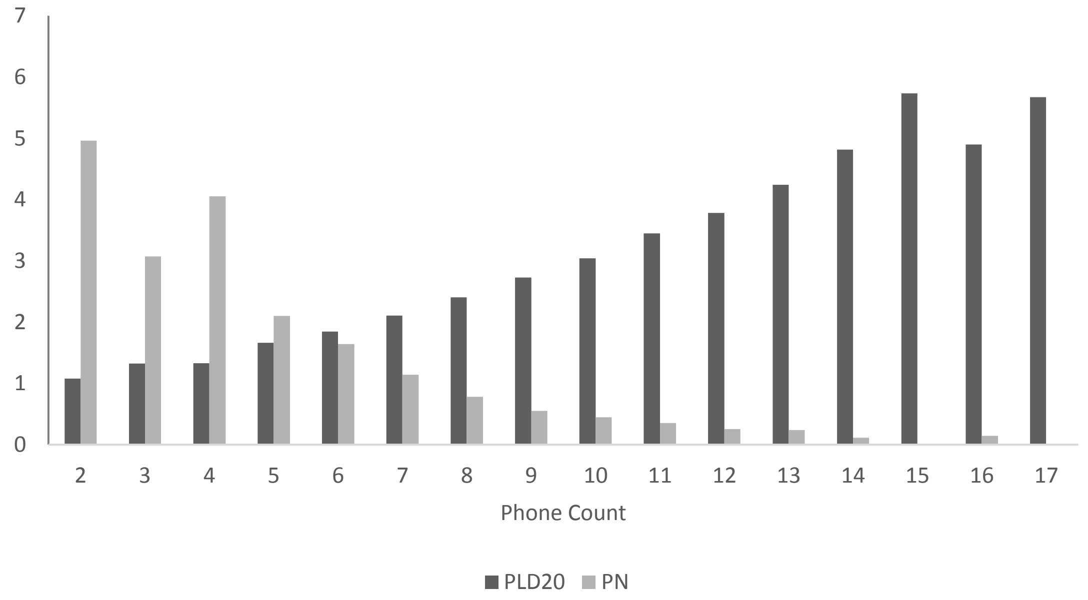

Figure 3-4. Mean phonological Levenshtein distance (PLD20) and phonological N (PN) as a function of length.

3.3.7 Phonotactic Probability

Phonotactic probability is defined as "the frequency with which phonological segments and sequences of phonological segments occur in words in a given language" (Vitevitch & Luce, 2004, p. 481). Phonotactic probability has been found to have facilitatory effects on spoken word processing (e.g. Vitevitch, 2003; Vitevitch & Luce, 1999; Vitevitch & Sommers, 2003), nonword repetition (e.g. Edwards, Beckman, & Munson, 2004; McKean, Letts, & Howard, 2013; Munson, Kurtz, & Windsor, 2005), and lexical segmentation (e.g. Al-Jasser, 2008; Gonzalez-Gomez & Nazzi, 2013; Mattys & Jusczyk, 2001; Mattys, Jusczyk, Luce, & Morgan, 1999; Mersad & Nazzi, 2011). It was thus important to include phonotactic probability variables so that interested researchers may use these variables or control for these variables when constructing stimuli for psycholinguistic experiments.

Following the work of Vitevich and colleagues (Aljasser & Vitevitch, 2017; Storkel & Hoover, 2010; Vitevitch & Luce, 2004), two token-based measures of position-specific phonotactic probability were computed: positional segment and biphone. Positional segment probability was calculated by dividing the sum of log (10) frequencies of all the items in the lexicon that contain a given segment in a given position by the total log (10) frequency of all the items in the lexicon that have a segment in that position (Storkel & Hoover, 2010; Vitevitch & Luce, 2004). Log-values of the frequency counts were used as they better reflect the distribution of frequency of occurrence and better correlate with performance than with raw frequency counts (Vitevitch & Luce, 2004). For each item in the Qur'an Lexicon, we then computed the positional segment sum (adding the positional segment probability for each sound in the target item) and positional segment average (dividing the positional segment sum by the number of sounds in the target item). On average, the probability of a segment in the Qur'an Lexicon occurring in a given position is .12 (see Table 3-2).

The biphone probability was computed in a similar manner, except that pairs of adjacent sounds were used in the calculations. Biphone probability was calculated by dividing the sum of log (10) frequencies of all the items in the lexicon that contain a given pair of sounds in a given position by the total log (10) frequency of all the items in the lexicon that have a pair of sounds in that position (Storkel & Hoover, 2010; Vitevitch & Luce, 2004). For each item in the Qur'an Lexicon, we then computed the biphone sum (adding the positional segment probability for each sound in the target item) and biphone average (dividing the positional segment sum by the number of sounds in the target item). On average, the probability of a biphone in the Qur'an Lexicon occurring in a given position is .02 (see Table 3-2).

3.3.8 Morphological Variables

Given the prevalence of root priming effects in Arabic morphological processing (see Boudelaa, 2014, 2015; Boudelaa & Marslen-Wilson, 2001, 2005, 2011, 2015; Boudelaa, Pulvermüller, Hauk, Shtyrov, & Marslen-Wilson, 2010), it was important to include morphological variables derived from roots so that researchers interested in Qur'anic Arabic morphological processing may use these variables or control for these variables when constructing stimuli for psycholinguistic experiments. A root is an abstract morpheme made up of consonants, usually conveying semantic information (Boudelaa & Marslen-Wilson, 2004a) and is also referred to as a consonantal melody unit (Watson, 2002). The following morphological variables were calculated based on the root information provided in the Qur'anic Arabic Corpus (Dukes, 2009). In total, there are 2295 root types in the Qur'an Lexicon.

3.3.8.1 Root Length

Root length is defined by the number of characters the root of the item has. For example, the root of كُتِبَ (was decreed: /kutɪba/) is (k t b), which has a root length of three. On average, a root in the Qur'an Lexicon is made up of three characters (see Table 3-2).

3.3.8.2 Root Frequency

Root frequency is defined as the number of times a root occurs in the corpus. Both raw and log-transformed root frequencies are provided for each item in the Qur'an Lexicon. For example, the root of كُتِبَ (was decreed: /kutɪba/) is (k t b), which occurs 319 times in the corpus and has a log (root frequency) of 2.51. On average, a root in the Qur'an corpus occurs about 30 times (see Table 3-2).

3.3.8.3 Root Family Size

Root family size, also known as root productivity, has been adapted by Boudelaa and Marslen-Wilson (2011) from the term “family size” (see Baayen, Lieber, & Schreuder, 1997; Bertram, Baayen, & Schreuder, 2000; De Jong, Schreuder, & Baayen, 2000; Schreuder & Baayen, 1997), which was defined as a type count for the number of morphologically related family members, or specifically, of the number of word forms incorporating a particular stem (e.g. class), either by derivation (e.g. classy) or by compounding (e.g. classroom). Root family size is thus defined as the type frequency of the root of the item. For example, the root of كُتِبَ (was decreed: /kutɪba/) is (k t b) which has a root family size of 36. On average, a root in the Qur’an corpus has about eight family members (see Table 3-2).

3.4 Conclusion

To summarise, we have generated and provided measures of frequency, length, orthographic and phonological similarity, phonotactic probabilities, and root for a set of 19,286 ‘phonetic’ types that are based on an overt contextual phonetic transcription which is unique to Qur’anic recitation. To our knowledge, the Qur’an Lexicon Project represents the first such lexical database for Qur’anic Arabic, a language used by over a billion people. This resource, which will be made freely available, should be useful for researchers studying Qur’anic Arabic lexical and phonological processing. More generally, it will also be useful to researchers who are interested in making systematic cross-linguistic comparisons that allow for a better delineation of language-specific and language-general processes in language processing. For this dissertation, the Qur’an Lexicon will be used in stimuli construction for the experiments in Chapters 5 to 7 that will examine the effects of the abovementioned variables on the visual word processing of non-Arabic-speaking Qur’anic memorisers.

Chapter 4. Individual-level Measures

4.1 Introduction

In the previous chapter, we developed item-level variables to examine the effects of various psycholinguistic variables on the visual word processing of our non-Arabic-speaking Qur'anic memorising population. In this chapter, we develop individual-level variables to examine individual differences in these psycholinguistic effects on visual word processing. First, we review the relevant literature, specifically looking at individual differences in vocabulary knowledge and exposure to print and how they interact with effects such as frequency and length on lexical decision and speeded pronunciation latencies. As described in Chapter 2, not only is there large variability in vocabulary knowledge and exposure to print (i.e., orthography and phonetics) in our non-Arabic-speaking population, exposure to print usually takes place with limited semantic knowledge, making it the perfect test case to examine simultaneously and tease apart the effects of both individual-level variables on visual word processing. Measures for vocabulary knowledge and exposure to print are then developed and validated for their use in the experiments in this dissertation.

4.2 Current Findings on Individual Differences in the Effects of Psycholinguistic Variables on Visual Word Processing

One of the key research areas in the field of visual word processing is visual word recognition, which seeks to answer the question of how people recognise or identify visually presented words, a task that is central to reading and literacy. Given the diversity of the population in terms of age and reading ability, current models and theories of word recognition need to move beyond describing the characteristics of the average "prototypical" adult reader (who is usually an undergraduate) and account for individual differences in visual word recognition processes (see Davies et al., 2017; Yap et al., 2012)

The current literature review focuses on studies that examined individual differences in visual word recognition through lexical decision and/or speeded pronunciation paradigms (e.g. Baluch, 1996; Butler & Hains, 1979; Chateau & Jared, 2000; Davies et al., 2017; Gayán & Olson, 2003; Geva, Yaghoub-Zadeh, & Schuster, 2000; Schilling, Rayner, & Chumbley, 1998; Sears, Siakaluk, Chow, & Buchanan, 2008; Yap et al., 2012). Although there have been numerous experimental tasks used in the study of visual word recognition processes, lexical decision and speeded pronunciation are two tasks that are the most commonly used and that underlie many models and theories of word recognition (Balota et al., 2006; Katz et al., 2012; Yap et al., 2012). In lexical decision, participants are asked to decide as quickly as possible if a target stimulus is a word or nonword, typically using a key or button press. In speeded pronunciation (also known as word naming or speeded naming), participants are asked to read aloud a visually presented target stimulus as quickly as possible. Given the differences in task demands, both tasks are typically used together to provide converging evidence in understanding the processes involved in word recognition, such as accessing and using lexical representations across different tasks (see Yap & Balota, 2009; Yap et al., 2012). Lexical decision and speeded pronunciation are also important tools in the study of individual differences in reading, significantly predicting individual differences in reading test measures such as word identification and vocabulary size (Katz et al., 2012).

Although individual differences can be measured in various ways, the focus here is on individual differences in vocabulary knowledge and exposure to print given the large variability in both constructs in the current population of interest as described in Chapter 2. Vocabulary knowledge can be defined as “knowledge of word forms and meaning” whereas exposure to print can be defined as “the amount of text a person reads” (Yap et al., 2012). Despite these two constructs being theoretically different, no study has attempted to disambiguate the two and tease apart their effects on visual word recognition performance (as measured by speed and accuracy) or whether they interact differently with psycholinguistic variables such as length and frequency in influencing visual word recognition performance.

This perhaps comes as no surprise as it is difficult to tease apart the unique contributions of print exposure and vocabulary knowledge in a typical population—researchers often describe the relationship between print exposure (or reading volume) and vocabulary development as a reciprocal one (see Cunningham & Stanovich, 1998). Print exposure provides a child with richer word-learning opportunities, thus contributing to individual differences in vocabulary development (and comprehension skills), which in turn contributes to children's differential proclivities towards reading, creating what is called the "Matthew effects" where the "rich get richer, poor get poorer" (see Mol & Bus, 2011, for a meta-analysis of the association between print exposure and components of reading across development). Furthermore, measures of vocabulary knowledge and print exposure have been shown to be significantly correlated (e.g. all *r*s > .50 in Lewellen et al., 1993), even after controlling for general cognitive ability and reading comprehension skill (Stanovich & Cunningham, 1992).

It is therefore difficult to tease apart the distinct roles of print exposure and vocabulary knowledge in influencing how different lexical variables affect visual word processing. For example, Lewellen and colleagues (1993) grouped participants into high- and low-ability readers based on the following measures of "lexical familiarity": subjective familiarity ratings of words, self-reported language experience that measures print exposure, and a vocabulary knowledge test. They found that high-ability readers were faster than low-ability readers in speeded pronunciation as well as faster and more accurate than low-ability readers in lexical decision. However, they did not find an interaction with reading ability and frequency or neighbourhood size effects in both tasks, concluding that reading ability does not influence those effects in speeded pronunciation and lexical decision. Null results aside, without disambiguating print exposure from vocabulary knowledge, one cannot tease apart the possibly differential roles of print exposure and vocabulary knowledge in the abovementioned effects. The implications of this in motivating the current study will be further discussed in later sections after reviewing studies that have attempted to look at either vocabulary knowledge or print exposure individually in word recognition.

4.2.1 Vocabulary Knowledge

Studies have shown mixed findings in the effects of vocabulary knowledge on psycholinguistic variables in visual word recognition. Here, we look at the findings for lexical decision and speeded pronunciation separately, given the different task demands.

4.2.1.1 Lexical Decision

Looking at the interactions between vocabulary knowledge and word frequency and well as word length, Butler and Hains (1979) found that participants with more vocabulary knowledge were slower in lexical decision than participants with less vocabulary knowledge but were less influenced by word length. However, there was no significant interaction between vocabulary knowledge and word frequency on lexical decision latencies. Limitations in Butler and Hains' study include a small sample size (N = 12) with only 300 data points collected, which raises the question of whether the null effect was caused by the lack of statistical power.

In a much larger-scale study using data from the English Lexicon Project (Balota et al., 2007) with 819 participants, Yap and colleagues (2012) found that participants with more vocabulary knowledge were less sensitive to the principal components of neighbourhood size (orthographic and phonological) than participants with less vocabulary knowledge, but vocabulary knowledge was only marginally related to the principal components indicating a word's structural properties (length, orthographic and phonological Levenshtein distance) and word frequency/semantics. The latter finding was congruent with that of Butler and Hains (1979). Further analysing the effect of word frequency in a more fine-grained manner by examining the correlations between vocabulary knowledge and word frequency effects at different regions of the RT distribution (via standardised residuals), Yap et al. (2012) found reliable positive correlations between vocabulary knowledge and frequency effects only in the fastest quantiles. They postulated that participants with higher vocabulary are better able to make use of word frequency or other familiarity-based information in lexical decision, thus facilitating responses to high frequency words. This was supported by their finding that steeper drift rates in diffusion model analyses (a marker for the speed of accumulating information) are associated with larger word frequency/semantics effects, thus participants who are more sensitive to familiarity-based information are also able to accumulate information about a target stimulus faster.

4.2.1.2 Speeded Pronunciation

Looking at the interactions between vocabulary knowledge and word frequency and well as word length in speeded pronunciation, Butler and Hains (1979) found that participants with more vocabulary knowledge pronounced words faster than participants with less vocabulary knowledge and were also less influenced by word length. However, there was no significant interaction between vocabulary knowledge and word frequency on speeded pronunciation latencies. Similar to their lexical decision experiment, the speeded pronunciation experiment in their study had a small sample size (N = 12), which raises the question of whether the null effect was caused by the lack of statistical power.

Unlike their findings in lexical decision described in the previous section, Yap and colleagues (2012) found that participants with more vocabulary knowledge were less sensitive to the principal components indicating a word’s structural properties (length, orthographic and phonological Levenshtein distance), neighbourhood size (orthographic and phonological), and word frequency/semantics than participants with less vocabulary knowledge, which supported their predictions based on the theory that better readers have more automatized processing mechanisms, and thus, are less influenced by the lexical characteristics of a word. They suggested that the contrast in these findings with those in lexical decision reflects differences in task demands, and thus, a dissociation of the effects between the two tasks, with word frequency affecting only lexical processes and possible production characteristics in speeded pronunciation but affecting both lexical access and postlexical decision-making stages in lexical decision. The latter was described in the previous section.

Surprisingly, Geva and colleagues (2000) examined word recognition skills in EL1 and ESL children as part of a larger study and found no effect of vocabulary knowledge (as measured by the PPVT-R) on reading aloud performance (as measured by a Word Identification score that combined the child’s scores on the WRAT-R and on a 16-item high-frequency word identification task). A possible explanation for the null effect may be due to reading aloud being measured with high-frequency words, thus decreasing the influence of vocabulary knowledge on reading aloud performance.

4.2.2 Exposure to Print

Similar to vocabulary knowledge, studies have shown mixed findings in the effects of exposure to print on psycholinguistic variables in visual word recognition. Here, we look at the findings for lexical decision and speeded pronunciation separately, given the different task demands.

4.2.2.1 Lexical Decision

Looking at a three-way interaction between exposure to print, word frequency, and neighbourhood size, Chateau and Jared (2000) found that not only were participants with a higher level of print exposure faster and more accurate in lexical decision with pseudohomophonic nonwords than participants with a lower level of print exposure, they were also less sensitive to word frequency and neighbourhood size, producing a smaller effect of neighbourhood size for low-frequency words. This finding was corroborated by Sears and colleagues (2008) who ran a similar experiment and found the same significant three-way interaction between exposure to print, word frequency, and neighbourhood size, with effects in the same direction. However, Yap et al. (2012) pointed out that these findings may be confounded with processing speed as participants with a lower level of print exposure were reliably slower and that a participant's overall processing time is positively correlated with the magnitude of his effect. Finding larger effects of frequency and neighbourhood size for participants with a lower level of print exposure may therefore simply be due to them being slow and not due to having less print exposure. This was supported by findings of null interactions of individual differences with word frequency effects when processing speed was controlled for by standardising raw latencies or matching overall latencies across groups by Butler and Hains (1979) and Lewellen et al. (1993), We discuss the implications of this argument in Chapter 8.

4.2.2.2 Speeded Pronunciation

Thus far, the above findings have all been in English, a deep orthography with fewer consistent grapheme-to-phoneme correspondences than those of Qur'anic Arabic, the transparent orthography used by our population of interest. To our knowledge, only one study has looked at individual differences in psycholinguistic effects on word recognition in transparent orthographies. Baluch (1996) examined how participants' degree of experience in reading their native Persian orthography would influence sensitivity to the word frequency effect in a speeded pronunciation task. He found a significant frequency effect for experienced readers of Persian and not for Persian adults who had migrated to the West, and thus, had very little exposure to reading materials over the past 15 years. The frequency effect showed that experienced readers named high frequency transparent Persian words significantly faster than matched low frequency words. This is both inconsistent with predictions based on the theory that better readers have more automatized processing mechanisms, and thus, are less influenced by the lexical characteristics of a word, as well as the idea that the size of the effect correlates positively with a participant's overall processing time; more experienced readers were significantly faster in speeded pronunciation than less experienced readers, but still showed a larger frequency effect.

4.2.3 Possible Explanations

Overall, we can see that in most studies, there is a general trend in which those with more vocabulary knowledge or print exposure show smaller psycholinguistic effects such as length, frequency, and neighbourhood size. However, there also appear to be task differences in these two-way interactions (cf. Yap et al., 2012, for lexical decision vs. speeded pronunciation).

Findings in which the increase in vocabulary knowledge or print exposure resulted in smaller psycholinguistic effects can be explained by hypotheses that propose an automatization of lexical processing mechanisms as readers acquire more experience with words (LaBerge & Samuels, 1974; Stanovich, 1980); as automatic mechanisms develop, word recognition may be less influenced by lexical characteristics. Better readers with larger vocabulary sizes or more print exposure should therefore be faster overall and show smaller effects such as length and frequency in lexical decision or speeded pronunciation.

This explanation is complemented by the lexical quality hypothesis which postulates that the quality of lexical representations drive the efficiency of lexical processing, freeing up cognitive resources to do other things such as comprehension; better readers have higher quality of lexical representations (Perfetti, 2007; Perfetti & Hart, 2002). However, it is important to note that high quality representations here involve three well-integrated constituents of orthography, phonology, and semantics. According to Perfetti and Hart (2002), "any representation that does not specify the value of one of its constituents is low quality". For example, a word may be familiar orthographically to a reader due to numerous encounters with it in print but may be lacking semantically if the reader does not bother to find out the meaning of the word, thus resulting in a low-quality lexical representation, which can take longer for lexical access. This can have implications in terms of looking at the separate roles of vocabulary knowledge and print exposure in visual word recognition processes, possibly accounting for why Baluch (1996) found larger frequency effects in participants with more print exposure; note that vocabulary knowledge was not measured in this study. Nonetheless, it is important to note that Baluch's study used transparent Persian words; the transparency of the orthography influencing the reliance of a particular route according to dual-route models of reading may also play a role here. The implications of orthographic transparency (or depth) on predictions for lexical variables influencing lexical decision and speeded pronunciation will be discussed in Chapters 5 and 6.

Connectionist models that are designed to learn from experience can also be used in tandem with the lexical quality hypothesis, especially with regards to the impact of practice or repeated exposure on word knowledge. Similar to the lexical quality hypothesis that postulate lexical representations being made up of three constituents of orthography, phonology, and semantics, connectionist models assume that the reading system operates over networks of subsymbolic representations of three units: orthography, phonology, and semantics (Harm & Seidenberg, 2004; Plaut, 1997; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989a). When an individual is exposed to a word, the weights on these network connections between the three units will be adapted to reduce error in output for whatever lexical task the individual will undertake; there will be increased input to output units that should be active (e.g. pronunciation pattern of a target stimulus) and decreased input to output units that should be inactive. More practice or exposure to a word will thus enable the system drive helpful weight changes towards the correct output in the future (Davies et al., 2017), which is consistent with the lexical quality hypothesis in which repeated exposure to a word may improve the quality of lexical representations, and thus, the efficiency of lexical processing and access. However, the connectionist account specifies that the function linking input to output activation is nonlinear, which means that as input activation increases, output activation will tend to asymptote towards 0 or 1, i.e., progressively smaller reductions in error (Plaut et al., 1996). This would therefore predict that as practice or exposure to a word increases, psycholinguistic effects such as frequency that influence the efficacy of the network connections between the three units should become smaller, which is consistent with the predictions of the automatization hypothesis and lexical quality hypothesis as previously discussed.

4.3 Current Study

The current study contributes to extant findings regarding individual differences in visual word processing in various ways. First, it is the first study to characterise individual differences in the visual word processing of a transparent orthography, Qur'anic Arabic. Second, other than being the first study to examine the effects of individual differences on various psycholinguistic variables in visual word processing, it further extends current findings by including non-concatenative morphological variables such as root frequency and examining individual differences in non-concatenative morphological processing. Last, with the benefit of a unique population of interest that has extensive exposure to print (Schilling et al., 1998) with limited vocabulary knowledge, the current study is able to tease apart the roles of vocabulary knowledge and print exposure in influencing the effects of various psycholinguistic variables in visual word processing. The following sections describe the development and validation of the individual-level measures of vocabulary knowledge and print exposure.

4.4 Development of Measure of Qur'an Vocabulary Knowledge: Qur'an Vocabulary Test (QVT)

The Qur'an Vocabulary Test (QVT) is the first multiple-choice standardised test used to measure Qur'an vocabulary knowledge, with 90 items ranked in the order of the easiest to the most difficult based on norms derived from a pilot sample. The QVT (see Appendix D) was modelled after the Shipley Vocabulary Test (Shipley, 1940) and Malay Vocabulary Test (Binte Faizal, 2009; Yap et al., 2010). Participants are asked to choose from four options the English word that best corresponds to the meaning of the Arabic word.

4.4.1 Piloting of the Qur'an Vocabulary Test (QVT)

To derive standardised norms for the QVT, we first piloted it on an online pilot sample (N = 163, M_{Age} = 27.28, SD_{Age} = 10.36). For the pilot test items, 60 Arabic words of various frequencies were selected from the Qur'an Lexicon (see Chapter 3). To increase the content validity of the QVT, two local *madrasah* teachers were asked to check the Arabic items and their English meanings for their suitability for local *madrasah* students. A native-Arabic speaker was also asked to check the Arabic items and their English meanings for accuracy. As there was a ceiling effect in the earlier online pilot sample which made it difficult to distinguish between participants with self-reported average and excellent vocabulary knowledge (see Table 4-1), local *madrasah* teachers were asked for test items that they thought would be very difficult for their students and 30 of these items were then added to the QVT. We then piloted it again on another online sample (N = 123, M_{Age} = 15.16, SD_{Age} = 1.11) and item analyses were done to rank the 90 items based on their index of discrimination from the easiest to the most difficult.

Table 4-1 below shows the descriptive statistics for group performance in both pilot tests respectively. The final 90-item QVT shows excellent discrimination between all three groups of proficiency, $F(2, 120) = 327.31$, $p < .001$. Pairwise comparisons between the lower, middle, and upper groups show a significant difference in scores between the middle and lower groups, $t(92) = 12.96$, $p < .001$, and the middle and upper groups, $t(88) = -13.64$, $p < .001$. Being able to show such discrimination demonstrates the concurrent validity of the QVT. Furthermore, the Cronbach's alpha for the QVT is .935, which indicates high reliability.

Table 4-1. QVT scores in the 60-item and 90-item QVT for three groups of proficiency (Low, Middle, High) in Qur'anic Arabic.

	QVT (60-item, *N* = 163)					QVT (90-item, *N* = 123)				
		Age	**Score**	***Score%***	**Score**		**Age**	**Score**	***Score%***	**Score**
Groups	***N***	***M***	***M***	***M***	***SD***	***N***	***M***	***M***	***M***	***SD***
Low	43	27.07	35.86	59.77	8.03	32	15.22	37.78	41.98	3.91
Middle	77	25.44	50.88	84.81	2.72	57	15.09	50.74	56.37	3.92
High	43	30.77	57.86	96.43	1.32	34	15.24	64.38	71.54	6.47
Grand Total	**163**	**27.28**	**48.76**	**81.27**	**9.43**	**123**	**15.16**	**51.14**	**56.82**	**10.86**

Construct validity of the QVT can be examined through both convergent and discriminant validity. To examine the convergent and discriminant validity of the QVT, analyses involving pairwise Pearson's correlations and ANOVAs were conducted with relevant measures from the Qur'an Recitation and Memorisation questionnaire done by a pilot sample of 165 participants (M_{Age} = 15.31, SD_{Age} = 1.07) from two full-time *madrasahs* and a full-time *tahfiz* school. These analyses are described in the following sections.

4.4.2 Convergent Validity

Convergent validity can be demonstrated if a measure is related with other measures that are theoretically measuring similar constructs. Here, we can examine relationships of the QVT with other similar measures such as Arabic proficiency, Arabic exam scores, the learning of Qur'anic Arabic, and the understanding of Qur'anic Arabic while reading and memorising. It is important to note that although ideally the goal for convergence is to achieve as high a correlation as possible, the benchmark for "high" is arbitrary and it is recommended instead to compare the correlations with those of discriminant measures; convergent correlations should therefore be higher relative to discriminant correlations (Trochim, 2006).

First, to measure Arabic proficiency, participants were asked to rate their fluency in Arabic reading, writing, and speaking on a scale of 1 to 9 (1 = "Very Poor", 9 = "Excellent"). QVT was significantly correlated with self-rated fluency in Arabic reading ($r = .355$, $p < .001$), writing ($r = .303$, $p < .001$), and speaking ($r = .331$, $p < .001$). QVT was also significantly correlated with self-reported Qur'anic Arabic proficiency that was rated on the same Likert scale, $r = .213$, $p < .01$. Participants who reported that they had learned Qur'anic Arabic also had significantly higher QVT scores ($M = 56.52$, $SD = 13.48$) than those who had not ($M = 52.19$, $SD = 15.53$), $t(163) = -2.44$, $p < .05$.

Next, we were able to obtain Arabic exam scores from the *tahfiẓ* school ($N = 41$). Their Arabic exam had two components: *Insha'* (composition) and *Nahu* (grammar). QVT had significant correlations with Arabic composition scores, $r = .442$, $p < .01$, and Arabic grammar scores (*Nahu*), $r = .395$, $p < .05$. The higher correlation of QVT with composition scores as compared to grammar scores reflected the higher emphasis on vocabulary in composition writing as compared to grammar, which has more to do with syntax.

Last, participants were asked to report how much of the Arabic in the Qur'an they understand while reading and while memorising; they chose from the following options: "None at all", "A little of it", "Some of it", "Most of it", "All of it". ANOVAs were conducted with QVT as the dependent variable as well as amount of Arabic in the Qur'an understood while reading it and amount of Arabic in the Qur'an understood while memorising it as individual variables in separate analyses. Results showed that self-reported amount of Arabic in the Qur'an understood while reading it significantly predicted QVT score, $F(3, 160) = 44.821$, $p < .001$, partial-$\eta^2 = .381$, explaining 38.1% of the variance in QVT scores. Self-reported amount of Arabic in the Qur'an understood while memorising it also significantly predicted QVT score, $F(4, 160) = 29.881$, $p < .001$, partial-$\eta^2 = .340$, explaining 34.0% of the variance in QVT scores. As seen in Figure 4-1 and Figure 4-2, the more Arabic in the Qur'an participants reported to have understood while reading or memorising it, the higher their QVT score was.

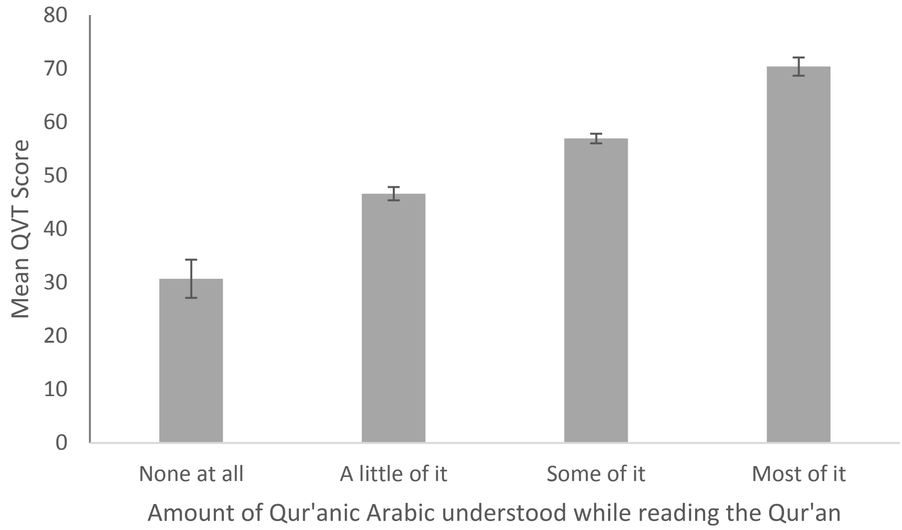

Figure 4-1. Mean QVT score across self-reported amount of Arabic in the Qur'an understood while reading it. "All of it" was removed from the analysis as only one participant reported it. Error bars are based on standard error.

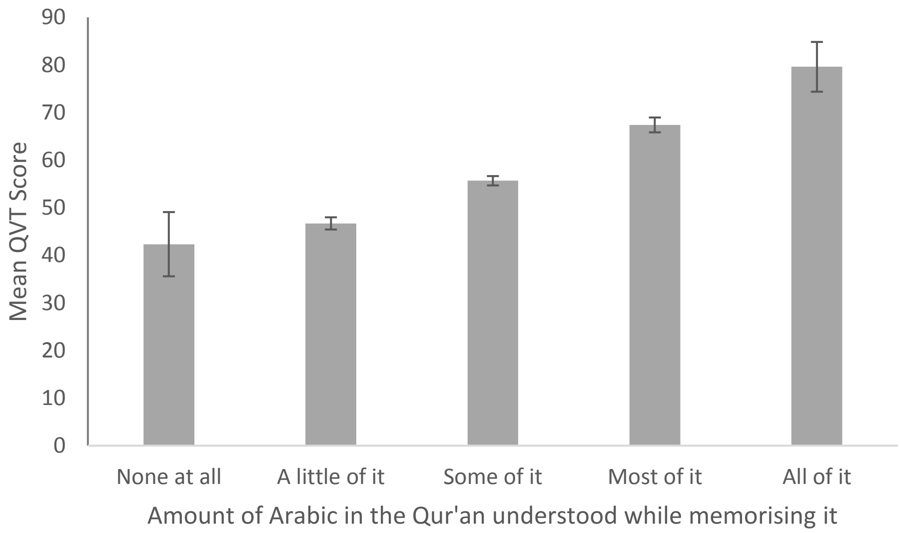

Figure 4-2. Mean QVT score across self-reported amount of Arabic in the Qur'an understood while memorising it. Error bars are based on standard error.

4.4.3 Discriminant Validity

Discriminant validity can be demonstrated if a measure is not related with other measures that are theoretically measuring dissimilar constructs. Here, we can examine relationships of the QVT with other dissimilar measures such as amount of memorisation (MemScore), memorisation of the entire Qur'an, and frequency of Qur'an memorisation practice. As abovementioned, the focus is on looking for discriminant correlations or effect sizes that are smaller than convergent correlations or effect sizes instead of “high” versus “low”.

First, there is discriminant validity as QVT scores do not significantly correlate with self-reported amount of Qur'an memorisation (MemScore), $r = -.035$, *ns*. (see Figure 4-3). Similarly, participants who reported that they had memorised the entire Qur'an had lower QVT scores ($M = 43.20$, $SD = 12.76$) than those who had not done so ($M = 51.54$, $SD = 9.99$), but this difference was not significant, $t(163) = 1.824$, *ns*. Theoretically, Qur'an memorisation and vocabulary knowledge should be two distinct constructs and this is evinced both by the lack of correlation between the two measures, as well as in practice, where Qur'an memorisation often takes place without the learning of what is being memorised such as vocabulary, as seen in our non-Arabic-speaking population in Chapter 2. This has significant implications because unlike other populations in which exposure to print and vocabulary knowledge typically has a symbiotic relationship (as discussed in the literature review) that makes it difficult to tease apart their effects, we are able to do so in our non-Arabic-speaking population with QVT and MemScore measuring two distinct constructs.

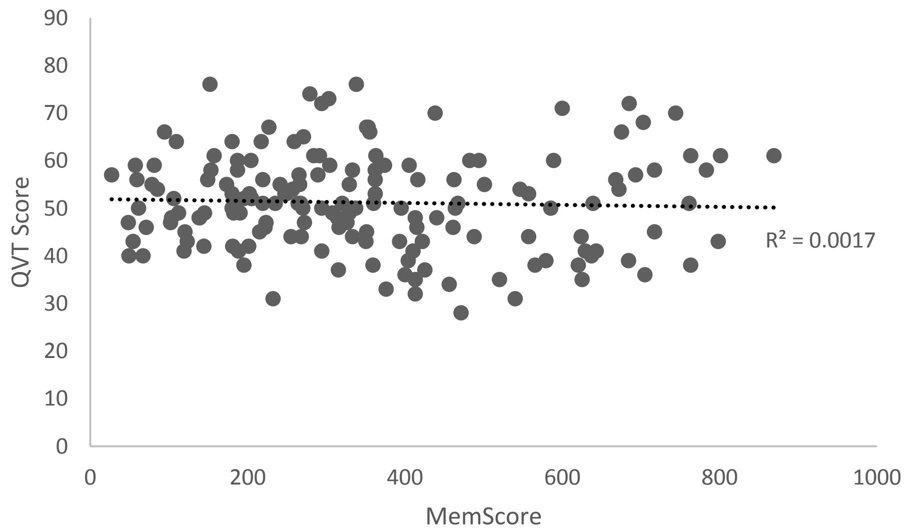

Figure 4-3. Amount of Qur'an vocabulary knowledge (QVT score) as a function of amount of Qur'an memorisation (MemScore).

Last, participants were asked to report how often they practise their memorisation of the Qur'an; they chose from the following options: "Daily", "Weekly", "Monthly", and "Rarely". An ANOVA was conducted with QVT as the dependent variable as well as self-reported frequency of Qur'an memorisation practice as the independent variable. Results showed that self-reported frequency of Qur'an memorisation practice did not significantly predict QVT score, $F(3, 161) = .766$, *ns.*, partial-$\eta^2 = .014$, explaining only 1.4% of the variance in QVT scores. As seen in Figure 4-4, how often someone practises memorising the Qur'an has no bearing on their Qur'an vocabulary knowledge.

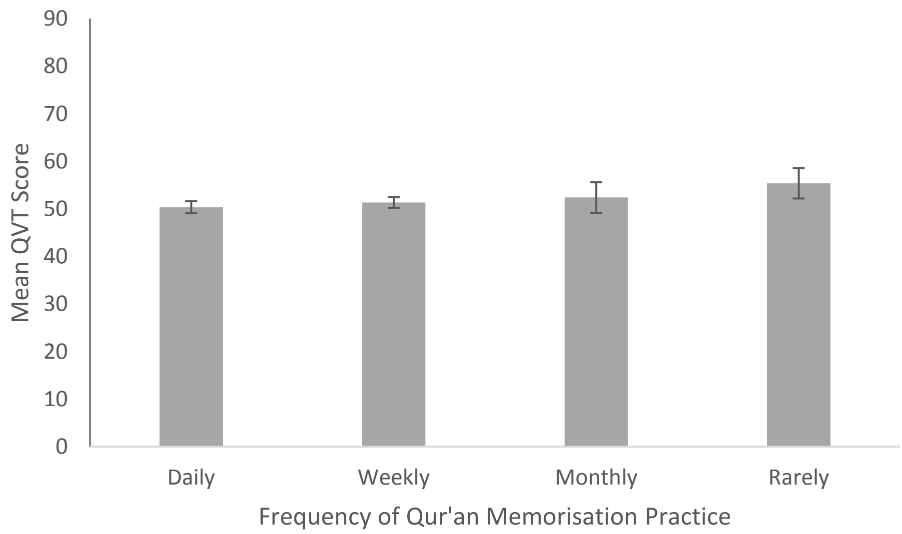

Figure 4-4. Mean QVT score across self-reported frequency of Qur'an memorisation practice. Error bars are based on standard error.

4.5 Development of Measure of Exposure to Print: Amount and Fluency of Qur'anic Memorisation (MemScore)

Exposure to print is operationalised as amount and fluency of Qur'anic memorisation because the reading-repetition-rehearsal process in Qur'anic memorisation (as described in Chapter 2) provides the memoriser with consistent exposure to the print (i.e., orthography and phonetics) of the Qur'an. One would thus expect that the more of the Qur'an an individual has memorised with fluency, the more of the Qur'an's print to which the individual would have been exposed.

To measure amount and fluency of Qur'anic memorisation, participants were asked to rate how fluently they can recite from memory each of the 114 *surahs* (chapters) in the Qur'an on a scale of 1 to 9 (1 = "very poor, a lot of errors", 9 = "very fluent, no errors"). For *surahs* they had not memorised at all, they were instructed to select the option "N/A (Haven't memorised at all)", which was then coded as "0" for data analysis. This means that someone who has fully memorised the entire Qur'an and can recite it fluently from memory in its entirety, i.e., a *hafidz*, would get the maximum self-reported Qur'an memorisation score (MemScore) of 1026.

4.5.1 Piloting of the Self-Rated Amount and Fluency of Memorisation Scale (MemScore)

The MemScore scale was included as part of the Qur'anic Recitation and Memorisation questionnaire (see Appendix C) mentioned in Chapter 2. It has high reliability with a Cronbach's alpha of .990. As this may have been inflated by having 114 items on the scale, the mean inter-item correlations of .474 (*Var* = .049) is also reported, which falls within the range of .15 to .50 recommended by Clark and Watson (1995).

More importantly, the pattern of memorisation across the 114 chapters in the Qur'an as seen in Figure 4-5 largely reflects the current memorisation practices in our non-Arabic-speaking population in which the chapters that were memorised the best are the first chapter (which is used in daily prayers) and the chapters in the last part of the Qur'an (*Juz* 30), which are much shorter, and therefore, easier to memorise as compared to the ones in the middle. This also reflects how memorising schools and the Islamic Religious Council of Singapore (MUIS) begin their students' memorisation with chapters in *Juz* 30 first before moving on to earlier chapters. The anomalies in the middle (with more memorisation) are chapters that have been highly recommended to be recited and memorised in the religion, therefore more people are likely to have memorised them. This demonstrates the concurrent validity of MemScore as it can discriminate between chapters that are typically memorised more and chapters that are typically memorised less in the population.

Concurrent validity of MemScore is further demonstrated by the wide range of amount and fluency of Qur'an memorisation reported by individual participants as seen in Figure 4-3 (*Min* = 27, *Max* = 869), thus allowing for the clear discrimination between "high" memorisers and "low" memorisers.

As was done for QVT, to demonstrate the construct validity of MemScore, we examined both its convergent and discriminant validity via analyses involving pairwise Pearson's correlations and ANOVAs that were conducted with relevant measures from the Qur'an Recitation and Memorisation questionnaire done by the same pilot sample. These analyses are described in the following sections.

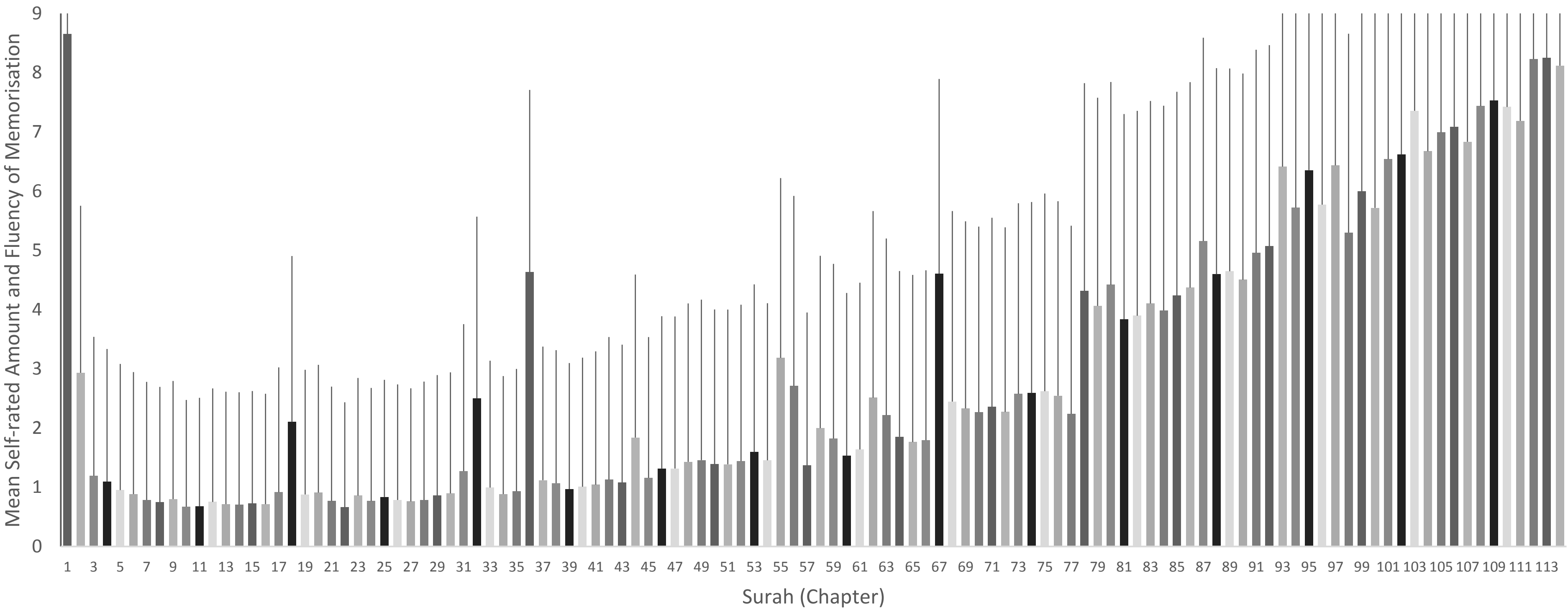

Figure 4-5. Mean self-rated amount and fluency of memorisation for each *surah* or chapter of the Qur’an. Error bars are based on standard deviation.

4.5.2 Convergent Validity

To demonstrate convergent validity, we can examine relationships of MemScore with other similar measures such as memorisation of the entire Qur'an, age started reading the Qur'an, Qur'an oral exam scores, and frequency of Qur'an memorisation practice. As abovementioned, the focus is on looking for convergent correlations or effect sizes that are larger than discriminant correlations or effect sizes instead of "high" versus "low".

First, unlike for QVT, participants who reported that they had memorised the entire Qur'an had higher MemScore (M = 616.80, SD = 147.48) than those who had not done so (M = 343.28, SD = 196.37), and this difference was significant, $t(162) = 3.083$, $p < .01$. Similarly, MemScore also significantly correlated with participants' self-reported age they started reading the Qur'an, $r = .290$, $p < .001$; the earlier they started reading the Qur'an, the higher their self-rated amount and fluency of Qur'an memorisation was.

Next, we were able to obtain participants' latest Qur'an oral examination scores from the *tahfiẓ* (memorising) school (N = 42). For their Qur'an oral examination, students were tested on five randomly selected questions based on the number of *juz* (section) of the Qur'an they have memorized. From the five questions, two were easy (e.g. reciting the beginning of a *surah,* or chapter, from memory), two were of medium difficulty (e.g. reciting from the middle of a page from memory), and one hard (e.g. reciting a section of a *surah* that has many similarities with another section from memory). Out of a total possible 100 points, 65 were given for *hifẓ* (memorisation), 25 were given for *tajweed* (elocution), and 10 were given for *fasahah* (fluency). Self-reported amount and fluency of memorisation for each student's tested Qur'an chapters was elicited and summed up to get a MemScore specific to their Qur'an oral exam. This was found to significantly correlate with their Qur'an oral examination scores, $r = .440$, $p < .01$.

Last, participants were asked to report how often they practise their memorisation of the Qur'an; they chose from the following options: "Daily", "Weekly", "Monthly", and "Rarely". An ANOVA was conducted with MemScore as the dependent variable as well as self-reported frequency of Qur'an memorisation practice as the independent variable. Results showed that unlike for QVT, self-reported frequency of Qur'an memorisation practice significantly predicted MemScore, $F(3, 160) = 12.959$, $p < .001$, partial-$\eta^2 = .195$, explaining 19.5% of the variance in MemScore. As seen in Figure 4-6, those who practised memorising the Qur'an daily had a higher MemScore on average, and thus, memorised more of the Qur'an with fluency as compared to those who don't.

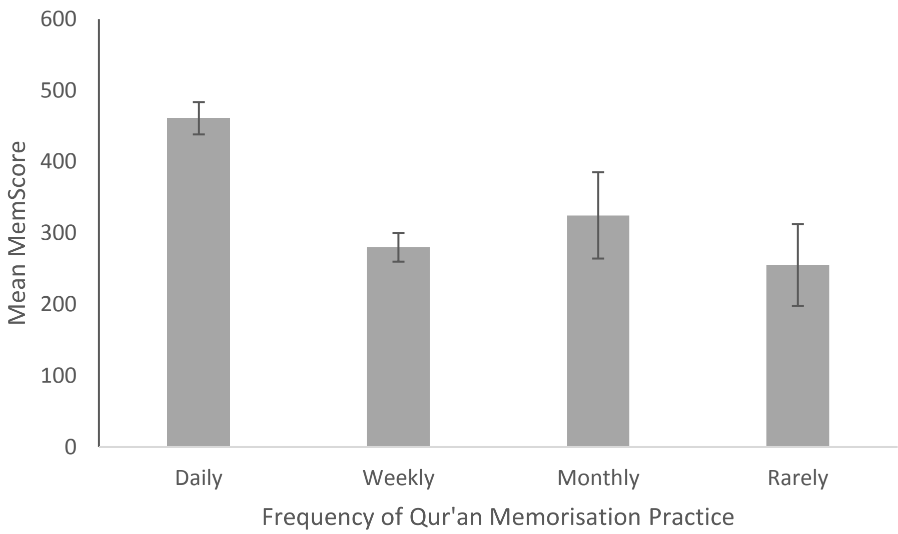

Figure 4-6. Mean MemScore across self-reported frequency of Qur'an memorisation practice. Error bars are based on standard error.

4.5.3 Discriminant Validity

To demonstrate discriminant validity, we can examine relationships of MemScore with other dissimilar measures such as Qur'an vocabulary knowledge (QVT), Arabic proficiency, Arabic exam scores, the learning of Qur'anic Arabic, and the understanding of Qur'anic Arabic while reading and memorising. As abovementioned, the focus is on looking for discriminant correlations or effect sizes that are smaller than convergent correlations or effect sizes instead of "high" versus "low".

First, there is discriminant validity as MemScore does not significantly correlate with QVT, $r = -.035$, *ns*. (see Figure 4-3). As discussed earlier, Qur'an memorisation and vocabulary knowledge should be two distinct constructs theoretically and this is evinced both by the lack of correlation between the two measures, as well as in practice, where Qur'an memorisation often takes place without the learning of what is being memorised such as vocabulary, as seen in our non-Arabic-speaking population in Chapter 2.

Next, to measure Arabic proficiency, participants were asked to rate their fluency in Arabic reading, writing, and speaking on a scale of 1 to 9 (1 = "Very Poor", 9 = "Excellent"). Unlike QVT, MemScore was not significantly correlated with self-rated fluency in Arabic reading (r = -.027, *ns.*), writing (r = -.059, *ns.*), and speaking (r = -.077, *ns.*).

Similarly, MemScore was also not significantly correlated with the following self-reported measures related to Qur'anic Arabic: self-reported Qur'anic Arabic proficiency that was rated on the same Likert scale, r = -.050, *ns*., age started to learn Qur'anic Arabic, r = .016, *ns.*, and number of years spent to learn Qur'anic Arabic, r = -.089, *ns*. Participants who reported that they had learned Qur'anic Arabic also did not have significantly different MemScore (M = 335.69, SD = 194.59) than those who had not (M = 406.30, SD = 212.69), $t(162)$ = 1.901, *ns*.

As abovementioned, we were able to obtain Arabic exam scores from the *tahfiẓ* school (N = 41). Their Arabic exam had two components: *Insha'* (composition) and *Nahu* (grammar). Unlike QVT, MemScore was not significantly correlated with Arabic composition scores, r = .305, *ns.*, and Arabic grammar scores (*Nahu*), r = .248, *ns*.

Last, participants were asked to report how much of the Arabic in the Qur'an they understand while reading and while memorising; they chose from the following options: "None at all", "A little of it", "Some of it", "Most of it", "All of it". ANOVAs were conducted with MemScore as the dependent variable as well as amount of Arabic in the Qur'an understood while reading it and amount of Arabic in the Qur'an understood while memorising it as individual variables in separate analyses. Results showed that self-reported amount of Arabic in the Qur'an understood while reading it did not significantly predict MemScore, $F(4, 159)$ = 1.024, *ns.*, partial-η^2 = .025, explaining only 2.5% of the variance in QVT scores. Self-reported amount of Arabic in the Qur'an understood while memorising it also did not significantly predict MemScore, $F(2, 161) = .199$, *ns.*, partial-$\eta^2 = .002$, explaining only .20% of the variance in MemScore[2].

4.6 Summary

Various studies have shown that individual differences as measured by vocabulary knowledge and print exposure can influence word recognition processes such as speed and accuracy as well as modulate lexical effects such as length, frequency, and neighbourhood size. However, there is a gap in the literature with regards to disambiguating the roles of vocabulary knowledge and print exposure in the abovementioned effects. This gives us the motivation to investigate the roles of vocabulary knowledge and print exposure separately in the visual word recognition processes of our non-Arabic-speaking population, which called for the development of Qur'an Vocabulary Test (QVT) and the Amount and Fluency of Qur'anic Memorisation Scale (MemScore).

We have provided evidence of QVT and MemScore having content validity, concurrent validity, as well as convergent and discriminant validity, thus demonstrating the construct validity of QVT as a measure of Qur'an vocabulary knowledge as well as MemScore as a measure of amount and fluency of Qur'an memorisation. More importantly, we have also shown that unlike in other populations, there is no statistical relationship between QVT and MemScore, making them distinct constructs that measure vocabulary knowledge and exposure to print as they theoretically should be. These individual-level measures were used in the experiments presented in Chapters 5, 6, and 7 to help address the current research gap in the field regarding individual differences in visual word processing, specifically teasing apart the effects of vocabulary knowledge and exposure to print on lexical variables that influence visual word processing.

[2] "None at all" and "All of it" were removed from the analysis as no participant had selected that option.

Chapter 5. Lexical Decision

5.1 Introduction

In this chapter, we describe a study that sought to explore factors that influence the visual word processing of non-Arabic-speaking Qur'anic memorisers through a lexical processing task: lexical decision. The study also examined individual differences in the influence of these factors on visual word processing by looking at whether Qur'an vocabulary knowledge (QVT) and amount of Qur'an memorisation (MemScore) interact with these factors in two- and three-way interactions, thereby teasing apart the possibly differential roles of vocabulary knowledge and print exposure in visual word processing.

5.2 Models of Visual Word Recognition

As noted earlier, the effects of a number of lexical variables on word recognition performance in English have been uncovered using two main paradigms: lexical decision and speeded pronunciation. Findings from experiments using these two paradigms have then been used to constrain models of visual word recognition. Current models have evolved from two main perspectives: a) the traditional view that word recognition is a process involving rules operating on explicit local representations (e.g. the DRC model, Coltheart et al., 2001; Ziegler, Perry, & Coltheart, 2000), as well as b) the connectionist approach that views processing as a result of competitive and cooperative interactions among distributed representations (e.g. the PDP model, Plaut et al., 1996).

The dual-route cascaded (DRC) model of visual word recognition is a computational version of the dual-route model (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart et al., 2001) that assumes the reading system operates via symbolic representations of knowledge about letters, words, and grapheme-to-phoneme correspondences (Davies et al., 2017). Dual-route models of reading essentially postulate that skilled readers use two different pathways: the lexical route, which involves a lexicon lookup procedure, and the sublexical route, which involves a letter-to-sound, or grapheme-to-phoneme, rule procedure (see Coltheart et al., 2001; 1993). The lexical route pertains to lexical storage, consisting of the following: the orthographic input lexicon, where the orthographic lexical units (print words) are stored; the phonological output lexicon, where the corresponding phonological lexical units are stored; and the semantic system, where word meanings are stored (Coltheart et al., 2001). In contrast, the sublexical route is where grapheme-to-phoneme rules are applied in the grapheme-phoneme rule system.

According to Coltheart et al. (2001), the DRC approach to lexical decision as developed by Coltheart et al. (1977) suggested that upon the presentation of a target stimulus, an activation criterion is set such that if any entry in the orthographic lexicon attains an activation exceeding this criterion, then the target stimulus would be recognised as a word and a 'yes' response would be made. If a certain processing duration has elapsed without the above activation criterion being attained, then the target stimulus would be rejected and a 'no' response would be made. The deadline for attaining the above activation criterion is computed relatively quickly after the onset of the target stimulus from the total activation of the orthographic lexicon at that time; a high total activation indicates a high likelihood that the target stimulus is a word, thus a long deadline is set to avoid a premature false rejection. A low total activation indicates a low likelihood that the target stimulus is a word, thus a shorter deadline can be set to enable a quick rejection of the target stimulus and a quick 'no' response. A third criterion for lexical decision as proposed by Grainger and Jacobs (1996) is also included—it involves a 'fast guess' procedure in which a target stimulus is guessed as a word and a 'yes' response is made even if no single lexical entry has reached the critical activation level as long as there is sufficiently high total activation of the orthographic lexicon early in processing. The inclusion of this 'fast guess' procedure was supported by Grainger and Jacobs (1996) observing effects of 'yes' latencies that could be attributed to strategic responses by readers as a function of the properties of the target stimuli as well as the three-criterion account being able to simulate the interaction between frequency and neighbourhood density on response latencies found by Andrews (1992) in which low-frequency words with more neighbours were responded to faster than those with fewer neighbours whereas no such neighbourhood density effect was found in high-frequency words. This suggested that the critical activation criterion is attained earlier in time than the fast-guess criterion for high-frequency words and that only the fast-guess criterion is sensitive to neighbourhood density (Coltheart et al., 2001).

In terms of reading aloud according to the DRC model (Coltheart et al., 2001), information is passed on to the various processing stages from print to sound in a cascaded manner. While the nonlexical route remains a grapheme-phoneme rule system in which a letter string is converted into a phoneme string using grapheme-to-phoneme correspondence rules, the lexical route consists of two pathways: (1) a *lexical nonsemantic* route, where letter units activate a word's entry in the orthographic lexicon that then activates the corresponding word entry in the phonological lexicon, which in turn activates the phonemes of the word; (2) a *lexical semantic* route, which involves the lexical process but is mediated by the semantic system (Binte Faizal, 2009).

It is important to note that dual route models are explicitly not adaptive in terms of learning in the lexical route because connections in the lexical route are prespecified and not learned (Davies et al., 2017), which will have implications on making predictions about individual differences in psycholinguistic effects; this will be discussed later. However, connectionist models such as the parallel-distributed processing (PDP) model of visual word recognition and pronunciation (Plaut, 1997; Plaut et al., 1996; Seidenberg & McClelland, 1989b, 1990) are designed to learn from experience, postulating that a single system is capable of learning to read words, nonwords and exception words. Lexical knowledge is developed from general learning principles applied to mappings among distributed representations of orthography, phonology, and semantics (Plaut, 1997).

According to Plaut (1997), the connectionist account of the lexical decision process is as follows: upon the presentation of a target stimulus, it is processed through the cooperative and competitive interactions among the orthographic, phonological, and semantic units of the network; the units interact through weighted connections between them until the network as a whole settles into a stable pattern of activity that corresponds to its interpretation of the input (word or nonword). These weighted connections collectively encode the individual's knowledge about how the different types of information (orthographic, phonological, and semantic) are related and these weights are learned based on the individual's exposure to written words, speech, and their meanings. A word or nonword decision is therefore made based on some measure of the familiarity of the stimulus that is computed from the orthographic, phonological and semantic information derived by the system. As for reading aloud, according to Plaut (1997), the orthographic pattern of the target stimulus is transformed into the appropriate phonological pattern through the abovementioned interactions until the network as a whole settles into a stable pattern of activity that corresponds to its interpretation of the input and a pronunciation output is produced.

However, there are at least two reasons as to why the PDP model may not be able to account for visual word recognition processes, especially for transparent orthographies. First, if there is parallel activation of phonemes, then PDP models cannot account for serial position effects on pronunciation latencies (Coltheart & Rastle, 1994). Second, and more importantly for transparent orthographies, the absence of a sublexical route (or a grapheme-phoneme rule) means that PDP models are unable to explain length effects which are markers of sublexical processing (see also Coltheart et al., 1993, for a more detailed critique of the PDP model). As we will discuss later, the greater reliance on sublexical processing in transparent orthographies as shown by effects of markers of sublexical processing such as length suggests that dual-route models, instead of the PDP model, is likely to provide a better understanding of the processes underlying visual word recognition of our non-Arabic-speaking Qur'anic memorisers. In the present study, we therefore focus the discussion of our findings in the context of dual-route models.

5.3 Orthographic Depth Hypothesis (ODH) and Psycholinguistic Grain Size Theory (PGST)

Given that Qur'anic Arabic is a transparent orthography with consistent grapheme-to-phoneme correspondences in contrast with English's opaque orthography with inconsistent grapheme-to-phoneme correspondences, it is also important to discuss our findings in the context of cross-linguistic theories of visual word recognition. Here, we will consider both the orthographic depth hypothesis (ODH) and psycholinguistic grain size theory (PGST).

Emerging from dual-route models, the ODH (Frost, Katz, & Bentin, 1987) proposes that one would find differences in word recognition processes across languages depending on their consistency of mappings between orthography and phonology, which would then result in the reader's differential reliance on the lexical route versus the nonlexical route. Transparent orthographies with more consistent mappings between orthography and phonology would be better able to support word recognition processes involving the sublexical phonological assembly pathway whereas opaque orthographies with less consistent mappings between orthography and phonology would be relying more on the lexical route to process printed words.

Support for the ODH came from Frost et al.'s (1987) landmark cross-linguistic study comparing lexical decision and speeded pronunciation performance across three languages that vary on a continuum of orthographic depth: Serbo-Croatian (a transparent alphabetic orthography with consistent grapheme-to-phoneme correspondences), English (an opaque alphabetic orthography with inconsistent grapheme-to-phoneme correspondences), and unvowelled Hebrew (the most opaque among the three orthographies as words can share an identical consonant structure but have different pronunciations). Findings showed that lexicality and semantic priming effects (markers for lexical processing) were the largest for Hebrew and then English, with lexicality effects being insignificant for Serbo-Croatian, while speeded pronunciation accuracy was adversely affected in Hebrew and English but not in Serbo-Croatian when there was an increase in the proportion of nonwords in the stimuli list, thus biasing towards a sublexical strategy in speeded pronunciation. These findings support the idea that there is differential reliance on a particular route depending on the depth of the orthography, with transparent orthographies relying more on the sublexical route whereas opaque orthographies rely more on the lexical route.

The strong ODH, which postulates that the sublexical route alone is sufficient for speeded pronunciation, has since given way to the weak ODH, which states that both lexical and sublexical routes may be used in speeded pronunciation; even readers of very shallow orthographies seem likely to develop an orthographic input lexicon and be able to map from the orthographic input lexicon to semantics or the phonological output lexicon, especially when processing less transparent words or foreign loan words (see Besner & Smith, 1992; Katz & Frost, 1992; Seidenberg, 1992). The degree to which a route, lexical or nonlexical, is relied upon in reading aloud would then be a function of the orthography's depth (Katz & Frost, 1992).

The psycholinguistic grain size theory (PGST) (Wydell & Butterworth, 1999; Ziegler & Goswami, 2005) proposes that differences in the task demands across orthographies lead to fundamental differences in processing (or phonological recoding) that are consistent with the optimal grain size(s) in lexical representations. In general, transparent or consistent orthographies have smaller grain sizes (e.g., grapheme or phoneme) while opaque or inconsistent orthographies have larger grain sizes (e.g., syllable or whole-word). Evidence in support of the PGST include the finding that skilled German readers showed stronger word length effects (markers for small-unit processing) whereas skilled English readers showed stronger orthographic rime effects (markers for large-unit processing) when reading identical cognate words aloud (Ziegler, Perry, Jacobs, & Braun, 2001). More support for PGST is discussed in the following sections. Ziegler and Goswami (2006) reasoned that readers of transparent orthographies are able to rely on smaller grain sizes in processing due to exposure to consistent grapheme-to-phoneme correspondences whereas readers of opaque orthographies have to adapt to larger grain sizes as inconsistency in spelling-to-sound mappings is typically higher for smaller units such as graphemes than for larger units such as rimes.

The main advantage of PGST is that readers adapt to the demands of the orthography instead of adapting to the different routes (lexical vs. sublexical) regardless of task (Binte Faizal, 2009). It is not driven by model architectures and thus provides a more continuous and fine-grained variable for looking at processing rather than a dichotomous concept such as 'lexical' or 'nonlexical' phonology (Frost, 2006). Nonetheless, as it is still important to be able to discuss the effects of lexical variables in the context of classic theoretical frameworks such as the DRC model, we will do so in the context of both the PGST and the weak ODH in this dissertation.

5.4 Factors Influencing Lexical Decision

As discussed in Chapter 4, lexical decision has been widely used in the study of visual word recognition and its findings underlie many models and theories of word recognition (Balota et al., 2006; Katz et al., 2012; Yap et al., 2012). In lexical decision, participants are asked to decide as quickly as possible if a target stimulus is a word or nonword, typically using a key or button press; their reaction times (RTs) and accuracy for each trial provide suitable dependent measures with which one can test the effects of particular variables.

The advantages of using the lexical decision paradigm for this study are numerous: a) It allows us to examine lexical access during visual word processing easily, and thus, the emergence of lexical representations in our non-Arabic-speaking memorisers. b) As it has been widely used, we can easily compare our results with those from other studies, especially of similar transparent orthographies such as Malay. c) When used with speeded pronunciation, it can provide converging evidence in understanding the processes involved in word recognition, such as accessing and using lexical representations across different tasks (see Yap & Balota, 2009; Yap et al., 2012). A discussion of the effects across tasks can be found in Chapter 8.

The list of lexical variables that influenced English lexical decision is very long (see Balota et al., 2004 for reviews; Balota et al., 2006; Yap & Balota, 2009). For this pioneer study on non-Arabic-speaking Qur'anic memorisers, it seems prudent to focus on the main standard lexical variables, namely item length (number of letters, syllables, and phones), item frequency, neighbourhood size (orthographic N and phonological N), Levenshtein distance (orthographic and phonological), phonotactic probability, and lexicality. Root variables (root frequency and root family size) are also added as the root plays a significant role in Arabic word recognition through morphological processing (see Boudelaa, 2014; Boudelaa & Marslen-Wilson, 2001, 2011, 2015); it would therefore be interesting to see if our non-Arabic-speaking Qur'anic memorisers are sensitive to root effects while visually processing Qur'anic words despite having limited semantic knowledge, which would suggest some form of implicit statistical learning taking place.

Based on the weak orthographic depth hypothesis (weak ODH) and psycholinguistic grain size theory (PGST), the transparency of the orthography in terms of its consistency in grapheme-to-phoneme correspondences may result in different patterns of findings of effects in visual word recognition. In this selective review of studies that have examined lexical variables in lexical decision, the focus is thus on describing the general trend of findings in lexical decision across various orthographies so as to provide the context for the weak ODH and PGST. We focus on English (a well-studied opaque orthography), Semitic languages such as Hebrew and Arabic that can be both opaque and transparent depending on vowelisation, and other transparent orthographies such as Malay.

5.4.1 Length

Length can be defined as number of letters or characters, number of syllables, or number of phonemes. In terms of their theoretical implications, length effects are used as markers of sublexical processing or an engagement with the sublexical pathway in conventional dual-route models of reading (Coltheart et al., 1993; Coltheart & Rastle, 1994; Yap & Balota, 2009; Yap et al., 2012).

In English lexical decision, number of letters have been found to significantly affect response latencies such that longer words generally elicit slower responses (e.g. Balota et al., 2004; see New, Ferrand, Pallier, & Brysbaert, 2006, for a review of length effects in latencies across tasks and languages; Yap & Balota, 2009). Number of syllables have also been found to inhibit lexical decision latencies such that words with more syllables elicit slower responses (New et al., 2006; Yap & Balota, 2009). Yap and Balota (2009) also found that number of syllables accounted for greater variance in lexical decision latencies than number of letters, which suggests an adaptation to a larger grain size of processing as hypothesised by PGST. However, there are task differences in both effects of number of letters and number of syllables. Balota et al. (2004) found smaller effects of number of letters in lexical decision than in speeded pronunciation while Yap and Balota (2009) found smaller effects of number of letters in lexical decision than in speeded pronunciation. These findings emphasize the different constellation of processes engaged in both tasks, as affirmed by the findings in other studies (e.g. Balota & Chumbley, 1985; Monsell, Doyle, & Haggard, 1989; Yap & Balota, 2009). This is similar to the smaller effects of number of syllables that were found in lexical decision than in speeded pronunciation (Yap & Balota, 2009). These findings speak to the greater demand for lexical processing and lesser demand for sublexical processing in lexical decision than in speeded pronunciation.

Both the weak ODH and PGST would predict that more transparent orthographies, especially those with smaller salient grain sizes, would show larger length effects in lexical decision as compared to less transparent orthographies. Using a principal component analysis to combine number of letters, number of syllables, number of phonemes, and number of morphemes into a principal component of length due to multicollinearity, inhibitory length effects were found in Malay lexical decision (Binte Faizal, 2009; Yap et al., 2010). More importantly, unlike English, length was the strongest predictor of lexical decision latencies and accuracy as compared to frequency, which speaks to a greater reliance on the sublexical route during word processing as well as an adaptation to smaller grain sizes in word processing, even in a task that requires some lexical access in order to be able to decide whether the target stimulus is a real word or a nonword.

Putting these findings together, length effects reflect sublexical or smaller grain size processing and they can be found across orthographies of various levels of transparency, although length effects play a larger role in more transparent orthographies than in less transparent orthographies, thereby reflecting a greater reliance on sublexical processing than on lexical processing for more transparent orthographies. Sensitivity to length effects in lexical decision would therefore suggest the implicit learning of sublexical representations through print exposure and being able to access those sublexical representations in visual word processing.

5.4.2 Frequency

The frequency effect is one of the more robust and most reported findings in lexical decision research—words that occur more frequently in print elicit faster responses. Word frequency effects are used as a marker for lexical or whole-word processing (Yap et al., 2012). Skilled readers develop lexical or whole word representations as a result of the frequency of exposure to a print word and these are stored in the orthographic input lexicon as proposed by dual-route models of reading.

In English lexical decision, Yap and Balota (2009) examined lexical decision performance for multisyllabic words using data from the English Lexicon Project (ELP; Balota et al., 2007) and found significant facilitatory frequency effects. Comparing across tasks, they found larger frequency effects in lexical decision than in speeded pronunciation, which speaks to the greater bias for sublexical processing in speeded pronunciation as well as the need to access the word's familiarity and meaningfulness to make an additional decision of lexicality on the target word in lexical decision. These findings are consistent with a previous large-scale study on monosyllabic words (Balota et al., 2004). More importantly, these megastudies found that frequency accounted for the greatest amount of variance in lexical decision as compared to other lexical variables (see Balota, Yap, Hutchison, & Cortese, 2012).

Both the ODH and PGST predict that opaque orthographies should show stronger frequency effects than transparent orthographies in word recognition tasks because their spelling-to-sound correspondences are too inconsistent for sublexical processing, and therefore, require an adaptation to larger grain sizes during lexical processing. Evidence in support of this prediction has accumulated from research on several different languages such as English (as seen above). Baluch (1993) examined readers of a Semitic writing system, Persian, which has both transparent (vowelled) and opaque (unvowelled) orthography, in a lexical decision task and found a word frequency by word transparency interaction. While transparent Persian words with lower frequency were responded to faster than matched opaque words, both opaque and transparent words with higher frequency were just as fast to be responded to by participants. Binte Faizal (2009) also found much larger length effects than frequency in Malay (a transparent orthography) lexical decision latencies, showing a greater reliance on sublexical processing, even in a task that requires some form of lexical access to be performed accurately. Nonetheless, as discussed earlier in the section on Length, the presence of frequency effects in tandem with large length effects for transparent orthographies indicates that lexical and sublexical processing are not necessarily mutually exclusive but could be activated in parallel, thus supporting the weaker version of the ODH that does not call for exclusivity of either type of processing in dual-route models of reading.

Putting these findings together, frequency effects reflect lexical or whole word processing and they can be found across orthographies of various levels of transparency, although frequency effects play a smaller role in more transparent orthographies than in less transparent orthographies, thereby reflecting a greater reliance on sublexical processing than on lexical processing for more transparent orthographies. Sensitivity to frequency effects in lexical decision would therefore suggest the implicit learning of lexical representations through print exposure and being able to access those lexical representations when processing words visually.

5.4.3 Neighbourhood Density

Here, we stick to the traditional definition of orthographic and phonological N, i.e., Coltheart's N (Coltheart et al., 1977). Orthographic N is the number of words or neighbours that can be obtained by replacing a letter in the target word whereas phonological N is the number of words that can be obtained by changing a phoneme in a target word. Findings for orthographic and phonological N effects have been inconsistent thus far in the lexical decision literature (Yap & Balota, 2009; see Andrews, 1997, for a review of recent research on the effects of orthographic neighbourhood across word identification tasks).

Looking at English lexical decision, Balota and colleagues (2004) did not find a significant orthographic N effect for monosyllabic words. However, Yap and Balota (2009) found significant facilitatory orthographic N effects for both monosyllabic and multisyllabic words, with orthographic N accounting for greater unique variance in lexical decision latencies for monosyllabic words as compared to multisyllabic words. This meant that words with many orthographic neighbours were recognised faster, which is consistent with what Andrews (1992) had found. Although this is inconsistent with the intuition that neighbours compete with one another during lexical identification, Andrews (1997) posited that these facilitatory effects arise due to visually similar words containing more common spelling-sound correspondences, reflecting characteristics of the sublexical phonological assembly process. In this process, words with more orthographic neighbours are responded to faster as they share more common grapheme-to-phoneme correspondences, facilitating the activation of phonology consistent with that of the target word, thereby reducing the time taken to make a lexical decision. Comparing across tasks, the smaller facilitatory orthographic N effects in lexical decision latencies as compared to in speeded pronunciation latencies (Balota et al., 2004; Yap & Balota, 2009) is consistent with Andrews' (1997) idea that these effects possibly reflect the sublexical phonological assembly process, which is relied on more during speeded pronunciation than in lexical decision.

With regards to phonological N, Yates (2005) found significant facilitatory phonological N effects for monosyllabic words, i.e., monosyllabic words with more phonological neighbours elicited faster responses in English lexical decision. However, this finding failed to extend to Yap and Balota (2009)'s study using a large database of multisyllabic words in the English Lexicon Project (Balota et al., 2007). They found facilitatory phonological N effects only in speeded pronunciation and not in lexical decision for multisyllabic words, as well as inhibitory phonological N effects in both speeded pronunciation and lexical decision for monosyllabic words, leading them to postulate that the discrepancy in results could have been driven by a subset of orthographic and phonological neighbours, or more specifically, phonographic neighbours, defined as words which are both orthographic and phonological neighbours (see Adelman & Brown, 2007; Peereman & Content, 1997). These findings suggest that orthographic N and phonological N may not be the most ideal measures of orthographic and phonological similarity respectively (Yap & Balota, 2009).

Looking at Malay lexical decision, Binte Faizal (2009) combined orthographic N and phonological N in a principal component called neighbourhood density (N) due to multicollinearity and found that N significantly facilitated lexical decision latencies, i.e., words with more orthographic and phonological neighbours elicited faster responses. However, as mentioned by Yap and Balota (2009) with regards to phonographic neighbours, it is important to note that given the transparency of the Malay orthography with its consistent grapheme-to-phoneme correspondences, the orthographic neighbours of a word are also its phonological neighbours, possessing both similar spellings and pronunciations as the word, making them phonographic neighbours (see Adelman & Brown, 2007). This principal component N is therefore more similar to phonographic neighbourhood size than orthographic N in English, making it easier to engage the sublexical phonological assembly process and activate similar grapheme-to-phoneme correspondences as the target word, thus making it faster to pronounce the target word. More importantly, the principal component of N was a weaker predictor than Levenshtein distance in lexical decision latencies, which provides further support for Yap and Balota's (2009) suggestion that orthographic N and phonological N may not be the most ideal measures of orthographic and phonological similarity respectively.

A pertinent issue relating to the internal structure of words across orthographies, and thus, defining what a neighbour is for a particular orthography (see Alsari, 2015; Frost, Kugler, Deutsch, & Forster, 2005; Perea, 2015; Velan & Frost, 2011), is applicable here for our non-Arabic-speaking Qur'anic memorisers because although Qur'anic Arabic is a transparent orthography with consistent phoneme-to-grapheme correspondences, it has a non-concatenative morphology in which word formation involves non-linear combinations of roots and word patterns (see Chapter 7). Frost et al. (2005) argued that the visual processing of words is first determined by morphological characteristics and that Semitic words are lexically organised by non-concatenative morphological principles of roots and word patterns instead of orthographic similarity such as orthographic N like in English. This argument is supported by their findings that Hebrew-English bilinguals show robust facilitatory form-orthographic priming effects with English words but not with Hebrew words. Therefore, participants responded faster to target words that share similar sequences of letters with prime words only in English but not in Hebrew. They also found robust root priming (with minimal letter overlap) effects in Hebrew and Arabic instead. These findings were corroborated by Velan and Frost (2011) who did not find form-orthographic priming effects or letter-transposition priming effects with Hebrew words that are morphologically complex and root-derived but found those effects in Hebrew words of non-Semitic origins that are morphologically simple and resemble base-words in European languages such as English (but see Perea, Mallouh, & Carreiras, 2014, for contradicting results). A question that one can then ask is whether the visual word processing of our non-Arabic-speaking Qur'anic memorisers is determined by orthographic characteristics (as shown by extant findings for alphabetic orthographies) or morphological characteristics as Frost et al. (2005) had argued.

Based on these incongruent theoretical assumptions with regards to the lexical organisation of words in the lexicon, we can make separate predictions for our non-Arabic-speaking Qur'anic memorisers—if they are more sensitive to N effects than root effects, then that would suggest that they organise words based on orthographic similarity and that words are not lexically organised based on the language's morphological principles, but rather, whether the readers themselves have been explicitly taught non-concatenative morphological principles or have semantic knowledge in order to be able to organise words based on the morphological principles of roots and word patterns. If the reverse occurs, then that would suggest that there is implicit learning of non-concatenative root information despite limited semantic knowledge and that words are lexically organised based on the language's morphological principles.

5.4.4 Levenshtein Distance

Levenshtein distance, which can be defined as orthographic or phonological Levenshtein distance (OLD20 or PLD20), is a new measure of orthographic distinctiveness or similarity that has been optimized for longer words (see Yarkoni et al., 2008). Using words from the English Lexicon Project (Balota et al., 2007), Yarkoni et al. (2008) found strong initial support for OLD20 being a more powerful metric of orthographic similarity than orthographic N in English, thus circumventing many limitations that are linked to traditional neighbourhood measures such as orthographic N (Yap & Balota, 2009; Yarkoni et al., 2008). For example, the utility of OLD20 and PLD20 extends to words of all lengths and especially to long words, wherein the utility of orthographic N and phonological N is limited, as most long words (e.g. computer) have few or no orthographic and phonological neighbours.

Looking at English, Yarkoni and colleagues (2008) found a significant inhibitory effect of OLD20 in lexical decision latencies; words that are orthographically more distinct, i.e., have further orthographic neighbours, elicited slower responses whereas words that have closer orthographic neighbours elicited faster responses. Similarly, Yap and Balota (2009) found significant inhibitory effects of OLD20 and PLD20 in the lexical decision of multisyllabic words; both OLD20 and PLD20 accounted for greater unique variance in multisyllabic words than in monosyllabic words. This speaks to the utility of Levenshtein distance extending to longer words. Importantly, in both studies (Yap & Balota, 2009; Yarkoni et al., 2008), OLD20 accounted for greater unique variance than orthographic N in multisyllabic words, whereas PLD20 also accounted for greater unique variance than phonological N for both monosyllabic and multisyllabic words in Yap and Balota's (2009) study. They also compared these effects across tasks and found that the effects of PLD20 were smaller in lexical decision than in speeded pronunciation for monosyllabic and multisyllabic words separately as well as when both sets of words are combined, but the effects of OLD20 were larger in lexical decision than in speeded pronunciation performance across all of the above three groups of words (Yap & Balota, 2009).

The utility of Levenshtein distance as a measure of orthographic similarity has been shown to be generalisable across orthographies, as evinced by findings in Malay lexical decision that corroborated those in English lexical decision. Reducing OLD20 and PLD20 to a principal component called Levenshtein distance (LD) due to multicollinearity, Binte Faizal (2009) found that LD significantly inhibited lexical decision latencies, i.e., words with further neighbours were slower to be read aloud correctly whereas words with closer neighbours were faster to be read aloud correctly. LD also accounted for greater unique variance than the principal component of neighbourhood size (N). Comparing these effects across tasks, the effect of LD was also found to be weaker in lexical decision than in speeded pronunciation.

Putting these findings together, LD was able to account for unique variance above and beyond the traditional measures of neighbourhood size across two orthographies of different orthographic depth. In general, the effects of LD indicated words with closer neighbours were faster to be read aloud correctly, i.e., more visually and phonologically confusable words were faster to be read aloud correctly. These facilitatory LD effects possibly reflect the processing characteristics of the sublexical phonological assembly process in dual route models of reading, in which words which are visually similar to many other words are recognised faster as they share more common grapheme-to-phoneme correspondences (Andrews, 1997). Therefore, like length effects, LD effects could be another marker for sublexical processing in visual word processing.

5.4.5 Phonotactic Probability

Although phonotactic probability has been more frequently used in spoken word processing, it can be another marker for sublexical processing, and thus, the use of sublexical representations in visual word processing (see Vitevitch, 2003; Vitevitch & Luce, 1998, 1999). Phonotactic probability is included to possibly corroborate evidence from other factors with regards to the sublexical processing of non-Arabic-speaking Qur'anic memorisers. If facilitatory phonotactic probability effects are shown in speeded pronunciation, that would suggest the implicit learning of phonotactic probabilities at the levels of phone and biphone, and thus, the access of these sublexical representations during lexical decision.

5.4.6 Root

There has yet to be a study that has explored non-concatenative root variables such as root frequency and root family size in lexical decision. However, root productivity, or root family size, does facilitate root priming effects in Arabic word recognition beyond shared phonology (Boudelaa & Marslen-Wilson, 2011); roots that are more productive have larger priming effects than roots that are less productive. One can then infer that if our non-Arabic-speaking readers develop root representations through implicit learning and access those representations during visual word processing, they would be sensitive to root variables in lexical decision. Importantly, as discussed earlier in the section on Neighbourhood Density, greater sensitivity to root variables as compared to measures of orthographic similarity such as orthographic N could suggest the salience of the root in lexical organisation that is based on the non-concatenative morphological principles of an orthography instead of orthographic similarity as assumed by extant models of word recognition.

5.4.7 Lexicality

Lexicality effects (contrasting real words with pseudowords, i.e., pronounceable nonwords) have been widely studied in word recognition research and is thought to reflect lexico-semantic processing, often coinciding with semantic effects in ERP data (see Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006). Lexicality effects typically show that words elicit faster responses than pseudowords as repeated exposure to an item may lead to the development of its lexical representation through its orthographic, phonological, and semantic representations, thus facilitating lexical access (Coltheart et al., 1993). Lexicality effects could therefore be a marker for word-specific representations (Fiez, Balota, Raichle, & Petersen, 1999); the presence of lexicality effects in our non-Arabic-speaking memorisers would suggest the implicit learning of these word-specific representations, facilitating lexical access, and thus, response times, as compared to pseudowords.

5.5 Overview of Current Study

The goals of this study are two-fold: First, to explore the influence of traditional variables (length, frequency, neighbourhood density, lexicality) and newer variables (Levenshtein distance, phonotactic probability, and root) on the lexical decision of non-Arabic-speaking Qur'anic memorisers; second, to examine individual differences in the influence of these factors on lexical decision by looking at whether Qur'an vocabulary knowledge (QVT) and amount of Qur'an memorisation (MemScore) interact with these factors in two- and three-way interactions, thereby teasing apart the possibly differential roles of vocabulary knowledge and print exposure in visual word processing.

5.5.1 Research Questions

The current study aimed to investigate the following research questions:

1. How does length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, root, and lexicality influence lexical decision latencies and accuracy?
2. Does amount of Qur'an memorisation (MemScore) modulate the effects of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, root, and lexicality on lexical decision latencies and accuracy?
3. Does Qur'an vocabulary knowledge (QVT) modulate the effects of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, root, and lexicality on lexical decision latencies and accuracy?
4. Do amount of Qur'an memorisation (MemScore) and Qur'an vocabulary knowledge (QVT) interact together in modulating the effects of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root, and lexicality on lexical decision latencies and accuracy?

5.5.2 Predictions

Given the psycholinguistic characteristics of Qur'anic Arabic and the linguistic input received by our non-Arabic-speaking Qur'anic memorisers, the following predictions can be made by extrapolating findings from other transparent orthographies with simple syllabic structures. Furthermore, like Malay and Serbo-Croatian, there would be a greater reliance on sublexical processing even in lexical decision, a task that requires some form of lexical access in order to decide if the target stimulus is a real word or a nonword.

First, based on previous findings in Malay and other transparent orthographies, we predict significant effects of length and frequency in opposite directions; longer words would be slower to be responded to correctly whereas words that occur more frequently in print would be faster to be responded to correctly. We also predict facilitatory neighbourhood density and inhibitory

Levenshtein distance effects; words with more neighbours and words with more closer neighbours would be faster to be responded to correctly. For the newer variables such as phonotactic probability and root, we also predict facilitatory effects, given the findings from other related studies. We also predict that lexicality effects would be found, with real words eliciting faster responses than nonwords. However, we predict that root will have the smallest predictive power (if any), as it may not be a salient unit of processing for our non-Arabic-speaking participants. More importantly, given that Qur'anic Arabic is a transparent orthography with consistent grapheme-to-phoneme correspondences, we predict that length effects would be larger than frequency effects on length, thus supporting the notion of a greater reliance on sublexical processing or the sublexical pathway in dual-route models as well as the adaptation to a smaller grain size of processing as predicted by both the ODH and PGST respectively.

Second, based on past findings of print exposure modulating effects of word frequency and neighbourhood density such that participants who have had more print exposure were less sensitive to effects of word frequency and neighbourhood size in lexical decision (Chateau & Jared, 2000; Sears et al., 2008), we predict the same for our population. More memorisation would provide greater familiarity with lexical items, thus helping to make lexical processing more automatized and efficient, and be less influenced by lexical characteristics of words.

Third, based on the premise that vocabulary knowledge helps to make lexical processing more automatized and efficient, and thus, be less influenced by lexical characteristics of words, we predict that if there is an interaction, more vocabulary knowledge will result in smaller effects of lexical variables such as frequency on lexical decision.

Last, any predictions with regards to the three-way interactions among amount of memorisation, vocabulary knowledge, and lexical effect will have to be speculative as this is the first study to explore such interactions. However, given that both vocabulary knowledge and amount of memorisation contribute to separate components (semantic and orthographic/phonetic respectively) in developing the quality of lexical representations, and thus, efficacy for accessing those representations, we expect significant three-way interactions to show that those with more memorisation and more vocabulary knowledge to be less influenced by lexical effects in lexical decision than participants with more memorisation and less vocabulary knowledge or less memorisation and more vocabulary knowledge.

5.6 Method

5.6.1 Participants

A group of 246 participants (148 females; M_{age} = 18.63; SD_{age} = 6.81) were sampled from a *tahfiẓ* (memorising) school, two *madrasahs* (religious school; non-memorising), and the general public in Singapore. All of them were at least Malay-English/English-Malay bilinguals with normal or corrected-to-normal vision and with at least upper secondary education. None of them had any history of hearing loss, reading or speech disorders. Written consent to take part in the study was obtained from either the participants themselves or from their guardians if they were a minor. Participants received a small token of appreciation for their participation. The study was approved by the Newcastle University Faculty of Humanities and Social Sciences Ethics Committee.

5.6.2 Individual-level Measures

As the development of the individual-level measures used in this study have been fully described in Chapter 4, only a brief description of the measures will be given. Figure 5-2 presents a scatterplot between both individual-level measures (Qur'an vocabulary knowledge and amount of Qur'an memorisation) of the final group of participants.

5.6.2.1 Qur'an Vocabulary Test

The Qur'an Vocabulary Test (QVT) is a 90-item multiple-choice standardised test used to measure Qur'an vocabulary knowledge, with items ranked in the order of the easiest to the most difficult based on norms derived from a pilot sample (see Chapter 4). Modelled after the Shipley Vocabulary Test

(Shipley, 1940) and Malay Vocabulary Test (Binte Faizal, 2009), participants were asked to choose from four options the English word that best corresponds to the meaning of the Arabic word. Participants from the experimental sample scored between 17 and 86 out of a maximum score of 90 (M = 53.73, SD = 13.90).

5.6.2.2 Self-reported Qur'an memorisation score

To measure amount and fluency of Qur'an memorisation, participants were asked to rate how fluently they can recite from memory each of the 114 *surahs* (chapters) in the Qur'an on a scale of 1 to 9 (1 = "very poor, a lot of errors", 9 = "very fluent, no errors"). For *surahs* they had not memorised at all, they were instructed to select the option "N/A (Haven't memorised at all)", which was then coded as "0" for data analysis. This means that someone who has fully memorised the entire Qur'an and can recite it fluently from memory in its entirety, i.e., a *hafiẓ*, would get the maximum self-reported Qur'an memorisation score of 1026. Participants from the experimental sample self-reported a range of memorisation scores from 21 to 948 (M = 341.47, SD = 206.98).

5.6.3 Item-level Variables

Item-level predictor variables were divided into three clusters: surface variables, lexical variables and distance variables (see Table 5-1 for the descriptive statistics of the predictors). Table 5-2 presents all the inter-correlations between the item-level predictors being examined. As can be seen in Table 5-2, there is evidence of extremely high correlations between number of characters, number of phones, and number of syllables, between log(orthographic frequency) and log(phonetic frequency), between orthographic and phonological N, as well as between Levenshtein orthographic and phonological distance, all rs ≥ .70. These high correlations are problematic for regression analyses, especially the issue of multicollinearity, which occurs when two or more independent variables are highly inter-correlated (see Binte Faizal, 2009; Davies et al., 2017; Yap et al., 2012). A possible solution, which is described later, is to identify groups of similar variables using a principal component analysis.

Table 5-1. *Descriptive statistics for item-level variables for lexical decision stimuli (N = 125).*

	M	*SD*	*Min*	*Max*
Number of Characters	4.152	1.362	2.000	8.000
Number of Phones	6.616	1.979	3.000	12.000
Number of Syllables	2.944	.910	1.000	6.000
Orthographic Item Frequency	24.952	44.014	1.000	412.000
Log(Orthographic Item Frequency)	1.105	.520	.301	2.616
Phonetic Item Frequency	25.568	56.727	1.000	416.000
Log(Phonetic Item Frequency)	1.023	.544	.301	2.620
Root Frequency	373.448	538.023	1.000	2851.000
Log(Root Frequency)	2.168	.682	.301	3.455
Root Family Size	26.616	18.876	1.000	84.000
Root Length	3.016	.126	3.000	4.000
Orthographic N	1.856	1.664	.000	6.000
Phonological N	2.880	2.690	.000	15.000
Orthographic Levenshtein Distance (OLD20)	2.039	1.264	1.000	7.300
Phonological Levenshtein Distance (PLD20)	1.728	.924	1.000	5.000
Positional Segment Average	.129	.048	.030	.231
Positional Segment Sum	.834	.319	.150	1.523
Biphone Average	.014	.008	.002	.053
Biphone Sum	.079	.051	.007	.222

Table 5-2. Correlations between item-level predictors in lexical decision[3].

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	No. of Characters	-												
2	No. of Phones	.877	-											
3	No. of Syllables	.846	.947	-										
4	Log(Orthographic Frequency)	-.444	-.445	-.459	-									
5	Log(Phonetic Frequency)	-.496	-.530	-.502	.809	-								
6	Log(Root Frequency)	-.212	-.235	-.257	.471	.435	-							
7	Root Family Size	.090	.081	.021	.115	.061	.600	-						
8	Orthographic N	-.456	-.472	-.453	.444	.488	.264	.077	-					
9	Phonological N	-.402	-.506	-.471	.342	.476	.268	.156	.719	-				
10	OLD20	.733	.717	.734	-.567	-.542	-.336	-.063	-.626	-.530	-			
11	PLD20	.754	.760	.765	-.620	-.563	-.405	-.106	-.607	-.575	.936	-		
12	Positional Segment Average	-.314	-.226	-.192	-.039	-.008	-.069	-.039	.224	.349	-.353	-.364	-	
13	Biphone Average	.078	.059	.064	-.141	-.109	-.025	.106	.137	.260	-.136	-.116	.616	-

[3] Correlations greater than .7 are in red text.

5.6.3.1 Surface Variables

Surface variables capture the variance associated with articulatory biases, voice key biases, and stress patterns (see Kessler, Treiman, & Mullennix, 2002; Rastle & Davis, 2002). As stress patterns are not specifically taught in typical Qur'anic recitation, only the onset (initial phone) of each word was taken into account as covariates. Although dichotomous coding into 13 phonetic features (e.g. affricative, alveolar, bilabial etc.) is typically used for onsets (e.g. Binte Faizal, 2009; Davies et al., 2017; Yap & Balota, 2009; Yap et al., 2010), we chose to use the initial phone itself instead as recommended by Kessler et al. (2002).

5.6.3.2 Lexical Variables

Lexical variables refer to item characteristics that are higher order than phonetic features but lower-level than semantic features. The descriptive statistics for the following lexical variables are shown in Table 5-1.

Number of characters. This refers to the number of characters in an item. For example, بَيْتٌ (house: /bajtun/) has three characters: ب, ي, ت. For the stimuli examined, the average Qur'anic Arabic item was about four characters long, with a range of two to eight characters.

Number of phones. This provides the phone count for an item. For example, بَيْتٌ (house; /b/ /aj /t/ /u/ /n/) has five phones. For the stimuli examined, the average Qur'anic Arabic item had about seven phones, with a range of three to 12 phones.

Number of syllables. This refers to the number of syllables in an item. For example, بَيْتٌ (house; /baj/-/tun/) has two syllables. In the 125 items examined, there were two monosyllabic words (1.6%), 38 disyllabic words (30.4%), 59 trisyllabic words (47.2%), 19 quadrasyllabic words (15.2%), 5 pentasyllabic words (4.0%) and two hexasyllabic words (1.6%).

Log(Orthographic item frequency). This refers to logarithm-transformed (i.e., log10(frequency + 1)) Qur'anic Arabic frequency norms for the 18 994 orthographic items in the database of the Qur'an Lexicon Project (Binte Faizal et al., 2015; see also Chapter 3). These norms were derived from a corpus of 77 430 orthographic items drawn from the Qur'an; a description is provided in Chapter 3.

Log(Phonetic item frequency). This refers to logarithm-transformed (i.e., log10(frequency + 1)) Qur'anic Arabic frequency norms for the 19 286 contextually and phonetically transcribed items in the database of the Qur'an Lexicon Project (Binte Faizal et al., 2015; see also Chapter 3). These norms were derived from a corpus of 77 430 orthographic items drawn from the Qur'an; a description is provided in Chapter 3.

Log(Root frequency). This refers to logarithm-transformed (i.e., log10(frequency + 1)) token frequency of the root of the item, as derived from the Qur'an Lexicon Project (Binte Faizal et al., 2015; see also Chapter 3). For example, the root of كُتِبَ (was decreed: /kutiba/) is (k t b) which occurs 319 times in the corpus and has a log(root frequency) of 2.51.

Root family size. This refers to the type frequency of the root of the item, as derived from the Qur'an Lexicon Project (Binte Faizal et al., 2015; see also Chapter 3). For example, the root of كُتِبَ (was decreed: /kutiba/) is (k t b) which has a root family size of 36.

Orthographic neighbourhood density (orthographic N). This refers to the number of items that can be obtained by changing a single character in the target item, while holding the identity and positions of the other characters constant (Coltheart et al., 1977; C. J. Davis, 2005). Here, supplementary diacritics or *tashkīl* are treated as separate characters from consonants and computed into the neighbourhood density calculation (see chapter 3 for this discussion). For example, the orthographic neighbours of وَلَدَ (he begot: /walada/) include وَرَدَ (he came: /warada/), وَلَدٌ (child: /waladun/), وَعَدَ (had promised: /waʕada/), and وَلَكَ (and for you: /walaka/).

Phonological neighbourhood density (phonological N). This is the phonological analogue of orthographic N and reflects the number of items that can be obtained by changing a single phone in the target item while holding the other phones constant and preserving the identity and positions of the other phones (Yates, 2005; Yates et al., 2004). As explained in chapter 3, the phonological N was computed using Qur'anic Arabic contextual phonetic transcription. For example, the phonological neighbours of عَقِيمٍ (barren: /ʕaqi:m/) are عَلِيمٌ (All-Knowing: /ʕali:m/), سَقِيمٌ (ill: /saqi:m/), and عَظِيمٌ (great: /ʕaðˤi:m/).

Positional Segment Average. This is a token-based measure of position-specific phonotactic probability that was computed in the following manner: First, *positional segment probability* was calculated by dividing the sum of log (10) frequencies of all the items in the lexicon that contain a given segment in a given position by the total log (10) frequency of all the items in the Qur'an lexicon that have a segment in that position (Aljasser & Vitevitch, 2017; Storkel & Hoover, 2010; Vitevitch & Luce, 2004). Log-values of the frequency counts were used as they better reflect the distribution of frequency of occurrence and better correlate with performance than with raw frequency counts (Vitevitch & Luce, 2004). For each item in the Qur'an lexicon, the *positional segment sum* was then computed by adding the positional segment probability for each sound in the target item. Last, *positional segment average* was computed by dividing the positional segment sum by the number of sounds in the target item.

Biphone Average. The *biphone average* is also a token-based measure of position-specific phonotactic probability that was computed in a similar manner as the positional segment average except that pairs of adjacent sounds were used in the calculations. First, *biphone probability* was calculated by dividing the sum of log (10) frequencies of all the items in the lexicon that contain a given pair of sounds in a given position by the total log (10) frequency of all the items in the Qur'an lexicon that have a pair of sounds in that position (Aljasser & Vitevitch, 2017; Storkel & Hoover, 2010; Vitevitch & Luce, 2004). The *biphone sum* was then computed for each item in the Qur'an lexicon (by adding the biphone probability for each sound in the target item). Last, the *biphone average* was computed by dividing the *biphone sum* by the number of sounds in the target item.

5.6.3.3 Distance Variables

Distance variables refer to the following Levenshtein measures (OLD20 and PLD20), which were developed from a standard computer science metric of string similarity defined as the number of insertions, deletions, and substitutions needed to generate a string of elements, such as characters or phones, from another (Yarkoni et al., 2008; see also Chapter 3).

Orthographic Levenshtein Distance (OLD20). This is a metric of orthographic similarity that represent the mean orthographic Levenshtein distance from an orthographic item to its 20 closest neighbours.

Phonological Levenshtein Distance (PLD20). This is a metric of phonological similarity that represent the mean phonological Levenshtein distance from a phonetic item to its 20 closest neighbours. Like phonological N, PLD20 was computed using Qur'anic Arabic contextual phonetic transcription.

5.6.4 Stimuli

The word target stimuli for the lexical decision task consisted of 125 orthographic items that were selected from the Qur'an Lexicon database (Binte Faizal et al., 2015). This database, referred to as the Qur'an Lexicon Project, comprises lexical statistics and phonotactic probabilities for 19 286 contextually and phonetically transcribed types in Qur'anic Arabic (see also Chapter 3). 125 pronounceable nonwords were then created by replacing a character in a corresponding target item with another. This was similar to what was done by Bentin and Ibrahim (1996). Care was taken to ensure that the nonwords were legal and true nonwords by checking them with an online Arabic dictionary (Almaany.com, 2018) as well as having a native Arabic speaker look through the nonwords. The full list of word and nonword stimuli can be found in Appendix E.

Due to logistical reasons, the lexical decision stimuli were presented either in person or online, depending on how the experiment was conducted. For experiments that were conducted by the experimenter in person, stimulus presentation and data recording were controlled by PsychoPy software (Peirce, 2007) running on either a PC or a laptop with Windows 7. For experiments that were conducted online, stimulus presentation and data recording were controlled by Inquisit Web 5.0 (Millisecond-Software, 2016). All stimuli were presented in black on white screen and in Traditional Arabic font (36-point font size).

5.6.5 Procedure

Both online and in-person participants were tested in two sessions. In the first session, they were assigned a participant number and asked to complete an online questionnaire detailing their demographic and language background information as well as their experience with Qur'an recitation and memorisation. They were then asked to complete the Qur'an vocabulary test online. The entire session took about 30 minutes.

In the second session, participants were tested either individually or in small groups with each individual having their own separate testing apparatus (either a PC or a laptop) with identical experimental software. After keying in their participant number into the system, they received written instructions in English to perform a lexical decision task. English was chosen as it was the language of instruction for all participants; not all participants would have understood instructions in Arabic otherwise. In this task, they were instructed to decide as quickly and as accurately as possible whether or not the presented letter string was an Arabic word. If they thought the presented letter string was an Arabic word, they then press the "/' key or the "z" key if otherwise. Participants were given 20 practice trials before beginning the experiment.

For the experiment, 250 experimental trials were presented in random order within five blocks of 50 trials each; each target was presented only once. Each block of 50 trials was followed by a rest break which was three minutes long, although participants were given the option to shorten the break if they wished to continue. Every trial started with the presentation of a centred fixation point ("+") for 500 ms. 200 ms later, this was then followed by the presentation of the word or nonword target, centred on the screen. The target stayed on the screen until the participant responded or until the maximum response time (3000 ms) was exceeded. An auditory tone was presented if the maximum response time was exceeded or if the response was incorrect. An incorrect response was also presented with the word "Incorrect" to alert the participant to a wrong response. The inter-trial interval was 500 ms.

The experiment took approximately 15 minutes long. At the end of the experiment, participants received a small token of appreciation for their participation, were debriefed, and thanked for their help.

5.7 Data Analysis

5.7.1 Data Cleaning

5.7.1.1 Participants

To ensure that the accuracy of participants was reliably above chance, calculations based on the binomial distribution showed that participants would have to get 138 out of 250 trials (55.20%) correct to be performing above chance at $p < .05$. 32 participants were excluded from the data as their task accuracy was below 55.2%, leaving a total of 214 participants. As can be seen in Figure 5-1, 20 of the 32 excluded participants did not make the passing mark (45) on the QVT; most of the excluded participants also did not memorise much of the Qur'an. Figure 5-2 presents a scatter plot of amount of Qur'an memorisation by QVT scores of the final group of participants.

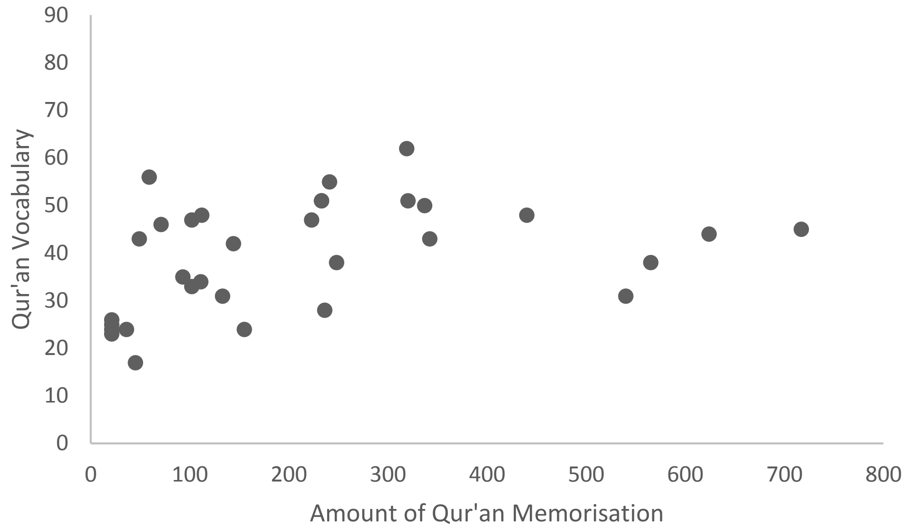

Figure 5-1. Scatterplot of excluded participants' QVT scores as a function of their amount of Qur'an memorisation.

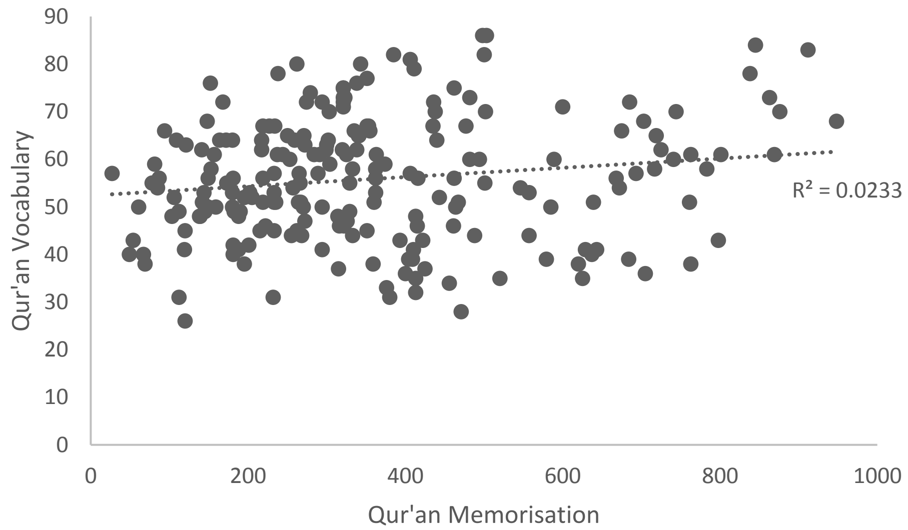

Figure 5-2. Scatterplot of final group of participants' QVT scores as a function of their amount of Qur'an memorisation.

5.7.1.2 Trials

To ensure that accuracy of responses on items was reliably above chance, calculations based on the binomial distribution showed that at least 119 out of 214 participants (55.61%) had to get a particular item correct for the item's accuracy to be above chance at $p < .05$. 10 real word items and 7 nonword items were thus excluded from the data, leaving a total of 233 items.

Typical data cleaning methods used for reaction time (RT) data in visual lexical decision tasks (e.g. Balota et al., 2004; Binte Faizal, 2009; Yap & Balota, 2009) were then followed to exclude extreme responses that may affect the analyses. First, trials with incorrect responses as well as trials that were faster than 200ms or slower than 3000ms were excluded from all RT analyses (20.65% of trials). Next, from the remaining trials, trials that were 2.5 standard deviations above or below each participant's mean RT were excluded (2.18% of trials). In total, 22.83% of LDT trials were removed and the remaining trials were used in RT analyses. Table 5-3 shows the group's overall RT and accuracy performance in lexical decision for words and nonwords respectively.

Table 5-3. Overall RT and accuracy in lexical decision for words and nonwords respectively.

	Words	Nonwords
	M (SD)	*M (SD)*
RT (ms)	895 (358)	1054 (399)
Accuracy (%)	87.4 (33.2)	75.2 (43.2)

5.7.2 Principal Component Analysis of Lexical Variables

Before performing any regression analyses, it was important to take note of the extremely high inter-correlations between the lexical variables (e.g. *r*s > .800 between syllable, phoneme, and character counts) due to the one-to-one grapheme-to-phoneme correspondences of Qur'anic Arabic. To prevent any potential problems of multicollinearity and suppression (brought about by high inter-correlations between predictor variables) occurring during regression analyses, a principal component analysis of the item-level variables was used to statistically regroup the lexical variables into several main components for future regression analyses (Baayen et al., 2006).

Similar to what was done by Binte Faizal (2009) for Malay (a transparent orthography), a preliminary exploratory principal component analysis was performed with the 13 item-level variables: number of characters, number of phones, number of syllables, log(orthographic frequency), log(phonetic frequency), log(root frequency), root family size, positional segment average, biphone average, orthographic and phonological N, as well as orthographic and phonological Levenshtein distance. The Kaiser-Meyer-Olkin measure of sampling adequacy for the 13 items was .794 and the Bartlett's Test of Sphericity was significant, χ^2 (78) = 1458.15, p < .001, indicating that a principal component analysis could be conducted. A principal components extraction method using varimax rotation with Kaiser normalisation was employed and the interpretation was based on the rotated component matrix. As one would theoretically expect six constructs (length, frequency, phonotactic probability, root, neighbourhood density, and Levenshtein distance) from these 13 item-level variables, an extraction of six principal components was specified and the maximum iterations for convergence were set to 25. Coefficients below .40 were also suppressed and not shown in the matrix; items with coefficients below .40 were thus not interpreted.

As expected, the principal component analysis extracted six interpretable components (see Table 5-4). With Eigenvalues ranging from .450 to .935, the six principal components explained 90.59% of the variance. As OLD20 and PLD20 had double factor loadings on two components, they were assigned to the component on which they loaded higher; this also facilitated the interpretations of the components. These components (1 to 6) were converted into the six lexical predictors in the following order: length (number of letters, number of phonemes, and number of syllables), frequency (orthographic and phonetic), phonotactic probability (positional segment average and biphone average), root (root frequency and root family size), neighbourhood density (orthographic and phonological), and Levenshtein distance (orthographic and phonological). The factor scores were then saved as variables via the regression method so that they could be used as fixed effects in subsequent mixed effects regression analyses.

Table 5-4. Rotated component matrix of principal component analysis.

	Principal Components					
	Length	Frequency	Neighbourhood Density	Phonotactic Probability	Root	Levenshtein Distance
Character Count	.903					
Phone Count	.934					
Syllable Count	.929					
Log(Orthographic Frequency)		.861				
Log(Phonetic Frequency)		.854				
Log(Root Frequency)					.811	
Root Family Size					.935	
ON			.833			
PN			.824			
OLD20	.530					.653
PLD20	.430					.689
Positional Segment Average				.865		
Biphone Average				.905		

5.7.3 Mixed Effects Regression Analyses (Word Targets)

As the purpose of these analyses was to investigate factors that influence response latencies and accuracy on word targets, responses for nonword targets were excluded. For RT analyses, given that RT data in general is positively skewed, a log transformation[4] of the cleaned RT data was performed so as to normalise the RT distribution and not violate the assumptions of normality and linearity of residuals needed for linear mixed effects regression analyses. All data were used for accuracy analyses. A mixed effects regression analysis of the two main dependent variables (RT and accuracy) for word targets were then conducted separately using R (R Core Team, 2016) and *lmerTest* (Kuznetsova, Brockhoff, & Christensen, 2017) with maximum likelihood.

R^2, the coefficient of determination, is traditionally used in regression modelling to represent the proportion of variance in a dependent variable explained by the fixed effects in a model with a single random effect. However,

[4] Only the analyses from the log(RT) models were reported in this chapter as Q-Q plots indicated that the log transformation ameliorated the skew in the raw RT distribution the best compared to other transformations, rendering the distribution closest to a normal distribution. However, models with inverse transformed RT data were also fitted for parity with the speeded pronunciation data analyses in Chapter 6; the estimated effects from these models can be found in Appendix H.

R^2 cannot simply be generalised to the context of mixed-effects modelling with multiple random effects, and thus, multiple sources of error or residual variances, which makes it challenging to calculate R^2 via the traditional calculation (see Nakagawa & Schielzeth, 2013). A pseudo-R^2 is instead calculated to provide an absolute value for the goodness-of-fit of a mixed-effects model and a summary statistic that describes the amount of variance explained by the model. Pseudo-R^2s for all mixed-effects models in this chapter and subsequent chapters were calculated using the 'r.squaredGLMM' function in the 'MuMIn' package (Barton, 2017) that is based on R code by Nakagawa and Schielzeth (2013) for models with random intercepts and by Johnson (2014) for an extension to models with random slopes. The conditional pseudo-R^2 represents the variance explained by the entire model (both fixed and random effects) and is calculated as follows, where σ_f^2 is the variance of fixed effect components, σ_α^2 is the variance of random effect components, and σ_ε^2 is the observation-level variance:

$$R^2_{(c)} = \frac{\sigma_f^2 + \sigma_\alpha^2}{\sigma_f^2 + \sigma_\alpha^2 + \sigma_\varepsilon^2}$$

The marginal pseudo-R^2 represents the variance explained by the fixed effects in the model and is calculated as follows:

$$R^2_{(m)} = \frac{\sigma_f^2}{\sigma_f^2 + \sigma_\alpha^2 + \sigma_\varepsilon^2}$$

5.7.3.1 Response Latencies

Fitting the random effects structure. The mixed effects model used in analysing response latencies included random intercepts for both participant and stimuli, as well as random slopes for each principal component (length, frequency, phonotactic probability, root, neighbourhood density, and Levenshtein distance) varying by participant, using a maximal random effects structure as recommended by Barr et al. (2013). This is because we expected these effects to vary across individuals. Furthermore, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for each effect by participant into the model improved the model fit and accounted for a significant amount of the random variance, $\chi^2(27) = 284.13$, $p < .001$.

Covariates. For this analysis, the following covariates were standardised using z-scores: age, trial order number, and display refresh rate. Both onset and sex were sum coded so that the analysis would show effects on RTs averaged across onset and sex respectively.

Fixed effects. In terms of main effects, the model included all six principal components (length, frequency, phonotactic probability, root, neighbourhood density, and Levenshtein distance), as well as *z*-scored memorisation and *z*-scored vocabulary knowledge. In terms of interactions, the model included the three-way interactions between memorisation, vocabulary knowledge, and each principal component, as well as their subsumed two-way interactions, i.e., memorisation × vocabulary knowledge, memorisation × principal component, and vocabulary knowledge × principal component.

A linear mixed effects regression analysis was then conducted using the 'lmer()' function in the 'lmerTest' package (Kuznetsova et al., 2017) and with maximum likelihood, running the model as follows:

```
Model_LDT <- lmer(log(RT) ~ (1 + Length + Freq + N + LD + Root +
    PP|participant) + (1|stimuli)
    + Onset + Trial Order Number + Display Refresh Rate + Sex + Age
    + MemScore + QVT
    + Length + Freq + N + PP + LD + Root
    + MemScore:QVT
    + MemScore:Length + MemScore:Freq + MemScore:N + MemScore:PP
    + MemScore:LD + MemScore:Root
    + QVT:Length + QVT:Freq + QVT:N + QVT:PP + QVT:LD + QVT:Root
    + MemScore:QVT:Length + MemScore:QVT:Freq + MemScore:QVT:N
    + MemScore:QVT:PP + MemScore:QVT:LD + MemScore:QVT:Root,
    data = all, REML = F, control=lmerControl(optCtrl=list(maxfun=1e6)))
```

In terms of computing *p*-values in linear mixed-effects modelling, Baayen et al. (2008) recommended using Monte Carlo Markov Chain (MCMC) simulation; however, as this is currently not possible in *lmerTest* for models with correlation parameters, simulations by Barr et al. (2013) suggest that the likelihood-ratio test is the best approach for obtaining *p*-values in the analyses of typically-sized psycholinguistic datasets where the number of observations usually far outnumbers the number of model parameters, as is the case for the current study. Therefore, *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. This method of computing *p*-values was also used in subsequent regression analyses in this study as well as in other chapters.

5.7.3.2 Accuracy

Fitting the random effects structure. Similar to response latencies, the mixed effects model for accuracy included random intercepts for both participant and stimuli, as well as random slopes for each principal component varying by participant, using a maximal random effects structure. This is because we expected these effects to vary across individuals. Furthermore, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for each effect by participant into the model improved the model fit and accounted for a significant amount of the random variance, $\chi^2(27) = 123.46$, $p < .001$.

The same covariates and fixed effects used in the previous model for RTs were also used in the fitting of this model, except for onsets and age, which were removed as they were not significant (onsets: $\chi^2(27) = 37.199$, *ns.;* age: $\chi^2(27) = .305$, *ns.*). However, as the dependent variable is a binary response, a mixed effects logistic regression analysis was conducted instead using the ‘glmer()’ function in the lme4 package (D. M. Bates, Maechler, Bolker, & Walker, 2015) and a binomial distribution was selected, running the model as follows:

```
Model_Accuracy <- glmer(Accuracy ~ (1 + Length + Freq + N + LD + Root +
        PP|participant) + (1|stimuli)
        + Trial Order Number + Display Refresh Rate + Sex
        + MemScore + QVT
        + Length + Freq + N + PP + LD + Root
        + MemScore:QVT
        + MemScore:Length + MemScore:Freq + MemScore:N + MemScore:PP
        + MemScore:LD + MemScore:Root
        + QVT:Length + QVT:Freq + QVT:N + QVT:PP + QVT:LD + QVT:Root
        + MemScore:QVT:Length + MemScore:QVT:Freq + MemScore:QVT:N
        + MemScore:QVT:PP + MemScore:QVT:LD + MemScore:QVT:Root,
        data = all_accuracy, control=glmerControl(optimizer="bobyqa",
        optCtrl=list(maxfun=1e6)), family="binomial")
```

5.7.4 Mixed Effects Regression Analyses (Lexicality)

The following analyses test whether participants' reaction times and accuracy were influenced by lexicality (whether a word is a real word or nonword) and whether such lexicality effects were influenced by amount of memorisation, Qur'an vocabulary knowledge, or both. Cleaned RT data for both word and nonword targets were therefore used in the analyses. All data were used for accuracy analyses. Similar to the previous analyses on word targets only, mixed effects models using maximum likelihood were fitted with log-transformed RT and accuracy as dependent variables separately.

5.7.4.1 Response Latencies

Fitting the random effects structure. The mixed effects model used in analysing response latencies included random intercepts for both participant and stimuli, as well as random slopes for lexicality varying by participant, using a maximal random effects structure. This is because we expected lexicality effects to vary across individuals. Furthermore, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for lexicality by participant into the model improved the model fit and accounted for a significant amount of the random variance, $\chi^2(2) = 653.90$, $p < .001$.

Covariates. For this analysis, the following covariates were standardised using *z*-scores: age, trial order number, and display refresh rate. Sex was sum coded so that the analysis would show effects on accuracy averaged across sex.

Unlike in the previous analysis, onsets and other principal components were excluded as covariates from this analysis as the focus is on target type (word vs. nonword) and both conditions were already matched for onsets and other variables that make up the principal components, such as number of characters, phones, syllables, etc.

Fixed effects. In terms of main effects, the model included lexicality as well as *z*-scored memorisation and *z*-scored vocabulary knowledge. In terms of interactions, the model included the three-way interaction between memorisation, vocabulary knowledge, and lexicality, as well as its subsumed two-way interactions, i.e., memorisation × vocabulary knowledge, memorisation × lexicality, and vocabulary knowledge × lexicality.

A linear mixed effects regression analysis was then conducted using the 'lmer()' function in the 'lmerTest' package (Kuznetsova et al., 2017) and using maximum likelihood, running the model as follows:

```
Model_lexicality <- lmer(log(RT) ~ (1 + TargetType|participant) + (1|stimuli) +
Trial Order Number + Display Refresh Rate + Sex + Age +
MemScore*QVT*TargetType, data=lexicality, REML = F)
```

5.7.4.2 Accuracy

Fitting the random effects structure. Similar to response latencies, the mixed effects model for accuracy included random intercepts for both participant and stimuli, as well as random slopes for lexicality varying by participant, using a maximal random effects structure. This is because we expected lexicality effects to vary across individuals. Furthermore, a likelihood-ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for lexicality by participant into the model improved the model fit and accounted for a significant amount of the random variance, $\chi^2(2) = 547.01$, $p < .001$.

The same covariates and fixed effects used in the previous model for RTs were also used in the fitting of this model, except age as it was not significant, $\chi^2(2) = .167$, *ns*. However, as the dependent variable is a binary response, a mixed effects logistic regression analysis was conducted instead using the ‘glmer()’ function in the lme4 package (D. M. Bates et al., 2015) and a binomial distribution was selected, running the model as follows:

```
Model_lexicality_accuracy <- glmer(accuracy ~ (1 + TargetType|participant)
    + (1|stimuli) + Trial Order Number + Display Refresh Rate + Sex +
    MemScore*QVT*TargetType, data=lexicality_accuracy,
    control=glmerControl(optimizer="optimx", optCtrl=list(method="nlminb")),
    family="binomial")
```

5.8 Results

In this section, in the case of significant two-way interactions with corresponding significant three-way interactions, I will be focusing on interpreting the three-way interactions instead as two-way interactions need to be interpreted in the context of three-way interactions if the latter are significant.

5.8.1 Word Targets

5.8.1.1 Response Latencies

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in this model described 55.74% of the variance in RTs; random effects described 33.69% of the variance in RTs while fixed effects described 22.05% of the variance in RTs. Table 5-5 presents the estimated standardised coefficients for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model are described in the following sub-sections.

Covariates. As seen in Table 5-5, the following covariates were significant: trial order number, refresh rate, sex, and age. Participants were more likely to be faster as they progressed through the lexical decision. They were also more likely to be slower when using a computer with a slower display refresh rate. There was also a main effect of sex, with females being more likely to be faster than males. Last, older participants were more likely to be slower in the task.

Onsets. It is worth noting that unlike in English (e.g. Balota et al., 2004) where onsets did not significantly affect lexical decision latencies, onsets on the whole significantly affected lexical decision latencies for our participants, $\chi^2(27) = 48.357$, $p < .01$. However, this is similar to the effect of onsets on latencies seen in Malay lexical decision, where onsets significantly accounted for 27.7% of the variance in latencies (Binte Faizal, 2009), which was explained due to possible affix stripping processes taking place during lexical decision. Figure 5-3 presents the predicted RT for each onset. This will be further discussed later.

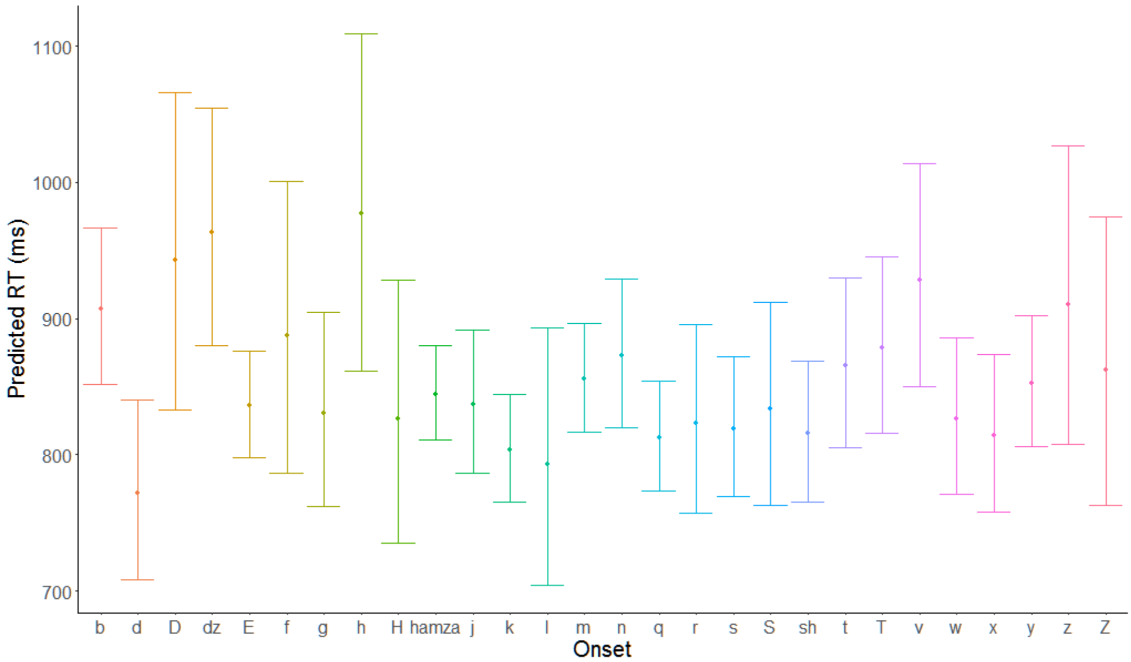

Figure 5-3. Predicted RT (ms) for each onset based on full linear mixed model for lexical decision. Error bars are based on 95% confidence intervals.

Individual-level predictors. Results revealed significant main effects of Qur'an vocabulary knowledge ($\beta = -.113$, $SE = .015$, $\chi^2(1) = 48.498$, $p < .001$) and amount of Qur'an memorisation ($\beta = .030$, $SE = .014$, $\chi^2(1) = 7.098$, $p < .05$) on RTs after controlling for all other variables. Participants with more Qur'an vocabulary knowledge were more likely to respond faster to word targets in lexical decision than participants with less Qur'an vocabulary knowledge while participants who have memorised more of the Qur'an were more likely to respond slower to word targets in lexical decision than participants who have memorised less of the Qur'an. These main effects will be further interpreted in the context of their two-way and three-way interactions with each item-level predictor.

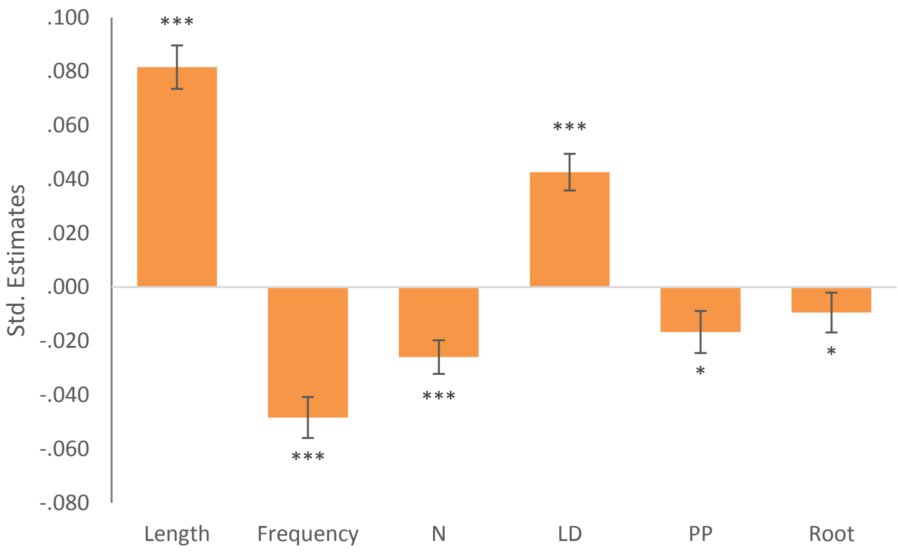

Figure 5-4. Bars represent standardised regression coefficients across item-level predictors for RTs in lexical decision in the full model. Error bars are based on standard error. Asterisks denote significance at the following levels: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Length. After controlling for onsets and other covariates, the principal component of length (number of characters, number of phones, and number of syllables) was positively associated with lexical decision latencies, $\beta = .082$, *SE* = .008, $\chi^2(1) = 76.290$, $p < .001$; participants were slower in responding to longer word targets than shorter word targets. Figure 5-4 also indicated that the predictive power of word length in lexical decision latencies was the largest compared to other lexical variables, especially frequency. Greater length effects compared to frequency effects suggest a greater reliance on the nonlexical pathway in visual word processing; this will be further discussed later.

Although there was no significant two-way interaction between amount of Qur'an memorisation and length, $\beta = -.001$, $SE = .003$, $\chi^2(1) = .158$, *ns.*, the two-way interaction between Qur'an vocabulary knowledge and length was significant, $\beta = -.012$, $SE = .003$, $\chi^2(1) = 20.616$, $p < .001$. Plotting the simple slopes of the two-way interaction showed that participants with more Qur'an vocabulary knowledge were less likely to be influenced by length effects when responding to word targets in lexical decision than participants with less Qur'an vocabulary knowledge (see Figure 5-6 where Z(Memorisation) = 0). This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller length effects in inhibiting RTs. Although the plotted three-way interaction between memorisation, vocabulary knowledge, and length showed an interesting trend in which the increase in length effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 5-5 and Figure 5-6), it was not significant, $\beta = -.004$, $SE = .003$, $\chi^2(1) = 1.714$, *ns*.

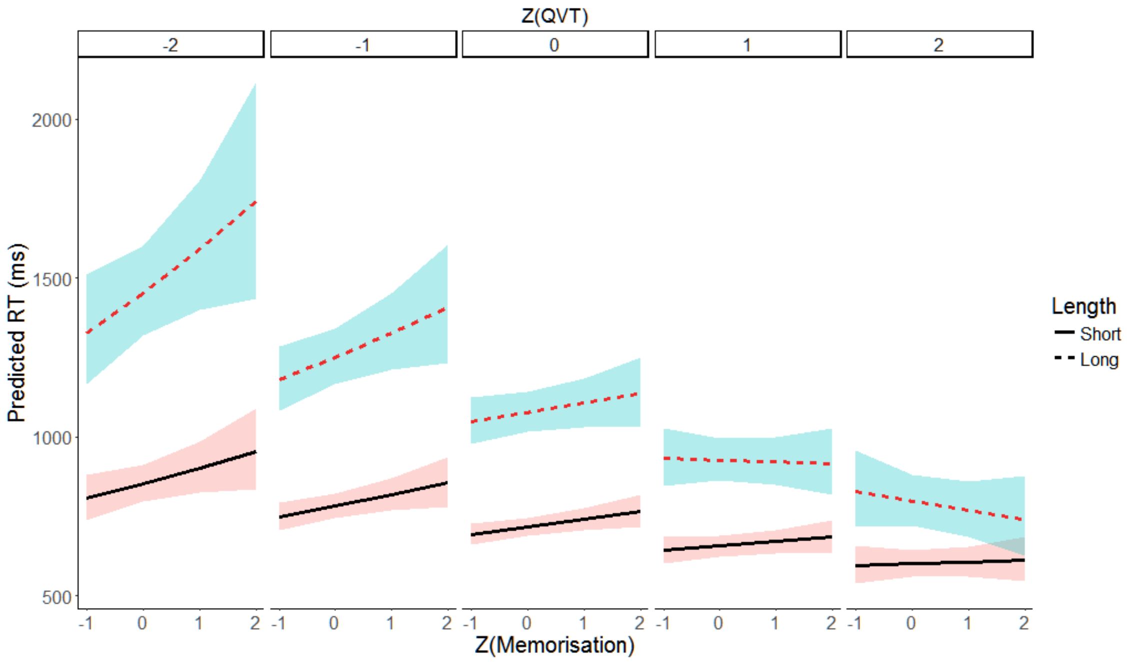

Figure 5-5. Memorisation × Vocabulary Knowledge × Length interaction: Predicted RTs for short (1.5 *SD* below the mean) and long (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

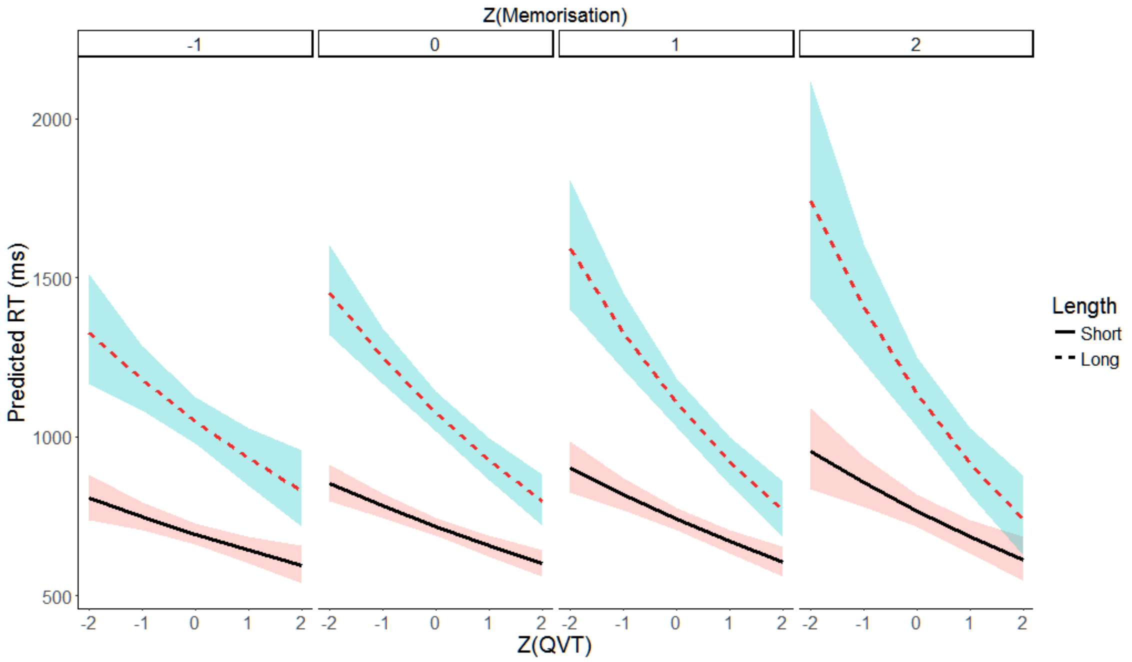

Figure 5-6. Memorisation × Vocabulary Knowledge × Length interaction: Predicted RTs for short (1.5 *SD* below the mean) and long (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of Qur'anic vocabulary knowledge (QVT) and memorisation *z*-scores. Bands are based on 95% confidence intervals.

Frequency. After controlling for onsets and other covariates, the principal component of item frequency (orthographic and phonetic) significantly predicted lexical decision RTs, with shorter RTs for more frequent word targets, β = -.048, *SE* = .008, $\chi^2(1)$ = 35.440, p < .001. As mentioned earlier, in terms of the predictive power of the variables in RTs, Figure 5-4 indicated length had the largest predictive power compared to other components, especially frequency. Although greater length effects compared to frequency effects indicate a greater reliance on the nonlexical pathway in language processing, the presence of frequency effects as the second largest predictor in RTs suggests that participants do not rely solely on the nonlexical pathway when processing Qur'anic Arabic words visually; both lexical and nonlexical pathways are in use concurrently, as suggested by the dual-route model. This will be further discussed later.

The two-way interaction between vocabulary knowledge and frequency was not significant, β = .0004, *SE* = .002, $\chi^2(1)$ = .040, *ns.*, whereas the two-way interaction between memorisation and frequency was marginally significant, β = -.004, SE = .002, $\chi^2(1) = 3.648$, $p < .1$. This marginally significant interaction indicated that more memorisation (but not more vocabulary knowledge) was related to larger frequency effects in facilitating RTs (see Figure 5-7 where Z(QVT) = 0). However, this two-way interaction must be further interpreted in the context of the significant three-way interaction among memorisation, vocabulary knowledge, and frequency, β = .007, SE = .002, $\chi^2(1) = 9.367$, $p < .01$.

Plotting the simple slopes of the three-way interaction shows that the increase in frequency effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge, to the extent that if one had very high vocabulary knowledge, one was not as influenced by frequency effects when responding to word targets across all levels of memorisation (see Figure 5-7). Furthermore, as can be seen in Figure 5-7, participants with less memorisation and less vocabulary knowledge [Z(Memorisation) = -1, Z(QVT) = -2] were not influenced by frequency when responding to word targets, i.e., whether or not a word occurred in the corpus more frequently did not influence the speed at which it was responded to by these participants. However, participants having that low level of vocabulary knowledge but who have memorised more of the Qur'an had the largest facilitatory frequency effect on RTs, i.e., they were the most likely to respond faster to words that occurred more frequently than to words that occurred less frequently.

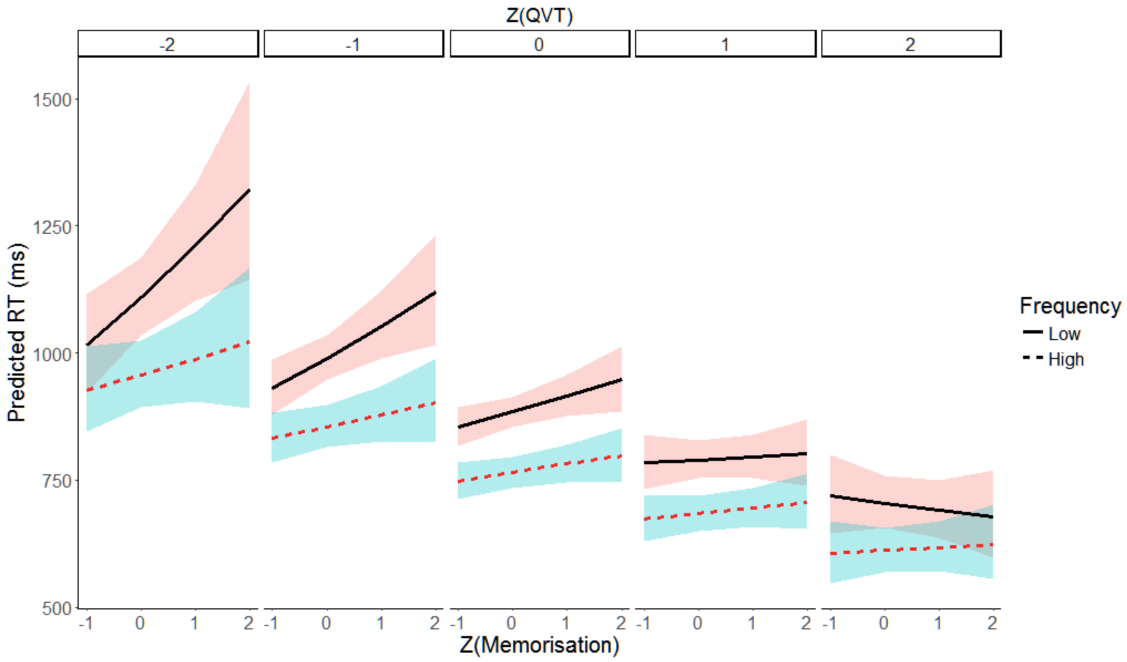

Figure 5-7. Memorisation × Vocabulary Knowledge × Frequency interaction: Predicted RTs for low (1.5 *SD* below the mean) and high frequency (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Neighbourhood density. After controlling for all other variables, the principal component of neighbourhood density (orthographic and phonological) significantly facilitated lexical decision latencies, β = -.026, *SE* = .006, $\chi^2(1)$ = 16.201, p < .001; the more orthographic and phonological neighbours a word target has, the faster it took to be recognised by participants. In terms of its predictive power, neighbourhood density was a weaker predictor of lexical decision latencies than its Levenshtein distance counterpart. This will be further discussed later.

Although there was no significant two-way interaction between amount of Qur'an memorisation and neighbourhood density, β = -.001, *SE* = .002, $\chi^2(1)$ = .478, *ns.*, the two-way interaction between Qur'an vocabulary knowledge and neighbourhood density was significant, β = .004, *SE* = .002, $\chi^2(1)$ = 4.741, p < .05. Plotting the simple slopes of the two-way interaction showed that participants with more Qur'an vocabulary knowledge were less likely to be influenced by neighbourhood effects when responding to word targets in lexical decision than participants with less Qur'an vocabulary knowledge [see Figure 5-9 where Z(Memorisation) = 0]. This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller neighbourhood effects in facilitating RTs. Although the plotted three-way interaction between memorisation, vocabulary knowledge, and neighbourhood density showed an interesting trend in which the increase in neighbourhood effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 5-8 and Figure 5-9), it was not significant, $\beta = .003$, $SE = .002$, $\chi^2(1) = 2.352$, *ns*.

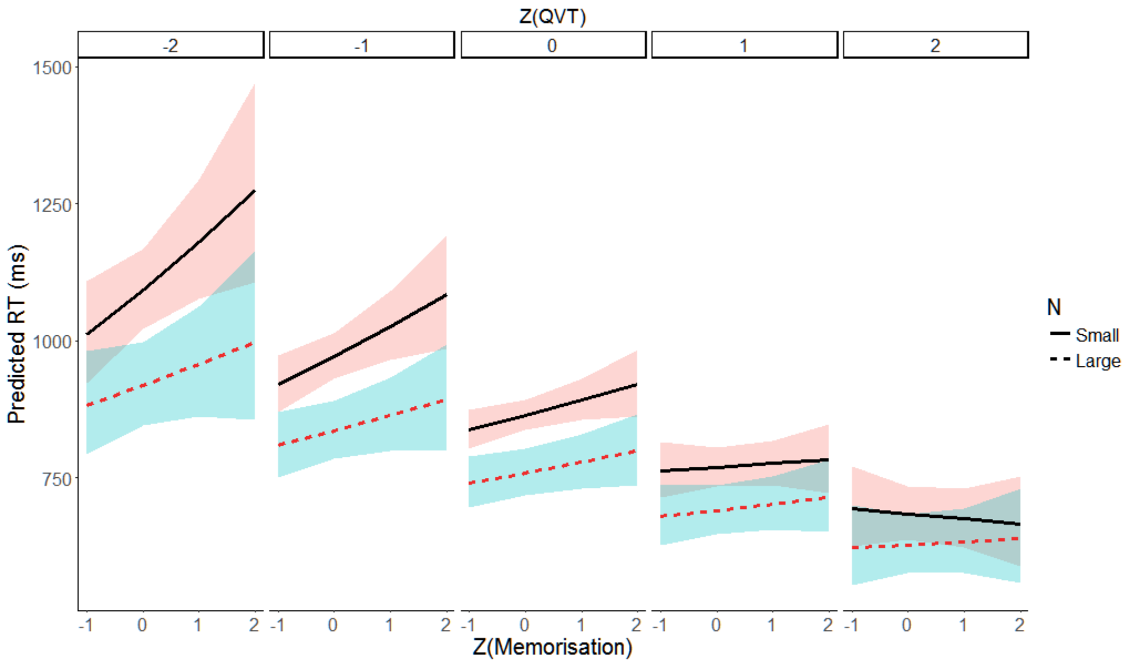

Figure 5-8. Memorisation × Vocabulary Knowledge × Neighbourhood Density interaction: Predicted RTs for small N (1.5 *SD* below the mean) and large N (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

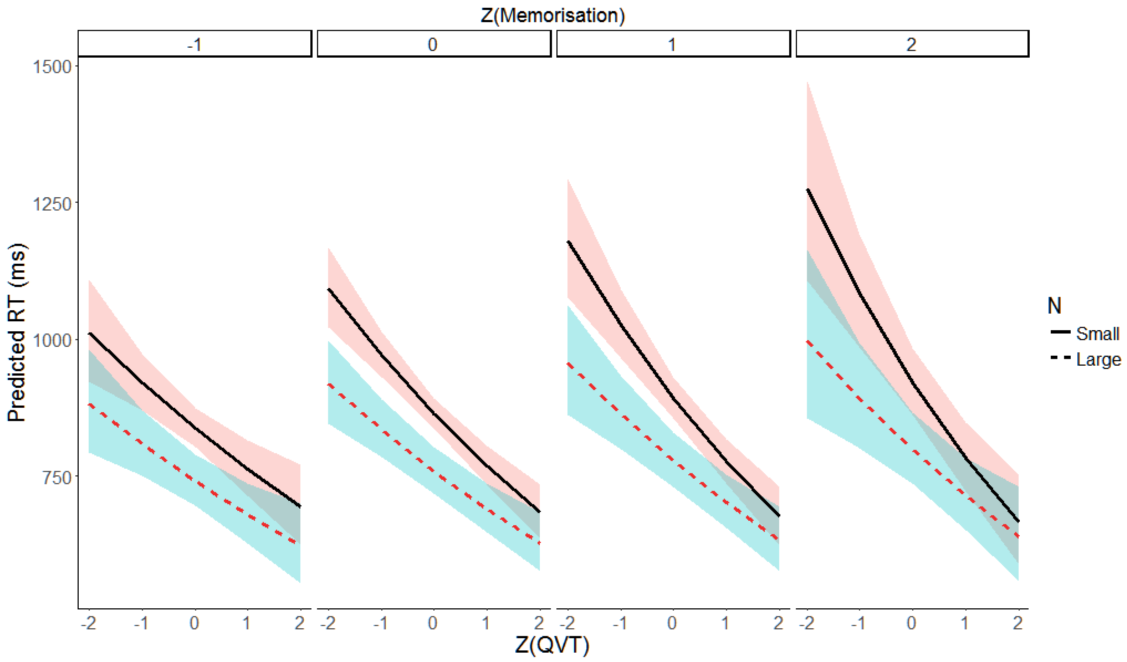

Figure 5-9. Memorisation × Vocabulary Knowledge × Neighbourhood Density interaction: Predicted RTs for small N (1.5 *SD* below the mean) and large N (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of Qur'anic vocabulary knowledge (QVT) and memorisation z-scores. Bands are based on 95% confidence intervals.

Levenshtein distance. Despite being a relatively new measure, the group of distance variables (OLD20 and PLD20) together significantly predicted lexical decision latencies, β = .043, *SE* = .007, $\chi^2(1)$ = 34.174, p < .001, after controlling all other variables. Word targets with greater LD20 had longer latencies, i.e., words that are orthographically or phonologically more distinct were recognised slower. Likewise, word targets with smaller LD20, or word targets that have neighbours that are closer to them, were recognised faster. Levenshtein distance was also a stronger predictor of lexical decision latencies than neighbourhood density, which speaks to Levenshtein distance being a better measure of orthographic or phonological similarity than Coltheart's N (see Yap & Balota, 2009; Yap et al., 2010; Yarkoni et al., 2008), especially for Arabic, which is an agglutinative language, and thus, has naturally longer words. This will be further discussed later.

The two-way interaction between vocabulary knowledge and Levenshtein distance was not significant, β = .003, *SE* = .002, $\chi^2(1)$ = 1.370, *ns.*, while the two-way interaction between memorisation and Levenshtein distance was marginally significant, $\beta = .004$, $SE = .002$, $\chi^2(1) = 3.244$, $p < .1$. This marginally significant interaction indicated that more memorisation (but not more vocabulary knowledge) was related to larger Levenshtein distance effects in inhibiting RTs (see Figure 5-10 where Z(QVT) = 0). However, this two-way interaction must be further interpreted in the context of the significant three-way interaction among memorisation, vocabulary knowledge, and Levenshtein distance, $\beta = -.003$, $SE = .002$, $\chi^2(1) = 4.606$, $p < .05$.

Plotting the simple slopes of the three-way interaction shows that the increase in Levenshtein distance effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge, to the extent that if one had very high vocabulary knowledge, one was not as influenced by Levenshtein distance effects when responding to word targets across all levels of memorisation (see Figure 5-10). Furthermore, as can be seen in Figure 5-10, participants with less memorisation and less vocabulary knowledge [Z(Memorisation) = -1, Z(QVT) = -2] were not influenced by Levenshtein distance when responding to word targets, i.e., whether or not a word has closer neighbours does not influence the speed at which it was responded to by these participants. However, participants having that low level of vocabulary knowledge but who have memorised more of the Qur'an had the largest inhibitory Levenshtein distance effect on RTs, i.e., they were the most likely to respond slower to words that have further neighbours than to words that have closer neighbours.

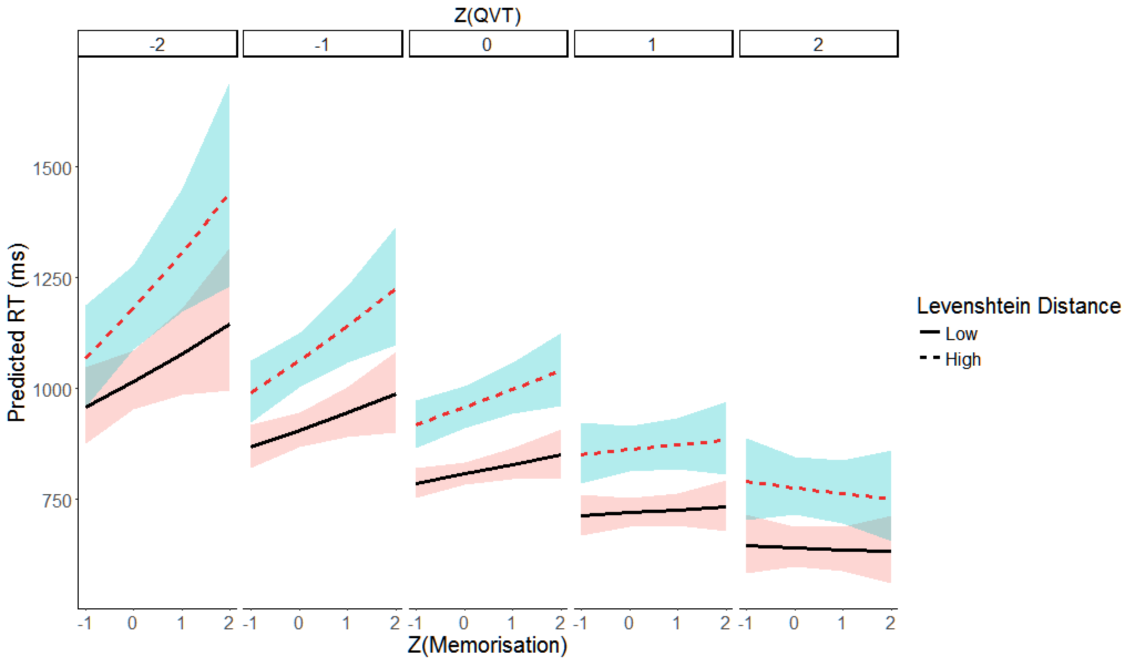

Figure 5-10. Memorisation × Vocabulary Knowledge × Levenshtein Distance interaction: Predicted RTs for low (1.5 *SD* below the mean) and high Levenshtein Distance (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Phonotactic probability. After controlling for all other variables, the principal component of phonotactic probability (positional segment average and biphone average) significantly facilitated lexical decision latencies, β = -.017, *SE* = .008, $\chi^2(1)$ = 4.454, $p < .05$. Participants were more likely to respond faster to targets with higher phonotactic probability than to targets with lower phonotactic probability.

Although there was no significant two-way interaction between amount of Qur'an memorisation and phonotactic probability, β = .002, *SE* = .002, $\chi^2(1)$ = 1.628, *ns.*, the two-way interaction between Qur'an vocabulary knowledge and phonotactic probability was significant, β = .005, *SE* = .002, $\chi^2(1)$ = 6.155, $p <$ .05. Plotting the simple slopes of the two-way interaction showed that participants with more Qur'an vocabulary knowledge were less likely to be influenced by facilitatory phonotactic probability effects when responding to word targets in lexical decision than participants with less Qur'an vocabulary knowledge [see Figure 5-12 where Z(Memorisation) = 0]. This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller phonotactic probability effects in facilitating RTs. Although the plotted three-way interaction between memorisation, vocabulary knowledge, and phonotactic probability showed an interesting trend in which the decrease in phonotactic probability effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 5-11), it was not significant, $\beta = -.001$, $SE = .002$, $\chi^2(1) = 2.751$, *ns*.

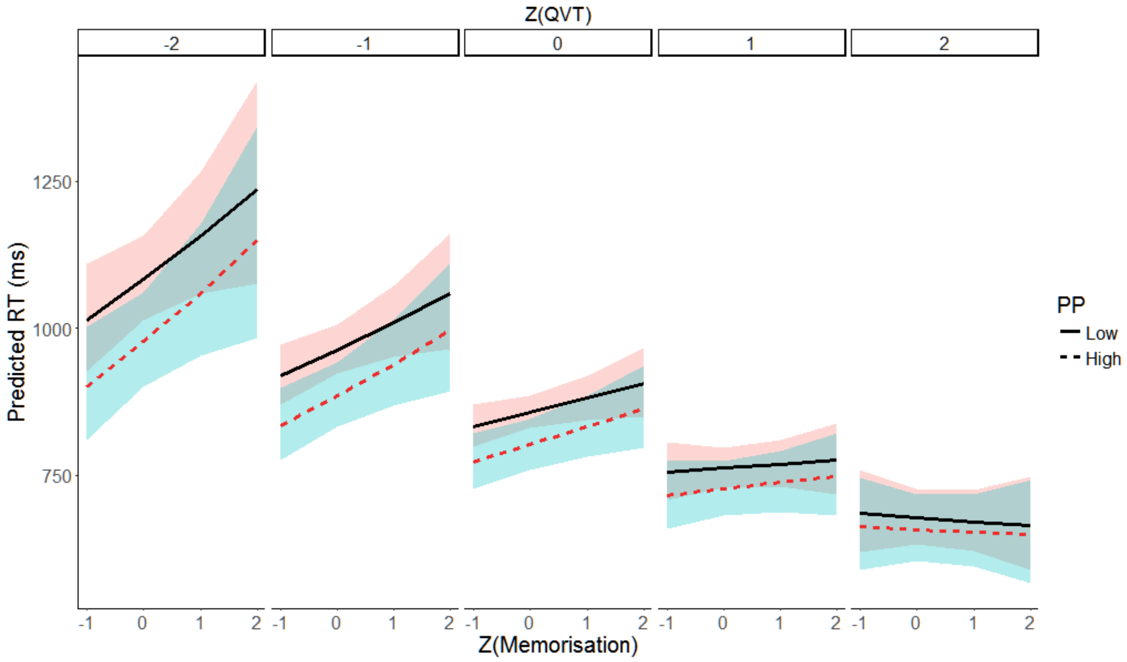

Figure 5-11. Memorisation × Vocabulary Knowledge × Phonotactic Probability interaction: Predicted RTs for word targets with low (1.5 *SD* below the mean) and high PP (1.5 *SD* above the mean) based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

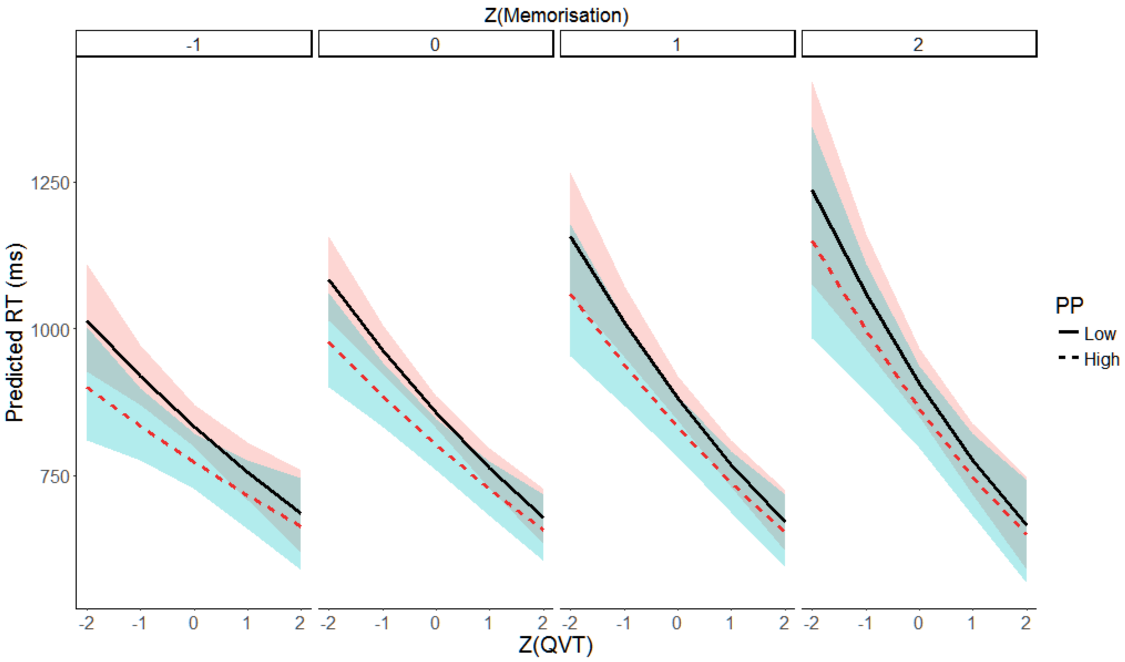

Figure 5-12. Memorisation × Vocabulary Knowledge × Phonotactic Probability interaction: Predicted RTs for word targets with low (1.5 *SD* below the mean) and high PP (1.5 *SD* above the mean) based on the full linear mixed effects model. Results are presented as a function of Qur'anic vocabulary knowledge (QVT) and memorisation *z*-scores. Bands are based on 95% confidence intervals.

Root. After controlling for all other variables, the principal component of root (root frequency and root family size) significantly facilitated lexical decision latencies, β = -.009, *SE* = .007, $\chi^2(1)$ = 4.197, $p < .05$. Participants were more likely to respond faster to targets with higher root frequency and larger root family size than to targets with lower root frequency and smaller root family size. More importantly, amongst all other principal components, root was the weakest predictor of lexical decision latencies, especially when compared to neighbourhood density or Levenshtein distance. This will be further discussed later.

Although there was no significant two-way interaction between amount of Qur'an memorisation and root, β = -.001, *SE* = .002, $\chi^2(1)$ = .494, *ns.*, the two-way interaction between Qur'an vocabulary knowledge and root was significant, β = -.003, *SE* = .002, $\chi^2(1)$ = 4.837, $p < .05$. Plotting the simple slopes of the two-way interaction showed that participants with more Qur'an vocabulary knowledge were more likely to be influenced by facilitatory root effects when responding to word targets in lexical decision than participants with less Qur'an vocabulary knowledge [see Figure 5-14 where Z(Memorisation) = 0]. This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to larger root effects in facilitating RTs. Although the plotted three-way interaction between memorisation, vocabulary knowledge, and root showed an interesting trend in which the increase in root effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 5-13 and Figure 5-14), it was not significant, β = .003, *SE* = .002, $\chi^2(1)$ = 1.676, *ns*.

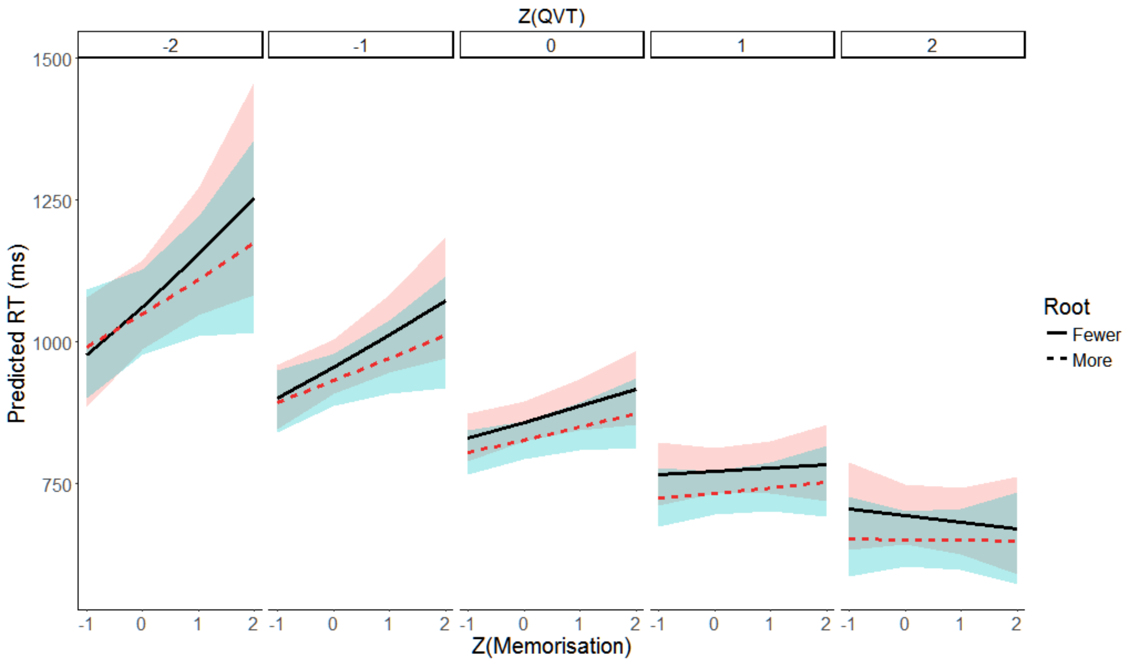

Figure 5-13. Memorisation × Vocabulary Knowledge × Root interaction: Predicted RTs for word targets with fewer (1.5 *SD* below the mean) and more roots (1.5 *SD* above the mean) based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

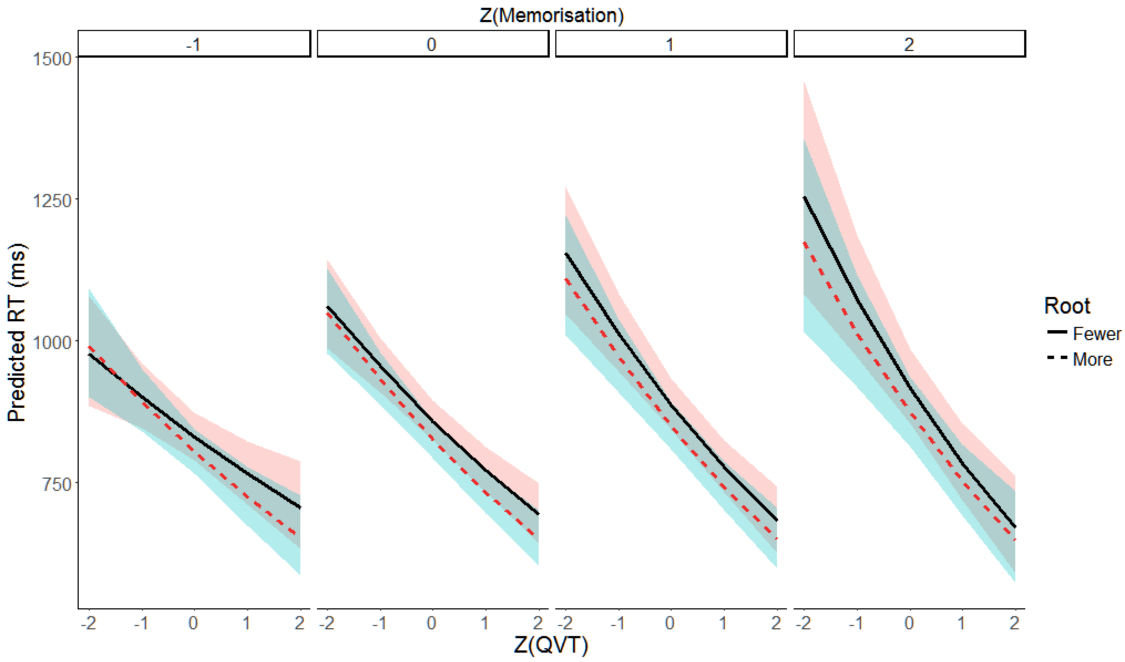

Figure 5-14. Memorisation × Vocabulary Knowledge × Root interaction: Predicted RTs for word targets with fewer (1.5 *SD* below the mean) and more roots (1.5 *SD* above the mean) based on the full linear mixed effects model. Results are presented as a function of Qur'anic vocabulary knowledge (QVT) and memorisation *z*-scores. Bands are based on 95% confidence intervals.

5.8.1.2 Accuracy

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in this model described 37.38% of the variance in accuracy; random effects described 16.65% of the variance in accuracy while fixed effects described 20.73% of the variance in accuracy. Table 5-6 presents the estimated standardised coefficients for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model is described in the following sub-sections.

Covariates. As seen in Table 5-6, the following covariates were significant: trial order number, refresh rate, and sex. Participants were less likely to be accurate as they progressed through the lexical decision. They were also less likely to be accurate when using a computer with a slower display refresh rate. Females were more likely to be accurate than males.

Onsets. Unlike in lexical decision latencies, onsets on the whole did not significantly affect lexical decision accuracy for participants, $\chi^2(27) = 29.016$, *ns.*, with the likelihood-ratio test only reaching marginal significance. Figure 5-15 presents the predicted probability of accuracy for each onset.

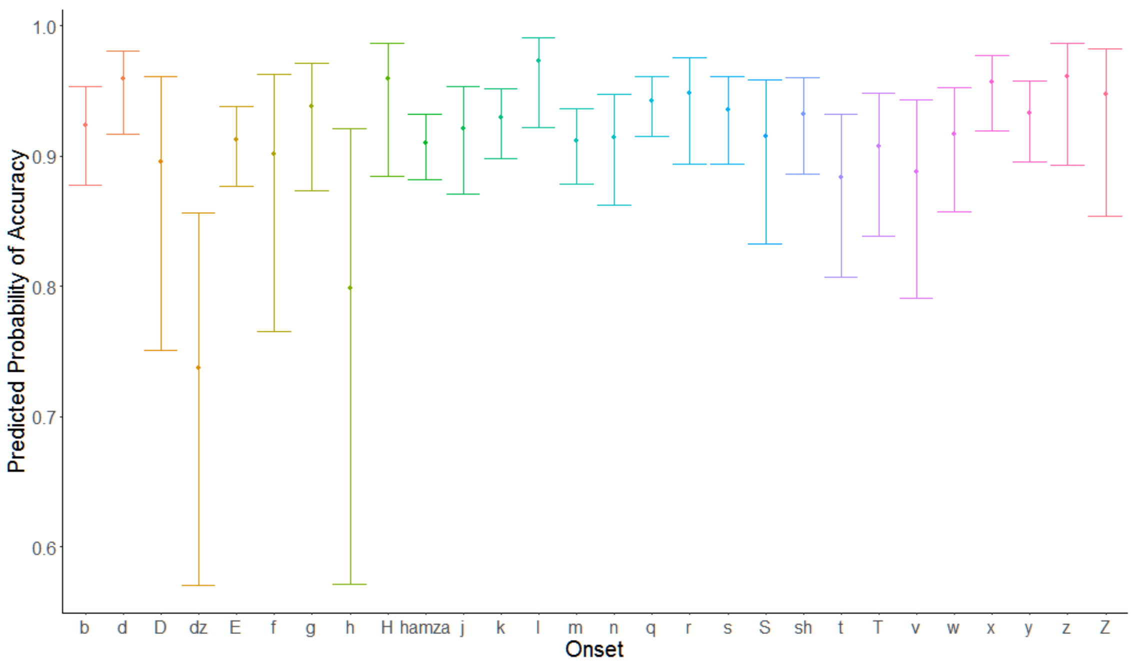

Figure 5-15. Predicted probability of accuracy for each onset based on the full generalized linear mixed model. Error bars are based on 95% confidence intervals.

Individual-level predictors. Results revealed a significant main effect of Qur'an vocabulary knowledge ($\beta = .540$, $SE = .048$, $\chi^2(1) = 109.260$, $p < .001$) but not amount of Qur'an memorisation, which was only marginally significant ($\beta = .079$, $SE = .046$, $\chi^2(1) = 2.916$, $p = .088$) on lexical decision accuracy after controlling for all other variables. Participants with more Qur'an vocabulary knowledge were more likely to have more correct responses in lexical decision; for each standardised unit increase in Qur'an vocabulary knowledge, the log odds of accuracy increase by .540.

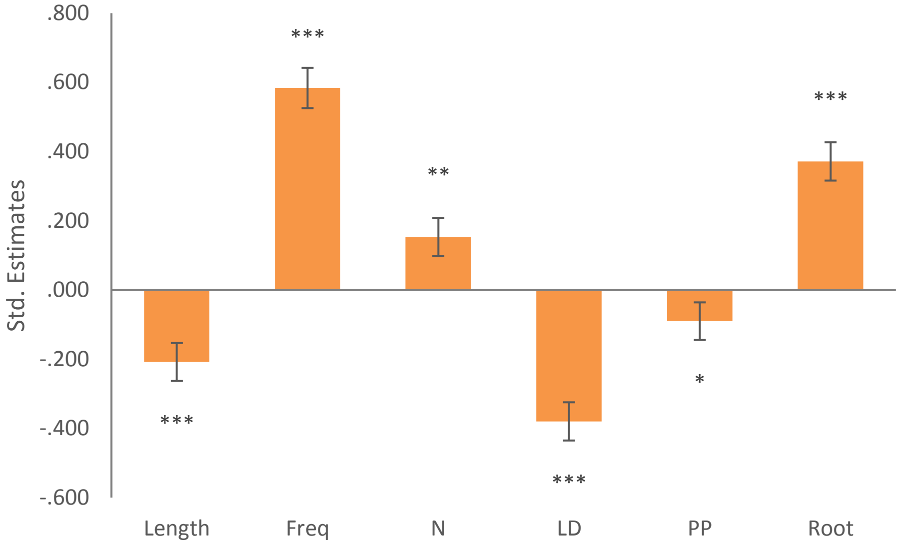

Figure 5-16. Bars represent standardised regression coefficients across item-level predictors for lexical decision accuracy in the preliminary model. Error bars are based on standard error. Asterisks denote significance at the following levels: * = *p* < .05, ** = *p* < .01, *** = *p* < .001.

Length. After controlling for all other variables, the principal component of length (number of characters, number of phones, and number of syllables) significantly predicted lexical decision accuracy, β = -.208, *SE* = .055, $\chi^2(1)$ = 13.705, *p* < .001. Participants were more likely to respond less accurately to longer targets than to shorter targets. As can be seen in Figure 5-16, unlike in lexical decision latencies, length was a poorer predictor of accuracy in lexical decision than frequency was. This will be further discussed later.

Although the two-way interaction between vocabulary knowledge and length was only marginally significant, β = -.041, *SE* = .021, $\chi^2(1)$ = 3.720, *p* = .054, the two-way interaction between memorisation and length was significant, β = .067, *SE* = .021, $\chi^2(1)$ = 9.861, *p* < .01. Plotting the simple slopes of the two-way interaction showed that participants with more memorisation were less likely to be influenced by length effects when identifying word targets accurately in lexical decision than participants with less memorisation (see Figure 5-17 where

Z(QVT) = 0). This interaction indicated that more memorisation (but not more vocabulary knowledge) was related to smaller length effects in lexical decision accuracy. However, this two-way interaction must be interpreted in the context of the significant three-way interaction between memorisation, vocabulary knowledge, and length, $\beta = .056$, $SE = .019$, $\chi^2(1) = 10.239$, $p < .01$.

Plotting the simple slopes of the three-way interaction showed an interesting trend in which the increase in length effects on lexical decision accuracy as memorisation increases was attenuated by the increase in vocabulary knowledge, to the extent that if one had very high vocabulary knowledge and very high amount of memorisation, one was not influenced by length effects when identifying word targets accurately (see Figure 5-17). Having more Qur'an vocabulary knowledge in tandem with more Qur'an memorisation appeared to help participants identify longer word targets more accurately. Furthermore, as can be seen in Figure 5-17, participants with less memorisation and less vocabulary knowledge [Z(Memorisation) = -1, Z(QVT) = -2] were not as influenced by length when identifying word targets accurately, i.e., whether or not a word is short or long did not influence their accuracy as compared to their counterparts with a similarly low level of vocabulary knowledge but who have memorised more of the Qur'an. For these 'HighMemLowQVT' participants, they had the largest length effect on accuracy, i.e., they were the most likely to respond more accurately to shorter word targets than to longer word targets.

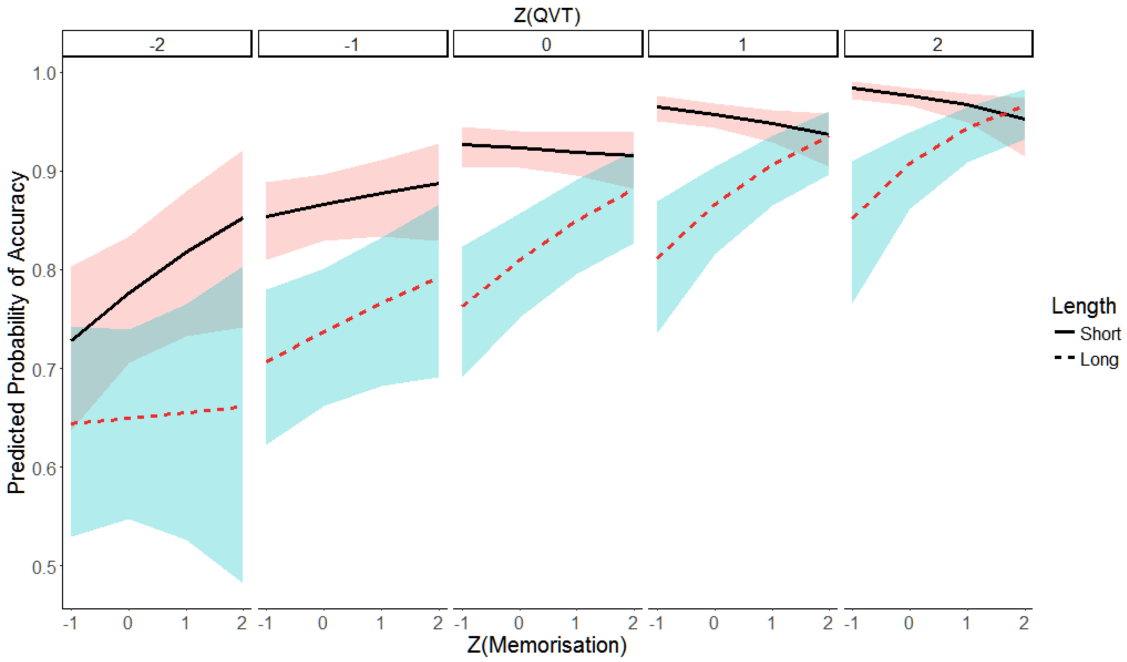

Figure 5-17. Memorisation × Vocabulary Knowledge × Length interaction: Predicted probability of accuracy for short (1.5 *SD* below the mean) and long (1.5 *SD* above the mean) word targets based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Frequency. After controlling for all other variables, the principal component of item frequency (orthographic and phonetic) significantly predicted lexical decision accuracy, β = .584, *SE* = .058, $\chi^2(1)$ = 78.019, p < .001. Participants were more likely to respond more accurately to more frequent targets than to less frequent targets. As can be seen in Figure 5-16, unlike in lexical decision latencies, frequency was the best predictor of accuracy in lexical decision amongst all the other principal components, especially as compared to length. This will be further discussed later.

Although the two-way interaction between memorisation and frequency was not significant, β = .014, *SE* = .027, $\chi^2(1)$ = 1.969, *ns*., the two-way interaction between vocabulary knowledge and frequency was significant, β = .118, *SE* = .028, $\chi^2(1)$ = 17.224, p < .001. Plotting the simple slopes of the two-way interaction showed that participants with more vocabulary knowledge were less likely to be influenced by frequency effects when identifying word targets accurately in lexical decision than participants with less vocabulary knowledge (see Figure 5-18). This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller frequency effects in lexical decision accuracy. However, this two-way interaction must be interpreted in the context of the significant three-way interaction between memorisation, vocabulary knowledge, and frequency, $\beta = .056$, $SE = .019$, $\chi^2(1) = 10.239$, $p < .01$.

However, the three-way interaction between memorisation, vocabulary knowledge, and frequency was significant, $\beta = -.112$, $SE = .024$, $\chi^2(1) = 20.557$, $p < .001$. Plotting the simple slopes of the three-way interaction shows that the increase in frequency effects on accuracy as memorisation increases was attenuated by the increase in vocabulary knowledge, to the extent that if one had very high vocabulary knowledge and very high level of memorisation, one was not influenced by frequency effects when identifying word targets accurately (see Figure 5-18). Having more Qur'an vocabulary knowledge in tandem with more Qur'an memorisation appeared to help participants identify low frequency word targets more accurately. Furthermore, as can be seen in Figure 5-18, participants with less memorisation and less vocabulary knowledge [Z(Memorisation) = -1, Z(QVT) = -2] were not as influenced by frequency when identifying word targets accurately, i.e., whether or not a word occurred in the corpus more frequently did not influence their accuracy as compared to their counterparts with a similarly low level of vocabulary knowledge but who have memorised more of the Qur'an. For these 'HighMemLowQVT' participants, they had the largest frequency effect on accuracy, i.e., they were the most likely to respond more accurately to word targets that occurred more frequently than to words that occurred less frequently.

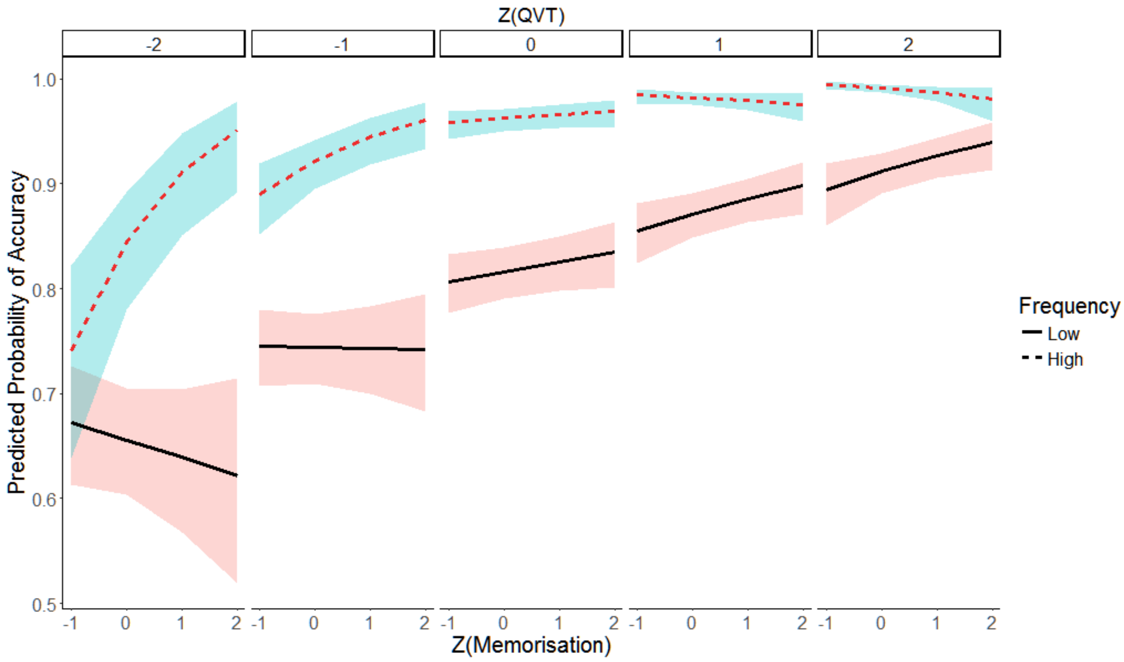

Figure 5-18. Memorisation × Vocabulary Knowledge × Frequency interaction: Predicted probability of accuracy for word targets with low (1.5 *SD* below the mean) and high frequency (1.5 *SD* above the mean) based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Neighbourhood density. After controlling for all other variables, the principal component of neighbourhood density (orthographic and phonological) significantly predicted lexical decision accuracy, β = .154, *SE* = .055, $\chi^2(1)$ = 7.580, $p < .01$. Participants were more likely to respond more accurately to targets with more orthographic and phonological neighbours than to targets with fewer orthographic and phonological neighbours. As can be seen in Figure 5-16, in terms of its predictive power, neighbourhood density was a weaker predictor of lexical decision accuracy than its Levenshtein distance counterpart. This will be further discussed later.

There were no significant two-way interactions between vocabulary knowledge and neighbourhood density, β = .025, *SE* = .021, $\chi^2(1)$ = 1.508, *ns.*, as well as between memorisation and neighbourhood density, β = .004, *SE* = .020, $\chi^2(1)$ = .035, *ns*. The three-way interaction between memorisation, vocabulary knowledge, and neighbourhood density was also not significant, β = -.021, *SE* = .018, $\chi^2(1)$ = 1.397, *ns*.

Levenshtein distance. After controlling for all other variables, the principal component of Levenshtein distance (orthographic and phonological) significantly predicted lexical decision accuracy, $\beta = -.380$, $SE = .055$, $\chi^2(1) = 40.934$, $p < .001$. Participants were more likely to respond less accurately to targets with greater Levenshtein distance, i.e., words with further neighbours, than to targets with smaller Levenshtein distance, i.e., words with closer neighbours. Surprisingly, Levenshtein distance was the second-best predictor of lexical decision accuracy after frequency; although similar to the previous analysis on lexical decision latencies, it was a better predictor of lexical decision accuracy than neighbourhood density was. This will be further discussed later.

Although the two-way interaction between memorisation and Levenshtein distance was not significant, $\beta = -.017$, $SE = .021$, $\chi^2(1) = .631$, *ns*., the two-way interaction between vocabulary knowledge and Levenshtein distance was significant, $\beta = -.057$, $SE = .022$, $\chi^2(1) = 8.327$, $p < .01$. Plotting the simple slopes of the two-way interaction showed that participants with more vocabulary knowledge were less likely to be influenced by Levenshtein distance effects when identifying word targets accurately in lexical decision than participants with less vocabulary knowledge (see Figure 5-19). This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller Levenshtein distance effects in lexical decision accuracy. The three-way interaction between memorisation, vocabulary knowledge, and Levenshtein distance was only marginally significant, $\beta = .022$, $SE = .019$, $\chi^2(1) = 3.012$, $p = .083$.

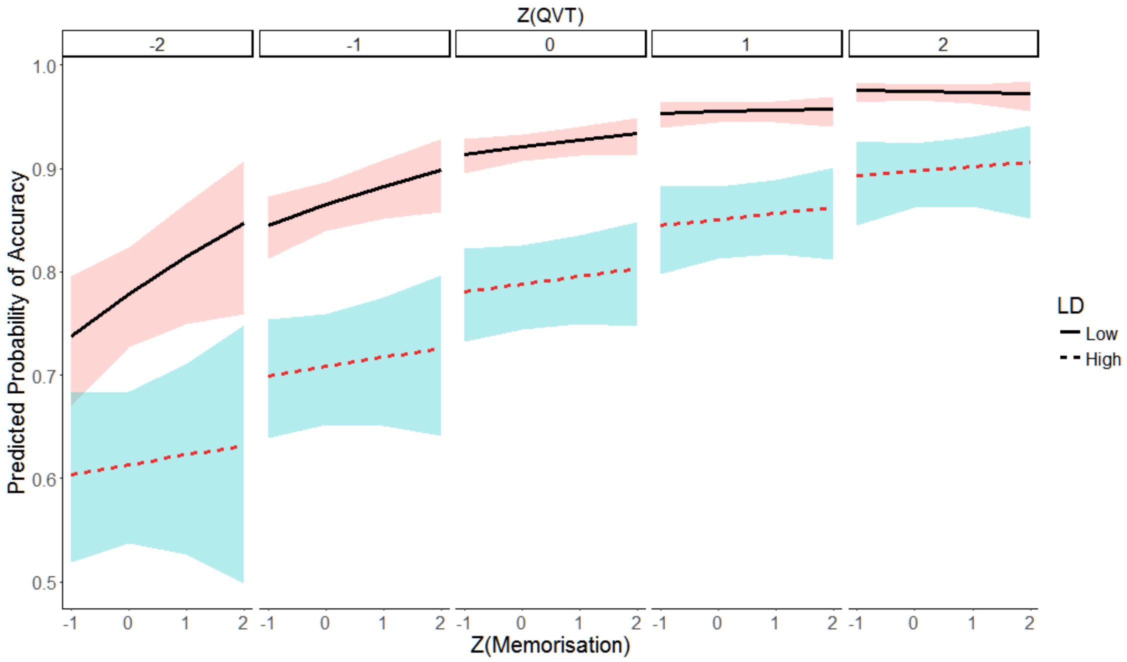

Figure 5-19. Memorisation × Vocabulary Knowledge × Levenshtein Distance interaction: Predicted probability of accuracy for word targets with low (1.5 *SD* below the mean) and high Levenshtein distance (1.5 *SD* above the mean) based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Phonotactic probability. After controlling for all other variables, the principal component of phonotactic probability (positional segment average and biphone average) significantly predicted lexical decision accuracy, β = -.090, *SE* = .054, $\chi^2(1)$ = 4.492, p < .05. Participants were more likely to respond more accurately to targets with lower phonotactic probability than to targets with higher phonotactic probability.

Although the two-way interaction between memorisation and phonotactic probability was not significant, β = .002, *SE* = .018, $\chi^2(1)$ = 1.722, *ns*., the two-way interaction between vocabulary knowledge and frequency was significant, β = -.036, *SE* = .019, $\chi^2(1)$ = 5.251, p < .05. Plotting the simple slopes of the two-way interaction showed that participants with more vocabulary knowledge were more likely to be influenced by phonotactic probability effects when identifying word targets accurately in lexical decision than participants with less vocabulary knowledge (see Figure 5-20). This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to larger phonotactic probability effects in lexical decision accuracy. However, the three-way interaction between memorisation, vocabulary knowledge, and phonotactic probability was only marginally significant, β = .029, *SE* = .017, $\chi^2(1)$ = 2.879, *p* = .090.

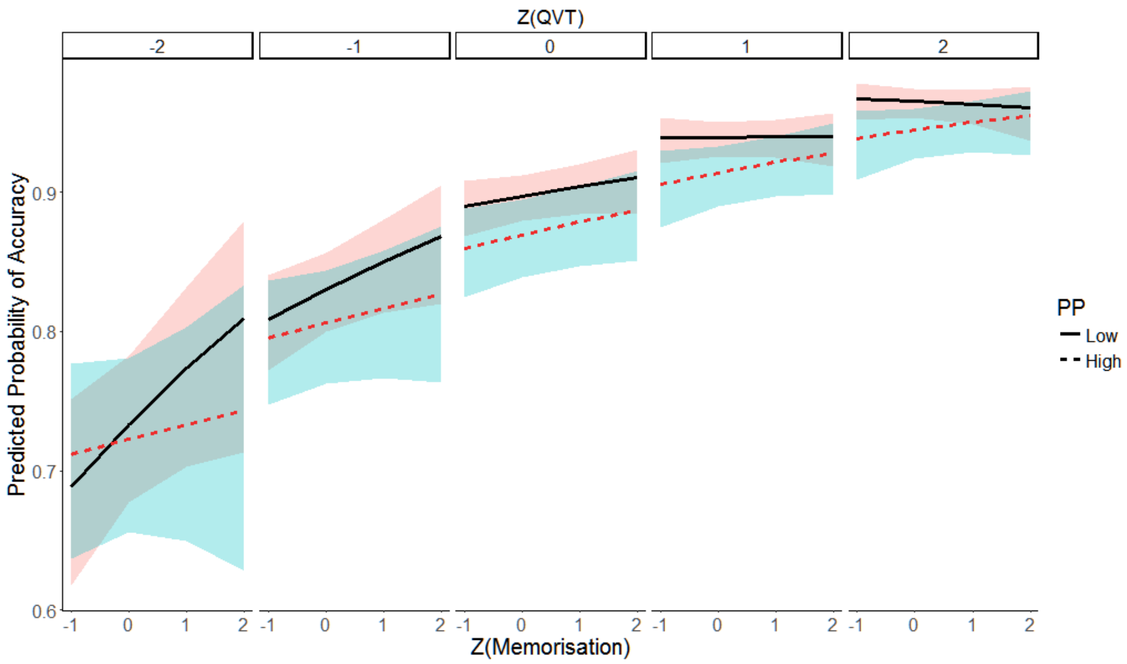

Figure 5-20. Memorisation × Vocabulary Knowledge × Phonotactic Probability interaction: Predicted probability of accuracy for word targets with low (1.5 *SD* below the mean) and high (1.5 *SD* above the mean) phonotactic probability based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Root. After controlling for all other variables, the principal component of root (root frequency and root family size) significantly predicted lexical decision accuracy, β = .372, *SE* = .055, $\chi^2(1)$ = 38.742, $p < .001$. Participants were more likely to respond more accurately to targets with higher root frequency and larger root family size than to targets with lower root frequency and smaller root family size.

Although the two-way interaction between memorisation and root was not significant, β = .008, *SE* = .022, $\chi^2(1)$ = 1.851, *ns*., the two-way interaction between vocabulary knowledge and root was significant, β = .107, *SE* = .022, $\chi^2(1)$ = 22.115, p < .001. Plotting the simple slopes of the two-way interaction showed that participants with more vocabulary knowledge were less likely to be influenced by root effects when identifying word targets accurately in lexical decision than participants with less vocabulary knowledge (see Figure 5-21). This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller root effects in lexical decision accuracy. The three-way interaction between memorisation, vocabulary knowledge, and root was only marginally significant, β = -.020, *SE* = .020, $\chi^2(1)$ = 2.708, p < .1.

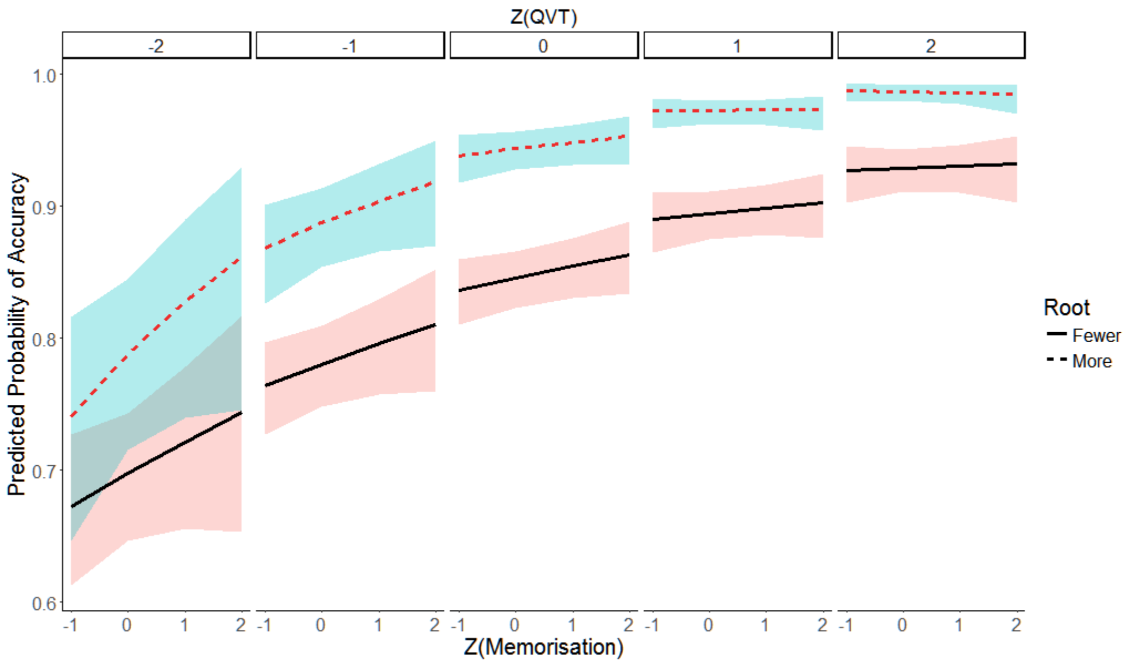

Figure 5-21. Memorisation × Vocabulary Knowledge × Root interaction: Predicted probability of accuracy for word targets with fewer (1.5 *SD* below the mean) and more (1.5 *SD* above the mean) roots based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

5.8.1.3 Word Targets (All Data)

It is important to note that there was a rather unusually high exclusion of RT data during the cleaning of the data to ensure that the analyses provided reliable and interpretable results. To examine the sensitivity of the results to the exclusion of observations, a supplementary analysis was done with all real word RT data that was more than 200ms as faster latencies typically indicate either a technical or participant error. Table 5-5 presents the estimates for the full linear mixed effects model.

Comparing the findings with those of the cleaned data, there were a few similarities and differences. The analysis with all data indicated that a similar pattern of results as the analysis with cleaned data for all covariates (trial order number, display refresh rate, sex, and age) except for onsets, which were no longer significant. In terms of main effects for the individual and item-level variables, there was also a similar pattern of results in terms of significance and the direction of the effects. However, in terms of two-way interactions, unlike the analysis with cleaned data, there were significant interactions of Qur'an memorisation with the following principal components: frequency, neighbourhood density. Unlike the analysis with cleaned data, there were significant two-way interactions of Qur'an vocabulary knowledge with frequency and Levenshtein distance respectively; the two-way interactions of Qur'an vocabulary knowledge with length and neighbourhood density respectively were also no longer significant. Nonetheless, two-way interactions of Qur'an vocabulary knowledge with phonotactic probability and root respectively remained significant like in the analysis with cleaned data.

In terms of three-way interactions, unlike the analysis with cleaned data, there were significant three-way interactions between Qur'an memorisation, Qur'an vocabulary knowledge, and length as well as between Qur'an memorisation, Qur'an vocabulary knowledge, and neighbourhood density. Nonetheless, the three-way interactions between Qur'an memorisation, Qur'an vocabulary knowledge, and frequency as well as between Qur'an memorisation, Qur'an vocabulary knowledge, and Levenshtein distance remained significant like in the analysis with cleaned data.

5.8.2 Lexicality

5.8.2.1 Response Latencies

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in this model described 55.89% of the variance in RTs for both word and nonword targets; random effects described 37.50% of the variance in RTs while fixed effects described 18.39% of the variance in RTs. Table 5-7 presents the estimated standardised coefficients for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model are described in the following sub-sections.

Covariates. As seen in Table 5-7, the following covariates were significant: trial order number, refresh rate, sex, and age. Participants were more likely to be faster as they progressed through the lexical decision. They were also more likely to be slower when using a computer with a slower display refresh rate. Females were more likely to be faster than males. Last, older participants were more likely to be slower.

Amount of Qur'an memorisation. There was a significant main effect of amount of memorisation on RTs, $\beta = .035$, $SE = .016$, $\chi^2(1) = 4.916$, $p < .05$. Participants who had memorised more of the Qur'an were more likely to be slower in lexical decision than participants who had memorised less.

Qur'an vocabulary knowledge. There was a significant main effect of Qur'an vocabulary knowledge on RTs, $\beta = -.109$, $SE = .017$, $\chi^2(1) = 38.374$, $p < .001$. Participants with more Qur'an vocabulary knowledge were more likely to be faster in lexical decision than participants with less Qur'an vocabulary knowledge. It may be worth noting that there is also a significant two-way interaction between memorisation and vocabulary knowledge on RTs, $\beta = -.033$, $SE = .015$, $\chi^2(1) = 6.637$, $p < .05$, but the interpretation of this interaction should be contextualised by the significant three-way interaction between lexicality, memorisation, and vocabulary knowledge, as described in the following section.

Lexicality. Overall, participants were more likely to be faster when responding to real words than when responding to nonwords, as shown by the pairwise comparison in the model, β = -.173, SE = .060, $\chi^2(1)$ = 331.780, p < .001.

A significant three-way interaction between lexicality, memorisation, and vocabulary knowledge indicated that this lexicality effect on RTs (difference in RTs of real words versus nonwords) was moderated by both amount of memorisation and vocabulary knowledge, β = -.013, SE = .006, $\chi^2(1)$ = 4.841, p < .05. As can be seen in Figure 5-22, as amount of vocabulary knowledge increases, the increase in lexicality effect on RTs as amount of memorisation increases gets smaller; participants who had very high vocabulary knowledge thus were much faster in identifying real words and in rejecting nonwords if they had memorised more of the Qur'an than if they had memorised less of the Qur'an.

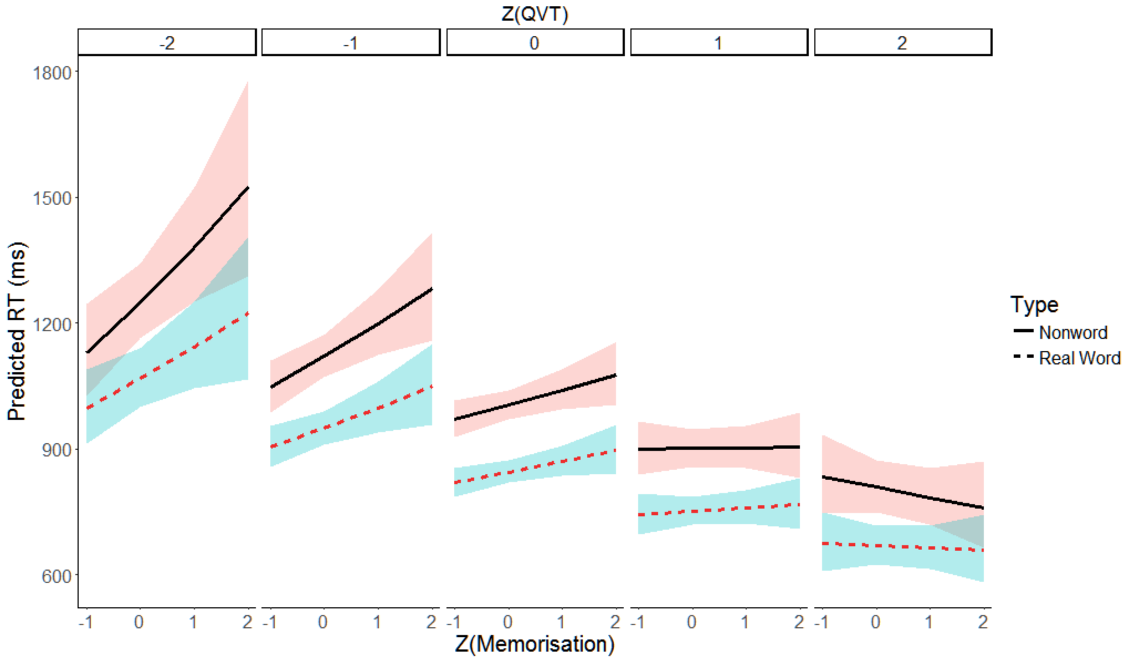

Figure 5-22. Lexicality × Vocabulary Knowledge × Memorisation interaction: Predicted RTs for word and nonword targets based on final linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

5.8.2.2 Accuracy

A pseudo-R^2 calculated for generalised linear mixed models showed that the random effects and fixed effects together in this model described 27.21% of the variance in accuracy for both word and nonword targets; random effects described 14.64% of the variance in accuracy while fixed effects described 12.57% of the variance in accuracy. Table 5-8 presents the estimated standardised coefficients and for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model are described in the following sub-sections.

Covariates. As seen in Table 5-8, the following covariates were significant: trial order number, refresh rate, sex. Participants were more likely to be accurate as they progressed through the lexical decision. They were also less likely to be accurate when using a computer with a slower display refresh rate. Females were more likely to be accurate than males.

Amount of memorisation. There was a significant main effect of amount of memorisation on accuracy, β = .211, *SE* = .059, $\chi^2(1)$ = 12.366, p < .001. Participants who had memorised more of the Qur'an were more likely to be accurate than participants who had memorised less; for each standardised unit change in amount of memorisation, the log odds of accuracy increase by .211.

Qur'an vocabulary knowledge. There was a significant main effect of Qur'an vocabulary knowledge on accuracy, β = .639, *SE* = .064, $\chi^2(1)$ = 83.669, p < .001. Participants with more Qur'an vocabulary knowledge were more likely to be accurate in lexical decision than participants with less Qur'an vocabulary knowledge; for every one standardised unit change in Qur'an vocabulary knowledge, the log odds of accuracy increase by .639.

Lexicality. Overall, participants were more likely to be accurate when responding to real words than when responding to nonwords, as shown by the pairwise comparison in the model, $\beta = .865$, $SE = .058$, $\chi^2(1) = 151.980$, $p < .001$.

Significant two-way interactions indicated that this lexicality effect was moderated by both amount of memorisation, $\beta = -.159$, $SE = .060$, $\chi^2(1) = 6.800$, $p < .05$, and Qur'an vocabulary knowledge, $\beta = -.172$, $SE = .065$, $\chi^2(1) = 6.837$, $p < .05$, respectively. As amount of memorisation increases, lexicality effect decreases, i.e., the difference in the accuracy of real words versus that of nonwords decreases (see Figure 5-23). Figure 5-23 also shows that participants who had memorised more of the Qur'an were predicted to have a higher probability of accurately rejecting nonwords (almost as high as accurately identifying real words) than participants who had memorised less of the Qur'an. Similarly, as Qur'an vocabulary knowledge increases, lexicality effect decreases (see Figure 5-24); participants who had more Qur'an vocabulary knowledge were predicted to have a higher probability of accurately rejecting nonwords (almost as high as accurately identifying real words) than participants who had less Qur'an vocabulary knowledge.

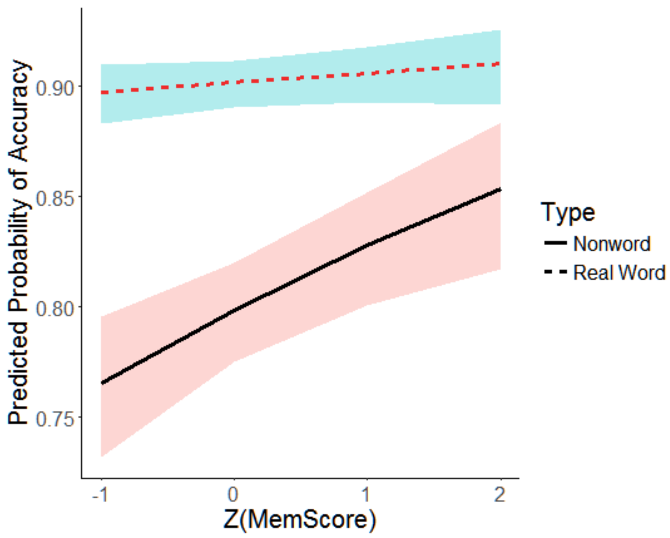

Figure 5-23. Lexicality × Memorisation interaction: Predicted probability of accuracy for word and nonword targets based on final linear mixed effects model. Results are presented as a function of amount of memorisation *z*-scores. Bands are based on 95% confidence intervals.

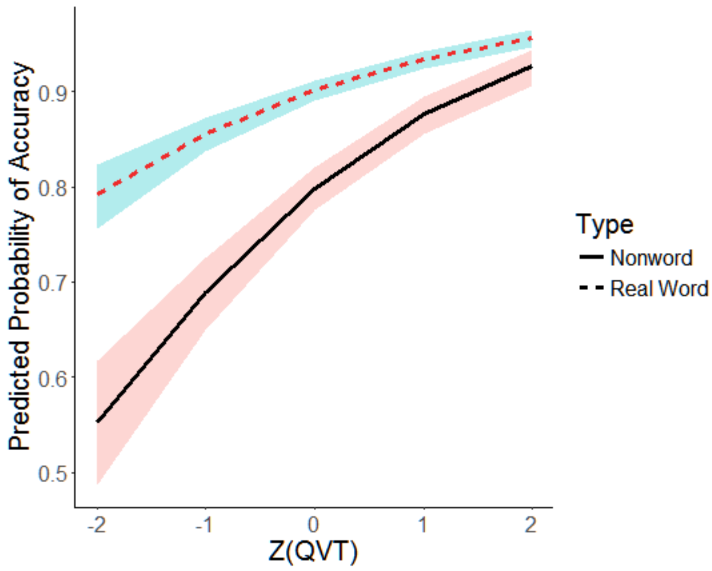

Figure 5-24. Lexicality × Vocabulary Knowledge interaction: Predicted probability of accuracy for word and nonword targets based on final linear mixed effects model. Results are presented as a function of Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Although the three-way Lexicality × Vocabulary Knowledge × Memorisation interaction was not significant, β = .076, *SE* = .063, $\chi^2(1) = 1.428$, *ns.*, plotting it showed an interesting trend in that the lexicality effect on accuracy can be attenuated by both memorisation and vocabulary knowledge. As can be seen in Figure 5-25, as amount of memorisation increases, the lexicality effect on accuracy tends to decrease as amount of vocabulary knowledge increases; memorising more Qur'an may thus help participants with lower Qur'an vocabulary knowledge in rejecting nonwords more accurately. Looking at the three-way interaction in another way in Figure 5-26, as vocabulary knowledge increases, the lexicality effect on accuracy also tends to decrease as amount of memorisation increases; knowing more Qur'an vocabulary not only helps to improve the probability of accurately identifying real words but also in improving the probability of accurately rejecting nonwords. The lexicality effect does not exist only for participants with very high vocabulary knowledge across all levels of memorisation or for participants with more memorisation across all levels of vocabulary knowledge. In contrast, participants with both less memorisation and smaller vocabulary knowledge were not only predicted to perform the poorest in identifying real words but were also predicted to perform even much worse in rejecting nonwords.

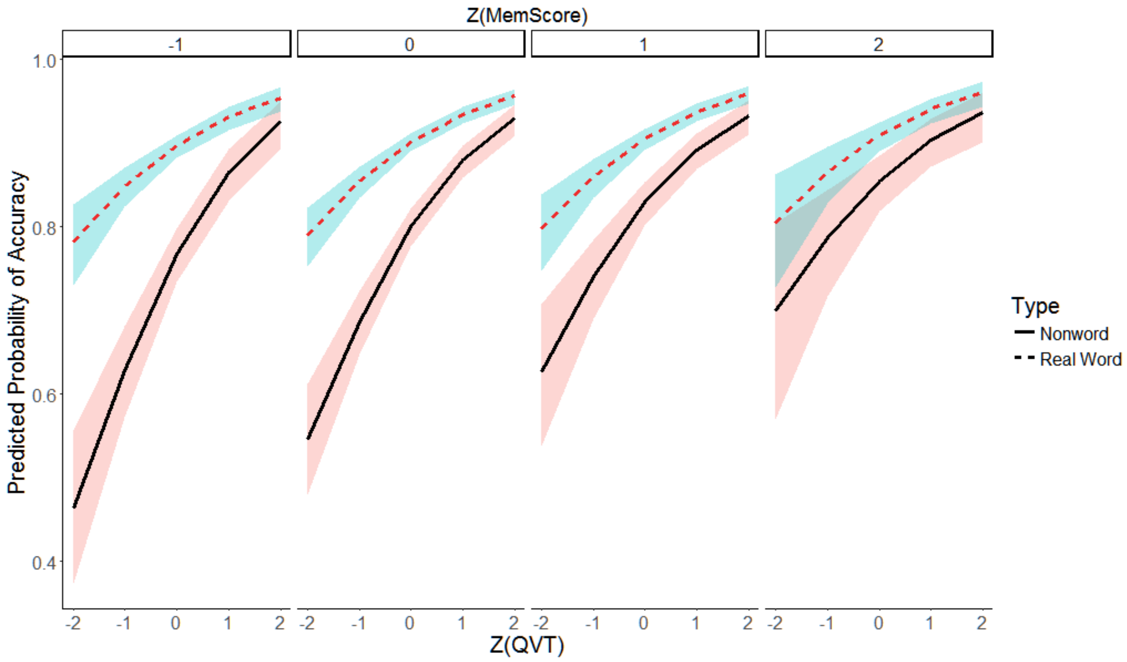

Figure 5-25. Lexicality × Vocabulary Knowledge × Memorisation interaction: Predicted probability of accuracy for word and nonword targets based on the full generalised linear mixed effects model. Results are presented as a function of Qur'an vocabulary knowledge (QVT) and memorisation *z*-scores. Bands are based on 95% confidence intervals.

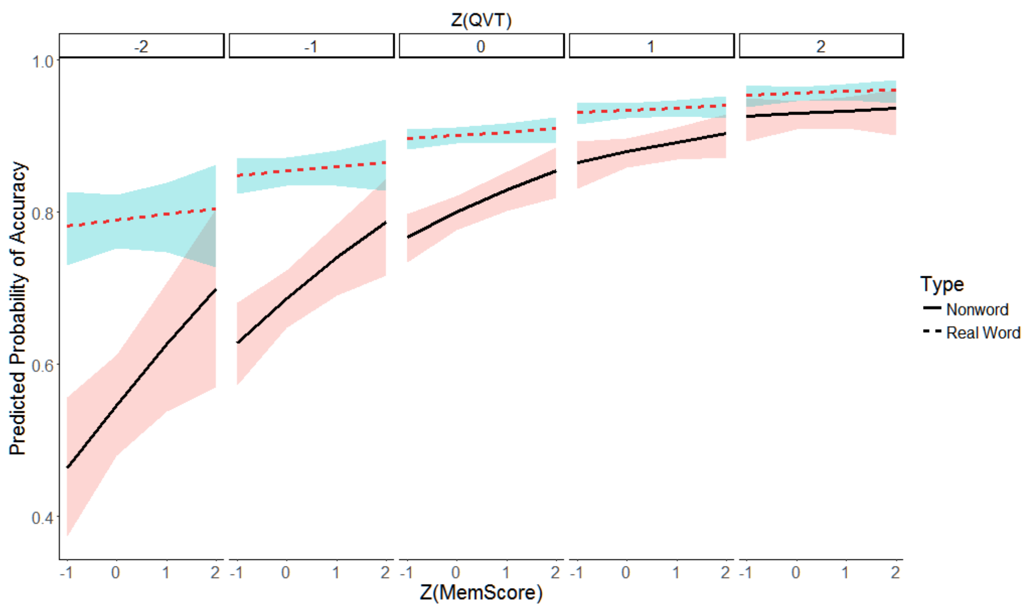

Figure 5-26. Lexicality × Vocabulary Knowledge × Memorisation interaction: Predicted probability of accuracy for word and nonword targets based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'anic vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

5.8.2.3 Lexicality (All Data)

Like the RT analyses with word targets, there was also a rather unusually high exclusion of RT data during the cleaning of the data to ensure that the lexicality RT analyses provided reliable and interpretable results. To examine the sensitivity of the results to the exclusion of observations, a supplementary analysis was done with all word and nonword RT data that was more than 200ms as faster latencies typically indicate either a technical or participant error. Table 5-7 presents the estimates for the full linear mixed effects model.

Overall, there was a similar pattern of findings for both the analyses with cleaned data and all data. The only difference was that unlike in the analysis with cleaned data, the analysis with all data showed a significant two-way interaction between Qur'an vocabulary knowledge and lexicality.

5.9 Discussion

In this study, behavioural data in the lexical decision performance of non-Arabic-speaking Qur'anic memorisers were collected to fulfil two objectives. The first objective was to examine the influence of seven variables—length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, root, and lexicality on the lexical decision of non-Arabic-speaking Qur'anic memorisers. The second objective was to examine individual differences in the effects of these variables on lexical decision by looking at whether Qur'an vocabulary knowledge (QVT) and amount of Qur'an memorisation (MemScore) interact with these factors in two- and three-way interactions, thereby teasing apart the possibly differential roles of vocabulary knowledge and print exposure in visual word processing.

Findings from this study essentially supported the four main predictions made with reference to research on other orthographies such as Malay with a couple of unexpected findings. First, after controlling for onsets and other covariates, all principal components of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root significantly predicted lexical decision latencies in the expected directions. Longer words and words that have further neighbours elicited slower responses, whereas words that occur more frequently in print, words with more orthographic and phonological neighbours, words with higher phonotactic probability, as well as words with more frequent roots and larger root family size elicited faster responses. Importantly, length effects were much larger than frequency effects, indicating a greater reliance on the sublexical route in word processing. Root effects were also the smallest compared to those of other principal components, especially neighbourhood density, suggesting that our participants were more sensitive to measures of orthographic similarity than non-linear morphological variables when making a lexical decision. Lexicality effects were also found; real words elicited faster responses than nonwords.

In terms of accuracy, all the principal components (length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability and root) significantly predicted lexical decision accuracy, with frequency having stronger predictive power than length. Participants were more accurate when responding to shorter words, more frequent words, words with more neighbours, words with closer neighbours, words with lower phonotactic probability, and words with more frequent roots or larger root family sizes.

Second, surprisingly, amount of Qur'an memorisation (MemScore) did not significantly modulate any lexical effects in lexical decision latencies, though it did so together with vocabulary knowledge in three-way interactions. It also significantly modulated only the length and lexicality effects in lexical decision accuracy. Those who have memorised more of the Qur'an were less influenced by length and lexicality when trying to make a lexical decision accurately.

Third, as predicted, Qur'an vocabulary knowledge (QVT) significantly modulated the effects of length, neighbourhood size, phonotactic probability, and root on lexical decision latencies; more vocabulary knowledge resulted in smaller effects of length, neighbourhood size, and phonotactic probability on lexical decision latencies. More vocabulary knowledge also resulted in smaller lexicality effects. However, more vocabulary knowledge resulted in larger effects of root on lexical decision latencies. QVT also significantly modulated the effects of frequency, Levenshtein distance, phonotactic probability, and root on lexical decision accuracy. Participants with more vocabulary knowledge were less influenced by frequency, Levenshtein distance, and root effects when trying to make a lexical decision accurately but they were more influenced by phonotactic probability when trying to make a lexical decision accurately.

Last, MemScore and QVT interacted together to significantly modulate the effects of frequency, Levenshtein distance, and lexicality on lexical decision latencies. In all the three-way interactions, larger frequency, Levenshtein distance, and lexicality effects as amount of memorisation increases were attenuated by the increase in vocabulary knowledge. The more memorisation and vocabulary knowledge one has, the less influenced one is by frequency, Levenshtein distance, and lexicality when making a lexical decision.

The above results will be further discussed in detail in the following sections.

5.9.1 Effects of Lexical Variables on Lexical Decision

5.9.1.1 Length and Frequency Effects

As expected, results showed that not only was length a much stronger predictor of lexical decision latencies than frequency, it was also the strongest predictor compared to other principal components. This is consistent with the findings from other transparent orthographies such as Malay (Binte Faizal, 2009; Yap et al., 2010) but contrasts with the findings in opaque orthographies such as English (Balota et al., 2004; Yap & Balota, 2009), which found frequency effects to be larger than length effects. The much larger length effects as compared to frequency indicate a reliance on the sublexical pathway during word processing based on dual-route models of reading. What is surprising is that there is still a much greater reliance on the sublexical pathway despite this being a task that requires lexical access. This really speaks to the differences in processing due to the demands of the orthography regardless of task as predicted by the PGST. They also indicate an adaptation to smaller grain sizes of processing due to the constant decoding of consistent grapheme-to-phoneme correspondences as predicted by the PGST.

The finding that frequency was the largest predictor of lexical decision accuracy was expected and corroborated what was found in Malay by Binte Faizal (2009), given the demands of the task; one would have had to access the lexicon in order to decide if the target word was a real word or a nonword. This speaks to the differences between the roles of both frequency and length in word recognition processes. How often a word occurs in print is associated with the familiarity of the stimulus, and unlike length, it is a reliable matrix that can be used to decide whether a stimulus is a real word or a nonword (Binte Faizal, 2009). However, the variance accounted for by lexical variables in the time taken to recognize a stimulus (RT) reflects whichever pathway the reader relies on to process that stimulus, thus explaining why the predictive power of frequency was greater than length in lexical decision accuracy but not in response latencies. This suggests that response latencies in lexical decision possibly reflect the processes that occur during word recognition whereas accuracy possibly reflects the proficiency of the reader.

Nonetheless, the finding that length and frequency effects were both significant in the lexical decision of a transparent orthography corroborated findings from other studies such as Malay (Binte Faizal, 2009), thus providing additional support for the weak ODH, which does not deny the parallel use of both lexical and sublexical pathways in word processing but rather postulates a greater reliance of one over the other, depending on the depth of the orthography as well as the specific demands of the task.

5.9.1.2 Neighbourhood Density and Levenshtein Distance

As predicted, neighbourhood density significantly facilitated lexical decision latencies whereas Levenshtein distance significantly inhibited them, with Levenshtein distance having stronger predictive power than neighbourhood density. This means that words with more neighbours and words with closer neighbours elicited faster responses than words with fewer neighbours and words with further neighbours. This is consistent with findings from studies in English (Yap & Balota, 2009; Yarkoni et al., 2008) and Malay (Binte Faizal, 2009). These facilitatory effects possibly reflect the processing characteristics of the sublexical phonological assembly process in dual route models of reading, in which words which are visually similar to many other words are recognised faster as they share more common grapheme-to-phoneme correspondences (Andrews, 1997), activating phonology that is consistent with that of the target item, thus facilitating lexical access and reducing lexical decision latencies. Distance effects are thus another way to capture the common grapheme-to-phoneme correspondences in Qur'anic Arabic. Taken together, these findings support the predictions of the weak ODH and PGST, which postulate that transparent orthographies will engage more in sublexical processing despite the demands of the task.

More importantly, Levenshtein distance has been shown consistently to be a stronger predictor of lexical decision latencies than traditional measures of neighbourhood density in English, (Yap & Balota, 2009; Yarkoni et al., 2008), Malay (Binte Faizal, 2009), and now, Qur'anic Arabic. Unlike standard measures of neighbourhood size (orthographic N and phonological N), this distance-based measure was not only applicable to words of all lengths but was also able to account for a substantial proportion of unique variance above and beyond the traditional measures, making it an excellent measure of orthographic similarity or distinctiveness.

5.9.1.3 Neighbourhood Density and Root

The principal component of root (root frequency and root family size) was found to have significantly facilitated lexical decision latencies, although it has the smallest predictive power out of all the principal components. Root also significantly facilitated lexical decision accuracy. The more frequent and more productive the root of a word is, the faster and more accurately it is responded to. This means that participants were sensitive enough to non-concatenative morphological information such as root, suggesting implicit statistical learning taking place and accessing these root representations despite having print exposure with limited semantic knowledge. This corroborates Zuhurudeen and Huang's (2016) finding in demonstrating that real-world exposure to the statistical properties of a natural language can facilitate learning despite having limited semantic cues; in their case, the acquisition of grammatical categories. Importantly, this gives us motivation to study whether this reflects true sensitivity to non-concatenative root morphemes or merely sensitivity to the statistical occurrence of various consonant combinations. We examine this by looking at root priming effects in Chapter 7.

Importantly, as discussed earlier in the literature review, greater sensitivity to root variables as compared to measures of orthographic similarity such as orthographic N could suggest the salience of the root in lexical organisation based on the non-concatenative morphological principles of an orthography instead of orthographic similarity as assumed by extant models of word recognition. However, this was not found as the predictive power of neighbourhood density was much larger than that of root in lexical decision latencies; participants were thus more sensitive to neighbourhood density effects than to root effects in lexical decision. Contrary to what Frost et al. (2005) had argued, this suggests that non-Arabic-speaking Qur'anic memorisers organise words based on orthographic similarity instead of the language's morphological principles, i.e., Qur'anic Arabic's non-concatenative morphological principles of roots and word patterns. It further suggests that for the lexical organisation of words to be based on non-concatenative morphological principles, there may be a process that has to be learned, either through the natural acquisition of the language or through explicit teaching. What is clear is that the nature of the orthography itself does not determine the lexical organisation of words, but rather how individuals themselves acquire the language.

5.9.1.4 Phonotactic Probability

As predicted, the principal component of phonotactic probability (positional segment average and biphone average) was found to significantly predict lexical decision latencies, albeit having smaller predictive power than length, frequency, neighbourhood density and Levenshtein distance. Participants were faster to respond to words with higher phonotactic probability than words with lower phonotactic probability. It also significantly predicted lexical decision accuracy, albeit having the smallest predictive power out of all the other principal components. Participants responded to words with higher phonotactic probability less accurately than to words with lower phonotactic probability. Together with length and Levenshtein distance effects, this finding provides corroborating evidence of non-Arabic-speaking Qur'anic memorisers' reliance on sublexical processing and the salience of smaller grain sizes of processing in lexical decision, thus supporting the predictions of the ODH and PGST. Importantly, this also suggests the implicit statistical learning of phonotactic probabilities at the levels of phone and biphone through print exposure, and thus, the access of these sublexical representations during speeded pronunciation.

5.9.1.5 Lexicality

As expected, lexicality effects were found such that real words elicited faster response latencies than nonwords. As lexicality effects are a marker for word-specific representations, the presence of lexicality effects in our non-Arabic-speaking memorisers suggest the implicit learning of these word-specific representations during memorisation, facilitating lexical access, and thus, response times, as compared to nonwords.

5.9.2 Individual Differences in Effects of Lexical Variables on Lexical Decision

Individual differences as measured by amount of Qur’an memorisation (MemScore) and Qur’an vocabulary knowledge (QVT) were found to significantly modulate the effects of the various principal components and lexicality on lexical decision latencies through two-way and three-way interactions. These interactions are discussed below.

5.9.2.1 Amount of Qur’an Memorisation (MemScore)

Surprisingly, amount of memorisation (MemScore) did not significantly modulate any effect of a lexical variable on its own, though it did so in tandem with vocabulary knowledge. This underscores the importance of examining both variables simultaneously and teasing apart their individual roles on visual word processing.

5.9.2.2 Qur'an Vocabulary Knowledge (QVT)

As predicted, Qur'an vocabulary knowledge (QVT) significantly modulated the effects of length, neighbourhood density, phonotactic probability, and root on lexical decision latencies; more vocabulary knowledge resulted in smaller effects of length, neighbourhood density, and phonotactic probability on lexical decision latencies. More vocabulary knowledge also resulted in smaller lexicality effects on lexical decision accuracy. However, more vocabulary knowledge resulted in larger effects of root on lexical decision latencies, which possibly suggests the need for semantic knowledge in order to be more sensitive to root information when making a lexical decision.

The finding that participants with more vocabulary knowledge were less influenced by neighbourhood density than participants with less vocabulary knowledge corroborates with Yap et al.'s (2012) finding. However, our other findings contrast with theirs as they had found that vocabulary knowledge was only marginally related to the principal components indicating a word's structural properties (length, orthographic and phonological Levenshtein distance) and word frequency/semantics. The latter finding was congruent with that of Butler and Hains (1979). Finer-grained analyses by Yap et al. (2012) showed that vocabulary knowledge was positively correlated with larger effects of word frequency, leading them to suggest that participants with more vocabulary are better able to make use of word frequency or other familiarity-based information in lexical decision, thus facilitating responses to high frequency words. This was supported by their finding that steeper drift rates in diffusion model analyses (a marker for the speed of accumulating information) are associated with larger word frequency/semantics effects, thus participants who are more sensitive to familiarity-based information are also able to accumulate information about a target stimulus faster. More work needs to be done in order to address the discrepancy in these findings.

Nonetheless, our findings supported hypotheses that propose an automatization of lexical processing mechanisms as readers acquire more experience with words; in this case, as proposed by the lexical quality hypothesis, gaining the meaning of words contributed to improving the semantic constituent in developing the quality of lexical representations, thus improving the efficacy in accessing these representations (Perfetti, 2007; Perfetti & Hart, 2002) and resulting in smaller influences of lexical characteristics in word processing.

5.9.2.3 MemScore and QVT

The hallmark of this study was to examine three-way interactions between MemScore, QVT, and each principal component, thereby allowing us for the first time to tease apart possibly differential roles of print exposure and vocabulary knowledge in modulating the effects of various principal components on lexical decision. Results showed that MemScore and QVT interacted together to significantly modulate the effects of frequency, Levenshtein distance, and lexicality on lexical decision latencies.

In all the three-way interactions, larger frequency, Levenshtein distance, and lexicality effects as amount of memorisation increases are attenuated by the increase in vocabulary knowledge. The more memorisation and vocabulary knowledge one has, the less influenced one is by frequency, Levenshtein distance, and lexicality when making a lexical decision as compared to their high vocabulary knowledge counterparts who had memorised less of the Qur'an and their high memorisation counterparts who had poorer vocabulary knowledge. This provides excellent support for the lexical quality hypothesis, which describes three separate constituents of orthography, phonology, and semantics in the development of the quality of lexical representations, and thus, in the facilitation of access to these lexical representations in word processes such as reading (Perfetti, 2007; Perfetti & Hart, 2002). Based on this, one can surmise that memorisation (or print exposure) and vocabulary knowledge provide separate contributions to the development of the quality of lexical representations. Memorisation provides constant repeated exposure to the orthographic and phonetic constituents of a lexical representation while vocabulary knowledge contributes to the semantic constituent of a lexical representation. Together, they help to develop high-quality lexical representations that facilitate access to these lexical representations, thus resulting in smaller influences of lexical characteristics in word processing.

5.10 Conclusions

The current study examined the effects of various psycholinguistic variables as well as individual differences in the effects of those variables on the lexical decision of non-Arabic-speaking Qur'anic memorisers. Overall, findings suggest that non-Arabic-speaking Qur'anic memorisers implicitly learn the lexical and sublexical characteristics of an orthography through consistent exposure to its print. The major contributions of this study are as follows: Not only is it the first study on lexical decision in Qur'anic Arabic, it is also the first study that have looked at non-Arabic-speaking Qur'anic memorisers, thereby providing a natural window into the disambiguation of the roles of vocabulary knowledge and print exposure in influencing the effects of various psycholinguistic variables on lexical decision. Furthermore, it is currently the only study of lexical decision in vowelled Arabic that utilizes a comprehensive array of traditional and novel predictors, and it is the only study of lexical decision in a transparent orthography that have examined individual differences in the effects of those predictors. Last, it is the first study to be able to investigate within the same population whether lexical organisation arises from a language's morphological principles or from how the individual himself acquires the language. Through this study, individual differences have been found to significantly modulate effects of various psycholinguistic variables on lexical decision either through two-way or three-way interactions, thus underscoring the importance of considering individual differences in visual word recognition research. Taken together, these findings will hopefully provide useful constraints for future researchers attempting to model Qur'anic Arabic visual word processing for non-Arabic-speakers.

Table 5-5. *Full model showing the fixed effects with standardised RT regression coefficients from a linear mixed effects regression analysis for lexical decision in word targets for both cleaned and all data with log transformation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 20557)				All Data >200ms (*N* = 23892)			
	β	*SE*	$\chi^2(1)$	*p*	*β*	*SE*	$\chi^2(1)$	*p*
(Intercept)	6.763	.016			6.779	.016		
Onsets (combined; df = 27)			48.357	**	-	-		--
Trial Order Number	-.009	.002	16.820	***	-.012	.002	38.978	***
Display Refresh Rate	.055	.013	19.050	***	.058	.013	22.105	***
Sex	-.045	.013	11.477	***	-.062	.013	35.511	***
Age	.064	.014	21.153	***	.065	.014	23.036	***
MemScore	.030	.014	4.534	*	.054	.015	27.958	***
QVT	-.113	.015	48.498	***	-.086	.015	33.873	***
Length	.082	.008	76.290	***	.087	.007	108.430	***
Freq	-.048	.008	35.440	***	-.070	.007	84.023	***
N	-.026	.006	16.201	***	-.035	.006	26.368	***
LD	.043	.007	34.174	***	.052	.007	65.899	***
PP	-.017	.008	4.454	*	-.017	.006	7.265	**
Root	-.009	.007	4.197	*	-.025	.007	13.564	***
MemScore:QVT	-.020	.014	2.140		-.055	.013	19.545	***
MemScore:Length	-.001	.003	.158		.003	.003	.919	
MemScore:Freq	-.004	.002	3.648	.	-.007	.003	8.297	**
MemScore:N	-.001	.002	.478		-.003	.002	4.201	*
MemScore:PP	.002	.002	1.628		.001	.002	.449	
MemScore:LD	.004	.002	3.244	.	.005	.003	2.973	.
MemScore:Root	-.001	.002	.494		.000	.003	.000	
QVT:Length	-.012	.003	20.616	***	-.001	.003	.074	
QVT:Freq	.000	.002	.040		-.006	.003	5.118	*
QVT:N	.004	.002	4.741	*	.002	.002	3.774	.
QVT:PP	.005	.002	6.155	*	.002	.002	15.247	***
QVT:LD	.003	.002	1.370		.011	.003	17.971	***
QVT:Root	-.003	.002	4.837	*	-.008	.003	10.374	**
MemScore:QVT:Length	-.004	.003	1.714		-.012	.003	13.175	***
MemScore:QVT:Freq	.007	.002	9.676	**	.011	.002	36.092	***
MemScore:QVT:N	.003	.002	2.352		.006	.002	9.053	**
MemScore:QVT:PP	-.001	.002	2.751		.001	.002	1.686	
MemScore:QVT:LD	-.003	.002	4.606	*	-.005	.002	6.881	**
MemScore:QVT:Root	.003	.002	1.676		.002	.002	.554	

Table 5-6. *Full model showing the fixed effects with log odds estimated coefficients for lexical decision accuracy in word targets. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	β	*SE*	*z*	*P*(>|*z*|)	$\chi^2(1)$	*p*
(Intercept)	2.053	.069	29.899	.000		
Trial Order Number	-.122	.024	-5.000	.000	24.356	***
Display Refresh Rate	-.134	.037	-3.682	.000	13.150	***
Sex	.100	.037	2.681	.007	7.037	**
MemScore	.079	.046	1.703	.089	2.916	.
QVT	.540	.048	11.236	.000	109.260	***
Length	-.208	.055	-3.793	.000	13.705	***
Freq	.584	.058	10.034	.000	78.019	***
N	.154	.055	2.794	.005	7.580	**
LD	-.380	.055	-6.883	.000	40.934	***
PP	-.090	.054	-1.661	.097	4.492	*
Root	.372	.055	6.704	.000	38.742	***
MemScore:QVT	-.043	.041	-1.034	.301	2.748	.
MemScore:Length	.067	.021	3.174	.002	9.861	**
MemScore:Freq	.014	.027	.513	.608	1.969	
MemScore:N	.004	.020	.188	.851	.035	
MemScore:PP	.002	.018	.123	.902	1.722	
MemScore:LD	-.017	.021	-.803	.422	.631	
MemScore:Root	.008	.022	.386	.699	1.851	
QVT:Length	-.041	.021	-1.936	.053	3.720	.
QVT:Freq	.118	.028	4.222	.000	17.224	***
QVT:N	.025	.021	1.237	.216	1.508	
QVT:PP	-.036	.019	-1.881	.060	5.251	*
QVT:LD	-.057	.022	-2.595	.009	8.327	**
QVT:Root	.107	.022	4.781	.000	22.115	***
MemScore:QVT:Length	.056	.019	2.957	.003	10.239	**
MemScore:QVT:Freq	-.112	.024	-4.737	.000	20.557	***
MemScore:QVT:N	-.021	.018	-1.207	.227	1.397	
MemScore:QVT:PP	.029	.017	1.713	.087	2.879	.
MemScore:QVT:LD	.022	.019	1.163	.245	3.012	.
MemScore:QVT:Root	-.020	.020	-1.011	.312	2.708	.

Table 5-7. *Full model showing the fixed effects with standardised RT regression coefficients from a linear mixed effects regression analysis for lexical decision in word (LDTRW) and nonword (LDTNW) targets for both cleaned and all data with log transformation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each likelihood-ratio test is represented by asterisks at the following levels: * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 38725)				All Data >200ms (*N* = 43997)			
	β	*SE*	$\chi^2(1)$	*p*	β	*SE*	$\chi^2(1)$	*p*
(Intercept)	6.924	.018			3.013	.008		
Trial Order Number	-.017	.001	153.890	***	-.009	.001	192.750	***
Display Refresh Rate	.048	.014	11.002	***	.022	.006	13.037	***
Sex	-.046	.014	9.551	**	-.028	.006	18.492	***
Age	.075	.015	23.017	***	.030	.006	21.120	***
MemScore	.035	.016	4.916	*	.027	.007	12.490	***
QVT	-.109	.017	38.374	***	-.024	.008	10.059	**
TargetTypeLDTRW	-.173	.006	331.780	***	-.068	.003	254.920	***
MemScore:QVT	-.033	.015	6.637	*	-.035	.007	28.220	***
MemScore:TargetTypeLDTRW	-.005	.006	0.554		-.004	.003	1.611	
QVT:TargetTypeLDTRW	-.008	.006	1.645		-.013	.003	17.772	***
MemScore:QVT:TargetTypeLDTRW	.013	.006	4.841	*	.011	.003	13.685	***

Table 5-8. *Full model showing the fixed effects with log odds estimated coefficients for lexical decision accuracy in word (LDTRW) and nonword (LDTNW) targets. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each likelihood-ratio test is represented by asterisks at the following levels: * = p < .05, ** = p < .01, *** = p < .001.*

	β	*SE*	*z*	*P*(>|*z*|)	$\chi^2(1)$	*p*
(Intercept)	1.252	.071	19.091	.000		
Trial Order Number	.035	.014	2.418	.016	5.777	*
Display Refresh Rate	-.150	.038	-3.860	.000	15.241	***
Sex	.106	.040	2.671	.008	6.826	**
MemScore	.211	.059	3.376	.001	12.366	***
QVT	.639	.064	9.952	.000	83.669	***
TargetTypeLDTRW	.865	.058	14.135	.000	151.980	***
MemScore:QVT	-.073	.061	-1.214	.225	1.655	
MemScore:TargetTypeLDTRW	-.159	.060	-2.483	.013	6.800	**
QVT:TargetTypeLDTRW	-.172	.065	-2.588	.010	6.837	**
MemScore:QVT:TargetTypeLDTRW	.076	.063	1.203	.229	1.428	

Chapter 6. Speeded Pronunciation

6.1 Introduction

In this chapter, we describe a study that sought to explore factors that influence the visual word processing of non-Arabic-speaking Qur'anic memorisers through a task that biases sublexical processing for transparent orthographies: speeded pronunciation. The study also examined individual differences in the influence of these factors on visual word processing by looking at whether Qur'an vocabulary knowledge (QVT) and amount of Qur'an memorisation (MemScore) interact with these factors in two- and three-way interactions, thereby teasing apart the possibly differential roles of vocabulary knowledge and print exposure in visual word processing.

6.2 Factors Influencing Speeded Pronunciation

As discussed in Chapter 4, speeded pronunciation, like lexical decision, has been widely used in the study of visual word recognition and its findings underlie many models and theories of word recognition (Balota et al., 2006; Katz et al., 2012; Yap et al., 2012). In speeded pronunciation (also known as word naming or speeded naming), participants are asked to read aloud a visually presented target stimulus as quickly as possible; their reaction times (RTs) and accuracy for each trial provide suitable dependent measures with which one can test the effects of particular variables.

The advantages of using the speeded pronunciation paradigm for this study are numerous: a) It has ecological validity as it resembles what our non-Arabic-speaking Qur'anic memorising population do while memorising the Qur'an, i.e., reading aloud verses. b) As it has been widely used, we can easily compare our results with those from other studies, especially of similar transparent orthographies such as Malay. c) When used with lexical decision, it can provide converging evidence in understanding the processes involved in word recognition, such as accessing and using lexical representations across different tasks (see Yap & Balota, 2009; Yap et al., 2012). A discussion of the effects across tasks can be found in Chapter 8.

As in lexical decision, the list of lexical variables that influenced English speeded pronunciation is very long (see Balota et al., 2004 for reviews; Balota et al., 2006; Yap & Balota, 2009). For this pioneer study on non-Arabic-speaking Qur'anic memorisers, as in Chapter 5, it seems prudent to focus on the main standard lexical variables, namely item length (number of letters, syllables, and phones), item frequency, neighbourhood size (orthographic N and phonological N), Levenshtein distance (orthographic and phonological), and phonotactic probability. Root variables (root frequency and root family size) are also added as the root plays a significant role in Arabic word recognition through morphological processing (see Boudelaa, 2014; Boudelaa & Marslen-Wilson, 2001, 2011, 2015); it would therefore be interesting to see if our non-Arabic-speaking Qur'anic memorisers are sensitive to root effects while visually processing Qur'anic words despite having limited semantic knowledge, which would suggest some form of implicit statistical learning taking place.

As discussed in Chapter 5, based on the weak orthographic depth hypothesis (weak ODH) and psycholinguistic grain size theory (PGST), the transparency of the orthography in terms of its consistency in grapheme-to-phoneme correspondences may result in different patterns of findings of effects in visual word recognition. In this selective review of studies that have examined lexical variables in speeded pronunciation, the focus is thus on describing the general trend of findings in speeded pronunciation across various orthographies so as to provide context for the weak ODH and PGST. We focus on English (a well-studied opaque orthography), Semitic languages such as Hebrew and Arabic that can be both opaque and transparent depending on vowelisation, and other transparent orthographies such as Malay.

6.2.1 Length

Length can be defined as number of letters or characters, number of syllables, or number of phonemes. However, as discussed in Chapter 5, it is important to note that due to the highly consistent grapheme-to-phoneme correspondences in transparent orthographies, there is typically a strong correlation between number of letters, number of syllables, and number of phonemes, resulting in the problem of multicollinearity. To resolve this problem, a principal component analysis is typically done to reduce these variables into the principal component of length. In terms of their theoretical implications, length effects are used as markers of sublexical processing or an engagement with the sublexical pathway in conventional dual-route models of reading (Coltheart et al., 1993; Coltheart & Rastle, 1994; Yap & Balota, 2009; Yap et al., 2012).

First, looking at English speeded pronunciation, number of letters has been found to have an inhibitory effect (e.g. Balota et al., 2004; Frederiksen & Kroll, 1976; Spieler & Balota, 1997; Yap & Balota, 2009). This means that the longer the word is, the longer it takes to respond to the word and read it aloud. Number of syllables has also been found to inhibit speeded pronunciation latencies (Yap & Balota, 2009); the more syllables a word has, the longer it takes to respond to the word and read it aloud. Yap and Balota (2009) also found that number of syllables accounted for greater variance in speeded pronunciation latencies than number of letters, which suggests an adaptation to a larger grain size of processing as hypothesised by PGST. However, there are task differences in both effects of number of letters and number of syllables. Balota et al. (2004) found larger effects of number of letters in speeded pronunciation than in lexical decision, emphasizing the different constellation of processes engaged in both tasks, as affirmed by the findings in other studies (e.g. Balota & Chumbley, 1985; Monsell et al., 1989; Yap & Balota, 2009). This is similar to the larger effects of number of syllables that were found in speeded pronunciation than in lexical decision (Yap & Balota, 2009). These findings speak to the greater demand for sublexical processing in speeded pronunciation than in lexical decision.

Both the weak ODH and PGST would predict that more transparent orthographies, especially those with smaller salient grain sizes, would show larger length effects in speeded pronunciation as compared to less transparent orthographies. Comparing Welsh (a transparent orthography) speeded pronunciation with that of English (an opaque orthography), Ellis and Hooper (2001) found that number of letters predicted 70% of the variance in Welsh speeded pronunciation latencies but only 22% of the variance in English speeded pronunciation latencies. This suggests that Welsh readers were much more reliant on sublexical phonological recoding at the grapheme-phoneme level during speeded pronunciation than English readers were.

Furthermore, the German (a more transparent orthography than English) DRC model of reading was able to simulate a linear increase in speeded pronunciation latencies as a function of word length (Ziegler et al., 2000). This simulation was corroborated by a study that found larger length effects in reading cognates (identical words across languages) aloud in German than in English (Ziegler et al., 2001). Despite having matched both sets of words in terms of psycholinguistic variables unrelated to orthographic length, such as orthographic neighbourhood size and word frequency, and having both sets requiring very similar articulatory output, they were still processed differently in both languages. This suggests that readers of German and English have adapted their visual word processing to different grain sizes due to the exposure to the inconsistencies of spelling-to-sound correspondences in English orthography, as predicted by the PGST.

Using a principal component analysis to combine number of letters, number of syllables, number of phonemes, and number of morphemes into a principal component of length due to multicollinearity, inhibitory length effects were found in Malay speeded pronunciation (Binte Faizal, 2009; Yap et al., 2010). More importantly, unlike English, length was the strongest predictor of speeded pronunciation latencies and accuracy as compared to frequency, which speaks to a greater reliance on the sublexical route during word processing as well as an adaptation to smaller grain sizes in word processing.

Putting these findings together, length effects reflect sublexical or smaller grain size processing and they can be found across orthographies of various levels of transparency, although length effects play a larger role in more transparent orthographies than in less transparent orthographies, thereby reflecting a greater reliance on sublexical processing than on lexical processing for more transparent orthographies. Sensitivity to length effects in speeded pronunciation would therefore suggest the implicit learning of sublexical representations through print exposure and being able to access those sublexical representations in visual word processing.

6.2.2 Frequency

As in lexical decision, the frequency effect is one of the more robust and most reported findings in speeded pronunciation research—words that occur more frequently in print are faster to be read aloud correctly. Word frequency effects are used as a marker for lexical or whole-word processing (Yap et al., 2012). Skilled readers develop lexical or whole word representations as a result of the frequency of exposure to a print word and these are stored in the orthographic input lexicon as proposed by dual-route models of reading.

In English speeded pronunciation, Yap and Balota (2009) examined speeded pronunciation performance for multisyllabic words using data from the English Lexicon Project (ELP; Balota et al., 2007) and found significant facilitatory frequency effects. Comparing across tasks, they found larger frequency effects in lexical decision than in speeded pronunciation, which speaks to the greater bias for sublexical processing in speeded pronunciation as well as the need to access the word's familiarity and meaningfulness to make an additional decision of lexicality on the target word in lexical decision. These findings are consistent with a previous large-scale study on monosyllabic words (Balota et al., 2004). More importantly, these megastudies found that frequency accounted for the greatest amount of variance in speeded pronunciation as compared to other lexical variables (see Balota et al., 2012).

As mentioned in Chapter 5, both the ODH and PGST predict that opaque orthographies should show stronger frequency effects than transparent orthographies in word recognition tasks because their spelling-to-sound correspondences are too inconsistent for sublexical processing, and therefore, require an adaptation to larger grain sizes during lexical processing. Evidence in support of this prediction has accumulated from research on several different languages such as English (as seen above). Looking at Hebrew speeded pronunciation, Frost (1994) provided strong support for the ODH when he found larger frequency effects in naming with unpointed (opaque) print than with pointed (transparent) print. Bentin and Ibrahim (1996) also found large frequency effects in unvowelled Arabic speeded pronunciation, although this was not compared with vowelled Arabic as that was not the goal of the study.

As predicted by both the weak ODH and PGST, although frequency effects have also been reported for speeded pronunciation in transparent orthographies, they are usually weaker than other markers of sublexical processing such as length. These transparent orthographies include Serbo-Croatian (Carello, Lukatela, & Turvey, 1988; Frost et al., 1987; Turvey, Feldman, Lukatela, & Henderson, 1984), vowelled Persian (Baluch & Besner, 1991), Italian (Barca, Burani, & Arduino, 2002; E. Bates, Burani, D'Amico, & Barca, 2001; Colombo, 1992), Spanish (Alvarez, Carreiras, & Taft, 2001; Sebastián-Galles, 1991), and Dutch (Hudson & Bergman, 1985). Both frequency and length effects have been documented to coexist in the speeded pronunciation of readers of orthographies with consistent grapheme-to-phoneme correspondences such Dutch (Hudson & Bergman, 1985), Malay (Binte Faizal, 2009) and Italian (Burani, Marcolini, & Stella, 2002). This indicates that lexical and sublexical processing are not necessarily mutually exclusive but could be activated in parallel, thus supporting the weaker version of the ODH that does not call for exclusivity of both types of processing in dual-route models of reading.

Baluch (1996) found frequency effects in a speeded pronunciation task in which skilled Persian readers named high frequency transparent Persian words significantly faster than matched low frequency transparent words. However, Baluch and Besner (1991) found similar frequency effects only when no nonwords were included in the stimuli list; they found no frequency effect when the same target words used for naming were mixed with nonwords. The null frequency effect reported by Baluch and Besner (1991) could thus indicate strategic shifts by skilled readers in relying solely on sublexical processing to read a list of words and nonwords with little cost as expected for readers of transparent orthographies, hence resulting in a null word frequency effect.

Putting these findings together, frequency effects reflect lexical or whole word processing and they can be found across orthographies of various levels of transparency, although frequency effects play a smaller role in more transparent orthographies than in less transparent orthographies, thereby reflecting a greater reliance on sublexical processing than on lexical processing for more transparent orthographies. Sensitivity to frequency effects in speeded pronunciation would therefore suggest the implicit learning of lexical representations through print exposure and being able to access those lexical representations even in a task that biases sublexical processing such as speeded pronunciation.

6.2.3 Neighbourhood Density

Here, we stick to the traditional definition of orthographic and phonological N, i.e., Coltheart's N (Coltheart et al., 1977). Orthographic N is the number of words or neighbours that can be obtained by replacing a letter in the target word whereas phonological N is the number of words that can be obtained by changing a phoneme in a target word. Unlike lexical decision, findings for orthographic N effects have been rather consistent thus far in the literature for speeded pronunciation (see Andrews, 1997, for a review of recent research on the effects of orthographic N across word identification tasks; Carreiras, Perea, & Grainger, 1997; Davies, Cuetos, & Glez-Seijas, 2007; Perea, 2015; Yap & Balota, 2009).

In English speeded pronunciation, Balota et al. (2004) found a significant facilitatory orthographic N effect for monosyllabic words. Words that have more orthographic neighbours were therefore faster to be read aloud correctly than words with fewer orthographic neighbours. This finding was replicated by Yap and Balota (2009), who found a significant facilitatory orthographic N effect for both monosyllabic and multisyllabic words. Comparing across tasks, the larger facilitatory orthographic N effects in speeded pronunciation relative to lexical decision (Balota et al., 2004; Yap & Balota, 2009) is consistent with Andrews' (1997) idea that these effects possibly reflect the sublexical phonological assembly process in dual-route models of reading, which is relied on more during speeded pronunciation than in lexical decision. In this process, words with more orthographic neighbours are read aloud faster as they share more common grapheme-to-phoneme correspondences, facilitating the activation of phonology consistent with that of the target word, thereby reducing the time taken to read the words.

The above findings were similar for phonological N. Yates (2005) found that monosyllabic words with larger phonological N elicited faster responses in English speeded pronunciation. Words with more phonological neighbours were faster to be read aloud correctly than words with fewer phonological neighbours. This finding was replicated in Yap and Balota (2009)'s study that used a large database of multisyllabic words and found that phonological N effects yielded shorter response latencies in speeded pronunciation.

In speeded pronunciation in French, also an opaque orthography, Peereman and Content (1997) found facilitatory effects only when the large orthographic N was commensurate with a large phonographic N. Phonographic N is the number of words that are both orthographic and phonological neighbours with a target word (see Adelman & Brown, 2007). Here, they found that pseudowords with many orthographic neighbours but with fewer phonographic neighbours were not read aloud faster than control words. Further findings from the same study extended the results to real words. This facilitation effect was attributed to the number of neighbours sharing the target rime, suggesting the sensitivity of French readers to rime (a larger unit of processing than syllable or phoneme) when processing words, thus supporting the grain size theory.

Turning to more transparent orthographies, Davies et al. (2007) found facilitatory orthographic N effects in the speeded pronunciation of Spanish children. In Malay speeded pronunciation, Binte Faizal (2009) combined orthographic N and phonological N in a principal component called neighbourhood size (N) due to multicollinearity and found that N significantly facilitated speeded pronunciation latencies, i.e., words with more orthographic and phonological neighbours were faster to be read aloud correctly. However, it is important to note that given the transparency of the Malay orthography with its consistent grapheme-to-phoneme correspondences, the orthographic neighbours of a word are also its phonological neighbours, possessing both similar spellings and pronunciations as the word, making them phonographic neighbours (see Adelman & Brown, 2007). This principal component N is therefore more similar to phonographic neighbourhood size than orthographic N in English, making it easier to engage the sublexical phonological assembly process and activate similar grapheme-to-phoneme correspondences as the target word, thus making it faster to pronounce the target word. More importantly, the principal component of N was a weaker predictor than Levenshtein distance in speeded pronunciation latencies, which provides further support for Yap and Balota's (2009) suggestion that orthographic N and phonological N may not be the most ideal measures of orthographic and phonological similarity respectively.

As discussed in Chapter 5, a question that one can ask is whether the visual word processing of our non-Arabic-speaking Qur'anic memorisers is determined by orthographic characteristics (as shown by extant findings for alphabetic orthographies) or morphological characteristics as Frost et al. (2005) argued. Like in lexical decision, based on incongruent theoretical assumptions with regards to the lexical organisation of words in the lexicon, we can make separate predictions for our non-Arabic-speaking Qur'anic memorisers—if they are more sensitive to N effects than root effects, then that would suggest that they organise words based on orthographic similarity and that words are not lexically organised based on the language's morphological principles, but rather, whether the readers themselves have been explicitly taught non-concatenative morphological principles or have semantic knowledge in order to be able to organise words based on the morphological principles of roots and word patterns. If the reverse occurs, then that would suggest that there is implicit learning of non-concatenative root information despite limited semantic knowledge and that words are lexically organised based on the language's morphological principles.

6.2.4 Levenshtein Distance

As discussed in Chapter 5, Levenshtein distance is a new measure of orthographic similarity optimized for longer words and can be defined as orthographic or phonological Levenshtein distance (OLD20 or PLD20), representing the mean orthographic or phonological Levenshtein distances from a word to its 20 closest neighbours (see Yap & Balota, 2009; Yarkoni et al., 2008).

Looking at English, Yarkoni and colleagues (2008) found a significant inhibitory effect of OLD20 in speeded pronunciation latencies; words that are orthographically more distinct, i.e., have further orthographic neighbours, elicited slower responses whereas words that have closer orthographic neighbours elicited faster responses. Similarly, Yap and Balota (2009) found significant inhibitory effects of OLD20 and PLD20 in the speeded pronunciation of multisyllabic words. Importantly, in both studies, OLD20 accounted for greater unique variance than orthographic N in multisyllabic words, whereas PLD20 also accounted for greater unique variance than phonological N in Yap and Balota's (2009) study. They also compared these effects across tasks and found that the effects of PLD20 were greater in speeded pronunciation than in lexical decision for monosyllabic and multisyllabic words separately as well as when both sets of words are combined, but the effects of OLD20 were smaller in speeded pronunciation than in lexical decision performance across all of the above three groups of words (Yap & Balota, 2009).

The utility of Levenshtein distance as a measure of orthographic similarity has been shown to be generalisable across orthographies, as evinced by findings in Malay speeded pronunciation that corroborated those in English speeded pronunciation. Reducing OLD20 and PLD20 to a principal component called Levenshtein distance (LD) due to multicollinearity, Binte Faizal (2009) found that LD significantly inhibited speeded pronunciation latencies, i.e., words with further neighbours were slower to be read aloud correctly whereas words with closer neighbours were faster to be read aloud correctly. LD also accounted for greater unique variance than the principal component of neighbourhood size (N). Comparing these effects across tasks, the effect of LD was also found to be stronger in speeded pronunciation than in lexical decision. However, unlike in English where frequency consistently has been shown to have the largest predictive power for speeded pronunciation (e.g. Yap & Balota, 2009), LD had the second largest predictive power (with length having the largest) for Malay speeded pronunciation latencies.

Putting these findings together, LD was able to account for unique variance above and beyond the traditional measures of neighbourhood size across two orthographies of different orthographic depth. In general, the effects of LD indicated words with closer neighbours were faster to be read aloud correctly, i.e., more visually and phonologically confusable words were faster to be read aloud correctly. These facilitatory LD effects possibly reflect the processing characteristics of the sublexical phonological assembly process in dual route models of reading, in which words which are visually similar to many other words are recognised faster as they share more common grapheme-to-phoneme correspondences (Andrews, 1997). Therefore, like length effects, LD effects could be another marker for sublexical processing in visual word processing.

6.2.5 Phonotactic Probability

As discussed in Chapter 5, although phonotactic probability has been more frequently used in spoken word processing, it can be another marker for sublexical processing, and thus, the use of sublexical representations in visual word processing (see Vitevitch, 2003; Vitevitch & Luce, 1998, 1999). Phonotactic probability is included to possibly corroborate evidence from other factors with regards to the sublexical processing of non-Arabic-speaking Qur'anic memorisers. If, like in lexical decision, facilitatory phonotactic probability effects are shown in speeded pronunciation, that would suggest the implicit learning of phonotactic probabilities at the levels of phone and biphone, and thus, the access of these sublexical representations during speeded pronunciation.

6.2.6 Root

There has yet to be a study that has explored non-concatenative root variables such as root frequency and root family size in speeded pronunciation. However, root productivity, or root family size, does facilitate root priming effects in Arabic word recognition beyond shared phonology (Boudelaa & Marslen-Wilson, 2011); roots that are more productive have larger priming effects than roots that are less productive. One can then infer that if, like in lexical decision, our non-Arabic-speaking readers develop root representations through implicit learning and access those representations during visual word processing, they would be sensitive to root variables in speeded pronunciation. Importantly, as discussed earlier in the section on Neighbourhood Density, greater sensitivity to root variables as compared to measures of orthographic similarity such as orthographic N could suggest the salience of the root in lexical organisation that is based on the non-concatenative morphological principles of an orthography instead of orthographic similarity as assumed by extant models of word recognition.

6.3 Overview of Current Study

The goals of this study are two-fold: First, to explore the influence of traditional variables (length, frequency, neighbourhood density) and newer variables (Levenshtein distance, phonotactic probability, and root) on the speeded pronunciation of non-Arabic-speaking Qur'anic memorisers; second, to examine individual differences in the influence of these factors on speeded pronunciation by looking at whether Qur'an vocabulary knowledge (QVT) and amount of Qur'an memorisation (MemScore) interact with these factors in two- and three-way interactions, thereby teasing apart the possibly differential roles of vocabulary knowledge and print exposure in visual word processing.

6.3.1 Research Questions

The current study aimed to investigate the following research questions:

5. How does length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root influence speeded pronunciation latencies and accuracy?
6. Does amount of Qur'an memorisation (MemScore) modulate the effects of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root on speeded pronunciation latencies and accuracy?
7. Does Qur'an vocabulary knowledge (QVT) modulate the effects of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root on speeded pronunciation latencies and accuracy?
8. Do amount of Qur'an memorisation (MemScore) and Qur'an vocabulary knowledge (QVT) interact together in modulating the effects of length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root on speeded pronunciation latencies and accuracy?

6.3.2 Predictions

Given the psycholinguistic characteristics of Qur'anic Arabic and the linguistic input received by our non-Arabic-speaking Qur'anic memorisers, the following predictions can be made by extrapolating findings from other transparent orthographies with simple syllabic structures. Furthermore, like Malay and Serbo-Croatian, there would be a greater reliance on sublexical processing, especially in speeded pronunciation as compared to lexical decision as the consistent grapheme-to-phoneme correspondences of Qur'anic Arabic allows words to be read aloud accurately without knowing its meaning.

First, based on previous findings in Malay and other transparent orthographies, we predict significant effects of length and frequency in opposite directions; longer words would be slower to be read aloud correctly whereas words that occur more frequently in print would be faster to be read aloud correctly. We also predict facilitatory neighbourhood density and inhibitory Levenshtein distance effects; words with more neighbours and words with more closer neighbours would be faster to be read aloud correctly. For the newer variables such as phonotactic probability and root, we also predict facilitatory effects, given the findings from other related studies. However, we predict that root will have the smallest predictive power (if any), as it may not be a salient unit of processing for our non-Arabic-speaking participants. More importantly, given that the task biases sublexical processing, especially for transparent orthographies, we predict that length effects would be larger than frequency effects on speeded pronunciation, thus supporting the notion of a greater reliance on sublexical processing or the sublexical pathway in dual-route models as well as the adaptation to a smaller grain size of processing as predicted by both the ODH and PGST.

Second, despite Baluch's (1996) finding of print exposure resulting in larger frequency effects in speeded pronunciation, we predict differently for our population given the nature of the task; the more Qur'an memorised, the more experience one has with reading aloud, the more automatized and efficient the processes of decoding and reading aloud become, the less influenced one would be by lexical variables such as frequency. However, this may mean a greater reliance on sublexical processing, and therefore, those who have memorised more may be more influenced by markers of sublexical processing such as length or Levenshtein distance.

Third, based on the premise that vocabulary knowledge helps to make lexical processing more automatized and efficient, and thus, be less influenced by lexical characteristics of words, we predict that if there is an interaction, more vocabulary knowledge will result in smaller effects of lexical variables such as frequency on speeded pronunciation.

Last, any predictions with regards to the three-way interactions among amount of memorisation, vocabulary knowledge, and lexical effect will have to be speculative as this is the first study to explore such interactions. However, given that both vocabulary knowledge and amount of memorisation contribute to separate components (semantic and orthographic/phonetic respectively) in developing the quality of lexical representations, and thus, efficacy for accessing those representations, we expect significant three-way interactions to show that those with more memorisation and more vocabulary knowledge to be less influenced by lexical effects in speeded pronunciation than participants with more memorisation and less vocabulary knowledge or less memorisation and more vocabulary knowledge.

6.4 Method

6.4.1 Participants

A group of 73 participants (40 females; M_{age} = 18.22; SD_{age} = 8.27) were sampled from a *tahfiẓ* (memorising) school, two madrasahs (religious school; non-memorising), and the general public. All of them were at least Malay-English/English-Malay bilinguals with normal or corrected-to-normal vision and were either in upper secondary or polytechnic in terms of education. None of them had any history of hearing loss, reading or speech disorders. Written consent to take part in the study was obtained from either the participants themselves or from their guardians if they were a minor. Participants received a small token of appreciation for their participation. The study was approved by the Newcastle University Faculty of Humanities and Social Sciences Ethics Committee.

6.4.2 Individual-level Measures

As the individual-level measures used in this study were identical to the ones used in the previous study (Chapter 5), only a brief description of the measures will be given. Figure 6-1 presents a scatterplot between both individual-level measures (Qur'an vocabulary knowledge and amount of Qur'an memorisation).

6.4.2.1 Qur'an Vocabulary Test (QVT)

The Qur'an Vocabulary Test (QVT) is a 90-item multiple-choice standardised test used to measure Qur'an vocabulary knowledge, with items ranked in the order of the easiest to the most difficult based on norms derived from a pilot sample (see Chapter 4). Modelled after the Shipley Vocabulary Test (Shipley, 1940) and Malay Vocabulary Test (Binte Faizal, 2009), participants were asked to choose from four options the English word that best corresponded to the meaning of the Arabic word (see Appendix D). Participants from the experimental sample scored between 17 and 72 out of a maximum score of 90 (*M* = 45.86, *SD* = 13.50).

6.4.2.2 Self-reported Qur'an Memorisation Score (MemScore)

To measure amount and fluency of Qur'an memorisation, participants were asked to rate how fluently they can recite from memory each of the 114 *surahs* (chapters) in the Qur'an on a scale of 1 to 9 (1 = "very poor, a lot of errors", 9 = "very fluent, no errors"). For *surahs* they had not memorised at all, they were instructed to select the option "N/A (Haven't memorised at all)", which was then coded as "0" for data analysis. This means that someone who has fully memorised the entire Qur'an and can recite it fluently from memory in its entirety, i.e., a *hafiẓ*, would get the maximum self-reported Qur'an memorisation score (MemScore) of 1026. Participants from the experimental sample self-reported a range of memorisation scores from 21 to 948 (*M* = 428.42, *SD* = 234.82).

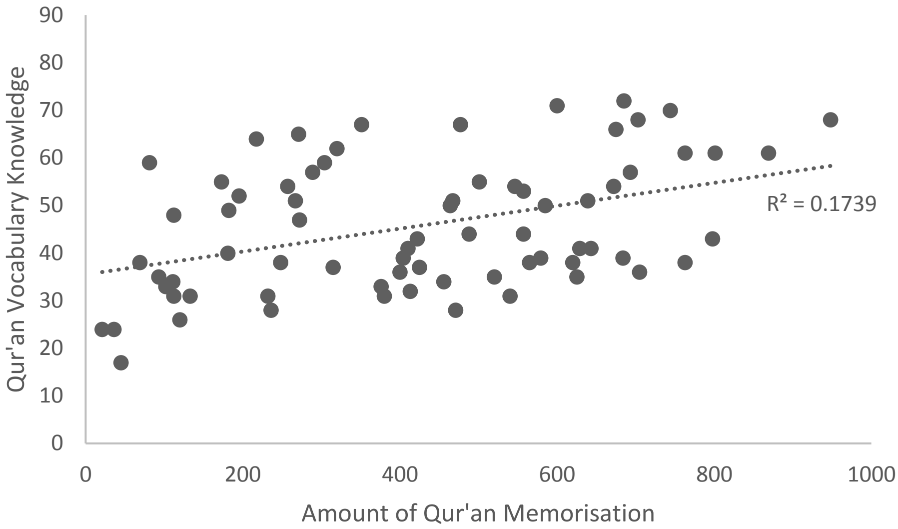

Figure 6-1. Scatterplot of Qur’an vocabulary knowledge as a function of amount of Qur’an memorisation of participants in the speeded pronunciation task.

6.4.3 Item-level Variables

As the item-level variables (i.e., surface variables, lexical variables, and distance variables) used in this study were identical to the ones used in the previous study (Chapter 5), only the descriptive statistics of the variables will be given (see Table 6-1).

Table 6-2 presents all the inter-correlations between the item-level predictors being examined. As can be seen in Table 6-2, similar to the lexical decision stimuli, there is evidence of extremely high correlations between number of characters, number of phones, and number of syllables, between log(orthographic frequency) and log(phonetic frequency), as well as between Levenshtein orthographic and phonological distance, all *r*s ≥ .70. These high correlations are problematic for regression analyses, especially in the issue of multicollinearity, which occurs when two or more independent variables are highly inter-correlated (see Binte Faizal, 2009; Davies et al., 2017; Yap et al., 2012). A possible solution, which is described later, is to identify groups of similar variables using a principal component analysis.

Table 6-1. *Descriptive statistics for item-level variables for speeded pronunciation stimuli (N = 125).*

	M	*SD*	*Min*	*Max*
Number of Characters	4.128	1.414	2.000	8.000
Number of Phones	6.664	2.200	3.000	13.000
Number of Syllables	2.992	1.066	1.000	6.000
Orthographic Item Frequency	23.032	39.816	1.000	323.000
Log(Orthographic Item Frequency)	1.040	.548	.301	2.511
Phonetic Item Frequency	21.152	41.831	1.000	323.000
Log(Phonetic Item Frequency)	.960	.557	.301	2.511
Root Frequency	294.472	460.897	1.000	2851.000
Log(Root Freq)	2.085	.643	.301	3.455
Root Family Size	27.008	19.782	1.000	84.000
Orthographic N (ON)	1.480	1.726	.000	7.000
Phonological N (PN)	2.712	2.577	.000	14.000
Orthographic Levenshtein Distance (OLD20)	2.236	1.247	1.000	7.300
Phonological Levenshtein Distance (PLD20)	1.842	.995	1.000	5.750
Positional Segment Average	.125	.051	.025	.257
Positional Segment Sum	.803	.325	.100	1.565
Biphone Average	.013	.009	.000	.052
Biphone Sum	.073	.047	.001	.204

Table 6-2. *Correlations between item-level predictors in speeded pronunciation*[5].

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	No. of Characters	-												
2	No. of Phones	.849	-											
3	No. of Syllables	.819	.955	-										
4	Log(Orthographic Frequency)	-.406	-.461	-.423	-									
5	Log(Phonetic Frequency)	-.377	-.476	-.407	.923	-								
6	Log(Root Frequency)	-.080	-.122	-.101	.467	.455	-							
7	Root Family Size	.073	.093	.086	.126	.076	.663	-						
8	Orthographic N	-.405	-.418	-.419	.442	.396	.259	.056	-					
9	Phonological N	-.408	-.522	-.488	.394	.422	.269	.049	.521	-				
10	OLD20	.774	.800	.801	-.542	-.480	-.259	-.040	-.598	-.507	-			
11	PLD20	.720	.793	.791	-.609	-.535	-.404	-.150	-.524	-.635	.912	-		
12	Positional Segment Average	-.388	-.224	-.208	-.021	-.020	-.045	-.055	.165	.405	-.300	-.345	-	
13	Biphone Average	-.071	.001	-.049	-.128	-.121	-.010	.015	.077	.261	-.116	-.167	.635	-

[5] Correlations greater than .7 are in red text.

6.4.4 Stimuli

The target stimuli for the speeded pronunciation task consisted of 125 orthographic items that were selected from the Qur'an Lexicon database (Binte Faizal et al., 2015; see also Chapter 3). The full list of stimuli can be found in Appendix F.

Stimulus presentation was controlled by PsychoPy software (Peirce, 2007) running on a laptop with Windows 7. Verbal data responses were recorded by a recording software Audacity 2.1.1 (Audacity-Team, 2015) via an ATR2500-USB audio-technica® condenser microphone.

6.4.5 Procedure

Similar to the lexical decision study in Chapter 5, in the first session, participants were tested either in person or online—they were asked to complete an online questionnaire detailing their demographics and language background information as well as their experience with Qur'an recitation and memorisation. They were then asked to complete the Qur'an vocabulary test online. The entire session took about 30 minutes.

In the second session, participants were tested individually in person in a quiet room. After keying in their participant number into the system, they received written instructions in English to perform a speeded pronunciation task. English was chosen as it was the language of instruction for all participants; not all participants would have understood instructions in Arabic otherwise. In this task, they were instructed to read the target word in Arabic aloud into the microphone as fast and as accurately as possible, after which they press the "/" key if they think they responded correctly or the "z" key if they think they responded incorrectly. Participants were given ten practice trials before beginning the experiment.

For the experiment, 125 experimental trials were presented in random order within five blocks of 25 trials each; each target was presented only once. Each block of 25 trials was followed by a rest break which was three minutes long, although participants were given the option to shorten the break if they wished to continue. Every trial started with the presentation of a centred fixation point (“+”) for 500 ms, followed by a “beep” for 500 ms. This was then immediately followed by the presentation of the target stimulus, centred on the screen. The target stayed on the screen until the participant pressed either the “/” key or the “z” key to go to the next trial. The inter-trial interval was 500ms.

The experiment took approximately 10 minutes long. At the end of the experiment, participants received a small token of appreciation for their participation, were debriefed, and thanked for their help.

6.5 Data Analysis

6.5.1 Dependent Variables

Accuracy of participants’ responses was checked offline by the experimenter via the voice recordings and were coded in two ways: 1) *Whole word accuracy*, where “1 = correct pronunciation of the target item” and “0 = incorrect pronunciation of the target item”; 2) *Phone accuracy*, which is the proportion of total phones of the target item correctly pronounced. The former is the *de facto* measure of accuracy for speeded pronunciation tasks (e.g. Balota et al., 2004; Balota et al., 2007; Yap & Balota, 2009; Yap et al., 2012) but is a rather coarse-grained measure of accuracy (see Edwards et al., 2004, for a discussion on coding responses). As this is typically the third or fourth language of the participants, *phone accuracy* was added as a finer-grained measure of accuracy. A sample of responses were checked by a phonetician to ensure that the experimenter was coding the accuracy of responses correctly.

To obtain reaction times, a command [Sound: To TextGrid (silences)] in Praat 5.4.16 (Boersma & Weenink, 2015) was first run on all audio files to mark the boundaries between the waveforms for the beep and verbal response in each trial. These segmental boundaries were then manually corrected for precision and labelled by the experimenter. Visual waveform inspections allow for a much more accurate determination of response time as compared to the use of voice keys, which has technical limitations including phonetic biases (Kessler et al., 2002). Reaction times were measured in milliseconds from the onset of the beep plus 500 ms (i.e., stimulus onset) to the onset of the verbal response. The onset of the beep was used instead of the offset as it was clearer and easier to mark than the offset. To ensure inter-rater reliability, the segmental boundaries of 2125 trials (17 participants; 23% of total trials) were also manually corrected for precision by a research assistant. A pairwise Pearson's correlation was calculated as a measure of inter-rater reliability between the two segmenters and it was found to be very high, $r = .991$, $p < .01$.

6.5.2 Data Cleaning

6.5.2.1 Participants

To ensure that the accuracy of participants in the task was reliably above chance, calculations based on the binomial distribution showed that participants would have to get 72 out of 125 trials (57.20%) correct to be performing above chance at $p < .05$. 4 participants were excluded from the data as their task accuracy was below 57.20%, leaving a total of 69 participants.

No other participants were removed based on phone accuracy as all the participants had a mean phone accuracy of greater than 65%.

6.5.2.2 Trials

63 trials were removed as there were no responses due to technical errors. To ensure that the accuracy of responses on items was reliably above chance, calculations based on the binomial distribution showed that at least 44 out of 73 participants (60.27%) had to get a particular item correct for the item's accuracy to be above chance at $p < .05$. 4 items were thus excluded from the data, leaving a total of 121 items.

No other items were removed based on phone accuracy as every item had a mean phone accuracy of greater than 90%.

Typical data cleaning methods used for reaction time (RT) data in speeded pronunciation tasks (e.g. Balota et al., 2004; Binte Faizal, 2009; Yap & Balota, 2009) were then followed to exclude extreme responses that may affect the analyses. First, trials with incorrect responses as well as trials that were faster than 200ms were excluded from all RT analyses (14.28% of trials). The upper cut off limit of 3000 ms that was used in lexical decision were not followed here as it was found that participants generally took a longer time to do the speeded pronunciation task than the lexical decision task; from the remaining trials, only trials that were 2.5 standard deviations above or below each participant's mean RT were excluded instead (1.99% of trials). In total, 16.28% of speeded pronunciation trials were removed and the remaining trials were used in RT analyses. Table 6-3 shows the group's overall RT, whole word accuracy, and phone accuracy in speeded pronunciation for words and nonwords.

Table 6-3. *Overall RT, accuracy, and phone accuracy in speeded pronunciation.*

	M (SD)
RT (ms)	782 (478)
Whole Word Accuracy (%)	85.72 (34.99)
Phone Accuracy (%)	97.88 (7.57)

6.5.3 Principal Component Analysis of Lexical Variables

Before performing any regression analyses, it was important to take note of the extremely high inter-correlations between the lexical variables (e.g., *r*s > .700 between syllable, phoneme, and character counts) due to the one-to-one grapheme-to-phoneme correspondences of Qur'anic Arabic. To prevent any potential problems of multicollinearity and suppression (brought about by high inter-correlations between predictor variables) occurring during regression analyses, a principal component analysis of the item-level variables was used to statistically regroup the lexical variables into several main components for future regression analyses (see Baayen et al., 2006).

Similar to what was done in Chapter 5 for lexical decision, a preliminary exploratory principal component analysis was performed with the 13 item-level variables: number of characters, number of phonemes, number of syllables, log(orthographic frequency), log(phonetic frequency), log(root frequency), root family size, positional segment average, biphone average, orthographic and phonological N, as well as orthographic and phonological Levenshtein distance (OLD20 and PLD20). The Kaiser-Meyer-Olkin measure of sampling adequacy for the 13 variables was .751 and the Bartlett's Test of Sphericity was significant, χ^2 (78) = 1572.51, $p < .001$, indicating that a principal component analysis could be conducted. A principal components extraction method using varimax rotation with Kaiser normalisation was employed and the interpretation was based on the rotated component matrix. As one would theoretically expect six constructs (length, frequency, phonotactic probability, root, neighbourhood density, and Levenshtein distance) from these 13 item-level variables, an extraction of six principal components was specified and the maximum iterations for convergence was set to 25. Coefficients below .40 were also suppressed and not shown in the matrix; items with coefficients below .40 were thus not interpreted.

Unlike the principal component analysis in lexical decision (Chapter 5), the principal component analysis here extracted six components that separated orthographic and phonological neighbourhood density into different components while number of characters, number of phones, number of syllables, as well as orthographic and phonological Levenshtein distance loaded onto the same component (see Table 6-4). This difference in PCA components between the two tasks was unexpected as *t*-tests comparing each of the 13 item-level variables in both tasks showed that both tasks did not significantly differ on any of the 13 item-level variables. However, comparing the correlations between item-level predictors across both tasks, orthographic Levenshtein distance appeared to have slightly higher correlations with number of characters (SP: $r = .774$ vs. LDT: $r = .733$), number of phones (SP: $r = .800$ vs. LDT: $r = .717$), and number of syllables SP: $r = .801$ vs. LDT: $r = .734$) in speeded pronunciation than in lexical decision (see Table 5-2 and Table 6-2). Although phonological Levenshtein distance had a lower correlation with number of characters in speeded pronunciation than in lexical decision (SP: $r = .720$ vs. LDT: $r = .754$), it had slightly higher correlations with number of phones (SP: $r = .793$ vs. LDT: $r = .760$)

and number of syllables SP: r = .791 vs. LDT: r = .765) in speeded pronunciation than in lexical decision (see Table 5-2 and Table 6-2). This could explain why these variables loaded onto the same component for speeded pronunciation and not for lexical decision.

For the sake of parsimony, a second principal component analysis was carried out using varimax rotation with Kaiser normalisation and an extraction of five principal components was specified while the maximum iterations for convergence was set to 25. With Eigenvalues ranging from .584 to .948, the five principal components explained 87.48% of the variance. Table 6-5 presents the rotated component matrix with the five principal components. These components (1 to 5) were converted into the five lexical predictors in the following order: length/LD (number of letters, number of phones, number of syllables, OLD20, and PLD20), frequency (orthographic and phonetic), phonotactic probability (positional segment average and biphone average), root (root frequency and root family size), and neighbourhood density (orthographic and phonological).

It is worth noting that although the loading of length and Levenshtein distance variables onto one principal component in this principal component analysis was unexpected and differed from that done for lexical decision in Chapter 5 as well as from the analysis by Binte Faizal (2009), it was similar to the results from the principal component analysis done for multisyllabic English words by Yap and colleagues (2012). Similar to the principal component analysis done here, Yap et al.'s (2012) principal component analysis, which had also employed varimax rotation with Kaiser normalisation, had number of letters, number of syllables, OLD20, PLD20, and number of morphemes loaded on the first component. Mirroring their interpretation of the extracted principal components, our first principal component (Length/LD) appears to capture the structural properties of words. Furthermore, they suggested that based on the dual-route perspective, the first principal component (Length/LD) appears to reflect the sublexical properties of words whereas the second principal component (Frequency) reflects lexical or whole-word properties. Therefore, the principal components extracted from this analysis are reliable, interpretable, and can be used in future analyses; factor scores were then saved as variables via the regression method so that they could be used as fixed effects in subsequent mixed effects regression analyses. The implications of using different principal components in both tasks on interpreting any comparisons of findings across both tasks will be discussed in Chapter 8.

Table 6-4. *Initial rotated component matrix of principal component analysis with six components extracted.*

	Principal Components					
	1	2	3	4	5	6
Character Count	.899					
Phone Count	.930					
Syllable Count	.933					
Log(Orthographic Frequency)		.894				
Log(Phonetic Frequency)		.915				
Log(Root Frequency)				.834		
Root Family Size				.948		
ON					.897	
PN						.835
OLD20	.826					
PLD20	.780					
Positional Segment Average			.866			
Biphone Average			.910			

Table 6-5. *Final rotated component matrix of principal component analysis with five components extracted.*

	Principal Components				
	Length/LD	Frequency	Phonotactic Probability	Root	Neighbourhood Density
Character Count	.897				
Phone Count	.931				
Syllable Count	.934				
Log(Orthographic Frequency)		.884			
Log(Phonetic Frequency)		.918			
Log(Root Frequency)				.833	
Root Family Size				.948	
ON					.886
PN					.584
OLD20	.821				
PLD20	.779				
Positional Segment Average			.872		
Biphone Average			.899		

6.5.4 Mixed Effects Regression Analyses

The purpose of these analyses was to investigate factors that influence the response latencies and accuracy of speeded pronunciation in our non-Arabic-speaking Qur'anic memorisers. For RT analyses, given that RT data in general is positively skewed, an inverse transformation[6] of the cleaned RT data was performed to normalise the RT distribution and not violate the assumptions of normality and linearity of residuals needed for linear regression analyses. All data were used for accuracy analyses. A mixed effects regression analysis of the three main dependent variables (RT, whole word accuracy, and phone accuracy) for speeded pronunciation were then conducted separately using R (R Core Team, 2016) and *lmerTest* (Kuznetsova et al., 2017) with maximum likelihood.

6.5.4.1 Response Latencies

Fitting the random effects structure. The mixed effects model used in analysing response latencies included random intercepts for both participant and stimuli, as well as random slopes for each principal component (length/LD, frequency, neighbourhood density, phonotactic probability, and root) varying by participant, using a maximal random effects structure as recommended by Barr et al. (2013). This is because we expected these effects to vary across individuals. Furthermore, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for each effect varying by participant into the model improved the model fit and accounted for a significant amount of the random variance, $\chi^2(20) = 98.15$, $p < .001$.

Covariates. For this analysis, the following covariates were standardised using z-scores: age and trial order number. Onset was sum coded so that the analysis would show effects on RTs averaged across onsets. Sex was initially

[6] An inverse transformation was selected instead of a log transformation like in lexical decision as Q-Q plots indicated that the inverse transformed data for speeded pronunciation fitted a normal distribution better than the log transformed data. Only the analyses from the inverse RT models were reported in this chapter as the inverse transformation ameliorated the skew in the raw RT distribution the best compared to other transformations, rendering the distribution closest to a normal distribution. However, models with log transformed RT data were also fitted for parity with the lexical decision data analyses in Chapter 5; the estimated effects from these models can be found in Appendix H.

included in a preliminary model but was not significant, $\chi^2(1) = .640$, *ns.*, so it was excluded from the full model for parsimony.

Fixed effects. In terms of main effects, the model included all five principal components (length/LD, frequency, neighbourhood density, phonotactic probability, and root), as well as *z*-scored memorisation and *z*-scored vocabulary knowledge. In terms of interactions, the model included the three-way interactions between memorisation, vocabulary knowledge, and each principal component, as well as their subsumed two-way interactions, i.e., memorisation × vocabulary knowledge, memorisation × principal component, and vocabulary knowledge × principal component.

A linear mixed effects regression analysis was then conducted using the 'lmer()' function in the 'lmerTest' package (Kuznetsova et al., 2017) and with maximum likelihood, running the model as follows:

```
Model_SP <- lmer(Inverse(RT) ~ (1 + Length_LD + Freq + N + Root
    + PP|participant) + (1|stimuli)
    + Onset + Trial Order Number + Age
    + MemScore + QVT
    + Length_LD + Freq + N + PP + Root
    + MemScore:QVT
    + MemScore:Length_LD + MemScore:Freq + MemScore:N
    + MemScore:PP + MemScore:Root
    + QVT:Length_LD + QVT:Freq + QVT:N + QVT:PP + QVT:Root
    + MemScore:QVT:Length_LD + MemScore:QVT:Freq +
    MemScore:QVT:N + MemScore:QVT:PP + MemScore:QVT:Root,
    data = all, REML = F, control=lmerControl(optimizer = "bobyqa",
    optCtrl=list(maxfun=1e6)))
```

As mentioned in Chapter 5, *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question.

6.5.4.2 Whole Word Accuracy

Fitting the random effects structure. Similar to response latencies, the mixed effects model for whole word accuracy included random intercepts for both participant and stimuli, as well as random slopes for each principal component varying by participant, using a maximal random effects structure as recommended by Barr et al. (2013). This is because we expected these effects to vary across individuals. However, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for each effect varying by participant into the model neither improved the model fit nor accounted for a significant amount of the random variance, $\chi^2(20) = 5.863$, *ns*. The random-intercepts-only model was thus used for the final full model.

Covariates. For this analysis, the same covariates used in the RT analyses were initially included in a preliminary model: *z*-scored age, z-scored trial order number, as well as sum-coded onset and sex. However, preliminary analyses showed that the effects of trial order number, onset, age, and sex on RTs were not significant and removing them from the full model did not affect model fit, $\chi^2(30) = 30.192$, *ns.*, therefore they were excluded from the full model for parsimony.

The same fixed effects used in the previous model for RTs were also used in the fitting of the full model. However, as the dependent variable (whole word accuracy) is a binary response, a mixed effects logistic regression analysis was conducted instead using the 'glmer()' function in the lme4 package (D. M. Bates et al., 2015) and a binomial distribution was selected, running the model as follows:

```
Model_WholeWord_Accuracy <- glmer(WholeWord Accuracy ~ (1|participant)
        + (1|stimuli)
        + MemScore + QVT
        + Length_LD + Freq + N + PP + Root
        + MemScore:QVT
        + MemScore:Length_LD + MemScore:Freq + MemScore:N
        + MemScore:PP + MemScore:Root
        + QVT:Length_LD + QVT:Freq + QVT:N + QVT:PP + QVT:Root
        + MemScore:QVT:Length_LD + MemScore:QVT:Freq
        + MemScore:QVT:N + MemScore:QVT:PP + MemScore:QVT:Root,
        data = all, control=glmerControl(optimizer = "bobyqa",
        optCtrl=list(maxfun=1e6)), family="binomial")
```

6.5.4.3 Phone Accuracy

Fitting the random effects structure. Similar to previous analyses, the mixed effects model for phone accuracy included random intercepts for both participant and stimuli, as well as random slopes for each principal component varying by participant, using a maximal random effects structure. This is because we expected these effects to vary across individuals. Furthermore, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for each effect varying by participant into the model improved the model fit and accounted for a significant amount of the random variance, $\chi^2(20) = 68.483$, $p < .001$.

Covariates. Similar to whole word accuracy analyses, the same covariates used in the RT analyses were initially included in a preliminary model: z-scored age, z-scored trial order number, as well as sum-coded onset and sex. However, preliminary analyses showed that the effects of trial order number, onset, and sex on RTs were not significant and removing them from the full model did not affect model fit, $\chi^2(29) = 29.187$, *ns.*, therefore they were excluded from the full model for parsimony.

The same fixed effects used in the previous model for whole word accuracy were also used in the fitting of the full model. However, although the dependent variable (phone accuracy) followed a binomial distribution like whole word accuracy, it was specified as a proportion between 0 and 1. A mixed effects logistic regression analysis was then conducted using the ‘glmer()’ function in the lme4 package (D. M. Bates et al., 2015) and a binomial distribution was selected with ‘total phone count of target’ specified as the ‘weight’ that gave the total number on which the proportion was based. For example, phone accuracy of .8 and a weight of 10 would be the same as 8 ‘successes’ and 2 ‘failures’ in binomial terms. The model was then run as follows:

```
Model_Phone_Accuracy <- glmer(Phone Accuracy ~ (1 + Length_LD + Freq
        + N + Root + PP|participant) + (1|stimuli)
        + Age
        + MemScore + QVT
        + Length_LD +Freq + N + PP + Root
        + MemScore:QVT + MemScore:Length_LD + MemScore:Freq
        + MemScore:N + MemScore:PP + MemScore:Root
        + QVT:Length_LD + QVT:Freq + QVT:N + QVT:PP + QVT:Root
        + MemScore:QVT:Length_LD + MemScore:QVT:Freq
        + MemScore:QVT:N + MemScore:QVT:PP + MemScore:QVT:Root,
        data = all, control=glmerControl(optimizer = "bobyqa",
        optCtrl=list(maxfun=1e6)), family="binomial", weights = PhoneCount)
```

6.6 Results

6.6.1 Response Latencies

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in this model described 63.01% of the variance in RTs; random effects described 40.10% of the variance in RTs while fixed effects described 22.91% of the variance in RTs. Table 6-6 presents the estimated standardised coefficients for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model are described in the following sub-sections[7].

Covariates. As seen in Table 6-6, the following covariates were significant: trial order number and age. Participants were more likely to be faster as they progressed through the speeded pronunciation. Older participants were also more likely to be slower in the task.

Onsets. As in English (e.g. Balota et al., 2004; Balota et al., 2007; Yap & Balota, 2009) and Malay (Binte Faizal, 2009), onsets on the whole significantly affected speeded pronunciation latencies for our participants, $\chi^2(27) = 79.90$, *p* <

[7] It is important to note that the estimated coefficients were based on an inverse transformation of the data, therefore the direction of the effects should be interpreted in the opposite direction of the estimated coefficients.

.001. Figure 6-2 presents the predicted RT for each onset. This will be further discussed later.

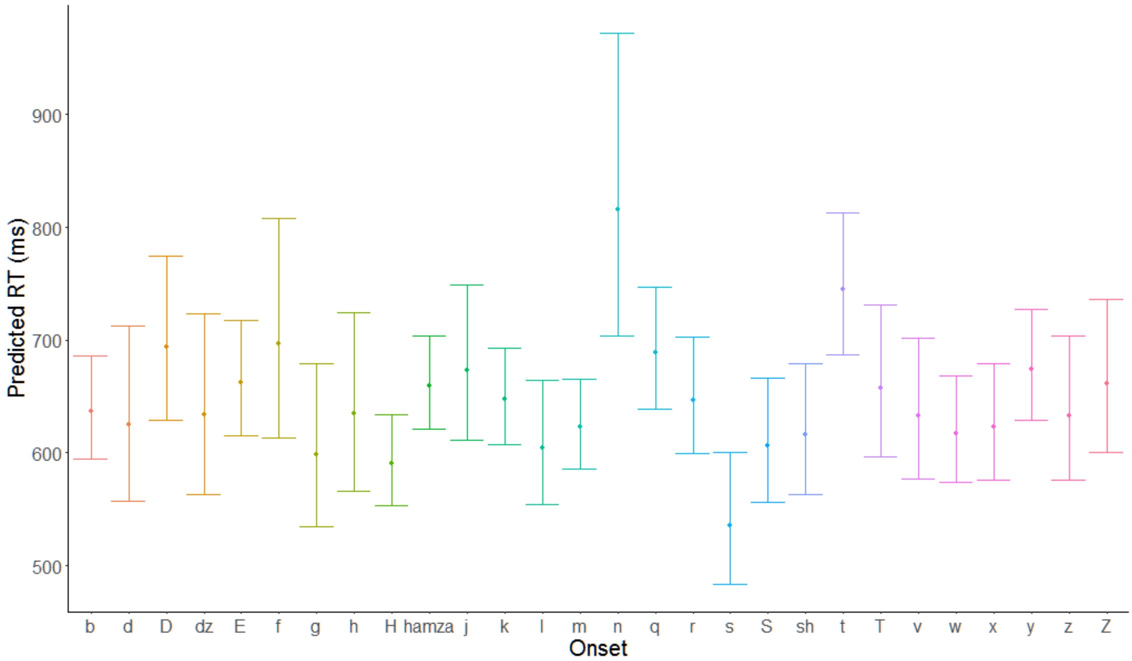

Figure 6-2. Predicted RT (ms) for each onset based on the full linear mixed effects model for speeded pronunciation. Error bars are based on 95% confidence intervals.

Individual-level predictors. Results revealed significant main effects of Qur'an vocabulary knowledge (β = .122, *SE* = .044, $\chi^2(1)$ = 10.988, p < .001) and amount of Qur'an memorisation (β = .088, *SE* = .047, $\chi^2(1)$ = 7.423, p < .01) on RTs after controlling for all other variables. Participants with more Qur'an vocabulary knowledge were more likely to be faster in speeded pronunciation than participants with less Qur'an vocabulary knowledge. Participants who have memorised more of the Qur'an were more likely to be faster in speeded pronunciation than participants who have memorised less of the Qur'an. These main effects will be further interpreted in the context of their two-way and three-way interactions with each item-level predictor.

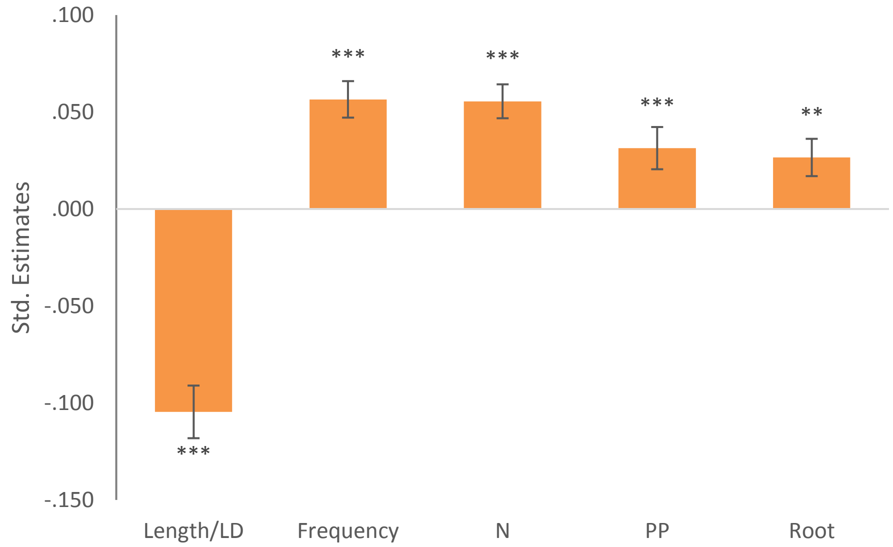

Figure 6-3. Bars represent standardised regression coefficients across item-level predictors for inversed RTs in speeded pronunciation in the full model. Error bars are based on standard error. Asterisks denote significance at the following levels: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Length/LD. After controlling for onsets and other covariates, the principal component of length/LD (number of characters, number of phones, number of syllables, OLD20, and PLD20) was positively associated with speeded pronunciation latencies, $\beta = -.105$, $SE = .014$, $\chi^2(1) = 50.457$, $p < .001$; participants were slower in reading aloud accurately longer word targets as well as word targets with further neighbours than shorter word targets and word targets with nearer neighbours. Figure 6-3 also indicated that the predictive power of length/LD in speeded pronunciation latencies was the largest compared to other lexical variables, especially frequency. Greater length or structural effects compared to frequency effects suggest a greater reliance on the sublexical pathway in visual word processing; this will be further discussed later.

There were also significant two-way interactions between Qur'an vocabulary knowledge and length/LD, $\beta = -.013$, $SE = .009$, $\chi^2(1) = 6.040$, $p < .05$, and between amount of Qur'an memorisation and length/LD, $\beta = -.013$, $SE = .009$, $\chi^2(1) = 6.137$, $p < .05$. Plotting the simple slopes of the two-way interactions showed that participants with more Qur'an memorisation were more likely to be influenced by inhibitory structural (length/LD) effects in speeded pronunciation latencies than participants with less Qur'an memorisation (see

Figure 6-4 where Z(QVT) = 0). Similarly, participants with more Qur'an vocabulary knowledge were more likely to be influenced by inhibitory structural (length/LD) effects in speeded pronunciation latencies than participants with less Qur'an vocabulary knowledge (see Figure 6-4).

Plotting the simple slopes of the three-way interaction among memorisation, vocabulary knowledge, and length/LD shows an interesting trend in that the increase in length/LD effects on RTs as memorisation increases was further augmented by the increase in vocabulary knowledge, to the extent that participants with very high vocabulary knowledge and very high memorisation were predicted to be much more influenced by inhibitory length/LD effects when reading aloud targets in speeded pronunciation accurately than their high vocabulary knowledge counterparts with less memorisation and their high memorisation counterparts with poorer vocabulary knowledge (see Figure 6-4). However, this three-way interaction was not significant, β = .000068, *SE* = .008, $\chi^2(1)$ = 3.883, *ns*.

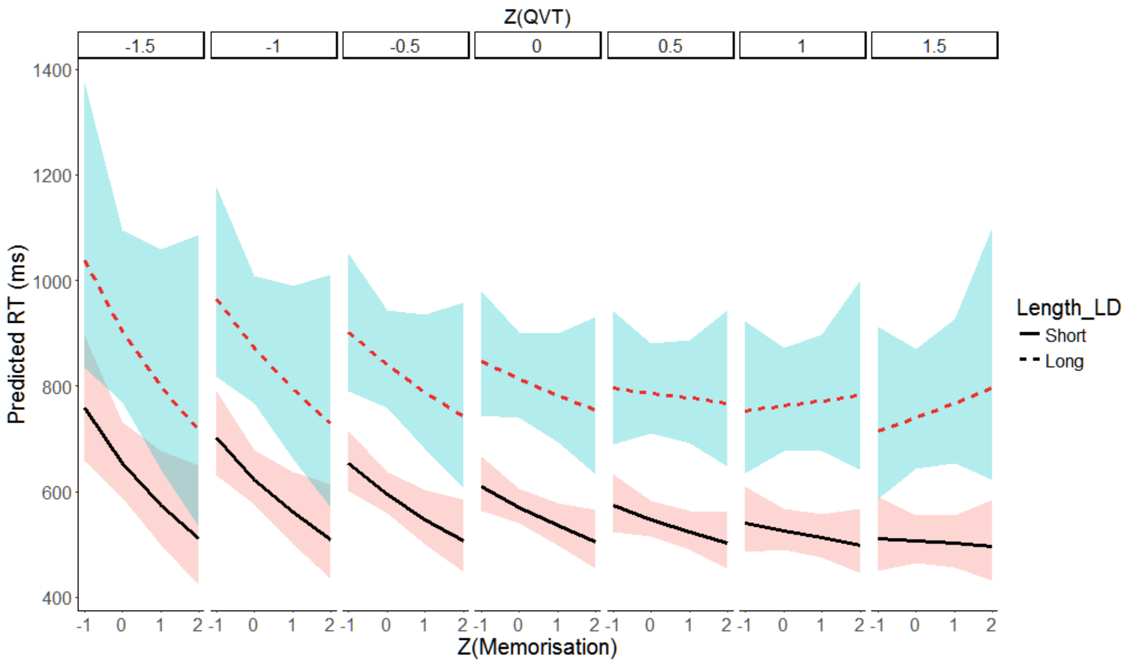

Figure 6-4. Memorisation × Vocabulary Knowledge × Length/LD interaction: Predicted RTs for short targets/targets with closer neighbours (1.5 *SD* below the mean) and long targets/targets with further neighbours (1.5 *SD* above the mean) based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Frequency. After controlling for onsets and other covariates, the principal component of item frequency (orthographic and phonetic) significantly predicted speeded pronunciation latencies, with shorter latencies for more frequent targets, $\beta = .057$, $SE = .009$, $\chi^2(1) = 31.607$, $p < .001$. As mentioned earlier, in terms of the predictive power of the variables in RTs, Figure 6-3 indicated that length/LD had the largest predictive power compared to other components, especially frequency. Although greater length effects compared to frequency effects indicate a greater reliance on the sublexical pathway in language processing, the presence of frequency effects as the second largest predictor in RTs suggests that participants do not rely solely on the sublexical pathway when processing Qur'anic Arabic words visually; both lexical and sublexical pathways are in use concurrently, as suggested by the dual-route model and a weak ODH. This will be further discussed later.

There were significant two-way interactions between amount of Qur'an memorisation and frequency, $\beta = -.001$, $SE = .005$, $\chi^2(1) = 4.018$, $p < .05$, as well as between Qur'an vocabulary knowledge and frequency, $\beta = -.007$, $SE = .005$, $\chi^2(1) = 6.366$, $p < .05$. Plotting the simple slopes of the Memorisation × Frequency interaction shows that more memorisation was related to smaller frequency effects in facilitating RTs (see Figure 6-5 where Z(QVT) = 0). Similarly, plotting the simple slopes of the Vocabulary Knowledge × Frequency interaction shows that more vocabulary knowledge was related to smaller frequency effects in facilitating RTs (see Figure 6-6 where Z(Memorisation) = 0).

Plotting the simple slopes of the three-way interaction among memorisation, vocabulary knowledge, and frequency shows that the decrease in facilitatory frequency effects on RTs as memorisation increases becomes even more pronounced with the increase in vocabulary knowledge, to the extent that participants with more Qur'an vocabulary knowledge and more Qur'an memorisation were less likely to be influenced by facilitatory frequency effects when reading aloud targets accurately in speeded pronunciation than their high vocabulary knowledge counterparts who had memorised less of the Qur'an and their high memorisation counterparts who had poorer vocabulary knowledge. (see Figure 6-5 and Figure 6-6). However, this three-way interaction was not significant, $\beta = -.005$, $SE = .005$, $\chi^2(1) = 1.158$, *ns*.

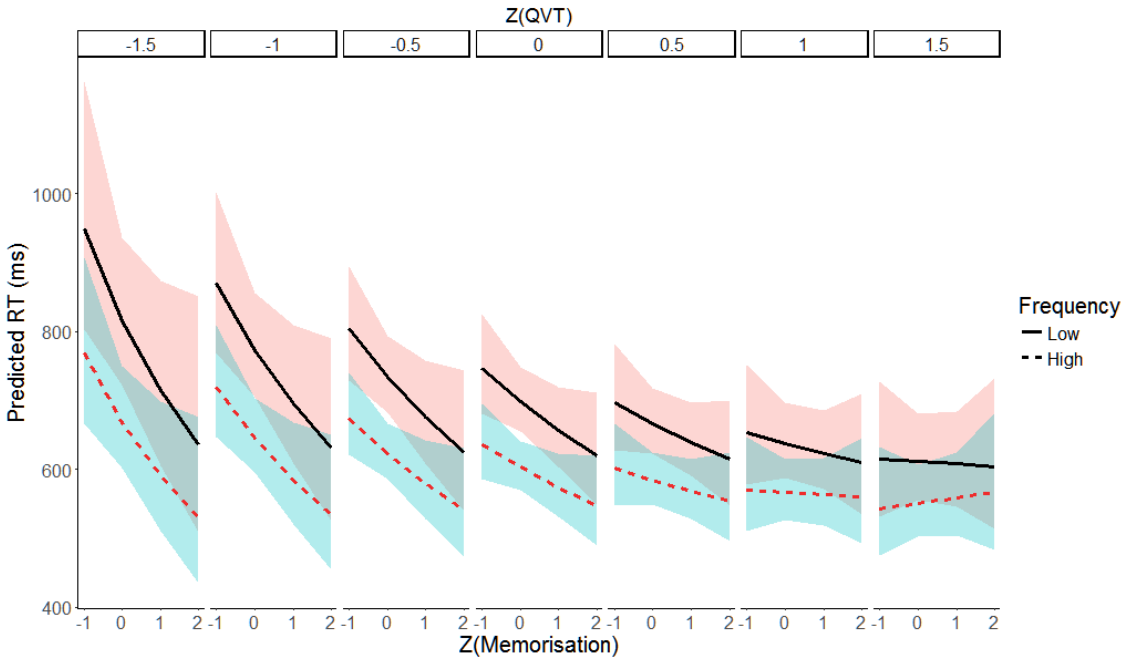

Figure 6-5. Memorisation × Vocabulary Knowledge × Frequency interaction: Predicted RTs for low (1.5 *SD* below the mean) and high frequency (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

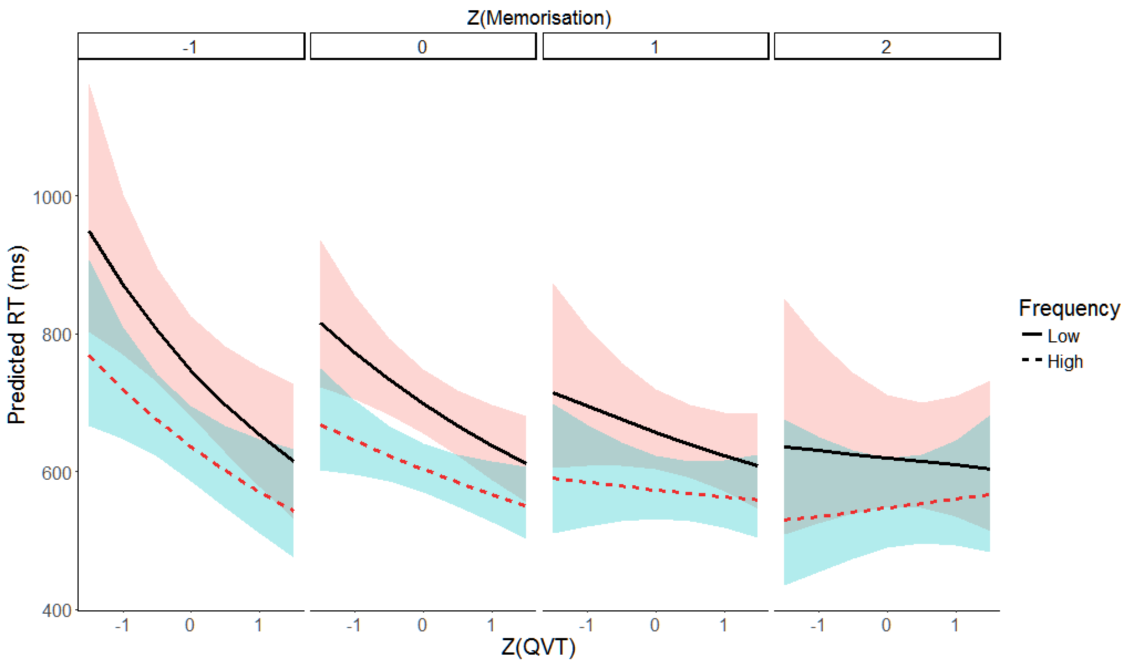

Figure 6-6. Memorisation × Vocabulary Knowledge × Frequency interaction: Predicted RTs for low (1.5 *SD* below the mean) and high frequency (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of Qur'an vocabulary knowledge (QVT) and memorisation *z*-scores. Bands are based on 95% confidence intervals.

Neighbourhood density. After controlling for all other variables, the principal component of neighbourhood density (orthographic and phonological) significantly facilitated speeded pronunciation latencies, $\beta = .056$, $SE = .009$, $\chi^2(1) = 34.937$, $p < .001$; the more orthographic and phonological neighbours a word target has, the faster it takes to be read aloud correctly by participants. In terms of its predictive power, although neighbourhood density has similar predictive power as frequency, it was still a weaker predictor of speeded pronunciation latencies than its length/LD counterpart. This will be further discussed later.

Although there was no significant two-way interaction between amount of Qur'an memorisation and neighbourhood density, $\beta = .003$, $SE = .004$, $\chi^2(1) = .434$, *ns.*, or between Qur'an vocabulary knowledge and neighbourhood density, $\beta = .0004$, $SE = .004$, $\chi^2(1) = .008$, *ns.*, the three-way interaction between amount of Qur'an memorisation, Qur'an vocabulary knowledge, and neighbourhood density was marginally significant, $\beta = -.007$, $SE = .004$, $\chi^2(1) = 2.842$, $p < .1$. Plotting the simple slopes of the three-way interaction showed an interesting trend in which the increase in facilitatory neighbourhood effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 6-7); participants with more Qur'an vocabulary knowledge and more Qur'an memorisation were less likely to be influenced by facilitatory neighbourhood effects when reading aloud targets accurately in speeded pronunciation than their high vocabulary knowledge counterparts who had memorised less of the Qur'an and their high memorisation counterparts who had poorer vocabulary knowledge.

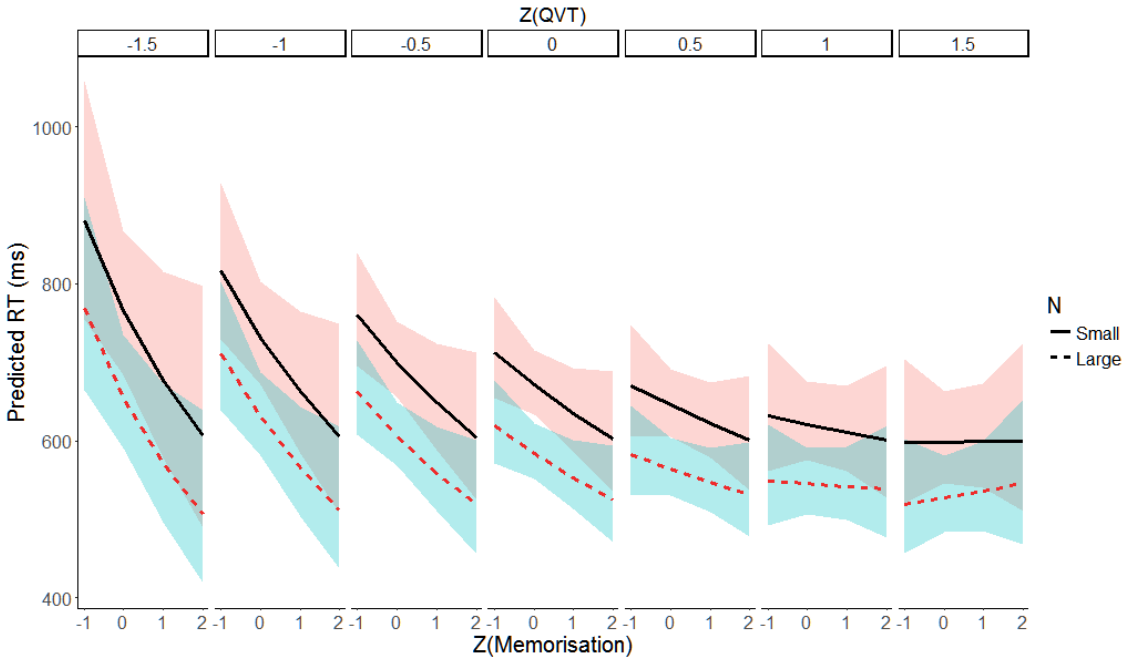

Figure 6-7. Memorisation × Vocabulary Knowledge × Neighbourhood Density interaction: Predicted RTs for small N (1.5 *SD* below the mean) and large N (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Phonotactic probability. After controlling for all other variables, the principal component of phonotactic probability (positional segment average and biphone average) significantly facilitated speeded pronunciation latencies, β = .031, *SE* = .011, $\chi^2(1)$ = 8.086, $p < .01$. Participants were more likely to read aloud correctly targets with higher phonotactic probability faster than targets with lower phonotactic probability.

Although there was no significant two-way interaction between Qur'an vocabulary knowledge and phonotactic probability, β = .002, *SE* = .005, $\chi^2(1)$ = .099, *ns.*, the two-way interaction between amount of Qur'an memorisation and phonotactic probability was significant, β = -.012, *SE* = .006, $\chi^2(1)$ = 8.540, $p < .01$. Plotting the simple slopes of the two-way interaction showed that participants with more Qur'an memorisation were less likely to be influenced by facilitatory phonotactic probability effects when reading aloud targets accurately in speeded pronunciation than participants with less Qur'an memorisation [see Figure 6-8 where Z(QVT) = 0]. This interaction indicated that more memorisation (but not more vocabulary knowledge) was related to smaller phonotactic probability effects in facilitating RTs. However, this two-way interaction must be further interpreted in the context of the significant three-way interaction among memorisation, vocabulary knowledge, and phonotactic probability, $\beta = -.001$, $SE = .005$, $\chi^2(1) = 3.900$, $p < .05$.

Plotting the simple slopes of the three-way interaction showed that the decrease in facilitatory phonotactic probability effects on RTs as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 6-8); participants with more Qur'an vocabulary knowledge and more Qur'an memorisation were less likely to be influenced by facilitatory phonotactic probability effects when reading aloud targets accurately in speeded pronunciation than their high vocabulary knowledge counterparts who had memorised less of the Qur'an but not than their high memorisation counterparts who had poorer vocabulary knowledge.

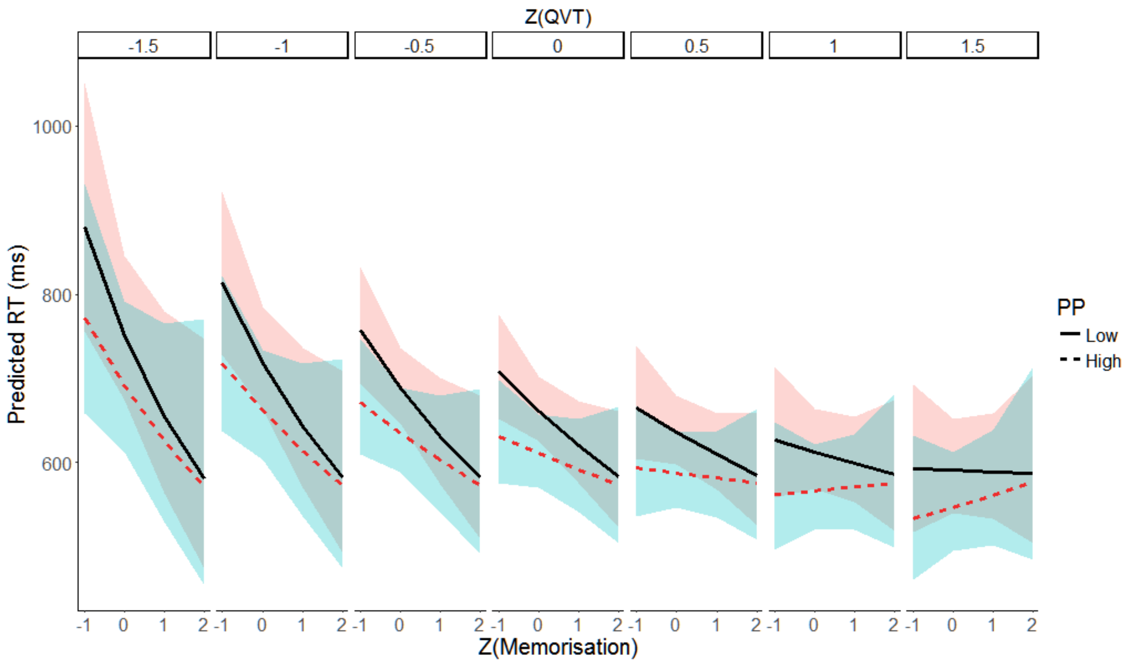

Figure 6-8. Memorisation × Vocabulary Knowledge × Phonotactic Probability interaction: Predicted RTs for low (1.5 *SD* below the mean) and high PP (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Root. After controlling for all other variables, the principal component of root (root frequency and root family size) significantly facilitated speeded pronunciation latencies, β = .027, *SE* = .010, $\chi^2(1) = 7.401$, $p < .01$. Participants were more likely to read aloud accurately targets with higher root frequency and larger root family size faster than targets with lower root frequency and smaller root family size. More importantly, amongst all other principal components, root was the weakest predictor of speeded pronunciation latencies, especially when compared to neighbourhood density. This will be further discussed later.

There were significant two-way interactions between Qur'an memorisation and root, β = -.006, *SE* = .005, $\chi^2(1) = 5.781$, $p < .05$, as well as between Qur'an vocabulary knowledge and root, β = .001, *SE* = .005, $\chi^2(1) = 3.951$, $p < .05$. Plotting the simple slopes of the Memorisation × Root interaction shows that more memorisation was related to smaller root effects in facilitating RTs (see Figure 6-9 where Z(QVT) = 0). However, plotting the simple slopes of the Vocabulary Knowledge × Root interaction shows that more vocabulary knowledge was related to larger root effects in facilitating RTs (see Figure 6-9). However, these two-way interactions must be further interpreted in the context of the significant three-way interaction among memorisation, vocabulary knowledge, and root, β = .001, *SE* = .004, $\chi^2(1) = 3.974$, $p < .05$.

Plotting the simple slopes of the three-way interaction among memorisation, vocabulary knowledge, and root shows that the decrease in facilitatory root effects on RTs as memorisation increases is attenuated with the increase in vocabulary knowledge, to the extent that participants with more Qur'an vocabulary knowledge and more Qur'an memorisation were less likely to be influenced by facilitatory root effects when reading aloud targets accurately in speeded pronunciation than their high vocabulary knowledge counterparts who had memorised less of the Qur'an but they were more likely to be influenced by facilitatory root effects when reading aloud targets accurately in speeded pronunciation than their high memorisation counterparts who had poorer vocabulary knowledge (see Figure 6-9).

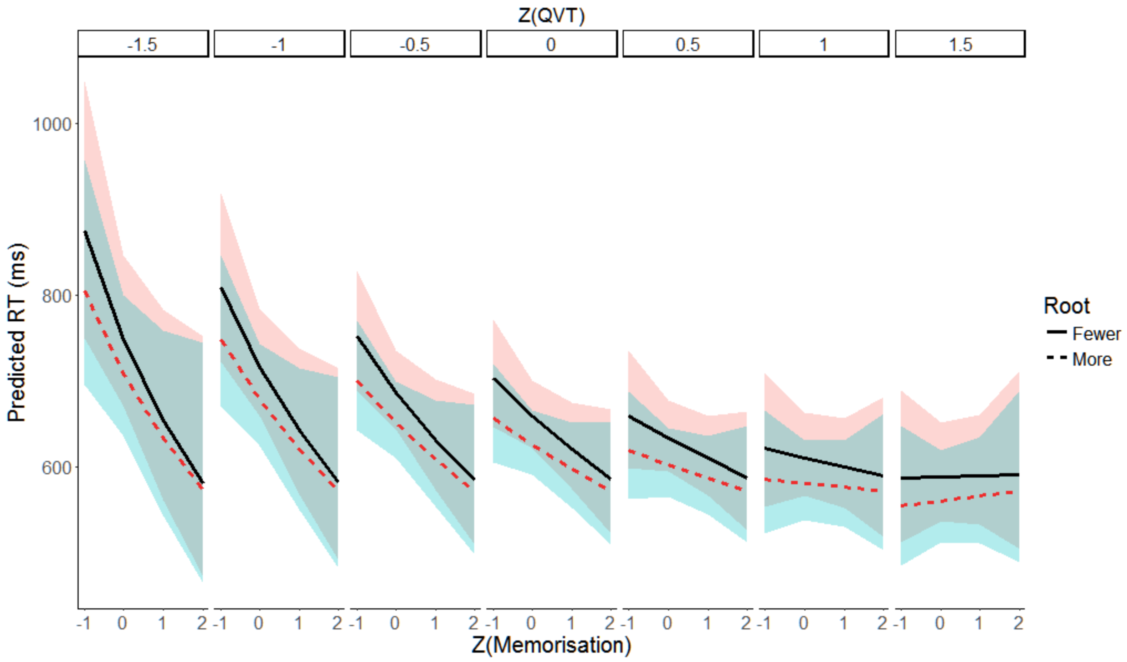

Figure 6-9. Memorisation × Vocabulary Knowledge × Root interaction: Predicted RTs for fewer (1.5 *SD* below the mean) and more Root (1.5 *SD* above the mean) word targets based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

6.6.1.1 Response Latencies (All Data)

Like the RT analyses for lexical decision, there was a considerable exclusion of RT data during the cleaning of the data to ensure that the speeded pronunciation RT analyses provided reliable and interpretable results. To examine the sensitivity of the results to the exclusion of observations, a supplementary analysis was done with all RT data that was more than 200ms as faster latencies typically indicate either a technical or participant error. Table 6-6 presents the estimates for the full linear mixed effects model.

Comparing the findings with those of the cleaned data, there were a few similarities and differences. The analysis with all data indicated that a similar pattern of results as the analysis with cleaned data for all covariates (onsets, trial order number, and age). In terms of main effects for the individual and item-level variables, there was also a similar pattern of results in terms of significance and the direction of the effects. However, in terms of two-way interactions, unlike the analysis with cleaned data, there were no longer significant interactions of Qur'an memorisation with the following principal components: frequency and root.

Nonetheless, the two-way interactions of Qur'an memorisation with length/LD and phonotactic probability respectively remained significant like in the analysis with cleaned data. Unlike the analysis with cleaned data, there were also no longer significant two-way interactions of Qur'an vocabulary knowledge with the following principal components: length/LD, frequency, and root.

In terms of three-way interactions, unlike the analysis with cleaned data, there were no longer significant three-way interactions between Qur'an memorisation, Qur'an vocabulary knowledge, and root as well as between Qur'an memorisation, Qur'an vocabulary knowledge, and phonotactic probability. However, unlike the analysis with cleaned data, the three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and frequency is significant.

6.6.2 Whole Word Accuracy

A pseudo-R^2 calculated for generalised linear mixed models showed that the random effects and fixed effects together in this model described 38.64% of the variance in whole word accuracy; random effects described 16.02% of the variance in whole word accuracy while fixed effects described 22.62% of the variance in whole word accuracy. Table 6-7 presents the estimated standardised coefficients for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model is described in the following sub-sections.

Covariates. As seen in Table 6-7, only age significantly affected whole word accuracy; older participants were more likely to be less accurate than younger participants when reading aloud target words.

Individual-level predictors. Results revealed a significant main effect of Qur'an vocabulary knowledge, β = .769, *SE* = .102, $\chi^2(1)$ = 42.881, p < .001, but not amount of Qur'an memorisation, β = .033, *SE* = .047, $\chi^2(1)$ = 3.495, *ns.*, on whole word accuracy after controlling for all other variables. Participants with more Qur'an vocabulary knowledge were more likely to have more correct whole word responses in speeded pronunciation than participants with less Qur'an vocabulary knowledge; for each standardised unit increase in Qur'an vocabulary knowledge, the log odds of accuracy increased by .769. However, this main effect should be further interpreted in the context of the significant two-way interaction between Qur'an memorisation and Qur'an vocabulary knowledge, β = -.250, *SE* = .084, $\chi^2(1) = 8.247$, $p < .01$.

Plotting the simple slopes of the two-way interaction showed that as amount of Qur'an memorisation increases for participants with poor Qur'an vocabulary knowledge, their whole word accuracy in speeded pronunciation was predicted to increase, while participants with high Qur'an vocabulary knowledge were predicted to have high whole word accuracy across all levels of Qur'an memorisation (see Figure 6-10). This suggests that Qur'an memorisation aids in reading whole words accurately, but only for those with low vocabulary knowledge.

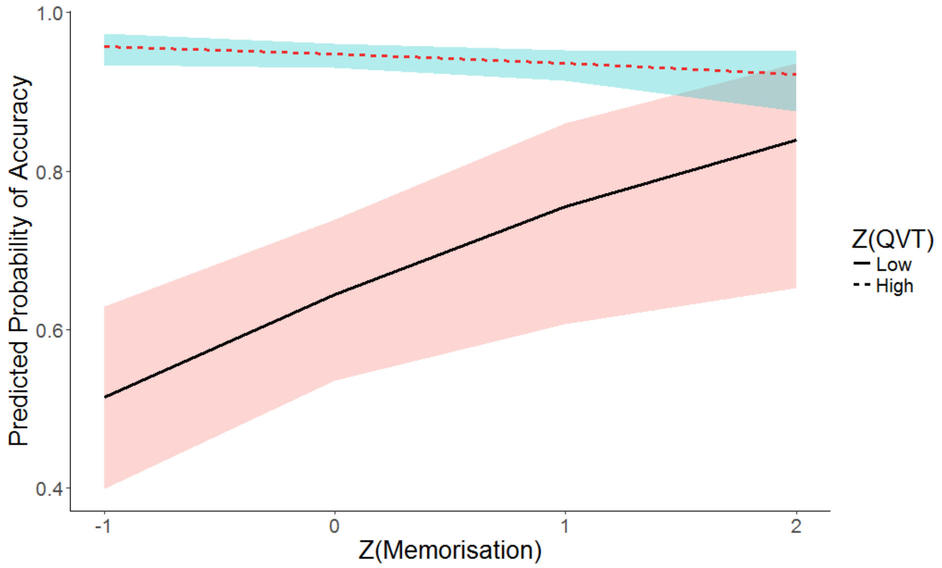

Figure 6-10. Memorisation × Vocabulary Knowledge interaction: Predicted probability of whole word accuracy for low (1.5 *SD* below the mean) and high (1.5 *SD* above the mean) Qur'an vocabulary knowledge (QVT) based on the full generalised linear mixed effects model. Results are presented as a function of memorisation *z*-scores. Bands are based on 95% confidence intervals.

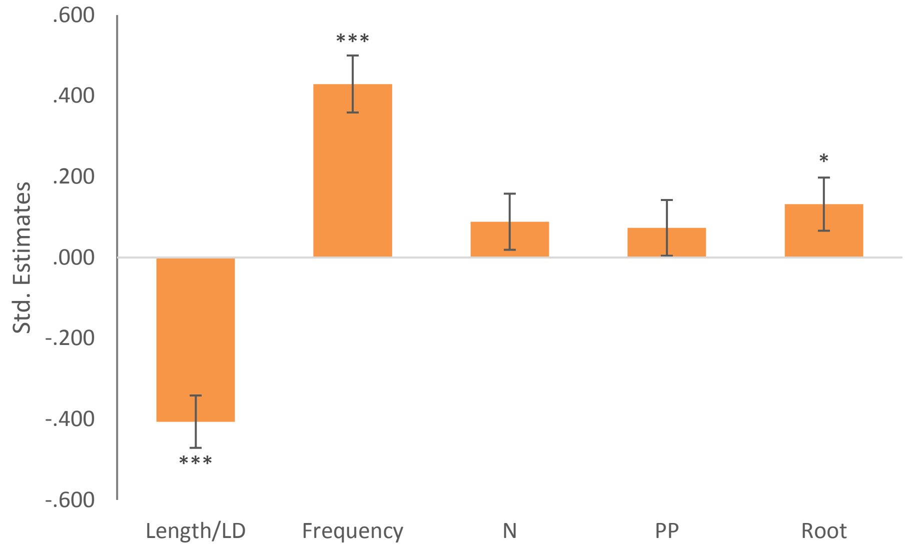

Figure 6-11. Bars represent standardised regression coefficients across item-level predictors for whole word accuracy in speeded pronunciation in the full model. Error bars are based on standard error. Asterisks denote significance at the following levels: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Length/LD. After controlling for all other variables, the principal component of length/LD (number of characters, number of phones, number of syllables, OLD20 and PLD20) was negatively associated with whole word accuracy in speeded pronunciation, $\beta = -.406$, $SE = .065$, $\chi^2(1) = 35.009$, $p < .001$; participants were less accurate in reading aloud longer word targets and words with further neighbours than shorter word targets and words with nearer neighbours. Figure 6-11 also indicated that the predictive power of length/LD in speeded pronunciation whole word accuracy was similar to that of frequency and the largest compared to other lexical variables. This will be further discussed later.

There were no significant two-way interactions between Qur'an memorisation and length/Levenshtein distance, $\beta = -.008$, $SE = .035$, $\chi^2(1) = .049$, *ns.*, or between Qur'an vocabulary knowledge and length/Levenshtein distance, $\beta = -.011$, $SE = .065$, $\chi^2(1) = .095$, *ns.* There was also no significant three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and length/Levenshtein distance, $\beta = -.009$, $SE = .029$, $\chi^2(1) = .089$, *ns.*

Frequency. After controlling for all other variables, the principal component of item frequency (orthographic and phonetic) significantly predicted whole word accuracy in speeded pronunciation, $\beta = .429$, $SE = .071$, $\chi^2(1) = 34.111$, $p < .001$. Participants were more likely to read aloud more frequent targets more accurately than less frequent targets. As can be seen in Figure 6-11, unlike in speeded pronunciation latencies, frequency, similar to length, was the best predictor of whole word accuracy in speeded pronunciation amongst all the other principal components. This will be further discussed later.

There were no significant two-way interactions between Qur'an memorisation and frequency, $\beta = .057$, $SE = .045$, $\chi^2(1) = 1.561$, *ns.*, or between Qur'an vocabulary knowledge and frequency, $\beta = .025$, $SE = .045$, $\chi^2(1) = .313$, *ns.* There was also no significant three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and frequency, $\beta = .003$, $SE = .035$, $\chi^2(1) = .929$, *ns.*

Neighbourhood density. After controlling for all other variables, the principal component of neighbourhood density (orthographic and phonological) did not significantly predict whole word accuracy in speeded pronunciation, $\beta = .089$, $SE = .069$, $\chi^2(1) = 1.591$, *ns*. There were also no significant two-way interactions between Qur'an memorisation and neighbourhood density, $\beta = -.005$, $SE = .045$, $\chi^2(1) = .011$, *ns.*, or between Qur'an vocabulary knowledge and neighbourhood density, $\beta = -.014$, $SE = .037$, $\chi^2(1) = .129$, *ns.* The three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and neighbourhood density was also not significant, $\beta = .052$, $SE = .036$, $\chi^2(1) = 2.130$, *ns.*

Phonotactic probability. After controlling for all other variables, the principal component of phonotactic probability (positional segment average and biphone average) did not significantly predict whole word accuracy in speeded pronunciation, $\beta = .073$, $SE = .069$, $\chi^2(1) = 1.106$, *ns*. There were also no significant two-way interactions between Qur'an memorisation and phonotactic probability, $\beta = .015$, $SE = .044$, $\chi^2(1) = .109$, *ns.*, or between Qur'an vocabulary knowledge and phonotactic probability, $\beta = -.010$, $SE = .044$, $\chi^2(1) = .051$, *ns.* The three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and phonotactic probability was also not significant, β = .025, *SE* = .035, $\chi^2(1)$ = .527, *ns.*

Root. After controlling for all other variables, the principal component of root (root frequency and root family size) significantly predicted whole word accuracy in speeded pronunciation, β = .132, *SE* = .066, $\chi^2(1)$ = 2.006, $p < .05$. Participants were more accurate in reading aloud targets with higher root frequency and larger root family size than targets with lower root frequency and smaller root family size. However, there were no significant two-way interactions between Qur'an memorisation and root, β = .027, *SE* = .037, $\chi^2(1)$ = .510, *ns.*, or between Qur'an vocabulary knowledge and root, β = -.014, *SE* = .037, $\chi^2(1)$ = .129, *ns.* The three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and root was also not significant, β = -.042, *SE* = .030, $\chi^2(1)$ = 1.880, *ns.*

6.6.3 Phone Accuracy

A pseudo-R^2 calculated for generalised linear mixed models showed that the random effects and fixed effects together in this model described 29.54% of the variance in phone accuracy; random effects described 9.53% of the variance in phone accuracy while fixed effects described 20.01% of the variance in phone accuracy. Table 6-8 presents the estimated standardised coefficients for the fixed effects in the model. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Results from the model is described in the following sub-sections.

Covariates. As seen in Table 6-8, only age significantly affected phone accuracy; older participants were more likely to make more errors when pronouncing phones in the target items than younger participants.

Individual-level predictors. Results revealed a significant main effect of Qur'an vocabulary knowledge (β = .897, *SE* = .108, $\chi^2(1)$ = 49.285, $p < .001$) but not amount of Qur'an memorisation (β = .076, *SE* = .109, $\chi^2(1)$ = .473, *ns.*) on phone accuracy after controlling for all other variables. Participants with more Qur'an vocabulary knowledge were more likely to pronounce more phones in the target items correctly than participants with less Qur'an vocabulary knowledge; for each standardised unit increase in Qur'an vocabulary knowledge, the log odds of phone accuracy increase by .897. However, this main effect must be further interpreted in the context of the significant two-way interaction between Qur'an memorisation and Qur'an vocabulary knowledge, (β = -.211, *SE* = .088, $\chi^2(1)$ = 5.415, $p < .05$).

Plotting the simple slopes of the two-way interaction showed that as amount of Qur'an memorisation increases for participants with poor Qur'an vocabulary knowledge, their phone accuracy in speeded pronunciation was predicted to increase, while participants with high Qur'an vocabulary knowledge were predicted to have high phone accuracy across all levels of Qur'an memorisation (see Figure 6-12). This suggests that memorisation aids in pronouncing more phones in words accurately, but only for those with low vocabulary knowledge.

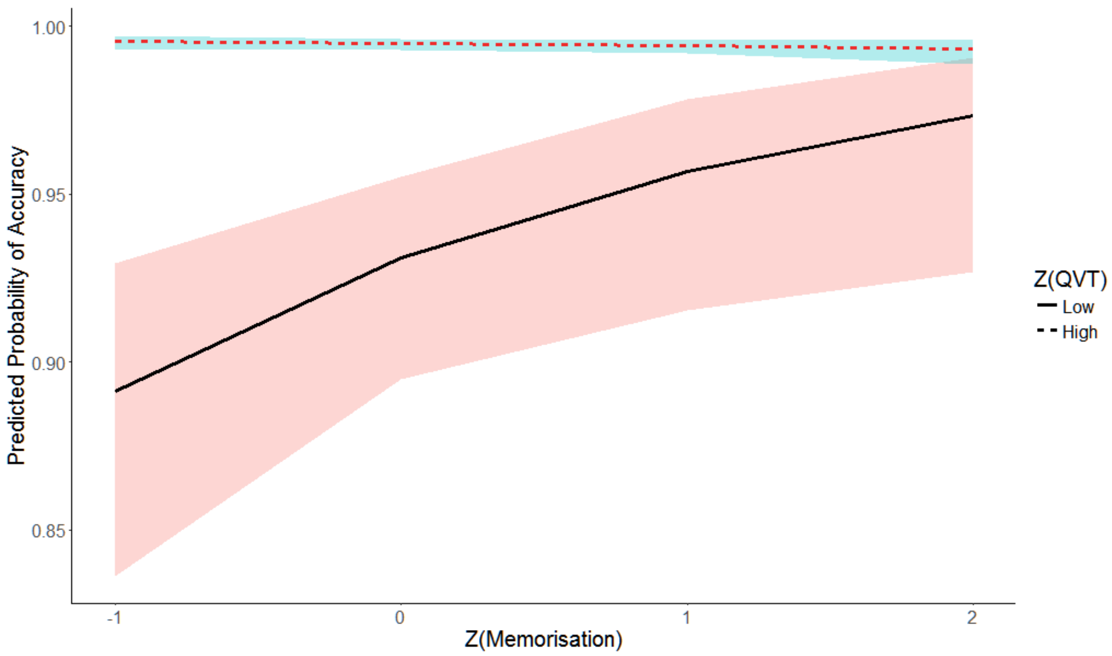

Figure 6-12. Memorisation × Vocabulary Knowledge interaction: Predicted probability of phone accuracy for low (1.5 *SD* below the mean) and high (1.5 *SD* above the mean) Qur'an vocabulary knowledge (QVT) based on the full generalised linear mixed effects model. Results are presented as a function of memorisation *z*-scores. Bands are based on 95% confidence intervals.

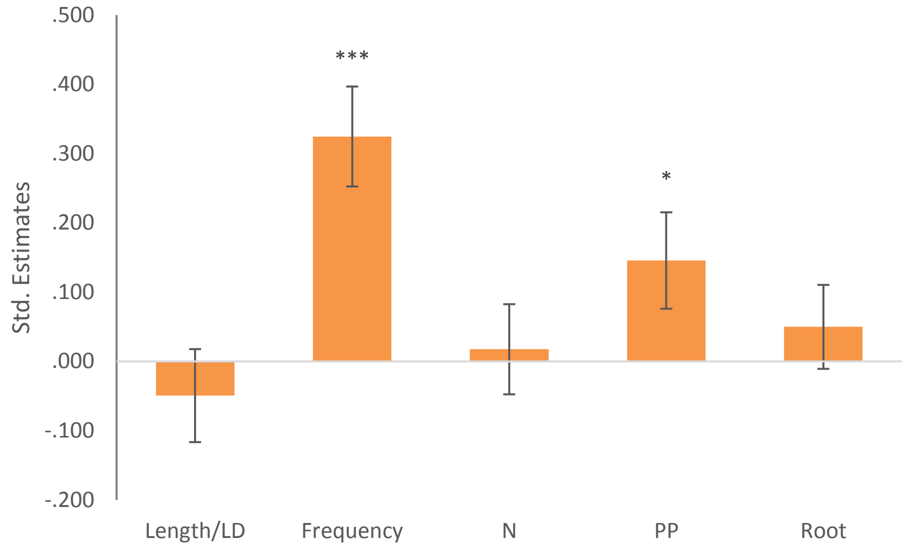

Figure 6-13. Bars represent standardised regression coefficients across item-level predictors for phone accuracy in speeded pronunciation in the full model. Error bars are based on standard error. Asterisks denote significance at the following levels: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Length/LD. After controlling for all other variables, the principal component of length/LD (number of characters, number of phones, number of syllables, OLD20 and PLD20) did not significantly predict whole word accuracy in speeded pronunciation, $\beta = -.049$, $SE = .067$, $\chi^2(1) = .513$, *ns*. Figure 6-13 also indicated that unlike for whole word accuracy, the predictive power of length/LD in speeded pronunciation phone accuracy was much lower than that of frequency and amongst the smallest compared to other lexical variables. This will be further discussed later.

There were no significant two-way interactions between Qur'an memorisation and length/Levenshtein distance, $\beta = -.049$, $SE = .045$, $\chi^2(1) = 1.138$, *ns.*, or between Qur'an vocabulary knowledge and length/Levenshtein distance, $\beta = -.031$, $SE = .047$, $\chi^2(1) = .439$, *ns.* There was also no significant three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and length/Levenshtein distance, $\beta = .021$, $SE = .037$, $\chi^2(1) = .327$, *ns.*

Frequency. After controlling for all other variables, the principal component of item frequency (orthographic and phonetic) significantly predicted phone accuracy in speeded pronunciation, β = .325, *SE* = .072, $\chi^2(1)$ = 19.244, p < .001. Participants were more likely to pronounce more phones correctly in more frequent targets than in less frequent targets. As can be seen in Figure 6-13, unlike in speeded pronunciation latencies, frequency was the best predictor of phone accuracy in speeded pronunciation amongst all the other principal components, especially when compared to length. This will be further discussed later.

Although there was no significant two-way interaction between Qur'an memorisation and frequency, β = .011, *SE* = .052, $\chi^2(1)$ = 1.138, *ns.*, the two-way interaction between Qur'an vocabulary knowledge and frequency was marginally significant, β = .95, *SE* = .054, $\chi^2(1)$ = 2.975, p = .085*.* Plotting the simple slopes of the two-way interaction showed a trend in which participants with more vocabulary knowledge were less likely to be influenced by frequency effects when pronouncing phones in target items correctly than participants with less vocabulary knowledge (see Figure 6-14 where Z(Memorisation) = 0). This marginally significant interaction suggests that more vocabulary knowledge (but not more memorisation) may be related to smaller frequency effects in phone accuracy in speeded pronunciation. However, there was no significant three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and frequency, β = .008, *SE* = .041, $\chi^2(1)$ = .035, *ns.*

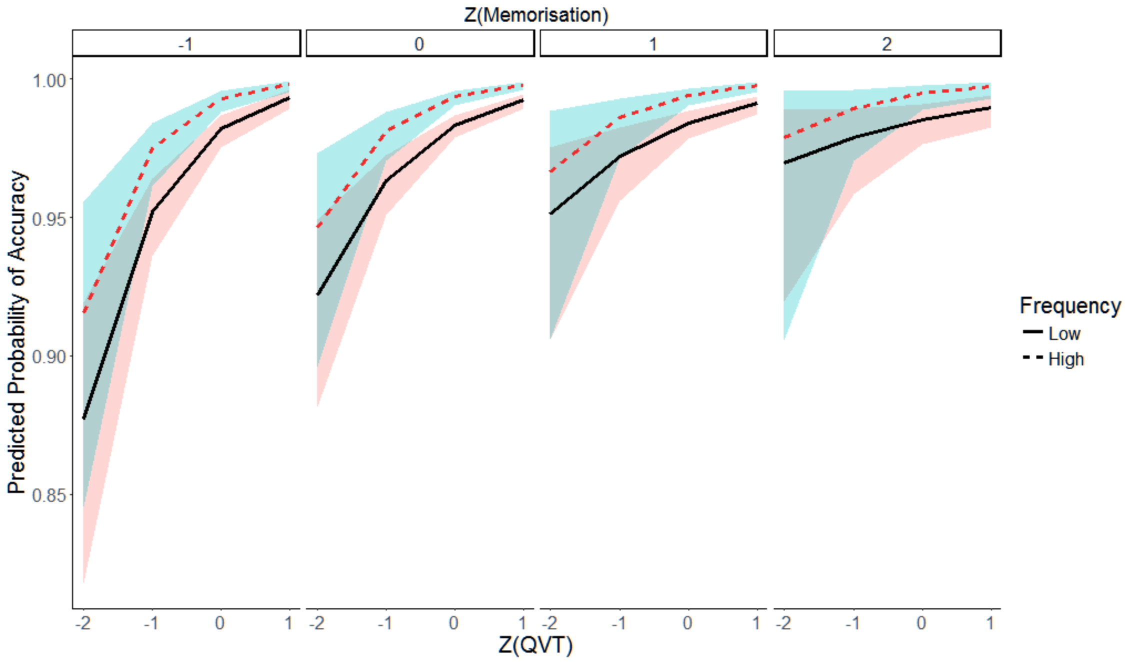

Figure 6-14. Memorisation × Vocabulary Knowledge × Frequency interaction: Predicted probability of phone accuracy for speeded pronunciation targets with low (1.5 *SD* below the mean) and high frequency (1.5 *SD* above the mean) based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Neighbourhood density. After controlling for all other variables, the principal component of neighbourhood density (orthographic and phonological) did not significantly predict phone accuracy in speeded pronunciation, β = .018, *SE* = .065, $\chi^2(1)$ = .071, *ns*. There were also no significant two-way interactions between Qur'an memorisation and neighbourhood density, β = .029, *SE* = .042, $\chi^2(1)$ = .443, *ns.*, or between Qur'an vocabulary knowledge and neighbourhood density, β = .022, *SE* = .044, $\chi^2(1)$ = .239, *ns.* Although the plotted three-way interaction between memorisation, vocabulary knowledge, and neighbourhood density showed an interesting trend in which the increase in facilitatory neighbourhood density effects on phone accuracy as memorisation increases was attenuated by the increase in vocabulary knowledge (see Figure 6-15), it was only marginally significant, β = .057, *SE* = .032, $\chi^2(1)$ = 3.140, *p* = .076.

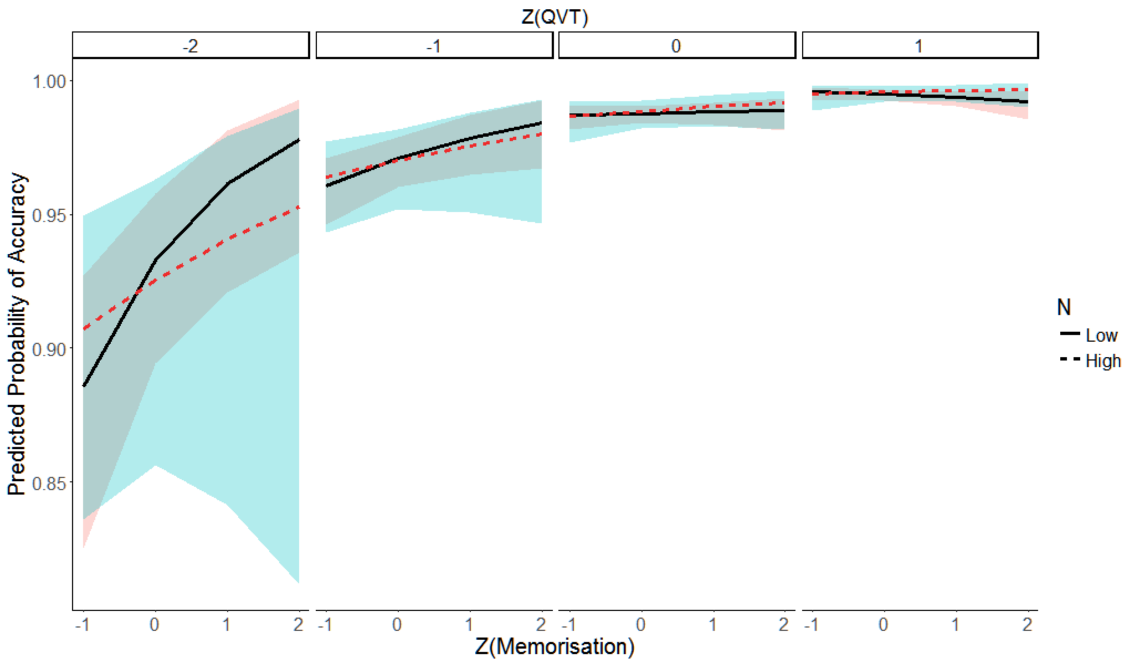

Figure 6-15. Memorisation × Vocabulary Knowledge × Neighbourhood Density interaction: Predicted probability of phone accuracy for speeded pronunciation targets with small N (1.5 *SD* below the mean) and large N (1.5 *SD* above the mean) based on the full linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

Phonotactic probability. After controlling for all other variables, the principal component of phonotactic probability (positional segment average and biphone average) significantly predicted phone accuracy in speeded pronunciation, $\beta = .146$, $SE = .070$, $\chi^2(1) = 4.316$, $p < .05$. Participants were more likely to pronounce more phones correctly in targets with higher phonotactic probability than in targets with lower phonotactic probability.

However, there were no significant two-way interactions between Qur'an memorisation and phonotactic probability, $\beta = .063$, $SE = .048$, $\chi^2(1) = 1.569$, *ns.*, or between Qur'an vocabulary knowledge and phonotactic probability, $\beta = -.028$, $SE = .050$, $\chi^2(1) = .279$, *ns.* The three-way interaction among Qur'an memorisation, Qur'an vocabulary knowledge, and phonotactic probability was also not significant, $\beta = .012$, $SE = .037$, $\chi^2(1) = .102$, *ns.*

Root. After controlling for all other variables, the principal component of root (root frequency and root family size) did not significantly predict phone accuracy in speeded pronunciation, β = .050, SE = .061, $\chi^2(1)$ = .655, *ns*. However, although there was no significant two-way interaction between Qur'an memorisation and root, β = .041, SE = .035, $\chi^2(1)$ = 1.325, *ns.*, the two-way interaction between Qur'an vocabulary knowledge and root was significant, β = -.093, SE = .036, $\chi^2(1)$ = 5.964, $p < .05$. Plotting the simple slopes of the two-way interaction showed that participants with more vocabulary knowledge were less likely to be influenced by root effects when pronouncing phones in target items correctly than participants with less vocabulary knowledge (see Figure 6-17 where Z(Memorisation) = 0). This interaction indicated that more vocabulary knowledge (but not more memorisation) was related to smaller root effects in lexical decision accuracy. However, this two-way interaction must be further interpreted in the context of the significant three-way interaction among memorisation, vocabulary knowledge, and root, β = -.053, SE = .026, $\chi^2(1)$ = 3.877, $p < .05$.

Plotting the simple slopes of the three-way interaction shows that the increase in root effects on phone accuracy as memorisation increases was attenuated by the increase in vocabulary knowledge, to the extent that if one had high vocabulary knowledge, one was not influenced by root effects when pronouncing phones in target items correctly across all levels of memorisation (see Figure 6-16). Furthermore, participants having a very low level of vocabulary knowledge but who have memorised more of the Qur'an had the largest facilitatory root effect on phone accuracy, i.e., they were the most likely to pronounce more phones correctly in target items with more roots and larger root family size as compared to target items with fewer roots and smaller root family size.

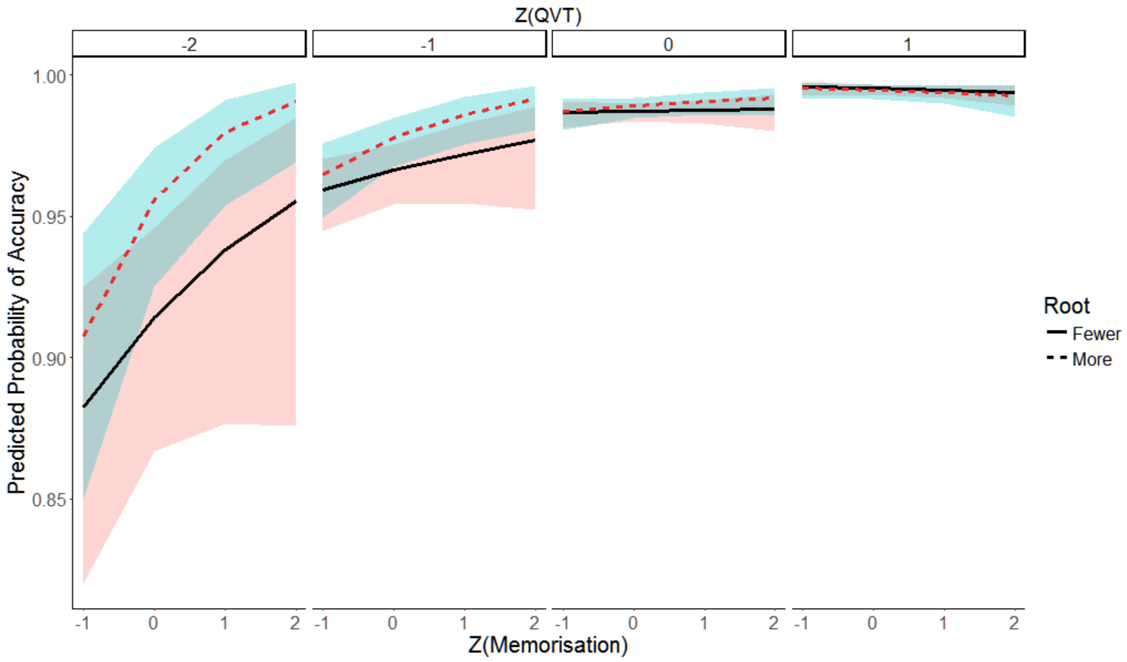

Figure 6-16. Memorisation × Vocabulary Knowledge × Root interaction: Predicted probability of phone accuracy for speeded pronunciation targets with fewer (1.5 *SD* below the mean) and more roots (1.5 *SD* above the mean) based on the full generalised linear mixed effects model. Results are presented as a function of memorisation and Qur'an vocabulary knowledge (QVT) *z*-scores. Bands are based on 95% confidence intervals.

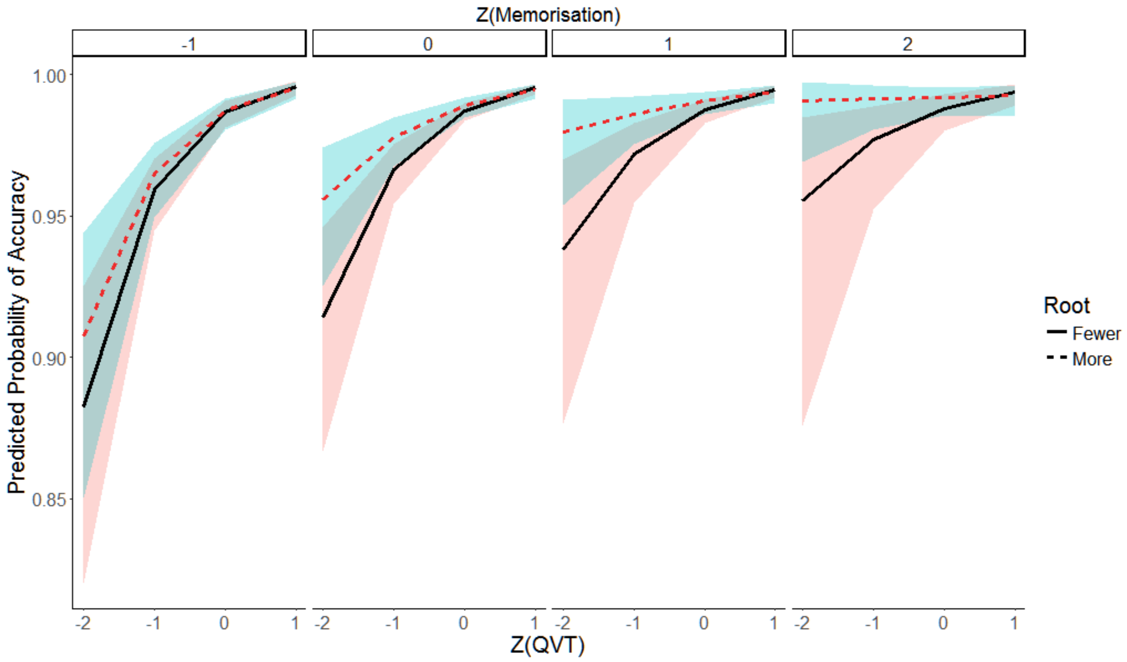

Figure 6-17. Memorisation × Vocabulary Knowledge × Root interaction: Predicted probability of phone accuracy for speeded pronunciation targets with fewer (1.5 *SD* below the mean) and more roots (1.5 *SD* above the mean) based on the full generalised linear mixed effects model. Results are presented as a function of Qur'an vocabulary knowledge (QVT) and memorisation *z*-scores. Bands are based on 95% confidence intervals.

6.7 Discussion

In this study, behavioural data in the speeded pronunciation performance of non-Arabic-speaking Qur'anic memorisers were collected to fulfil two objectives. The first objective was to examine the influence of six variables—length, frequency, neighbourhood density, Levenshtein distance, phonotactic probability, and root on the speeded pronunciation of non-Arabic-speaking Qur'anic memorisers. The second objective was to examine individual differences in the effects of these variables on speeded pronunciation by looking at whether Qur'an vocabulary knowledge (QVT) and amount of Qur'an memorisation (MemScore) interact with these factors in two- and three-way interactions, thereby teasing apart the possibly differential roles of vocabulary knowledge and print exposure in visual word processing.

Findings from this study essentially supported the four main predictions made with reference to research on other orthographies such as Malay with a couple of unexpected findings. First, after controlling for onsets and other covariates, all principal components of length/LD, frequency, neighbourhood density, phonotactic probability, and root significantly predicted speeded pronunciation latencies in the expected directions. Longer words and words that have further neighbours were slower to be read aloud correctly, whereas words that occur more frequently in print, words with more orthographic and phonological neighbours, words with higher phonotactic probability, as well as words with more frequent roots and larger root family size were faster to be read aloud correctly. Importantly, length/LD effects were much larger than frequency effects, indicating a greater reliance on the sublexical route in word processing. Root effects were also the smallest compared to those of other principal components, especially neighbourhood density, suggesting that our participants were more sensitive to measures of orthographic similarity than non-linear morphological variables when reading words aloud.

In terms of whole word accuracy, only the principal components of length/LD, frequency, and root significantly predicted speeded pronunciation whole word accuracy, with frequency unexpectedly having stronger predictive power than length/LD. Participants were more accurate when reading shorter words and words with closer neighbours, more frequent words, and words with more frequent roots or larger root family sizes. In terms of phone accuracy, only the principal components of frequency and phonotactic probability significantly predicted speeded pronunciation phone accuracy, though the interpretation of these findings must be made with caution given the high phone accuracy of these participants, and thus, a ceiling effect in reading aloud individual phones accurately. The implications of these findings will be discussed later.

Second, amount of Qur'an memorisation (MemScore) significantly modulated the effects of length/LD, frequency, phonotactic probability, and root on speeded pronunciation latencies; more memorisation resulted in smaller effects of frequency, phonotactic probability, and root but in larger effects of length/LD. It did not modulate any other effects on speeded pronunciation whole word and phone accuracy.

Third, Qur'an vocabulary knowledge (QVT) significantly modulated the effects of length/LD, frequency, and root on speeded pronunciation latencies; more vocabulary knowledge resulted in smaller effects of frequency on speeded pronunciation latencies but in larger effects of length/LD and root. However, it is important to note that the effects of frequency on speeded pronunciation were modulated more by vocabulary knowledge than by memorisation. It did not modulate any other effects on speeded pronunciation whole word accuracy but it significantly modulated the effect of root on phone accuracy; more vocabulary knowledge resulted in larger facilitatory effects of root on phone accuracy. Nonetheless, as previously mentioned, the interpretation of this finding must be made with caution given the ceiling effect in reading aloud individual phones accurately.

Last, MemScore and QVT interacted together to significantly modulate the effects of phonotactic probability and root on speeded pronunciation latencies. The more memorisation and vocabulary knowledge one has, the less influenced one is by phonotactic probability and root when reading aloud words correctly. Both MemScore and QVT did not modulate any other effects on speeded pronunciation whole word accuracy but they did significantly modulate the effect of root on phone accuracy; more memorisation and vocabulary knowledge resulted in larger facilitatory effects of root on phone accuracy. Nonetheless, as previously mentioned, the interpretation of this finding must be made with caution given the ceiling effect in reading aloud individual phones accurately.

The above results will be further discussed in detail in the following sections.

6.7.1 Effects of Principal Components on Speeded Pronunciation

6.7.1.1 Length and Frequency Effects

Due to multicollinearity issues, the combining of length and Levenshtein distance into a single principal component (length/LD) was inevitable. However, the effects of either one can still be discussed as both reflect structural properties of a word and effects of both length and LD are typically in the same direction (see Binte Faizal, 2009; Yap et al., 2012).

As expected, results show that not only was length a much stronger predictor of speeded pronunciation latency than frequency, it was also the strongest predictor compared to other principal components. This is consistent with the findings from other transparent orthographies such as Malay (Binte Faizal, 2009; Yap et al., 2010), Welsh (Ellis & Hooper, 2001) and German (Perry & Ziegler, 2002; Ziegler et al., 2001) but contrasts with the findings in opaque orthographies such as English (Balota et al., 2004; Yap & Balota, 2009), which found frequency effects to be larger than length effects. The much larger length effects as compared to frequency indicate a reliance on the sublexical pathway during word processing based on dual-route models of reading. This is unsurprising given Qur'anic Arabic's very transparent orthography where direct grapheme-phoneme decoding can be done in reading and reading a word aloud correctly does not require one to access the lexical or semantic route to read a word aloud correctly. They also indicate an adaptation to smaller grain sizes of processing due to the constant decoding of consistent grapheme-to-phoneme correspondences as predicted by the PGST.

However, the finding that frequency was the largest predictor of speeded pronunciation accuracy was unexpected. This was inconsistent with the findings from a similarly transparent orthography such as Malay (Binte Faizal, 2009; Yap et al., 2010), which found length to be a much stronger predictor of speeded pronunciation accuracy, followed by LD, and then frequency. Our finding was also inconsistent with the transparency of the Qur'anic orthography in which like Malay, reading a word aloud correctly can be done through simple decoding of consistent grapheme-to-phoneme correspondences and does not require accessing the lexical route. A possible explanation may be that as participants are reading in a language that may be their third or fourth language, their reading accuracy may be much more influenced by how often the word occurs in print, and thus, how much experience they have had in reading that word aloud. This is even more so given their reading (aloud)-repetition-rehearsal process during memorisation.

Nonetheless, the finding that length and frequency effects were both significant in the speeded pronunciation of a transparent orthography corroborated findings from other studies such as Dutch (Hudson & Bergman, 1985), Malay (Binte Faizal, 2009) and Italian (Burani et al., 2002), thus providing additional support for the weak ODH, which does not deny the parallel use of both lexical and sublexical pathways in word processing but rather postulates a greater reliance of one over the other, depending on the depth of the orthography as well as the specific demands of the task.

6.7.1.2 Neighbourhood Density and Levenshtein Distance

As predicted, neighbourhood density significantly facilitated whereas Levenshtein distance significantly inhibited speeded pronunciation latencies, with length/LD having stronger predictive power than neighbourhood density. This means that words with more neighbours and words with closer neighbours were read aloud correctly faster than words with fewer neighbours and words with further neighbours. This is consistent with findings from studies in English (Yap & Balota, 2009; Yarkoni et al., 2008) and Malay (Binte Faizal, 2009). These facilitatory effects possibly reflect the processing characteristics of the sublexical phonological assembly process in dual route models of reading, in which words which are visually similar to many other words are recognised faster as they share more common grapheme-to-phoneme correspondences (Andrews, 1997), activating phonology that is consistent with that of the target item, thus facilitating lexical access and reducing speeded pronunciation latencies. Distance effects are thus another way to capture the common grapheme-to-phoneme correspondences in Qur'anic Arabic. Taken together, these findings support the predictions of the ODH and PGST, which postulate that transparent orthographies will engage more in sublexical processing, and even more so in speeded pronunciation.

More importantly, Levenshtein distance has been shown consistently to be a stronger predictor of speeded pronunciation latencies than traditional measures of neighbourhood density in English, (Yap & Balota, 2009; Yarkoni et al., 2008), Malay (Binte Faizal, 2009), and now, Qur'anic Arabic. Unlike standard measures of neighbourhood size (orthographic N and phonological N), this distance-based measure was not only applicable to words of all lengths but was also able to account for a substantial proportion of unique variance above and beyond the traditional measures, making it an excellent measure of orthographic similarity or distinctiveness.

6.7.1.3 Neighbourhood Density and Root

The principal component of root (root frequency and root family size) was found to have significantly facilitated speeded pronunciation latencies, although it has the smallest predictive power out of all the principal components. Root also significantly facilitated speeded pronunciation accuracy. The more frequent and more productive the root of a word is, the faster and more accurately it is read aloud. This means that participants were sensitive enough to non-concatenative morphological information such as root, suggesting implicit statistical learning taking place and accessing these root representations despite having print exposure with limited semantic knowledge. This corroborates Zuhurudeen and Huang's (2016) finding in demonstrating that real-world exposure to the statistical properties of a natural language can facilitate learning despite having limited semantic cues; in their case, the acquisition of grammatical categories. Importantly, this gives us motivation to study whether this reflects true sensitivity to non-concatenative root morphemes or merely sensitivity to the statistical occurrence of various consonant combinations. We examine this by looking at root priming effects in Chapter 7.

Importantly, as discussed earlier in the literature review, greater sensitivity to root variables as compared to measures of orthographic similarity such as orthographic N could suggest the salience of the root in lexical organisation based on the non-concatenative morphological principles of an orthography instead of orthographic similarity as assumed by extant models of word recognition. However, this was not found as the predictive power of neighbourhood density was much larger than that of root; participants were thus more sensitive to neighbourhood density effects than to root effects in speeded pronunciation latencies. Contrary to what Frost et al. (2005) argued, this suggests that non-Arabic-speaking Qur’anic memorisers organise words based on orthographic similarity instead of the language’s morphological principles, i.e., Qur’anic Arabic’s non-concatenative morphological principles of roots and word patterns. It further suggests that for the lexical organisation of words to be based on non-concatenative morphological principles, there may be a process that has to be learned, either through the natural acquisition of the language or through explicit teaching. What is clear is that the nature of the orthography itself does not determine the lexical organisation of words, but rather how individuals themselves acquire the language.

6.7.1.4 Phonotactic Probability

As predicted, the principal component of phonotactic probability (positional segment average and biphone average) was found to significantly predict speeded pronunciation latencies, albeit having smaller predictive power than length/LD, frequency, and neighbourhood density. Participants were faster to read aloud correctly words with higher phonotactic probability than words with lower phonotactic probability. Together with length/LD, this finding provides corroborating evidence of non-Arabic-speaking Qur’anic memorisers’ reliance on sublexical processing and the salience of smaller grain sizes of processing in speeded pronunciation, thus supporting the predictions of the ODH and PGST. Importantly, this also suggests the implicit statistical learning of phonotactic probabilities at the levels of phone and biphone through print exposure, and thus, the access of these sublexical representations during speeded pronunciation.

6.7.2 Individual Differences in Effects of Principal Components on Speeded Pronunciation

Individual differences as measured by amount of Qur'an memorisation (MemScore) and Qur'an vocabulary knowledge (QVT) were found to significantly modulate the effects of the various principal components on speeded pronunciation latencies through two-way and three-way interactions. These interactions are discussed below.

6.7.2.1 Amount of Quran Memorisation (MemScore)

Amount of Qur'an memorisation (MemScore) was used as a measure of print exposure. Findings show that MemScore significantly modulated the effects of length/LD, frequency, phonotactic probability, and root on speeded pronunciation latencies. As predicted, more memorisation resulted in smaller effects of frequency, phonotactic probability, and root on speeded pronunciation latencies. Although this was contrary to Baluch's (1996) finding of greater print exposure resulting in larger frequency effects in speeded pronunciation, it supported hypotheses that propose an automatization of lexical processing mechanisms as readers acquire more experience with words (LaBerge & Samuels, 1974; Stanovich, 1980); as automatic mechanisms develop, word recognition may be less influenced by lexical characteristics. However, this explanation does not account for more memorisation leading to larger effects of length/LD on speeded pronunciation latencies. At this point, we can only speculate that this suggests memorisation is needed to be able to organise the lexicon in terms of orthographic and phonological similarity, and thus, be sensitive to it during speeded pronunciation. Nonetheless, the two-way interactions between amount of memorisation and root as well as amount of memorisation and phonotactic probability must be interpreted in the context of their significant three-way interactions, which will be discussed below.

6.7.2.2 Qur'an Vocabulary Knowledge (QVT)

As predicted, Qur'an vocabulary knowledge (QVT) was found to have significantly modulated the effects of length/LD, frequency, and root on speeded pronunciation latencies; more vocabulary knowledge resulted in smaller effects of frequency on speeded pronunciation latencies but in larger effects of length/LD and root on speeded pronunciation latencies. The former finding is consistent with Yap et al.'s (2012) finding that participants with more vocabulary knowledge were less sensitive to the principal component of word frequency/semantics in speeded pronunciation but contrasts with Butler and Hains' (1979) study that did not find a significant interaction between vocabulary knowledge and word frequency on speeded pronunciation latencies. As in memorisation, our finding supported hypotheses that propose an automatization of lexical processing mechanisms as readers acquire more experience with words; in this case, as proposed by the lexical quality hypothesis, gaining the meaning of words contributed to improving the semantic constituent in developing the quality of lexical representations, thus improving the efficacy in accessing these representations (Perfetti, 2007; Perfetti & Hart, 2002) and resulting in smaller influences of lexical characteristics in word processing. However, this explanation does not account for more vocabulary knowledge leading to larger effects of length/LD and root on speeded pronunciation latencies. The former finding is also not consistent with Yap et al.'s (2012) finding that participants with more vocabulary knowledge were less influenced by the principal component of length/LD. At this point, we can only speculate that this suggests vocabulary knowledge is needed to be able to organise the lexicon in terms of orthographic similarity, and thus, be sensitive to it during speeded pronunciation. Regardless, the two-way interaction between vocabulary knowledge and root must be interpreted in the context of the significant three-way interaction between amount of memorisation, vocabulary knowledge, and root, which will be discussed below.

6.7.2.3 MemScore and QVT

The hallmark of this study was to examine three-way interactions between MemScore, QVT, and each principal component, thereby allowing us for the first time to tease apart possibly differential roles of print exposure and vocabulary knowledge in modulating the effects of various principal components on speeded pronunciation. Results showed that MemScore and QVT interacted together to significantly modulate the effects of phonotactic probability and root on speeded pronunciation latencies.

Looking at phonotactic probability and root, the more memorisation and vocabulary knowledge one has, the less one is influenced by phonotactic probability and root when reading aloud words correctly. In Figure 6-8, participants with more vocabulary knowledge and more memorisation were less likely to be influenced by facilitatory phonotactic probability effects than their high vocabulary knowledge counterparts who had memorised less of the Qur'an and their high memorisation counterparts who had poorer vocabulary knowledge. In Figure 6-9, participants with more vocabulary knowledge and more memorisation were less likely to be influenced by facilitatory root effects than their high vocabulary knowledge counterparts who had memorised less of the Qur'an but not their high memorisation counterparts who had poorer vocabulary knowledge. This provides excellent support for the lexical quality hypothesis, which describes three separate constituents of orthography, phonology, and semantics in the development of the quality of lexical representations, and thus, in the facilitation of access to these lexical representations in word processes such as reading (Perfetti, 2007; Perfetti & Hart, 2002). Based on this, one can surmise that memorisation (or print exposure) and vocabulary knowledge provide separate contributions to the development of the quality of lexical representations. Memorisation provides constant repeated exposure to the orthographic and phonetic constituents of a lexical representation while vocabulary knowledge contributes to the semantic constituent of a lexical representation. Together, they help to develop high-quality lexical representations that facilitate access to these lexical representations, thus resulting in smaller influences of lexical characteristics in word processing.

6.8 Conclusions

The current study examined the effects of various psycholinguistic variables as well as individual differences in the effects of those variables on the speeded pronunciation of non-Arabic-speaking Qur'anic memorisers. Overall, findings suggest that non-Arabic-speaking Qur'anic memorisers implicitly learn the lexical and sublexical characteristics of an orthography through consistent exposure to its print. The major contributions of this study are as follows: Not only is it the first study on speeded pronunciation in Qur'anic Arabic, it is also the first study that have looked at non-Arabic-speaking Qur'anic memorisers, thereby providing a natural window into the disambiguation of the roles of vocabulary knowledge and print exposure in influencing the effects of various psycholinguistic variables on speeded pronunciation. Furthermore, it is currently the only study of speeded pronunciation in vowelled Arabic that utilizes a comprehensive array of traditional and novel predictors, and it is the only study of speeded pronunciation in a transparent orthography that have examined individual differences in the effects of those predictors. Last, it is the first study to be able to investigate within the same population whether lexical organisation arises from a language's morphological principles or from how the individual himself acquires the language. Through this study, individual differences have been found to significantly modulate effects of various psycholinguistic variables on speeded pronunciation either through two-way or three-way interactions, thus underscoring the importance of considering individual differences in visual word recognition research. Taken together, these findings will hopefully provide useful constraints for future researchers attempting to model Qur'anic Arabic visual word processing for non-Arabic-speakers.

Table 6-6. *Full model showing the fixed effects with standardised RT regression coefficients from a linear mixed effects regression analysis for speeded pronunciation for both cleaned and all data with inverse transformation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = p < .1,* = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 6944)				All Data > 200ms (*N* = 7357)			
	β	*SE*	$\chi^2(1)$	*p*	*β*	*SE*	$\chi^2(1)$	*p*
(Intercept)	1.553	.046			1.535	.046		
Onsets (combined: df =27)			79.902	***			77.444	***
Trial Order Number	.045	.008	31.907	***	.046	.008	33.423	***
Age	-.119	.039	11.643	***	-.083	.034	5.406	*
MemScore	.088	.047	7.423	**	.114	.046	5.911	*
QVT	.122	.044	10.988	***	.140	.044	9.451	**
Length_LD	-.105	.014	50.457	***	-.102	.014	47.159	***
Freq	.057	.009	31.607	***	.061	.010	35.364	***
N	.056	.009	34.937	***	.057	.009	40.403	***
PP	.031	.011	8.086	**	.035	.011	9.106	**
Root	.027	.010	7.401	**	.025	.010	6.737	**
MemScore:QVT	-.064	.042	6.188	*	-.105	.036	7.966	**
MemScore:Length_LD	-.013	.009	6.137	*	-.018	.009	4.424	*
MemScore:Freq	-.001	.005	4.018	*	.001	.005	.076	
MemScore:N	.003	.004	.434		.002	.005	.105	
MemScore:PP	-.012	.006	8.540	**	-.012	.006	4.127	*
MemScore:Root	-.006	.005	5.781	*	-.006	.005	1.711	
QVT:Length_LD	-.013	.009	6.040	*	-.016	.009	2.935	.
QVT:Freq	-.007	.005	6.366	*	-.008	.005	2.336	
QVT:N	.000	.004	.008		.003	.005	.324	
QVT:PP	.002	.005	.099		.000	.006	.004	
QVT:Root	.001	.005	3.951	*	.002	.005	.239	
MemScore:QVT:Length_LD	.000	.008	.000		.006	.008	.640	
MemScore:QVT:Freq	-.005	.005	1.158		-.009	.004	4.091	*
MemScore:QVT:N	-.007	.004	2.842	.	-.008	.004	3.734	.
MemScore:QVT:PP	-.001	.005	3.900	*	.000	.005	.000	
MemScore:QVT:Root	.001	.004	3.974	*	.002	.004	.179	

Table 6-7. *Full model showing the fixed effects with log odds estimated coefficients for whole word accuracy in speeded pronunciation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	β	*SE*	*z*	P(>|*z*|)	$\chi^2(1)$	*p*
(Intercept)	2.130	.113	18.878	.000		
Age	-.268	.091	-2.940	.003	8.1068	**
MemScore	.033	.105	.311	.756	.095	
QVT	.769	.102	7.569	.000	42.881	***
Length_LD	-.406	.065	-6.265	.000	35.009	***
Freq	.429	.071	6.088	.000	34.111	***
N	.089	.069	1.274	.203	1.591	
PP	.073	.069	1.062	.288	1.106	
Root	.132	.066	2.006	.045	3.949	*
MemScore:QVT	-.250	.084	-2.969	.003	8.247	**
MemScore:Length_LD	-.008	.035	-.226	.822	.049	
MemScore:Freq	.057	.045	1.274	.203	1.561	
MemScore:N	-.005	.045	-.106	.916	.011	
MemScore:PP	.015	.044	.337	.736	.109	
MemScore:Root	.027	.037	.726	.468	.510	
QVT:Length_LD	-.011	.036	-.311	.756	.095	
QVT:Freq	.025	.045	.567	.570	.313	
QVT:N	.032	.045	.714	.475	.495	
QVT:PP	-.010	.044	-.231	.817	.051	
QVT:Root	-.014	.037	-.366	.715	.129	
MemScore:QVT:Length_LD	-.009	.029	-.303	.762	.089	
MemScore:QVT:Freq	.003	.035	.091	.928	.929	
MemScore:QVT:N	.052	.036	1.472	.141	2.130	
MemScore:QVT:PP	.025	.035	.738	.461	.527	
MemScore:QVT:Root	-.042	.030	-1.390	.164	1.880	

Table 6-8. *Full model showing the fixed effects with log odds estimated coefficients for phone accuracy in speeded pronunciation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	β	*SE*	*z*	P(>|z|)	$\chi^2(1)$	*p*
(Intercept)	4.396	.115	38.290	.000		
Age	-.241	.078	-3.100	.002	8.919	**
MemScore	.076	.109	.700	.486	.473	
QVT	.897	.108	8.330	.000	49.285	***
Length_LD	-.049	.067	-.740	.462	.513	
Freq	.325	.072	4.500	.000	19.244	***
N	.018	.065	.270	.788	.071	
PP	.146	.070	2.090	.036	4.316	*
Root	.050	.061	.820	.411	.655	
MemScore:QVT	-.211	.088	-2.390	.017	5.415	*
MemScore:Length_LD	-.049	.045	-1.100	.273	1.138	
MemScore:Freq	.011	.052	.210	.831	.043	
MemScore:N	.029	.042	.680	.494	.443	
MemScore:PP	.063	.048	1.310	.189	1.569	
MemScore:Root	.041	.035	1.190	.233	1.325	
QVT:Length_LD	.031	.047	.670	.504	.439	
QVT:Freq	.095	.054	1.780	.076	2.975	.
QVT:N	.022	.044	.500	.616	.239	
QVT:PP	-.028	.050	-.560	.577	.279	
QVT:Root	-.093	.036	-2.600	.009	5.964	*
MemScore:QVT:Length_LD	.021	.037	.590	.557	.327	
MemScore:QVT:Freq	.008	.041	.190	.847	.035	
MemScore:QVT:N	.057	.032	1.770	.077	3.140	.
MemScore:QVT:PP	.012	.037	.330	.742	.102	
MemScore:QVT:Root	-.053	.026	-2.040	.041	3.877	*

Chapter 7. Morphological Processing

7.1 Introduction

This chapter describes the third and final study of the dissertation, which looks at visual word processing of non-Arabic-speaking Qur'anic memorisers at the morphological level. In this study, participants were presented with a visual lexical decision task with unmasked morphological priming. A selective review of the literature on Arabic morphology and Arabic morphological development provides support for a non-concatenative morphology with the root and word pattern functioning as abstract morphological units with separate roles; the presence of root and/or word pattern priming effects in non-Arabic-speaking Qur'anic memorisers would indicate the implicit learning of such non-concatenative morphological units through rote memorisation. Individual differences in root and word pattern priming effects on lexical decision were also explored through two-way and three-way interactions of the effects with amount of memorisation and vocabulary knowledge, thereby looking at the roles of statistical exposure and semantic knowledge in the development of non-concatenative morphological representations.

7.2 Background

The last decade has seen major advances in research on the mental representation of Arabic morphology, particularly through work on Modern Standard Arabic (e.g. Abu-Rabia, 2012; Abu-Rabia & Awwad, 2004; Abu–Rabia, 2002; Alamri, 2017; Boudelaa, 2014, 2015; Boudelaa & Marslen-Wilson, 2001, 2004a, 2004b; Boudelaa & Marslen-Wilson, 2005, 2011, 2015; Boudelaa et al., 2010; Gwilliams & Marantz, 2015; Idrissi & Kehayia, 2004; Idrissi, Prunet, & Béland, 2008), but more recently on dialects as well (e.g. Schluter, 2013, on Moroccan Arabic). Using state-of-the-art neuropsychological techniques, these studies have shown that discontinuous root and pattern morphemes are represented in Arabic speakers' minds and play a role in spoken and visual word processing. Their work further points to an intricate relationship between the semantic and morphological function of roots and word patterns, which raises the question of whether non-concatenative morphological representation can take place without semantic representation. One context that lends itself to investigating this question is that of rote learning of Arabic through Qur'anic memorisation with little semantic input, a phenomenon occurring in our non-Arabic-speaking population. Through studying the visual word processing of non-Arabic-speaking memorisers at the morphological level, one can investigate this question. Furthermore, as seen in Chapter 2, the large variability in memorisation and vocabulary knowledge in the population allows us to explore the roles of statistical exposure and semantic knowledge in the development of non-concatenative morphological representation.

7.2.1 Qur'anic Arabic Morphology

Unlike the orthography and phonology of Qur'anic Arabic which has slight differences with those of Modern Standard Arabic (MSA) (see Chapter 2), the morphology of Qur'anic Arabic and MSA are both based on the same underlying structure of derivational morphology involving roots and word patterns. This derivational morphology is based on non-concatenative word building (root + word pattern), contrasting with concatenative word building (stem + affix) used by Indo-European languages such as English (Boudelaa & Marslen-Wilson, 2015).

In concatenative morphology, morphemes such as stems and affixes are attached to one another in a linear fashion. However, in non-concatenative morphology, morphemes such as roots and word patterns are attached to one another in a non-linear fashion that can involve infixing or the internal modification of the root, thus resulting in discontinuous morphemes (Katamba & Stonham, 2006). According to McCarthy's (1981) prosodic theory of non-concatenative morphology, words have multiple tiers at the underlying level of representation in the lexicon: the root tier (or consonantal tier), the skeletal tier (or the CV tier), and the vocalic melody tier (or vowel tier). Roots are made up of three or four consonants and are proposed to be the fundamental lexical unit of Semitic languages (McCarthy, 1981; McCarthy & Prince, 1990) that carry semantic information whereas the skeletal and the vocalic melody tiers come from word patterns carrying phonological and morpho-syntactic information (Boudelaa, 2014, 2015; Boudelaa & Marslen-Wilson, 2001, 2004a, 2015). For example, the root (ktb), which semantically has to do with writing, and the word pattern (a-a-a), which is used to indicate past tense in the third person, come together non-linearly to form /kataba/, which means ‘he wrote’. The simultaneous affixation of the consonantal root within fixed slots in the word pattern template often results in discontinuous or broken phonological and/or orthographic representations of the root, thereby contributing to morphological opacity (Saiegh-Haddad & Geva, 2008).

Numerous psycholinguistic studies have provided support for the psychological status of roots and word patterns in native Arabic speakers’ mental representations (but see Abu-Rabia & Awwad, 2004, for contradictory findings; Boudelaa, 2014, 2015; Boudelaa & Marslen-Wilson, 2001, 2005, 2011, 2015; Boudelaa et al., 2010), with root priming effects being more stable than word pattern priming effects. Here, we will focus on studies that use visually presented targets given that the current study is looking at visual word processing. These studies typically employed visual masked and cross-modal priming tasks to test for root and word pattern priming effects (e.g. Boudelaa, 2015; Boudelaa & Marslen-Wilson, 2015). The logic underlying priming is that priming effects indicate the activation of a representational link between the prime and target in question (Boudelaa & Marslen-Wilson, 2001, 2015), and thus, influencing reaction times in the task either in a facilitatory or competitive way. In visual masked priming, participants are presented with a prime word that appears after a front masking pattern and then a visual target to which they make a speeded lexical decision (e.g. Abu-Rabia & Awwad, 2004). In cross-modal priming, participants make a speeded lexical decision about a visual target presented immediately at the offset of an auditory full word or word-fragment prime (e.g. Boudelaa, 2015; Boudelaa & Marslen-Wilson, 2015).

In the abovementioned studies, robust facilitatory root priming effects have been found; when the prime and target shares a root, response latencies in lexical decision are facilitated. More importantly, these root priming effects occur even beyond semantic transparency and shared phonology, thereby suggesting the psychological reality of roots functioning as abstractive cognitive entities in native Arabic speakers (Boudelaa & Marslen-Wilson, 2015). However, compared to root priming effects, word pattern priming effects are less robust and may differ depending on the type of word pattern {see \Boudelaa, 2015 #394}.

It is important to note that the focus of this study is not on contributing to the debate on the psychological status of root and word pattern in Arabic morphology, but more on whether non-concatenative morphological representations can be developed through implicit statistical learning and accessed during visual word processing. Native Arabic speakers may be deeply aware of roots and word patterns because most Arabic words are built based on that non-concatenative strategy and that it is part of the productive morphology of the language. Arabic dictionaries are organised based on roots and roots are formally taught in school, familiarising native learners with the term ‘root’ as part of their cultural heritage (e.g. Ravid, 2003, for Palestinian Arabic). However, it remains to be seen whether such discontinuous morphological units can be implicitly learned in the absence of explicit instruction and semantic knowledge. We have seen in Chapters 5 and 6 that our participants are sensitive to root variables in lexical decision and speeded pronunciation, but the predictive power of root variables in lexical decision and speeded pronunciation latencies is much weaker than measures of orthographic similarity such as Levenshtein distance or neighbourhood density.

7.3 Overview of Current Study

The goal of this study was to investigate whether non-Arabic-speaking Qur’an memorisers implicitly gain morphological representations when processing what they read or memorise in the Qur’an, and thus, be primed by Qur’anic Arabic roots and word patterns in a lexical processing task such as lexical decision. Roots and word patterns have been shown by Boudelaa and colleagues to play significant yet independent roles in Arabic morphology and lexical processing; therefore, any priming effects of roots and/or word patterns should suggest some kind of morphological representation and processing in the mental lexicon of the non-Arabic-speaking Qur’an memoriser. We also examined whether the priming of roots and word patterns interact with Qur’an vocabulary knowledge and amount of Qur’an memorisation, thereby informing us of the roles of semantics and statistical exposure to the language respectively in morphological representation and processing.

7.3.1 Research Questions

This study seeks to answer the following specific research questions:

a) Do non-Arabic-speaking Qur'anic memorisers visually process Qur'anic Arabic words at the morphological level, and thus, are primed by root and/or word patterns during a visual word processing task?
b) Do vocabulary knowledge and amount of memorisation interact with root and word pattern priming effects?

7.3.2 Predictions

Given the non-concatenative nature of Qur'anic Arabic morphology, we predict that it would be difficult for our non-Arabic-speaking Qur'anic memorising population to implicitly learn how to extract root and word patterns in the absence of explicit instruction and semantic knowledge. Therefore, they would not be able to morphologically decompose Qur'anic Arabic words into roots and word patterns, and thus, show no overall root and word pattern priming effects during a visual word processing task.

In terms of root priming, given that root morphemes convey semantic information, we predict that vocabulary knowledge would interact with root priming effects such that root priming effects would be larger for participants with more vocabulary knowledge. However, given that word pattern morphemes do not convey semantic information, but rather, express phonological and morpho-syntactic information, we predict a smaller role of vocabulary knowledge, and thus, having little-to-no moderating effect on word pattern priming.

Overall, we predict that amount of memorisation and vocabulary knowledge interacting together would affect root priming such that root priming effects would be the largest for participants with more vocabulary knowledge and more memorisation, thus supporting the idea that the development of root representations require that semantic knowledge be supported with statistical exposure to the language (and vice versa). However, we predict that the same pattern would not hold for any word pattern priming effects as word pattern morphemes, i.e., vowels, do not convey semantic information, but rather, express phonological and morpho-syntactic information, which may be much more difficult to learn implicitly through mere statistical exposure to the language and requires grammatical knowledge in addition to semantic knowledge.

7.4 Method

7.4.1 Participants

A group of 242 participants (150 females; M_{age} = 18.68; SD_{age} = 6.62) were sampled from a *tahfiẓ* (memorising) school, two *madrasahs* (religious school; non-memorising), and the general public. All of them were at least Malay-English/English-Malay bilinguals with normal or corrected-to-normal vision and were either in upper secondary or polytechnic in terms of education. None of them had any history of hearing loss, reading or speech disorders. Written consent to take part in the study was obtained from either the participants themselves or from their guardians if they were a minor. Participants received a small token of appreciation for their participation. The study was approved by the Newcastle University Faculty of Humanities and Social Sciences Ethics Committee.

7.4.2 Individual-level Measures

As the individual-level measures used in this study were identical to the ones used in the previous studies (Chapters 5 and 6), only the descriptive statistics of the measures will be given.

7.4.2.1 Qur'an Vocabulary Test (QVT)

Participants were given the QVT (see Chapter 4) to measure their Qur'an vocabulary knowledge, scoring between 17 and 87 out of a maximum score of 90 (M = 54.01, SD = 14.20).

7.4.2.2 Self-reported Qur’an Memorisation Score (MemScore)

MemScore was used to measure amount and fluency of Qur’an memorisation of participants (see Chapter 4). Participants self-reported a range of memorisation scores from 9 to 948 out of a maximum score of 1026 (M = 341.83, SD = 210.83).

7.4.3 Stimuli and Design

7.4.3.1 Root Priming

For root priming, 26 orthographically and phonetically unambiguous words, i.e., words pronounced exactly how they are written, were selected from the Qur’an Lexicon for use as priming targets. The full list of experimental materials is provided in Appendix G. Each target was paired with three different primes to generate three experimental conditions each with 26 sets of prime-target pairs (see Table 7-1).

In the +R+P condition, both primes and targets share a root (+R), and thus, the same phonology (consonants; +P). The –R+P condition, in which both primes and targets do not share a root (-R) but share the same phonology (consonants; +P), serves as a phonological control to test whether any root priming effects are due to shared phonology instead of morphology. In this condition, a non-linear phonological overlap between prime and target was ensured by selecting pairs of words from roots that share the same characters but in a different order, e.g., ع م ل and ع ل م as seen in Table 7-1. This improves upon the +Phonology conditions in previous root priming experiments by Boudelaa and colleagues (e.g., Boudelaa, 2015; Boudelaa & Marslen-Wilson, 2001, 2015) where the non-linear phonological overlap between prime and target was always less than the non-linear phonological overlap between prime and target in the +Root conditions.

A standard unrelated baseline for the +R+P and –R+P conditions is provided by the Baseline condition, where both prime and target have no semantic, morphological, or phonological properties in common.

The targets were on average 4.38 letters (*SD* = .94), 7.31 phonemes (*SD* = 1.41), and 3.19 syllables (*SD* = 0.94) long. They had an average item frequency of 6.19 (*SD* = 9.55). Table 7-1 also lists the relevant psycholinguistic properties of the primes in each condition, including length in letters, phonemes, and syllables, item and root frequencies, as well as root family size, a.k.a. root productivity, which is defined as the number of word types formed by a given root. All three conditions were matched for length, but the restrictions on choice of stimuli in the -R+P condition, where primes and targets needed to phonologically overlap without sharing a root, led to an inability to match the three conditions in item and root frequencies as well as root family size. However, *F*-tests showed that all three conditions did not significantly differ on log(item frequency), $F(2, 75) = .297$, *ns*., root frequency, $F(2, 75) = .251$, *ns*., and root family size, $F(2, 75) = 2.05$, *ns*.

Table 7-1. Descriptive statistics for root priming stimuli (*N* = 26).

			Letters		Phonemes		Syllables		Item Frequency		Root Frequency		Root Family Size	
Condition	**Prime**	**Target**	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
+R+P	يَعْمَلْ /jaʕmal/ *(he worked)*	عَمِلَ /ʕamila/ *(he has done)*	4.27	0.83	6.23	0.95	2.69	0.55	3.88	4.96	149.81	204.84	24.50	16.77
-R+P	يَعْلَمْ /jaʕlam/ *(he knew)*	عَمِلَ /ʕamila/ *(he has done)*	4.27	0.83	6.23	0.95	2.69	0.55	7.12	13.00	113.62	232.71	15.46	18.46
Baseline	تَغْفِرْ /taɣfir/ *(you forgive)*	عَمِلَ /ʕamila/ *(he has done)*	4.27	0.83	6.23	0.95	2.69	0.55	4.46	5.43	121.38	129.73	23.81	18.46

7.4.3.2 Word pattern priming

For word pattern priming, sets of word patterns were selected from the Qur'an Lexicon and differentiated according to whether the forms were for deverbal nouns, verbs, or primitive nouns. This is because Boudelaa and Marslen-Wilson (2015) found significant word pattern priming effects only for deverbal nouns that share a core morpho-syntactic function with the target as well as for verbs, but not for primitive nouns.

Deverbal nouns. Twenty orthographically and phonetically unambiguous deverbal nouns, i.e., words pronounced exactly how they are written, were selected from the Qur'an Lexicon for use as priming targets. The full list of experimental materials is provided in Appendix G. Each target was paired with three different primes to generate three experimental conditions each (+WP+P, -WP+P, -WP-P) with 26 sets of prime-target pairs (see Table 7-2).

In the +WP+P condition, both primes and targets share word patterns matched for form and morpho-syntactic properties (+WP), and thus share the same phonology in terms of vowels (+P). None of the prime-target pairs share a semantic relationship.

The –WP+P condition, in which both primes and targets do not share a root and a word pattern (-WP) but share the same phonology (consonants; +P), serves as a phonological control to test whether any word pattern priming effects are due to shared phonology instead of morphology. In this condition, a non-linear phonological overlap between prime and target was ensured by selecting pairs of words from roots that share the same letters but in a different order, e.g., ح س ب and س ح ب as seen in Table 7-2. Similar to the root priming experiment, this improves upon the +Phonology conditions in previous word pattern priming experiments by Boudelaa and colleagues (e.g., Boudelaa, 2015; Boudelaa & Marslen-Wilson, 2001, 2015) in which the non-linear phonological overlap between prime and target was always less than the non-linear phonological overlap between prime and target in the +Word Pattern conditions.

A standard unrelated baseline for the +WP+P and –WP+P conditions is provided by the –WP-P condition, where prime and target share neither word pattern (-WP) nor phonology (-P), and thus have no semantic, morphological, or phonological properties in common.

The targets were on average 4.15 letters (*SD* = .82), 6.74 phonemes (*SD* = 1.02), and 2.85 syllables (*SD* = .50) long. They had an average item frequency of 3.65 (*SD* = 5.53). Table 7-2 below lists the relevant psycholinguistic properties of the primes in each condition, including length in letters, phonemes, and syllables, item and root frequencies, as well as root family size. All three conditions were matched for length, but the restrictions on choice of stimuli in the –WP+P condition, where primes and targets needed to phonologically overlap without sharing a root and a word pattern, led to the inability to match the three conditions in item and root frequencies as well as root family size. However, *F*-tests showed that all three conditions did not significantly differ on log(item frequency), $F(2, 57) = 1.12$, *ns*., root frequency, $F(2, 57) = .924$, *ns*., and root family size, $F(2, 57) = .011$, *ns*.

Table 7-2. Descriptive statistics for word pattern priming stimuli (deverbal nouns).

			Letters		Phonemes		Syllables		Item Frequency		Root Frequency		Root Family Size	
Condition	**Prime**	**Target**	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
	كَاتِبٌ	عَامِلٌ	4.15	0.82	6.74	1.02	2.85	0.50	3.09	6.14	82.59	86.79	20.32	13.82
+WP+P	/ka:tibun/	/ʕa:milun/												
	(scribe)	*(worker)*												
	عَلِيمٌ	عَامِلٌ	4.12	0.84	6.74	1.02	2.85	0.50	4.59	12.69	102.71	203.68	17.26	17.78
-WP+P	/ʕali:mun/	/ʕa:milun/												
	(All-Knower)	*(worker)*												
	رُسُلًا	عَامِلٌ	4.12	0.84	6.74	1.02	2.85	0.50	2.32	3.01	67.71	99.27	17.82	14.42
-WP-P	/rusulan/	/ʕa:milun/												
	(messenger)	*(worker)*												

Verbs. In addition to the deverbal noun word pattern stimuli, 24 verbal prime-target pairs were selected from the Qur'an Lexicon and the same three conditions (+WP+P, -WP+P, -WP-P) were generated. The targets were on average 3.75 letters ($SD = .44$), 6.63 phonemes ($SD = .65$), and 2.96 syllables ($SD = .36$) long. They had an average item frequency of 1.75 ($SD = 1.51$). Table 7-3 below lists the relevant psycholinguistic properties of the primes in each condition, including length in letters, phonemes, and syllables, item and root frequencies, as well as root family size. All three conditions were matched for length, but the restrictions on choice of stimuli in the –WP+P condition, where primes and targets needed to phonologically overlap without sharing a root and a word pattern, led to the inability to match the three conditions in item and root frequencies as well as root family size. However, *F*-tests showed that all three conditions did not significantly differ on log(item frequency), $F(2, 69) = .496$, *ns*., root frequency, $F(2, 69) = .840$, *ns*., and root family size, $F(2, 69) = 1.29$, *ns*.

Table 7-3. Descriptive statistics for word pattern priming stimuli (verbs).

			Letters		Phones		Syllables		Item Frequency		Root Frequency		Root Family Size	
Condition	**Prime**	**Target**	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
+WP+P	صَدَّقَ /sˤaddaqa/ (he has found the truth)	حَرَّمَ /ħarrama/ (he has forbidden)	3.75	0.44	6.63	0.65	2.96	0.36	2.17	2.58	120.42	278.03	21.33	14.27
-WP+P	رَّحِمَ /raħima/ (he bestows mercy)	حَرَّمَ /ħarrama/ (he has forbidden)	3.75	0.44	6.63	0.65	2.96	0.36	1.63	1.06	80.50	92.74	17.54	10.75
-WP-P	تَبِعَ /tabiʕa/ (he follows)	حَرَّمَ /ħarrama/ (he has forbidden)	3.75	0.44	6.63	0.65	2.96	0.36	1.46	0.88	56.29	62.69	15.96	10.34

Primitive nouns. Fourteen primitive noun prime-target pairs were selected from the Qur'an Lexicon and the same three conditions (+WP+P, -WP+P, -WP-P) were generated. Table 7-4 below lists the relevant psycholinguistic properties of the primes in each condition, including length in letters, phonemes, and syllables, item and root frequencies, as well as root family size. All three conditions were matched for length, but the restrictions on choice of stimuli in the –WP+P condition, where primes and targets needed to phonologically overlap without sharing a root and a word pattern, led to the inability to match the three conditions in item and root frequencies as well as root family size. *F*-tests showed that all three conditions significantly differed on log(item frequency), $F(2, 39) = 4.60$, $p < .05$, although differences in root frequency were only marginally significant, $F(2, 39) = 3.09$, $p = .06$, and root family size, $F(2, 39) = 1.42$, *ns*., was not significantly different across the three conditions. We address the item frequency mismatch across conditions using analyses of covariance (ANCOVA) in our data analyses.

Table 7-4. Descriptive statistics for word pattern priming stimuli (primitive nouns).

			Letters		Phones		Syllables		Item Frequency		Root Frequency		Root Family Size	
Condition	**Prime**	**Target**	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
+WP+P	عَقِيمًا /ʕaqiːman/ (barren old woman)	كَفِيلًا /kafiːlan/ (a surety)	3.79	0.80	6.29	1.20	2.64	0.63	3.21	7.73	68.50	90.70	17.43	14.61
-WP+P	سَحَابًا /saħaːban/ (orbit)	كَفِيلًا /kafiːlan/ (a surety)	3.71	0.83	6.29	1.20	2.64	0.63	1.43	0.94	27.43	44.30	10.07	10.86
-WP-P	لَهَبٍ /lahabin/ (blaze)	كَفِيلًا /kafiːlan/ (a surety)	3.71	0.83	6.29	1.20	2.64	0.63	1.43	0.76	35.86	39.23	12.36	9.00

Test-pairs from the three conditions in both root and word pattern stimuli were rotated across three counterbalanced experimental lists such that each target word only occurred once in each list, thus avoiding repetition of primes and targets within participants. Each list thus had 84 test-pairs in total. The overall proportion of related pairs was reduced to a third by including 42 unrelated word-word pairs as fillers. This further minimised any possible strategic responses due to the longer SOA in the visual unmasked priming paradigm used here. Another 126 word-nonword pairs with similar characteristics as the word-word pairs were used to provide the nonword targets needed for the lexical decision task used here. In total, there were 252 prime-target pairs, 126 of which were word targets and 126 of which were nonword targets.

For experiments that were conducted by the experimenter, stimulus presentation and data recording were controlled by PsychoPy software (Peirce, 2007) running on either a PC or a laptop with Windows 7. For experiments that were conducted online, stimulus presentation and data recording were controlled by Inquisit Web 5.0 (Millisecond-Software, 2016).

7.4.4 Procedure

Participants were tested in two sessions either in person or online—in the first session, they were asked to complete an online questionnaire detailing their demographics and language background information as well as their experience with Qur'an recitation and memorisation. They were then asked to complete the Qur'an vocabulary test online. The entire session took about 30 minutes.

In the second session, participants were tested either individually (in person or online) or in small groups with each individual having their own separate testing apparatus (either a PC or a laptop) with identical experimental software. Participants were randomly assigned to one of the three counterbalanced stimuli lists. After keying in their participant number into the system, they received written instructions in English to perform a visual lexical decision task. In this task, they were instructed that they would be seeing two letter strings one at a time; they should ignore the first letter string and decide as quickly and as accurately as possible whether or not the second letter string was an Arabic word. If they thought the second letter string was an Arabic word, they then press the "/' key or the "z" key if otherwise. Participants were given 20 practice trials before beginning the experiment.

For the experiment, 252 experimental trials were presented in random order within three blocks of 84 trials each. Each block of 84 trials was followed by a rest break which was three minutes long. Every trial started with the presentation of a centred fixation point ("+") for 500 ms. This was then immediately followed by a prime word that appeared for 250 ms, which was chosen to allow the conscious appreciation of the primes, yet brief enough to minimize strategic behaviour (Rastle et al., 2000). This was then immediately followed by presentation of the word or nonword target, centred on the screen. The target stayed on the screen until the participant responded or until the maximum response time (3000 ms) was exceeded. An auditory tone was presented if the maximum response time was exceeded or if the response was incorrect. An incorrect response was also presented with "Incorrect" to alert the participant to a wrong response. The inter-trial interval was 500 ms.

All stimuli were presented in black on white screen and in Traditional Arabic font; the prime in 24-point font size and the target in 36-point font size as there is no upper case/lower case distinction in the Arabic script (see Boudelaa & Marslen-Wilson, 2001). This ensures that the primes and targets are physically distinct from each other, and thus, the target is not a continuation of the prime (Forster, Mohan, & Hector, 2003).

The experiment took approximately 15 minutes long. At the end of the experiment, participants received a small token of appreciation for their participation, were debriefed, and thanked for their help.

7.5 Data Analysis

7.5.1 Data Cleaning

7.5.1.1 Participants

One participant was excluded as he did not complete the task. To ensure that the accuracy of the remaining participants was reliably above chance, calculations based on the binomial distribution showed that participants would have to get 139 out of 252 trials (55.16%) correct to be performing above chance at $p < .05$. 44 participants were excluded from the data as their task accuracy was below 55.2%. Ten other participants were also removed as they did not get any trials correct in any one of the item conditions, while another 13 participants were removed as their RTs were 2.5 standard deviations above or below the group's mean, leaving a total of 174 participants. As can be seen in Figure 7-1, of the 67 excluded participants, 19 of them did not make the passing mark (45) on the QVT. Figure 7-2 presents a scatterplot of QVT scores by amount of Qur'an memorisation of the final group of participants.

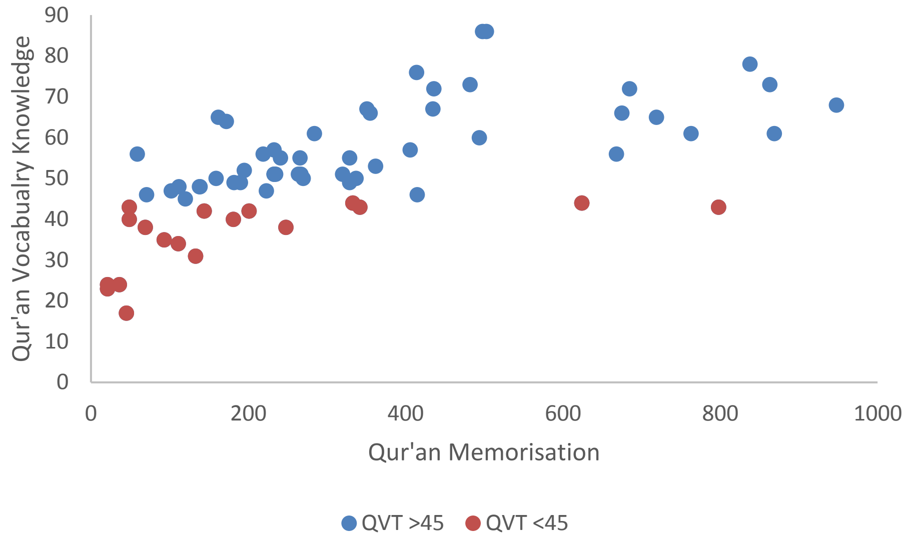

Figure 7-1. Scatterplot of QVT scores by amount of Qur'an memorisation for excluded participants (*N* = 67).

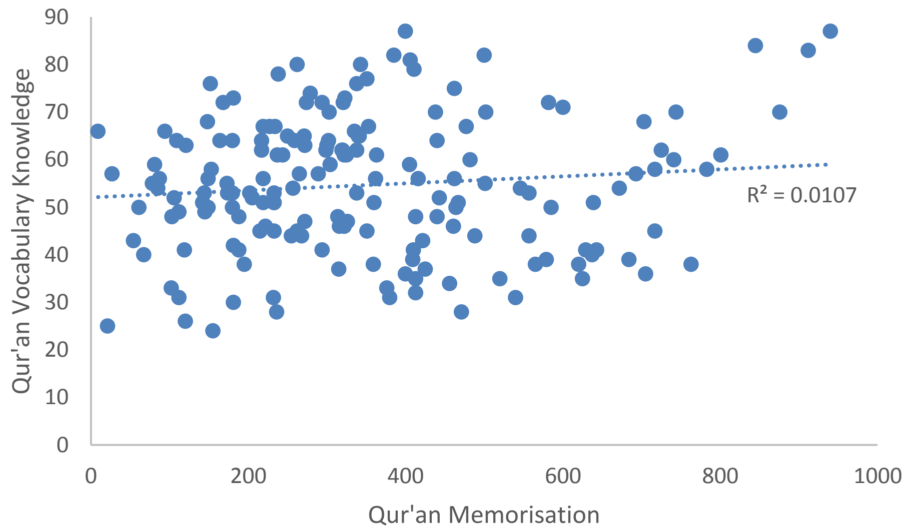

Figure 7-2. Scatterplot of QVT scores by amount of Qur'an memorisation for final group of participants (*N* = 174).

7.5.1.2 Trials

To ensure that accuracy of responses on items was reliably above chance, calculations based on the binomial distribution showed that at least 98 out of 174 participants (56.32%) had to get a particular item correct for the item's accuracy to be above chance at $p < .05$. Two target items were thus excluded from the data, leaving a total of 82 target items.

Typical data cleaning methods (as those used in previous chapters) were then followed to exclude extreme responses that may affect the analyses. First, trials with incorrect responses as well as trials that were faster than 200ms or slower than 3000ms were excluded from all RT analyses (25.85% of trials). Next, from the remaining trials, trials that were 2.5 standard deviations above or below each participant's mean RT were excluded (1.34% of trials). In total, 27.19% of trials were removed and the remaining trials were used in RT analyses. Table 7-5, Table 7-6, and Table 7-7 show the group's overall RT and accuracy across all conditions.

Table 7-5. Overall RT and accuracy across root priming conditions.

	RT (ms)		Accuracy (%)	
Condition	*M*	*SD*	*M*	*SD*
+R+P	910	380	85.25	35.47
-R+P	914	384	82.11	38.34
Baseline	926	377	82.36	38.13
Total	917	380	83.21	37.38

Table 7-6. Overall RT (ms) across word pattern priming conditions for deverbal nouns, verbs, primitive nouns, and all types.

	Deverbal Noun		Verb		Primitive Noun		All	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
+WP+P	882	353	897	360	883	332	888	350
-WP+P	905	332	911	357	914	353	910	348
-WP-P	892	355	919	346	896	360	904	353
Total	893	347	909	354	898	348	901	350

Table 7-7. Overall accuracy (%) across word pattern priming conditions for deverbal nouns, verbs, primitive nouns, and all types.

	Deverbal Noun		Verb		Primitive Noun		All	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
+WP+P	87.26	33.36	79.20	40.61	81.26	39.05	82.38	38.11
-WP+P	83.41	37.22	81.79	38.61	84.13	36.57	82.92	37.64
-WP-P	83.93	36.75	78.33	41.22	80.06	39.98	80.64	39.52
Total	84.82	35.89	79.79	40.16	81.81	38.58	82.41	38.07

7.5.2 Mixed Effects Regression Analyses

As the purpose of these analyses was to investigate whether item-level priming condition and individual-level variables (QVT and MemScore) influence response latencies on targets, a mixed effects regression analysis of the dependent variable (RT) for targets in root priming and word pattern priming were then conducted separately using R (R Core Team, 2016) and *lmerTest* (Kuznetsova et al., 2017) with maximum likelihood. Given that RT data in general is positively skewed, a log transformation of the cleaned RT data was performed so as to normalise the RT distribution and not violate the assumptions of normality and linearity of residuals needed for linear regression analyses. As mentioned in Chapter 5, *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Pseudo-R^2s for all models were calculated using the 'r.squaredGLMM' function in the 'MuMIn' package (Barton, 2017).

7.5.2.1 Root priming

Fitting the random effects structure. The initial mixed effects model that was used for root priming latencies included random intercepts for both participant and stimuli, as well as random slopes for condition varying by participant, using a maximal random effects structure. This is because we expected priming effects to vary across individuals. However, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for condition by participant into the model neither improved the model fit nor accounted for a significant amount of the random variance, $\chi^2(5) = 5.339$, *ns*. The more parsimonious random-intercepts-only model was thus used for the final full model.

Covariates. For this analysis, the following covariates were initially included in a preliminary model: *z*-scored age, *z*-scored trial order number, *z*-scored display refresh rate, and sum-coded sex. However, preliminary analyses showed that the effects of trial order number and display refresh rate on RTs were not significant and removing them from the full model did not affect model fit, $\chi^2(2) = 3.934$, *ns.*, therefore they were excluded from the full model for parsimony.

Fixed effects. In terms of main effects, the model included condition as well as *z*-scored memorisation and *z*-scored vocabulary knowledge. In terms of interactions, the model included the three-way interaction between memorisation, vocabulary knowledge, and condition, as well as their subsumed two-way interactions, i.e., memorisation × vocabulary knowledge, memorisation × condition, and vocabulary knowledge × condition.

A linear mixed effects regression analysis was then conducted using the ‘lmer()’ function in the ‘lmerTest’ package (Kuznetsova et al., 2017) and using maximum likelihood, running the model as follows:

```
Model(Root) <- lmer(Log(RT) ~ (1 | participant) + (1 | stimuli)
          + Age + Sex
          + MemScore + QVT + Condition
          + MemScore:QVT
          + MemScore:Condition + QVT:Condition
          + MemScore:QVT:Condition, REML = F, data=all)
```

Given the focus on priming effects, ‘Baseline’ was used as the reference condition so that pairwise comparisons in the model would test the significance of any priming effects as well as any relevant interactions with priming effects, e.g., RT(+R+P) - RT(Baseline) for root priming and RT(-R+P) - RT(Baseline) for phonological priming.

7.5.2.2 Word pattern priming: All types

Fitting the random effects structure. Similar to the previous model fitting for root priming, the initial mixed effects model that was used for word pattern priming latencies (all types) included random intercepts for both participant and stimuli, as well as random slopes for condition varying by participant, using a maximal random effects structure. This is because we expected priming effects to vary across individuals. However, a likelihood ratio test comparing the random-intercepts-only model with the random-intercepts-and-random-slopes model showed that adding the random slopes for condition by participant into the model neither improved the model fit nor accounted for a significant amount of the random variance, $\chi^2(5) = .7491$, *ns*. The more parsimonious random-intercepts-only model was thus used for the final full model.

Covariates. For this analysis, the following covariates were initially included in a preliminary model: *z*-scored age, *z*-scored trial order number, *z*-scored display refresh rate, and sum-coded sex. However, preliminary analyses showed that the effect of display refresh rate on RTs was not significant and removing it from the full model did not affect model fit, $\chi^2(1) = 2.112$, *ns.*, therefore it was excluded from the full model for parsimony.

The same fixed effects used in the previous model for root priming were also used in the fitting of the full model for word pattern priming (all types). A linear mixed effects regression analysis was then conducted using the 'lmer()' function in the 'lmerTest' package (Kuznetsova et al., 2017) and using maximum likelihood, running the model as follows:

```
Model(WP_all) <- lmer(Log(RT) ~ (1 | participant) + (1 | stimuli)
          + Age + Trial_Order_Number + Sex
          + MemScore + QVT + Condition
          + MemScore:QVT
          + MemScore:Condition + ZQVT:Condition
          + MemScore:QVT:Condition, REML = F, data=all)
```

Given the focus on priming effects, '-WP-P' was used as the reference condition so that pairwise comparisons in the model would test the significance of any priming effects as well as any relevant interactions with priming effects, e.g., RT(+WP+P) - RT(-WP-P) for word pattern priming and RT(-WP+P) - RT(-WP-P) for phonological priming. The same was done for subsequent analyses on word pattern priming of the three types: deverbal nouns, verbs, and primitive nouns.

7.6 Results

Results from the full linear mixed models for root priming and word pattern priming are presented in their respective sub-sections. Only results pertaining to priming effects and their interactions with individual-level variables (QVT and MemScore) will be presented given the focus of the study.

7.6.1 Root Priming

7.6.1.1 Individual-Level Variables as Continuous Variables

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in the model for root priming described 55.74% of the variance in RTs; random effects described 48.58% of the variance in RTs while fixed effects described 7.16% of the variance in RTs. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Table 7-9 presents the likelihood ratio tests for the main effects and interactions in the model. Table 7-10 presents the estimated standardised coefficients for the fixed effects and pairwise comparisons in the model. Results from the model are described in the following sub-sections.

Priming condition. As can be seen in Table 7-9, results showed no significant main effect of priming condition on RTs overall, $\chi^2(2) = .309$, *ns*. Pairwise comparisons between conditions also indicated no significant effect of root priming on RTs [+R+P vs. Baseline: $\beta = -.020$, $SE = .037$, $t(77) = -.538$, *ns.*] as well as no significant effect of phonological priming on RTs [-R+P vs. Baseline: $\beta = -.014$, $SE = .037$, $t(77) = -.392$, *ns.*] (see Table 7-10).

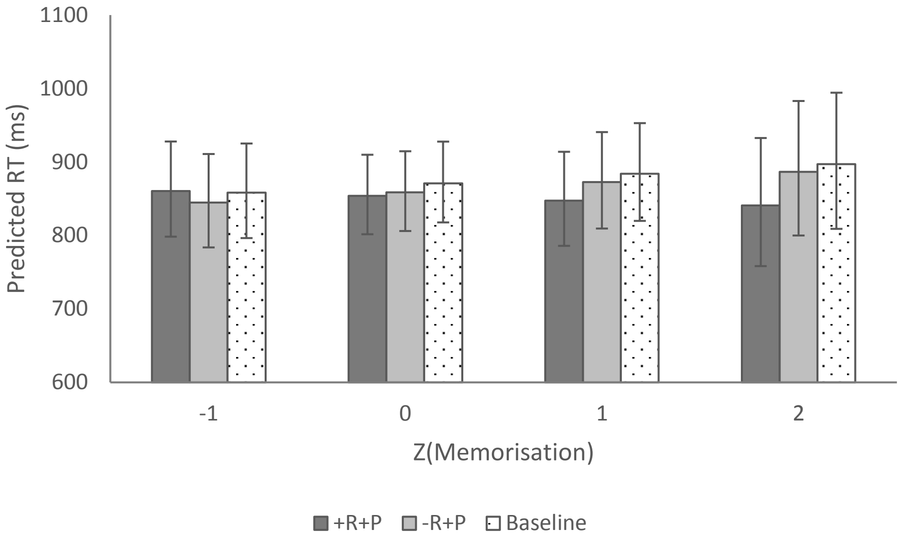

Figure 7-3. Memorisation × Condition interaction: Predicted RTs for targets based on the full linear mixed effects model across root priming conditions. Results are presented as a function of memorisation z-scores. Error bars are based on 95% confidence intervals.

Effect of memorisation on priming. Results showed that the interaction between memorisation and priming condition on RTs was marginally significant, $\chi^2(2) = 5.125$, $p = .077$. Plotting the simple slopes of the two-way interaction showed that as amount of memorisation increases, root priming appears to increase while there does not appear to be any phonological priming across all levels of memorisation (see Figure 7-3). Participants who have memorised more Qur'an may thus be faster in reacting to a target word if it was preceded by a prime that shared the same root as the target word than if it was preceded by a prime that only shared the same phonology or a prime that shared neither the same root nor the same phonology. This was confirmed by the pairwise comparisons between conditions in Table 7-10 that indicated a marginally significant interaction between memorisation and root priming on RTs [MemScore × (+R+P vs. Baseline): $\beta = -.022$, $SE = .012$, $t(3263) = -.1.900$, $p = .058$] but no significant interaction between memorisation and phonological priming on RTs [MemScore × (-R+P vs. Baseline): $\beta = .001$, $SE = .012$, $t(3219) = .130$, *ns.*].

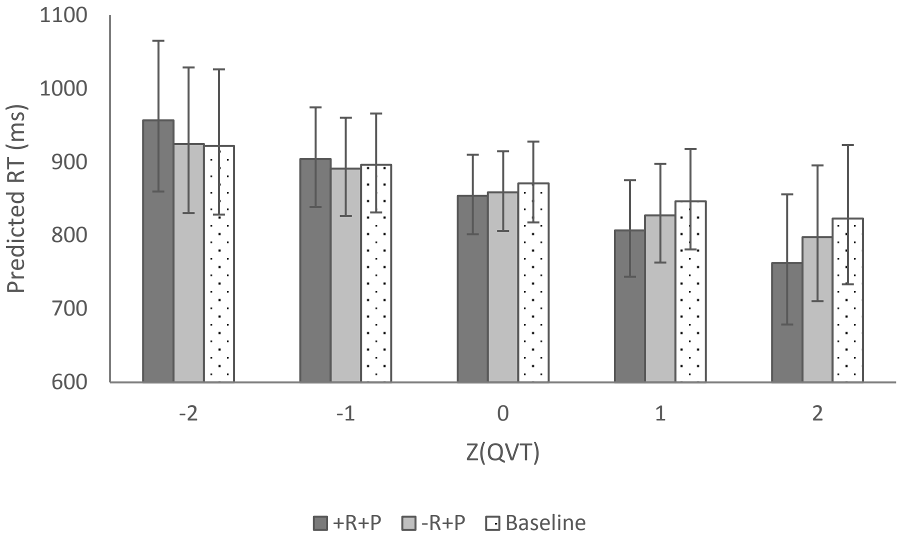

Figure 7-4. Vocabulary Knowledge × Condition interaction: Predicted RTs for targets based on the full linear mixed effects model across root priming conditions. Results are presented as a function of Qur'an vocabulary knowledge (QVT) z-scores. Error bars are based on 95% confidence intervals.

Effect of vocabulary knowledge on priming. Results showed that the interaction between vocabulary knowledge and priming condition on RTs was significant, $\chi^2(2) = 6.018$, $p < .05$. Plotting the simple slopes of the two-way interaction showed that as amount of vocabulary knowledge increases, the increase in root priming appears to be greater than the increase in phonological priming (see Figure 7-4). Participants with more vocabulary knowledge were thus much more likely to be faster in reacting to a target word if it was preceded by a prime that shared the same root as the target word than if it was preceded by a prime that only shared the same phonology or a prime that shared neither the same root nor the same phonology. This was confirmed by the pairwise comparisons between conditions in Table 7-10 that indicated a significant interaction between vocabulary knowledge and root priming on RTs [QVT × (+R+P vs. Baseline): $\beta = -.028$, $SE = .012$, $t(3228) = -2.400$, $p < .05$] but no significant interaction between vocabulary knowledge and phonological priming on RTs [QVT × (-R+P vs. Baseline): $\beta = -.008$, $SE = .012$, $t(3224) = -.717$, *ns.*].

Effect of memorisation and vocabulary knowledge on priming. Results showed that the three-way interaction between memorisation, vocabulary knowledge, and priming condition on RTs was not significant, $\chi^2(2) = 1.652$, *ns*.

Pairwise comparisons between conditions also indicated no significant interaction between memorisation, vocabulary knowledge, and root priming on RTs [MemScore × QVT × (+R+P vs. Baseline): β = .013, *SE* = .010, $t(3223) = -.538$, *ns.*] as well as no significant interaction between memorisation, vocabulary knowledge, and phonological priming on RTs [MemScore × QVT × (-R+P vs. Baseline): β = -.014, *SE* = .037, $t(3213) = -.392$, *ns.*] (see Table 7-10).

7.6.1.2 Individual-Level Variables as Categorical Variables

To ensure that the lack of significance in the above three-way interaction was not due to the lack of statistical power from fitting too many parameters in the model, a simpler model was fitted using the individual-level variables as categorical variables. Participants were divided into four groups based on whether they were High/Low in their memorisation (MemScore) and in their Qur'an vocabulary knowledge (QVT), in which High/Low was based on median splits (median of MemScore = 319.5, median of QVT = 54). Descriptive statistics of the four groups are presented in Table 7-8 and a scatterplot of the groups' QVT scores by memorisation can be seen in Figure 7-5. Pairwise comparisons between groups were conducted to ensure the following:

- That the HighMem groups did not significantly differ in MemScore, $F(1, 83) = .230$, *ns*., but significantly differed in QVT, $F(1, 83) = 207.24$, $p < .001$.
- That the LowMem groups did not significantly differ in MemScore, $F(1, 87) = 2.26$, *ns*., but significantly differed in QVT, $F(1, 87) = 157.60$, $p < .001$.
- That the HighQVT groups did not significantly differ in QVT, $F(1, 85) = 2.98$, *ns*., but significantly differed in MemScore, $F(1, 85) = 98.24$, $p < .001$.
- That the LowQVT groups did not significantly differ in QVT, $F(1, 85) = 1.16$, *ns*., but significantly differed in MemScore, $F(1, 85) = 219.10$, $p < .001$.

Table 7-8. Descriptive statistics of participants in the four groups formed from the median splits of MemScore and QVT.

		QVT		MemScore		Task Accuracy (%)	
Group	*N*	*M*	*SD*	*M*	*SD*	*M*	*SD*
HighMemHighQVT	42	68.43	9.53	518.64	190.51	89.13	31.13
HighMemLowQVT	43	42.09	7.21	502.09	120.43	79.38	40.47
LowMemHighQVT	45	64.24	6.51	210.07	82.81	83.64	37.00
LowMemLowQVT	44	43.93	8.63	184.91	74.65	75.86	42.80
Total	174	54.64	14.21	350.36	199.83	82.41	38.07

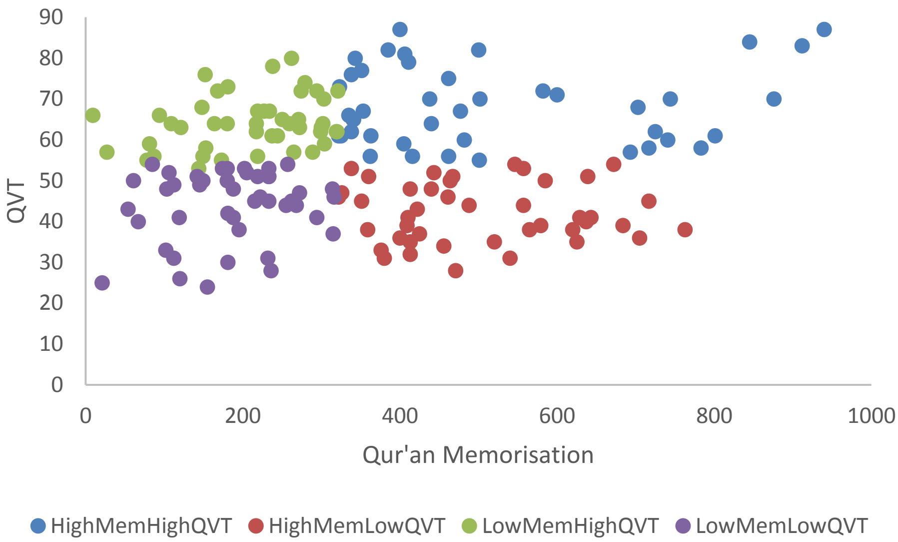

Figure 7-5. Scatterplot of QVT scores by amount of Qur'an memorisation for grouped participants (*N* = 174).

A linear mixed effects model similar to the one in the previous analysis was then fitted using the same dependent variable (log-transformed RTs), random effects structure (random intercepts of participant and item), covariates (z-scored age and sum-coded sex), and fixed effect (condition). The only difference between both models was that "Group" and "Group:Condition" replaced the individual-level variables MemScore and QVT as well as their relevant interactions. A linear mixed effects regression analysis was then conducted using the 'lmer()' function in the 'lmerTest' package (Kuznetsova et al., 2016) and maximum likelihood, running the model as follows:

```
Root.group <- lmer(Log(RT) ~ (1 | participant) + (1 | stimuli)
          + Age + Sex
          + Group + Condition
          + Group:Condition, REML = F, data=all)
```

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in the above model for root priming described 55.96% of the variance in RTs; random effects described 49.03% of the variance in RTs while fixed effects described 6.93% of the variance in RTs. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Table 7-11 presents the likelihood ratio tests for the main effects and interactions in the model. Table 7-12 presents the estimated standardised coefficients for the fixed effects and pairwise comparisons in the model. Results from the model are described in the following sub-sections.

Priming condition. As can be seen in Table 7-11, results showed no significant main effect of priming condition on RTs overall, $\chi^2(2) = .219$, *ns*. However, pairwise comparisons between conditions indicate a marginally significant effect of root priming on RTs (+R+P vs. Baseline: $\beta = -.080$, $SE = .041$, $t(119) = -1.948$, $p = .054$) but no significant effect of phonological priming on RTs (-R+P vs. Baseline: $\beta = -.015$, $SE = .041$, $t(118) = -.365$, *ns.*) (see Table 7-12).

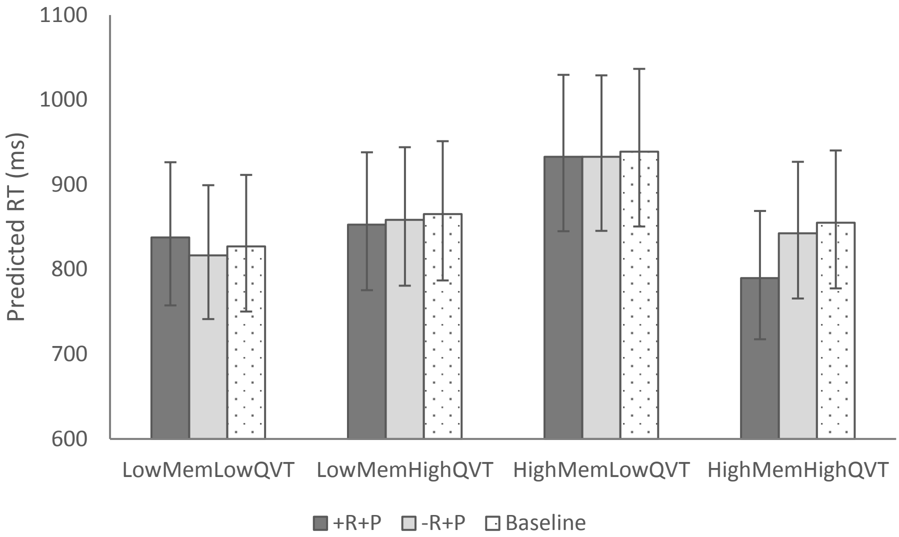

Figure 7-6. Group × Condition interaction: Predicted RTs for targets based on the full linear mixed effects model across individual-level groups by root priming condition. Groups are based on a combination of amount of Qur'an memorisation (High/Low Mem) and Qur'an vocabulary knowledge (High/Low QVT), in which "High/Low" was defined as above or below the median split of that variable. Error bars are based on 95% confidence intervals.

Effect of group on priming. Results showed that the interaction between group and priming condition on RTs was significant, $\chi^2(6) = 22.564$, $p < .001$. Plotting the simple slopes of the two-way interaction showed that although the effect of phonological priming did not seem to differ across groups, the effect of root priming appeared to be the largest in the HighMemHighQVT group (see Figure 7-6).

Although post-hoc pairwise comparisons between each condition within each group indicated that there was no significant root or phonological priming in each group (see Table 7-13: contrasts 1 to 4), pairwise comparisons in the full linear mixed effects model between conditions and groups (see Table 7-12) indicated that the effect of root priming in HighMemHighQVT was indeed significantly larger than that of the other three groups:

- (HighMemHighQVT vs. HighMemLowQVT) × (+R+P vs. Baseline): β = .073, *SE* = .033, $t(3217) = 2.230$, $p < .05$
- (HighMemHighQVT vs. LowMemHighQVT) × (+R+P vs. Baseline): β = .065, *SE* = .030, $t(3203) = 2.188$, $p < .05$

- (HighMemHighQVT vs. LowMemLowQVT) × (+R+P vs. Baseline): β = .128, *SE* = .032, *t*(3230) = 3.942, *p* < .001

Changing the reference group to the other three groups when re-running the pairwise comparisons in the model did not indicate any other significant differences in the effect of root priming amongst them. However, the effect of root priming was found to be larger in LowMemHighQVT than in LowMemLowQVT, though this difference was only marginally significant: (LowMemHighQVT vs. LowMemLowQVT) × (+R+P vs. Baseline): β = .063, *SE* = .032, *t*(3226) = 1.931, *p* = .054.

Furthermore, the effect of phonological priming in HighMemHighQVT did not significantly differ from that of the other three groups:

- (HighMemHighQVT vs. HighMemLowQVT) × (-R+P vs. Baseline): β = .008, *SE* = .032, *t*(3211) = .253, *ns.*
- (HighMemHighQVT vs. LowMemHighQVT) × (-R+P vs. Baseline): β = .007, *SE* = .030, *t*(3200) = .243, *ns.*
- (HighMemHighQVT vs. LowMemLowQVT) × (-R+P vs. Baseline): β = -.010, *SE* = .033, *t*(3226) = -.311, *ns.*

Changing the reference group to the other three groups when re-running the pairwise comparisons in the model also did not indicate any other significant differences in the effect of phonological priming amongst them. Participants in the HighMemHighQVT group were thus the most likely to be faster in reacting to a target word if it was preceded by a prime that shared the same root as the target word than if it was preceded by a prime that only shared the same phonology or a prime that shared neither the same root nor the same phonology.

7.6.1.3 Root Priming: All Data

Just like the lexical decision analyses in Chapter 5, there was also a rather unusually high exclusion of RT data during the cleaning of the data to ensure that the root priming analyses provided reliable and interpretable results. To examine the sensitivity of the results to the exclusion of observations, supplementary analyses were done with all RT data that was more than 200ms as faster latencies typically indicate either a technical or participant error. For analyses in which Qur'an memorisation and Qur'an vocabulary knowledge were continuous variables, Table 7-9 presents the likelihood ratio tests for the main effects and interactions in the model whereas Table 7-10 presents the estimated standardised coefficients for the fixed effects and pairwise comparisons in the model. For analyses in which Qur'an memorisation and Qur'an vocabulary knowledge were categorical variables, Table 7-11 presents the likelihood ratio tests for the main effects and interactions in the model whereas Table 7-12 presents the estimated standardised coefficients for the fixed effects and pairwise comparisons in the model.

Overall, regardless of whether the individual-level variables were continuous or categorical, findings from the analyses with all data indicated no significant main effects of interest (priming condition) as well as no significant two- or three-way interactions between Qur'an memorisation, Qur'an vocabulary knowledge, and priming condition. This is in contrast with the analyses from the cleaned data which had a significant two-way interaction with Qur'an vocabulary knowledge (as continuous) and priming condition as well as a significant two-way interaction between MemScoreQVT group and priming condition.

7.6.2 Word Pattern Priming: All

7.6.2.1 Individual-level variables as continuous variables

A pseudo-R^2 calculated for linear mixed models showed that the random effects and fixed effects together in the model for overall word pattern priming described 52.57% of the variance in RTs; random effects described 42.14% of the variance in RTs while fixed effects described 10.44% of the variance in RTs. Visual inspection of residual plots for the model also did not reveal any obvious deviations from homoscedasticity or normality, thus the model was kept as the full model in which *p*-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Table 7-14 presents the likelihood ratio tests for the main effects and interactions in the model. Table 7-15 presents the estimated standardised coefficients for the fixed effects and pairwise comparisons in the model. Results from the model are described in the following sub-sections.

Priming condition. As can be seen in Table 7-14, results showed no significant main effect of priming condition on RTs overall, $\chi^2(2) = .867$, *ns*. Pairwise comparisons between conditions also indicated no significant effect of word pattern priming on RTs [+WP+P vs. -WP-P: $\beta = -.012$, $SE = .016$, $t(162) = -.756$, *ns.*] as well as no significant effect of phonological priming on RTs [-WP+P vs. -WP-P: $\beta = .002$, $SE = .016$, $t(160) = .093$, *ns.*] (see Table 7-10).

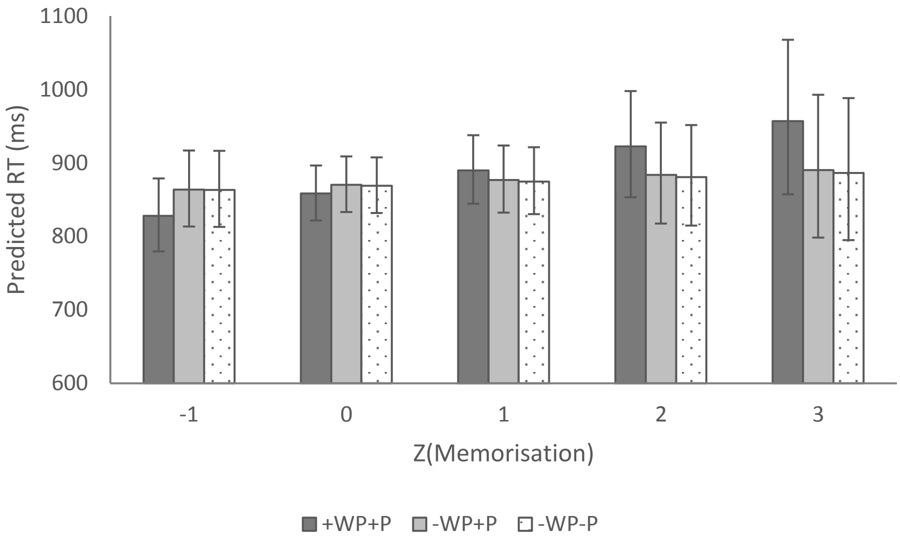

Figure 7-7. Memorisation × Condition interaction: Predicted RTs for targets based on the full linear mixed effects model across word pattern priming conditions (all types). Results are presented as a function of memorisation z-scores. Error bars are based on 95% confidence intervals.

Effect of memorisation on priming. Results showed that the interaction between memorisation and priming condition on RTs was significant, $\chi^2(2) = 14.411$, $p < .001$. Plotting the simple slopes of the two-way interaction showed that as amount of memorisation increases, inhibitory word pattern priming appears to increase while there does not appear to be any phonological priming across all levels of memorisation (see Figure 7-7). Participants who have memorised more Qur'an were thus more likely to be slower in reacting to a target word if it was preceded by a prime that shared the same word pattern as the target word than if it was preceded by a prime that only shared the same phonology or a prime that shared neither the same word pattern nor the same phonology. This was confirmed by the pairwise comparisons between conditions in Table 7-15 that indicated a significant interaction between memorisation and word pattern priming on RTs [MemScore × (+WP+P vs. -WP-P): β = .030, *SE* = .009, *t*(6206) = 3.346, *p* < .001] but no significant interaction between memorisation and phonological priming on RTs [MemScore × (-WP+P vs. -WP-P): β = .001, *SE* = .009, *t*(6204) = .112, *ns.*].

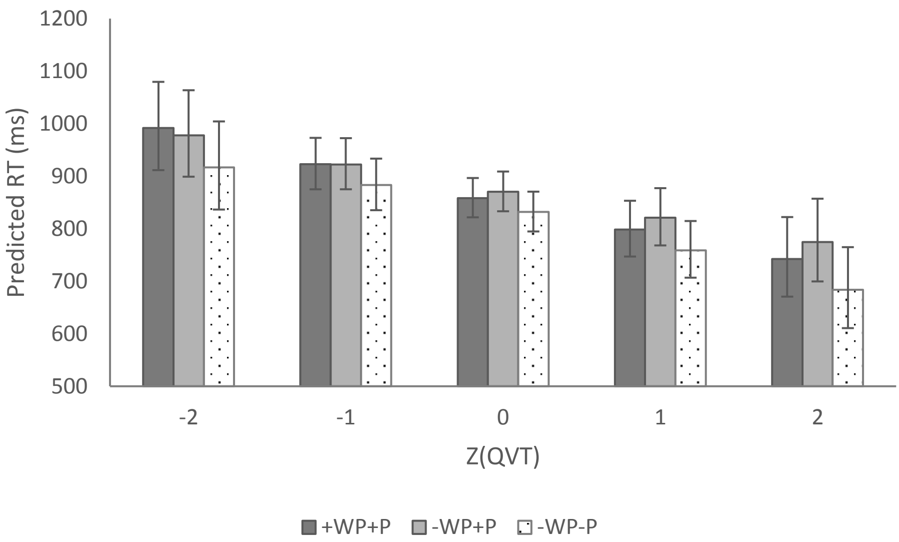

Figure 7-8. Vocabulary Knowledge × Condition interaction: Predicted RTs for targets based on the full linear mixed effects model across word pattern priming conditions (all types). Results are presented as a function of Qur'an vocabulary knowledge (QVT) z-scores. Error bars are based on 95% confidence intervals.

Effect of vocabulary knowledge on priming. Results showed that the interaction between vocabulary knowledge and priming condition on RTs was not significant, $\chi^2(2)$ = 2.960, *ns*. Pairwise comparisons between conditions in Table 7-15 also indicated no significant interaction between vocabulary knowledge and word pattern priming on RTs [QVT × (+WP+P vs. -WP-P): β = -.004, *SE* = .009, *t*(6176) = -.407, *ns.*] as well as no significant interaction between vocabulary knowledge and phonological priming on RTs [QVT × (-WP+P vs. -WP-P): β = .011, *SE* = .008, *t*(6163) = 1.241, *ns.*].

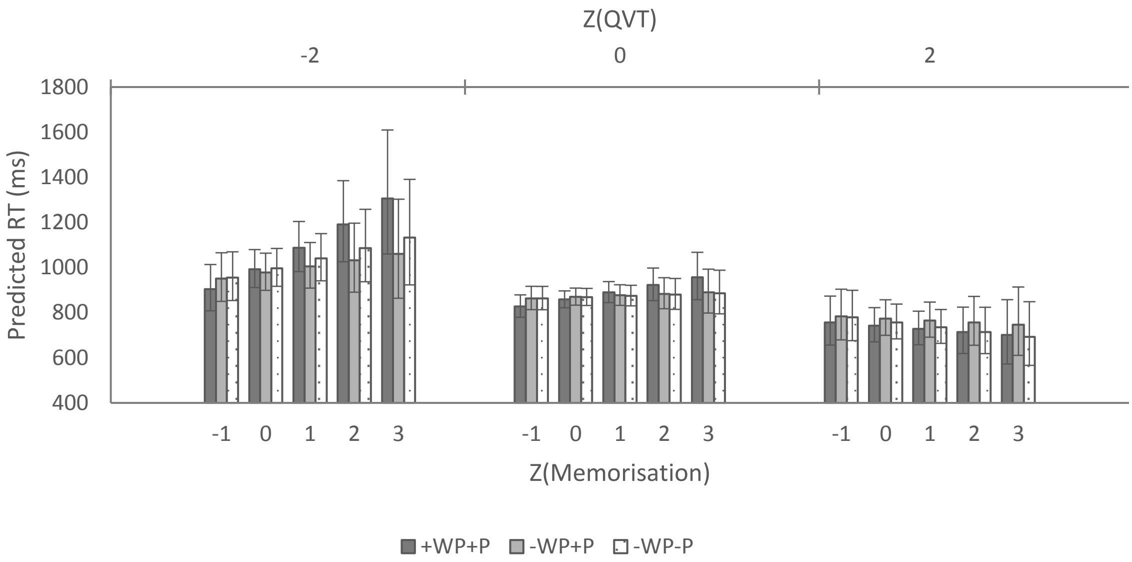

Figure 7-9. Memorisation × Vocabulary × Condition interaction: Predicted RTs for targets based on the full linear mixed effects model across word pattern priming conditions (all types). Results are presented as a function of Qur'an vocabulary knowledge (QVT) and memorisation z-scores. Error bars are based on 95% confidence intervals.

Effect of memorisation and vocabulary knowledge on priming. Results showed that the three-way interaction between memorisation, vocabulary knowledge, and priming condition on RTs was significant, $\chi^2(2) = 6.567$, $p < .05$. Plotting the three-way interaction showed the increase in inhibitory word pattern priming as amount of memorisation increases gets smaller with the increase in vocabulary knowledge (see Figure 7-9). Participants who have memorised more Qur'an were thus more likely to be slower in reacting to a target word if it was preceded by a prime that shared the same word pattern as the target word than if it was preceded by a prime that only shared the same phonology or a prime that shared neither the same word pattern nor the same phonology, but only if they have poor Qur'an vocabulary knowledge. However, pairwise comparisons between conditions indicated no significant interaction between memorisation, vocabulary knowledge, and word pattern priming on RTs [MemScore × QVT × (+WP+P vs. -WP-P): $\beta = -.010$, *SE* = .007, $t(6198) = -1.372$, *ns.*] as well as no significant interaction between memorisation, vocabulary knowledge, and phonological priming on RTs [MemScore × QVT × (-WP+P vs. -WP-P): $\beta = .008$, *SE* = .007, $t(6179) = 1.166$, *ns.*] (see Table 7-15).

7.6.2.2 Word Pattern Priming (All Data)

Just like the root priming analyses, there was also a rather unusually high exclusion of RT data during the cleaning of the data to ensure that the word pattern priming analyses provided reliable and interpretable results. To examine the sensitivity of the results to the exclusion of observations, supplementary analyses were done with all RT data that was more than 200ms as faster latencies typically indicate either a technical or participant error. Table 7-14 presents the likelihood ratio tests for the main effects and interactions in the model. Table 7-15 presents the estimated standardised coefficients for the fixed effects and pairwise comparisons in the model.

Both analyses with cleaned and all data did not have a significant main effect of word pattern priming condition. The analysis with all data had a significant two-way interaction between Qur'an vocabulary knowledge and word pattern priming condition but had no other significant two-way or three-way interactions. This is in contrast with the analysis from the cleaned data which had a significant two-way interaction between Qur'an memorisation and word pattern priming condition as well as a significant three-way interaction between Qur'an memorisation, Qur'an vocabulary knowledge, and word pattern priming condition, but did not have a significant two-way interaction between Qur'an vocabulary knowledge and word pattern priming condition.

7.7 Discussion

This study is the first to investigate whether non-concatenative morphological representations can be developed through implicit learning in the absence of limited semantic knowledge. It is also the first study to tease apart the roles of print exposure (as measured by amount of memorisation) and semantic knowledge (as measured by vocabulary knowledge) in the development of non-concatenative morphological representations.

The first research question examined whether non-Arabic-speaking Qur'anic readers/memorisers are able to visually process Qur'anic Arabic words at the morphological level, and thus, be primed by root and word patterns during a visual word processing task. Findings showed that at least at 250ms SOA, participants were not primed by either the root or word pattern during a visual unmasked priming lexical decision task.

7.7.1 Effects of Vocabulary Knowledge and Amount of Memorisation on Root Priming

The second research question examined whether vocabulary knowledge and amount of memorisation interact with root priming effects. Findings showed that vocabulary knowledge significantly interacted with root priming effects such that as vocabulary knowledge increased, facilitatory root priming increased; this relationship was not significant for orthographic/phonological priming, suggesting that the relationship between vocabulary knowledge and facilitatory root priming goes beyond shared orthographic/phonological similarities. However, amount of memorisation did not significantly interact with root priming effects, although there was a trend towards significance. These findings supported the prediction that vocabulary knowledge would play a bigger role than print exposure in developing and accessing root representations, given that the root morpheme carries semantic information.

7.7.2 Effects of Vocabulary Knowledge and Amount of Memorisation on Word Pattern Priming

The second research question also examined whether vocabulary knowledge and amount of memorisation interact with word pattern priming effects. Findings showed that vocabulary knowledge did not significantly interact with word pattern priming effects. However, amount of memorisation significantly interacted with word pattern priming such that as amount of memorisation increases, inhibitory word pattern priming increases; this relationship was not significant for orthographic/phonological priming, suggesting that the relationship between amount of memorisation and inhibitory word pattern priming goes beyond shared orthographic/phonological similarities. These findings supported the prediction that vocabulary knowledge would play a smaller role than statistical exposure in developing and accessing word pattern representations, given that the word pattern morpheme carries phonological and morpho-syntactic information.

Nevertheless, there was also a significant three-way interaction between amount of memorisation, vocabulary knowledge, and word pattern priming, showing that the increase in inhibitory word pattern priming effects as memorisation increases is attenuated by the increase in vocabulary knowledge. This possibly suggests that having vocabulary knowledge helps to improve the quality of lexical representations, and thus, facilitating lexical access to the extent that it helps to counter any competition arising from shared vowel patterns.

7.8 Conclusions

The goals of this study were to examine the visual word processing of non-Arabic-speaking at the morphological level by testing for root and word pattern priming effects, which are markers for non-concatenative morphological processing, as well as to examine whether these root and word pattern priming effects are modulated by amount of memorisation and vocabulary knowledge, thereby teasing apart the possibly differential roles of print exposure and vocabulary knowledge in morphological processing. Findings showed that there was no evidence of significant facilitatory root or word pattern priming effects in lexical decision. However, there were individual differences in these priming effects—amount of memorisation and vocabulary knowledge modulated root and word pattern priming effects differently. Vocabulary knowledge, and not amount of memorisation, significantly increased facilitatory root priming effects, whereas amount of memorisation, and not vocabulary knowledge, significantly increased inhibitory word pattern priming effects. The increase in vocabulary knowledge also attenuated the effect of memorisation on word pattern priming effects. These findings underscore the importance of looking at individual differences in morphological priming effects.

Table 7-9. Full model showing the main effects and interactions from a linear mixed effects regression analysis for root priming with continuous individual-level variables for both cleaned and all data. χ^2 and *p*-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The *p*-value for each coefficient is represented by asterisks at the following levels: *. = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 3445)			All Data > 200 ms (*N* = 4402)		
	df	$\chi2$	*p*	df	$\chi2$	*p*
Age	1	14.889	.000 ***	1	8.531	.003***
Sex	1	11.113	.001 ***	1	9.837	.002**
MemScore	1	.497	.481	1	.404	.525
QVT	1	1.477	.224	1	.000	.996
Condition	2	.309	.857	2	.406	.817
MemScore:QVT	-	-	-	-	-	-
MemScore:Condition	2	5.125	.077 .	2	.270	.874
QVT:Condition	2	6.018	.049 *	2	.130	.937
MemScore:QVT:Condition	2	1.652	.438	2	1.525	.467

Table 7-10. Full model showing standardised estimates for fixed effects and pairwise comparisons from a linear mixed effects regression analysis for root priming with continuous individual-level variables for both cleaned and all data. Pairwise comparisons used 'Baseline' as the reference condition. *T*-tests used Satterthwaite approximations to compute degrees of freedom (df). The *p*-value for each coefficient is represented by asterisks at the following levels: *. = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 3445)					All Data > 200 ms (*N* = 4402)				
	β	*SE*	df	*t*	*p*	*β*	*SE*	df	*t*	*p*
(Intercept)	6.785	.033	163	208.409	.000 ***	6.798	.032	161	213.603	.000***
Age	.087	.022	164	3.954	.000 ***	.055	.018	214	2.954	.003**
Sex	-.071	.021	165	-3.384	.001 ***	-.061	.019	217	-3.179	.002**
MemScore	.015	.021	207	.705	.481	.013	.020	278	.637	.525
QVT	-.028	.023	199	-1.219	.224	.000	.021	274	.005	.996
condition-R+P	-.014	.037	77	-.392	.696	.003	.037	78	.074	.942
condition+R+P	-.020	.037	77	-.538	.592	-.019	.037	78	-.512	.610
MemScore:QVT	-.035	.018	206	-1.893	.060 .	-.055	.017	284	-3.225	.001**
MemScore:condition-R+P	.001	.012	3219	.130	.897	-.002	.012	4119	-.178	.859
MemScore:condition+R+P	-.022	.012	3236	-1.900	.058 .	-.006	.012	4133	-.513	.608
QVT:condition-R+P	-.008	.012	3224	-.717	.474	.000	.012	4134	.025	.980
QVT:condition+R+P	-.028	.012	3228	-2.400	.016 *	-.004	.012	4144	-.300	.764
MemScore:QVT:condition-R+P	.004	.010	3213	.387	.699	.012	.010	4108	1.140	.254
MemScore:QVT:condition+R+P	.013	.010	3223	1.262	.207	.001	.011	4126	.139	.889

Table 7-11. Full model showing the main effects and interaction from a linear mixed effects regression analysis for root priming with categorical individual-level variables for both cleaned and all data. χ^2 and *p*-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The *p*-value for each coefficient is represented by asterisks at the following levels: *. = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 3445)			All Data > 200 ms (*N* = 4402)		
	df	*χ2*	*p*	df	*χ2*	*p*
Age	1	12.069	.001 ***	1	6.400	.011*
Sex	1	12.264	.000 ***	1	10.037	.002**
Group	3	5.543	.136	3	1.622	.655
Condition	2	.219	.896	2	.458	.795
Group:Condition	6	22.564	.001 ***	6	6.087	.414

Table 7-12. Full model showing standardised estimates for fixed effects and pairwise comparisons from a linear mixed effects regression analysis for root priming with categorical individual-level variables for both cleaned and all data. Pairwise comparisons used ‘HighMemHighQVT’ as the reference group and ‘Baseline’ as the reference condition. T-tests used Satterthwaite approximations to compute degrees of freedom (df). The *p*-value for each coefficient is represented by asterisks at the following levels: *. = p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 3445)					All Data > 200 ms (*N* = 4402)				
	β	*SE*	df	*t*	*p*	*β*	*SE*	df	*t*	*p*
(Intercept)	6.768	.049	253	138.589	***	6.799	.044	286	155.995	***
Age	.079	.022	164	3.541	***	.048	.019	214	2.551	*
Sex	-.074	.021	166	-3.563	***	-.064	.020	218	-3.209	**
MemQVTGroupHMLQ	.094	.062	201	1.519		.008	.059	276	.129	
MemQVTGroupLMHQ	.012	.058	194	.203		-.017	.053	264	-.315	
MemQVTGroupLMLQ	-.033	.061	203	-.548		-.051	.052	273	-.978	
condition-R+P	-.015	.041	118	-.365		.014	.040	106	.363	
condition+R+P	-.080	.041	119	-1.948	.	-.037	.040	106	-.940	
MemQVTGroupHMLQ:condition-R+P	.008	.032	3211	.253		-.040	.033	4135	-1.191	
MemQVTGroupLMHQ:condition-R+P	.007	.030	3200	.243		.014	.029	4103	.470	
MemQVTGroupLMLQ:condition-R+P	-.010	.033	3226	-.311		-.019	.030	4119	-.644	
MemQVTGroupHMLQ:condition+R+P	.073	.033	3217	2.230	*	.018	.034	4134	.528	
MemQVTGroupLMHQ:condition+R+P	.065	.030	3203	2.188	*	.051	.030	4108	1.710	.
MemQVTGroupLMLQ:condition+R+P	.128	.032	3230	3.942	***	.018	.030	4126	.589	

NB. HMLQ = HighMemLowQVT, LMHQ = LowMemHighQVT, LMLQ = LowMemLowQVT.

Table 7-13. Post-hoc pairwise comparisons for root priming conditions by group *with* results averaged over the levels of sex. Planned contrasts for the three conditions (+R+P, -R+P, Baseline) within each group was labelled as follows: 1 (HighMemHighQVT); 2 (HighMemLowQVT); 3 (LowMemHighQVT); and 4 (LowMemLowQVT). *p*-values were adjusted using the Tukey method for comparing a family of 12 estimates with a confidence level of 95%.

contrast	Group	Condition	Group	Condition	Estimate	SE	df	*t*.ratio	p
1	HighMemHighQVT	Baseline	- HighMemHighQVT	-R+P	.015	.041	121.450	.360	1.000
1	HighMemHighQVT	Baseline	- HighMemHighQVT	+R+P	.080	.041	122.290	1.923	.743
1	HighMemHighQVT	-R+P	- HighMemHighQVT	+R+P	.065	.042	125.420	1.553	.922
2	HighMemLowQVT	Baseline	- HighMemLowQVT	-R+P	.007	.043	143.250	.157	1.000
2	HighMemLowQVT	Baseline	- HighMemLowQVT	+R+P	.007	.043	147.620	.155	1.000
2	HighMemLowQVT	-R+P	- HighMemLowQVT	+R+P	.000	.043	142.940	-.001	1.000
3	LowMemHighQVT	Baseline	- LowMemHighQVT	-R+P	.008	.041	119.500	.187	1.000
3	LowMemHighQVT	Baseline	- LowMemHighQVT	+R+P	.014	.041	121.120	.346	1.000
3	LowMemHighQVT	-R+P	- LowMemHighQVT	+R+P	.007	.041	121.940	.159	1.000
4	LowMemLowQVT	Baseline	- LowMemLowQVT	-R+P	.025	.043	145.000	.580	1.000
4	LowMemLowQVT	Baseline	- LowMemLowQVT	+R+P	-.048	.043	141.040	-1.126	.993
4	LowMemLowQVT	-R+P	- LowMemLowQVT	+R+P	-.073	.043	143.230	-1.704	.864
	HighMemHighQVT	Baseline	- HighMemLowQVT	Baseline	-.094	.063	218.230	-1.495	.941
	HighMemHighQVT	Baseline	- LowMemHighQVT	Baseline	-.012	.059	210.300	-.200	1.000
	HighMemHighQVT	Baseline	- LowMemLowQVT	Baseline	.033	.062	220.230	.539	1.000
	HighMemHighQVT	Baseline	- HighMemLowQVT	-R+P	-.087	.072	279.000	-1.211	.988
	HighMemHighQVT	Baseline	- LowMemHighQVT	-R+P	-.004	.069	275.030	-.059	1.000
	HighMemHighQVT	Baseline	- LowMemLowQVT	-R+P	.058	.072	285.300	.818	1.000
	HighMemHighQVT	Baseline	- HighMemLowQVT	+R+P	-.087	.072	281.580	-1.209	.988
	HighMemHighQVT	Baseline	- LowMemHighQVT	+R+P	.003	.069	275.950	.036	1.000
	HighMemHighQVT	Baseline	- LowMemLowQVT	+R+P	-.015	.071	281.550	-.208	1.000
	HighMemLowQVT	Baseline	- LowMemHighQVT	Baseline	.082	.064	215.880	1.283	.981
	HighMemLowQVT	Baseline	- LowMemLowQVT	Baseline	.127	.060	236.970	2.106	.619
	HighMemLowQVT	Baseline	- HighMemHighQVT	-R+P	.108	.072	285.870	1.503	.939
	HighMemLowQVT	Baseline	- LowMemHighQVT	-R+P	.090	.073	282.240	1.225	.987
	HighMemLowQVT	Baseline	- LowMemLowQVT	-R+P	.152	.070	299.170	2.171	.572
	HighMemLowQVT	Baseline	- HighMemHighQVT	+R+P	.173	.072	286.010	2.399	.410
	HighMemLowQVT	Baseline	- LowMemHighQVT	+R+P	.096	.073	282.980	1.314	.977
	HighMemLowQVT	Baseline	- LowMemLowQVT	+R+P	.079	.070	295.350	1.128	.993
	LowMemHighQVT	Baseline	- LowMemLowQVT	Baseline	.045	.063	218.500	.717	1.000
	LowMemHighQVT	Baseline	- HighMemHighQVT	-R+P	.027	.069	277.090	.387	1.000
	LowMemHighQVT	Baseline	- HighMemLowQVT	-R+P	-.075	.073	277.280	-1.032	.997
	LowMemHighQVT	Baseline	- LowMemLowQVT	-R+P	.070	.072	283.720	.970	.998
	LowMemHighQVT	Baseline	- HighMemHighQVT	+R+P	.091	.069	277.500	1.324	.975
	LowMemHighQVT	Baseline	- HighMemLowQVT	+R+P	-.075	.073	279.990	-1.030	.997
	LowMemHighQVT	Baseline	- LowMemLowQVT	+R+P	-.003	.072	280.310	-.042	1.000
	LowMemLowQVT	Baseline	- HighMemHighQVT	-R+P	-.019	.072	285.700	-.259	1.000
	LowMemLowQVT	Baseline	- HighMemLowQVT	-R+P	-.120	.070	292.400	-1.728	.854
	LowMemLowQVT	Baseline	- LowMemHighQVT	-R+P	-.038	.072	282.450	-.519	1.000
	LowMemLowQVT	Baseline	- HighMemHighQVT	+R+P	.046	.072	285.940	.645	1.000

contrast	Group	Condition		Group	Condition	Estimate	SE	df	*t*.ratio	p
	LowMemLowQVT	Baseline	-	HighMemLowQVT	+R+P	-.120	.070	295.170	-1.724	.856
	LowMemLowQVT	Baseline	-	LowMemHighQVT	+R+P	-.031	.072	283.510	-.427	1.000
	HighMemHighQVT	-R+P	-	HighMemLowQVT	-R+P	-.102	.063	216.880	-1.627	.897
	HighMemHighQVT	-R+P	-	LowMemHighQVT	-R+P	-.019	.059	213.720	-.321	1.000
	HighMemHighQVT	-R+P	-	LowMemLowQVT	-R+P	.044	.062	224.850	.700	1.000
	HighMemHighQVT	-R+P	-	HighMemLowQVT	+R+P	-.102	.072	284.550	-1.412	.961
	HighMemHighQVT	-R+P	-	LowMemHighQVT	+R+P	-.012	.069	278.940	-.179	1.000
	HighMemHighQVT	-R+P	-	LowMemLowQVT	+R+P	-.030	.071	284.310	-.416	1.000
	HighMemLowQVT	-R+P	-	LowMemHighQVT	-R+P	.083	.064	213.470	1.301	.978
	HighMemLowQVT	-R+P	-	LowMemLowQVT	-R+P	.145	.060	235.320	2.414	.401
	HighMemLowQVT	-R+P	-	HighMemHighQVT	+R+P	.166	.072	282.090	2.314	.469
	HighMemLowQVT	-R+P	-	LowMemHighQVT	+R+P	.089	.073	279.340	1.226	.987
	HighMemLowQVT	-R+P	-	LowMemLowQVT	+R+P	.072	.070	291.200	1.036	.997
	LowMemHighQVT	-R+P	-	LowMemLowQVT	-R+P	.063	.063	222.100	.988	.998
	LowMemHighQVT	-R+P	-	HighMemHighQVT	+R+P	.084	.069	278.420	1.212	.988
	LowMemHighQVT	-R+P	-	HighMemLowQVT	+R+P	-.083	.073	281.300	-1.134	.993
	LowMemHighQVT	-R+P	-	LowMemLowQVT	+R+P	-.011	.072	281.410	-.149	1.000
	LowMemLowQVT	-R+P	-	HighMemHighQVT	+R+P	.021	.072	288.400	.294	1.000
	LowMemLowQVT	-R+P	-	HighMemLowQVT	+R+P	-.145	.070	298.060	-2.077	.640
	LowMemLowQVT	-R+P	-	LowMemHighQVT	+R+P	-.056	.073	285.870	-.772	1.000
	HighMemHighQVT	+R+P	-	HighMemLowQVT	+R+P	-.166	.063	219.220	-2.655	.256
	HighMemHighQVT	+R+P	-	LowMemHighQVT	+R+P	-.077	.059	215.170	-1.301	.978
	HighMemHighQVT	+R+P	-	LowMemLowQVT	+R+P	-.094	.062	221.620	-1.520	.934
	HighMemLowQVT	+R+P	-	LowMemHighQVT	+R+P	.089	.064	216.870	1.400	.963
	HighMemLowQVT	+R+P	-	LowMemLowQVT	+R+P	.072	.060	234.270	1.198	.989
	LowMemHighQVT	+R+P	-	LowMemLowQVT	+R+P	-.017	.063	219.800	-.275	1.000

Table 7-14. Full model showing the main effects and interactions from a linear mixed effects regression analysis for word pattern priming (all types) using both cleaned and all data. χ^2 and *p*-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = *p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 6374)			All Data > 200 ms (*N* = 8396)		
	df	$\chi 2$	*p*	df	$\chi 2$	*p*
Age	1	22.320	.000 ***	1	14.571	.000***
Sex	1	12.365	.000 ***	1	12.312	.000***
Trial Order Number	1	6.954	.008 **	1	4.391	.036*
Display Refresh Rate	-	-	- -	1	4.957	.026*
MemScore	1	.135	.714	1	3.628	.057.
QVT	1	10.419	.001	1	.769	.380
Condition	2	.867	.648	2	.963	.618
MemScore:QVT	-	-	-	-	-	--
MemScore:Condition	2	14.411	.001 ***	2	3.146	.207
QVT:Condition	2	2.960	.228	2	12.245	.002**
MemScore:QVT:Condition	2	6.567	.038 *	2	2.825	.246

Table 7-15. Full model showing standardised estimates for fixed effects and pairwise comparisons from a linear mixed effects regression analysis for word pattern priming (all types) using both cleaned and all data. Pairwise comparisons used '-WP-P' as the reference condition. *T*-tests used Satterthwaite approximations to compute degrees of freedom (df). The *p*-value for each coefficient is represented by asterisks at the following levels: . = *p < .1, * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 6374)					All Data > 200 ms (*N* = 8396)				
	β	*SE*	df	*t*	*p*	*β*	*SE*	df	*t*	*p*
(Intercept)	6.785	.023	242	295.463	***	6.805	.023	320	300.108	***
Age	.105	.021	158	4.907	***	.079	.020	208	3.895	***
Sex	-.070	.020	165	-3.584	***	-.067	.019	218	-3.563	***
Trial Order Number	-.009	.004	6180	-2.638	**	-.008	.004	7878	-2.096	*
Display Refresh Rate	-	-	-	-	-	.040	.018	220	2.243	*
MemScore	.007	.018	198	.367		.036	.019	264	1.917	.
QVT	-.069	.021	187	-3.275	**	-.018	.020	251	-.879	
condition-WP+P	.002	.016	160	.093		.012	.017	171	.705	
condition+WP+P	-.012	.016	162	-.756		-.004	.017	172	-.239	
MemScore:QVT	-.018	.015	196	-1.202		-.061	.015	262	-3.979	***
MemScore:condition-WP+P	.001	.009	6204	.112		-.012	.009	8144	-1.292	
MemScore:condition+WP+P	.030	.009	6206	3.346	***	.004	.009	8139	.402	
QVT:condition-WP+P	.011	.008	6163	1.241		.016	.009	8164	1.795	.
QVT:condition+WP+P	-.004	.009	6176	-.407		-.015	.009	8172	-1.697	.
MemScore:QVT:condition-WP+P	.008	.007	6179	1.166		.013	.007	8111	1.680	.
MemScore:QVT:condition+WP+P	-.010	.007	6198	-1.372		.006	.008	8122	.829	

Chapter 8. General Discussion

8.1 Introduction

The goals of the current work were two-fold: First, to characterise the effects of psycholinguistic variables that influence the visual word processing of non-Arabic-speaking Qur'anic memorisers through three tasks (lexical decision, speeded pronunciation, and lexical decision with unmasked morphological priming); second, to examine individual-differences in the effects of these variables on the visual word processing of non-Arabic-speaking Qur'anic memorisers through two- and three-way interactions between amount of memorisation, vocabulary knowledge, and the effect. In this chapter, the findings from the three studies are summarised and discussed. We end this chapter with the limitations of the current work, future directions, and overall conclusions.

8.2 Contributions of the Current Work

The current work breaks ground in numerous ways. Not only is it the first study on visual word processing in Qur'anic Arabic, it is also the first study that has looked at the visual word processing of non-Arabic-speaking Qur'anic memorisers, a unique population that engages in rote memorisation of a text with limited semantic knowledge, thereby providing a natural window into the disambiguation of the roles of vocabulary knowledge and print exposure in influencing the effects of various psycholinguistic variables on visual word processing. Furthermore, it is currently the only study of visual word processing in vowelled Arabic that utilizes a comprehensive array of traditional and novel predictors, and it is the only study of visual word processing in a transparent orthography that have examined individual differences in the effects of those predictors. Last, given the non-linear morphology of Qur'anic Arabic, this is the first study to have investigated within the same population whether lexical organisation arises from a language's morphological principles or from how the individual himself acquires the language. The implications of the current work are discussed in the following sections.

8.3 Summary of Findings

There were a number of noteworthy findings. First, systematic relationships between visual word recognition performance (as measured by response latencies and accuracies) and underlying lexical dimensions (principal components of length, frequency, neighbourhood size, Levenshtein distance, phonotactic probability, and root) were uncovered in both lexical decision and speeded pronunciation.

Second, individual differences in the effects of those principal components on visual word recognition performance were also uncovered. Vocabulary knowledge in general attenuated sensitivity to underlying lexical characteristics such as frequency. It also interacted with amount of memorisation to modulate sensitivity to certain underlying lexical characteristics.

Third, although participants were sensitive to root variables (i.e., root frequency and root family size) in lexical decision and speeded pronunciation, there was no evidence of them showing significant facilitatory root or word pattern priming effects in lexical decision. However, there were individual differences in these priming effects—amount of memorisation and vocabulary knowledge modulated root and word pattern priming effects differently. Vocabulary knowledge, and not amount of memorisation, significantly increased facilitatory root priming effects, whereas amount of memorisation, and not vocabulary knowledge, significantly increased inhibitory word pattern priming effects. The increase in vocabulary knowledge also attenuated the effect of memorisation on word pattern priming effects.

These findings will be discussed in the following sections.

8.4 Role of Onsets

One of the surprising findings in this study is that onsets significantly influenced lexical decision and speeded pronunciation latencies. For Malay, this was explained by a bias to certain onsets suggesting prelexical morphological decomposition in which affixes must be stripped before the stem can be processed and a lexical decision can be made; once the onsets of those prefixes were removed, the variance accounted for by onsets were greatly reduced (Binte Faizal, 2009). However, a check with our stimuli showed that the most common prefix in the list, /m/, was not predicted to have significantly inhibited response times. It may be that participants' engagement with the sublexical phonological assembly pathway was so strong, even in lexical decision, but at this point, any interpretation would be purely speculative. The role of onsets in visual word processing of Qur'anic Arabic is worth exploring further, especially since Alamri (2017) found that phonological onsets play a significant role in Arabic spoken word recognition.

8.5 Visual Word Processing with Limited Semantic Knowledge

Despite having limited semantic knowledge, non-Arabic-speaking Qur'anic memorisers were found to visually process Qur'anic Arabic words similarly to other native readers of transparent orthographies such as Malay. Like native Malay readers, they relied more on sublexical processing than lexical processing and smaller grain sizes when doing visual word processing tasks such as lexical decision and speeded pronunciation. This was demonstrated by their much larger length effects than frequency effects in both tasks as well as their sensitivity to facilitatory phonotactic probability and inhibitory distance effects, which are also markers of sublexical processing.

Nonetheless, like native Malay readers, non-Arabic-speaking Qur'anic memorisers also engaged in the lexical pathway during visual word processing, as evinced by their significant facilitatory frequency effects in both lexical decision and speeded pronunciation latencies. However, unlike native Malay readers who were more influenced by length than frequency in speeded pronunciation accuracy, non-Arabic-speaking Qur'anic memorisers were more influenced by frequency than length in speeded pronunciation accuracy. This was surprising as the nature of the speeded pronunciation task meant that one should be able to read aloud words in a very transparent orthography correctly through pure decoding, and thus, without relying much on the lexical pathway. We postulate that the reading accuracy of non-Arabic-speaking Qur'anic memorisers may be more influenced by how often the word occurs in print, and thus, how much experience they have had in reading that word aloud, because of their reading (aloud)-repetition-rehearsal process during memorisation. This is consistent with the lexicality and frequency effects Burani and colleagues have found with reading aloud in Italian (see Burani, Arduino, & Barca, 2007; Pagliuca, Arduino, Barca, & Burani, 2008), which suggest the use of a lexical route even for readers of a transparent orthography because of the efficiency of the mappings between orthographic and phonological representations developed when encountering written and spoken word forms during the learning of reading. Similarly, during Qur'anic reading development, with increasing practice in reading, functional lexical representations are acquired; memorisation provides constant repeated exposure to the orthographic and phonetic constituents of a lexical representation while vocabulary knowledge contributes to the semantic constituent of a lexical representation, all of which aid in the development of high-quality and stable lexical representations. As per the automatization hypothesis, lexical access becomes more efficient and automatic with more stable lexical representations (Balota et al., 2004; LaBerge & Samuels, 1974), which may explain why when trying to read aloud accurately, non-Arabic-speaking Qur'anic memorisers appear to rely more on the lexical pathway, accessing the lexical representations directly instead of inefficiently decoding the grapheme-to-phoneme correspondences through the sublexical pathway.

Putting these findings together, they provide excellent support for the weak orthographic depth hypothesis (ODH) and psycholinguistic grain size theory (PGST), which not only predicted greater reliance on sublexical processing and smaller grain sizes for more transparent orthographies such as Qur'anic Arabic, but also the parallel use of both lexical and sublexical routes in dual-route models of reading. Furthermore, the sensitivity to these lexical and sublexical variables also indicate that implicit learning of the lexical and sublexical characteristics of a writing system has taken place through consistent exposure to orthographic and phonetic input during reading and memorisation despite having limited semantic knowledge. Together with Zuhurudeen and Huang's (2016) study that showed statistical learning in grammar despite limited semantic knowledge for non-Arabic-speaking Qur'anic memorisers, the findings in this study contribute nicely to the field of statistical learning by providing a natural study of statistical learning with greater ecological validity than artificial statistical learning paradigms done in the lab.

8.6 Lexical Organisation: Orthographic Similarity versus Morphological Principles

Findings across the three studies in our work consistently showed that non-Arabic-speaking Qur'anic memorisers are much more sensitive to measures of orthographic similarity in visual word processing as compared to non-concatenative morphological variables. In both lexical decision and speeded pronunciation, participants showed larger facilitatory neighbourhood density effects as well as larger inhibitory Levenshtein distance effects than root effects in response latencies. Furthermore, they also did not show significant root and word pattern priming effects in lexical decision, although those effects were shown to be modulated by levels of vocabulary knowledge and amount of memorisation.

This suggests that contrary to what Frost et al. (2005) argued for with regards to the psychological reality of the internal structure of words, non-Arabic-speaking Qur'anic memorisers organise words based on orthographic similarity instead of the language's morphological principles, i.e., Qur'anic Arabic's non-concatenative morphological principles of roots and word patterns. It further suggests that for the lexical organisation of words to be based on non-concatenative morphological principles, there may be a process that has to be learned, either through the natural acquisition of the language or through explicit teaching. What is clear is that the nature of the orthography itself does not determine the lexical organisation of words, but how individuals themselves acquire the language.

8.7 Individual Differences in Effects of Psycholinguistic Variables on Visual Word Processing

One of the advantages of studying this unique population was the large variability in levels of vocabulary knowledge as well as print exposure (as measured by amount of memorisation). Not only does this allow for the examination of individual differences in the effects of various psycholinguistic variables on visual word processing, it also allows for the disambiguation of the roles of vocabulary knowledge and print exposure in modulating these effects through three-way interactions between vocabulary knowledge, print exposure, and the effect.

Findings across the three studies in our work have shown that vocabulary knowledge and print exposure significantly modulated the effects of psycholinguistic variables on visual word processing. These findings can be explained by theories that propose an automatization of lexical processing mechanisms as readers acquire more experience with words (LaBerge & Samuels, 1974; Stanovich, 1980); as automatic mechanisms develop, word recognition may be less influenced by lexical characteristics such as frequency. More importantly, they provide support for the lexical quality hypothesis which postulates that the quality of lexical representations drive the efficiency of lexical processing; better readers have higher quality of lexical representations (Perfetti, 2007; Perfetti & Hart, 2002). The idea that high quality representations involve three well-integrated constituents of orthography, phonology, and semantics helps to account for the different yet interdependent roles of print exposure (which contributes to the constituents of orthography and phonology) and vocabulary knowledge (which contributes to the constituent of semantics) in developing high quality lexical representations, and thus, facilitating lexical access during visual word processing and being less influenced by lexical characteristics. This supports the findings that showed participants with high levels of both memorisation and vocabulary knowledge being less influenced by frequency than participants with high levels of memorisation but poorer vocabulary knowledge as well as than participants with better vocabulary knowledge but less memorisation.

These findings are also consistent with the gradual ceiling effect predicted by connectionist models given distributed representations, adaptive learning, and nonlinear activation functions as discussed in Chapter 4. When an individual is exposed to a word, the weights on these network connections between the three units of orthography, phonology, and semantics will be adapted to reduce error in output for whatever lexical task the individual will undertake; there will be increased input to output units that should be active (e.g. pronunciation pattern of a target stimulus) and decreased input to output units that should be inactive. More practice or exposure to a word will thus enable the system to drive helpful weight changes towards the correct output in the future (Davies et al., 2017), which is consistent with the lexical quality hypothesis in which repeated exposure to a word may improve the quality of lexical representations, and thus, the efficiency of lexical processing and access. However, the connectionist account specifies that the function linking input to output activation is nonlinear, which means that as input activation increases, output activation will tend to asymptote towards 0 or 1, i.e., progressively smaller reductions in error (Plaut et al., 1996). This would therefore predict that as practice or exposure to a word increases, psycholinguistic effects such as frequency that influence the efficacy of the network connections between the three units should become smaller, which is consistent with the predictions of the automatization hypothesis and lexical quality hypothesis as previously discussed. Importantly, this prediction is also consistent with our findings of smaller psycholinguistic effects with the increase in both vocabulary knowledge and memorisation.

However, it appears that vocabulary knowledge appears to play a bigger role than memorisation in automatizing word recognition processes and facilitating lexical access, especially in lexical decision, a task that requires the individual to decide whether a target stimulus is a word or a nonword. In lexical decision, participants with more vocabulary knowledge (and not more memorisation) showed smaller effects in length, neighbourhood density, and phonotactic probability, whereas in speeded pronunciation (which has a smaller demand for lexical access), vocabulary knowledge only modulated the effect of frequency more than amount of memorisation did. These differences underscore the importance of teasing apart the roles of vocabulary knowledge and print exposure in visual word recognition rather than looking at either of them in isolation or conflating both constructs together, as have been done in past studies (e.g. Lewellen et al., 1993; Yap et al., 2012).

It is important to note that the idea of automatization of lexical processing mechanisms with more experience with words or with higher quality lexical representations cannot account for the larger length/LD effects as amount of memorisation and vocabulary knowledge increase. The idea that processing speed is inversely related to the magnitude of effects as postulated by Yap et al. (2012) also cannot account for some of our findings in which larger effects are found in faster participants. Theories on individual differences in visual word processing will need to be able to account for these incongruent findings.

Theories on individual differences in visual word processing will also need to be able to account for differences in task demands that have been found to modulate the three-way interactions between vocabulary knowledge, print exposure, and the effect of psycholinguistic variable. For lexical decision, the typical pattern appears to be that the larger effects of a variable on response latencies as amount of memorisation increases were attenuated by the increase in vocabulary knowledge. However, for speeded pronunciation, the typical pattern appears to be that the larger effects of variable on response latencies as amount of memorisation decreases were attenuated by the increase in vocabulary knowledge. These task differences in modulating the three-way interactions between vocabulary knowledge, print exposure, and the effect of psycholinguistic variable have interesting implications in that they potentially suggest two contrasting developmental trajectories, or at least in the development of different reading processes: *word recognition* vs. *reading aloud*. The *word recognition* trajectory may be characterised by initial lexicalisation that is seen by a growth in the size of psycholinguistic effects with increasing memorisation and then by the increasing efficiency of lexical access with increasing vocabulary knowledge that is seen by a later diminution of effects as supported by connectionist accounts that predict a gradual ceiling effect in terms of the influence of psycholinguistic variables on lexical access as discussed earlier (e.g. Plaut et al., 1996). In contrast, the *pronunciation* trajectory may be characterised by increasing efficiency with the development of more efficient mappings between the orthographic and phonological representations of words that is seen by the diminution of the size of psycholinguistic effects with increasing memorisation, which then leads to a gradual ceiling effect in terms of the influence of psycholinguistic variables on reading aloud with increasing vocabulary knowledge as supported by connectionist accounts of reading development.

8.8 Building a Qur'anic Arabic DRC model

Relating the effects of lexical variables on Qur'anic Arabic word recognition to the DRC model (Coltheart et al., 1993; Coltheart & Rastle, 1994; Coltheart et al., 2001), it appears that when processing isolated words, non-Arabic-speaking Qur'anic memorisers use both the lexical and sublexical pathways, as evinced by the significant frequency effects in lexical decision and speeded pronunciation. However, non-Arabic-speaking Qur'anic memorisers seem to rely more on the sublexical pathway in word processing, as demonstrated by the much greater length effects as compared to that of frequency in both tasks. The presence of neighbourhood density and Levenshtein distance effects further supports a dual-route theory of word recognition that involves both the lexical and sublexical pathways, even for a transparent orthography with regular grapheme-to-phoneme correspondences. As Qur'anic Arabic is as an excellent example of a transparent orthography, it will be instructive for future researchers to consider how well current models can reproduce the item-level and individual-level effects in this dataset via computational modelling.

8.9 Limitations and Future Directions

The current work could have been improved in numerous ways. First, given the small sample size in the speeded pronunciation task in Chapter 6 as compared to lexical decision in Chapter 5, there may not have been enough statistical power to examine that many two-way and three-way interactions in a single model at once. This may have limited our ability to find significant individual differences in the effects of our principal components on speeded pronunciation, especially for accuracy. Future research could attempt to replicate the study on a much larger scale.

Second, despite having examined the influence of a large number of lexical variables on the lexical decision and speeded pronunciation of non-Arabic-speaking Qur'anic memorisers, there are still several areas that remain unexplored. The list of lexical variables is obviously not exhaustive; for example, we did not consider the number of morphemes as a lexical variable. Not only that, other orthographic variables such as orthographic connectivity or visual complexity have yet to be examined; such variables have been shown to influence word recognition even in native Arabic readers (see Abdelhadi, Ibrahim, & Eviatar, 2011; Khateb, Khateb-Abdelgani, Taha, & Ibrahim, 2014). Effects of these variables remain an open empirical question and is clearly an important next step for research in this field.

Third, while the linear effects of variables are emphasized in all three studies, it is important to note that psycholinguistic variables are not always linearly related to word recognition latencies and that they may interact with other lexical variables. For example, Yap and Balota (2009) found curvilinear log(frequency) and length effects as well as length × frequency and orthographic N × frequency interactions, hence affirming the need to identify variables with non-linear relationships with latencies as well as the possible interaction between these variables and other variables in future studies.

8.10 Conclusion

The current work underscores the importance of looking at understudied populations as well as individual differences to further inform visual word recognition research. Findings across the three studies provided converging evidence for systematic differences in visual word processing brought about not only by differences in orthographic depth, but also differences in levels of vocabulary knowledge and print exposure. With each writing system having its own distinctive linguistic properties and each individual having their own distinctive experience with linguistic input, it becomes even more vital for future developers of models of word recognition to account for these parameters.

Appendix A. List of Diacritics in the Qur'an

Diacritics	Description
◌َ	/a/
◌ِ	/i/
◌ُ	/u/
◌ً	/an/
◌ٍ	/in/
◌ٌ	/un/
◌ّ	Consonant doubling
◌ْ	Above any letter, indicates consonant sukun and is read with *izhār*
◌ٓ	Above the *Harf* to indicate the reading with *Madd* beyond 2 *harakāt* (beats) as in *Madd Lāzim*, *Madd Wājib*, and *Madd Jā'iz*
◌ۜ	Above the final word to indicate *Saktah* (momentary pause of 2 *harākat* without taking a breath)
◌۟	Above *Alif*, *Wau* or *Ya'* to indicate an added letter upon *Wasl* and *Waqf*.
◌۠	Above *Alif* to indicate as *Harf Madd* only upon *Waqf*. However, upon *Wasl*, the letter *Alif* is non-functional.
ۥ	*Hurūf Al-Matrūkah* indicates the original *Harf* that was left out and must be read
ۦ	*Hurūf Al-Matrūkah* indicates the original *Harf* that was left out and must be read
◌ۢ	Indicates the rule of *Iqlab* where the sound of *Mīm* is read instead of *Nūn* when the second part of *Tānwin* or *Nūn Sākinah* precedes the letter *Bā'*
◌۪	Indicate the reading with *Imālah (*inclination of *Fathah* to *Kasrah)*
◌۫	Indicate the reading with *Ishmām* (pouting of the lips) to signify the silent *Dammah*
◌۬	Above the second *Hamzah* to indicate *Tashil* reading between *Hamzah* and *Alif*
۩	Perform *Sujūd Tilāwah* (prostration of recitation) after the symbol
۝	Indicates the end of the sentence in a particular s*ūrah* with the verse number in it
۞	Indicates the end of a *Juz* (Chapter), *Hizb*, *Nisf* or *Rubu*.

Stopping Signs	Description
م	Compulsory stop – Otherwise meaning is changed
ع	End of a section
ط	Should stop – End of a sentence
قف	Better to stop
ج	Can stop or continue
ص	Must continue, can take a breath
صل	Must continue, can take a breath
ز	Must continue, can take a breath
لا	Better NOT to stop
∴ ∴	Stop at the first or the second symbol but not at both
قلے	Better to stop but permissible to continue
صلے	Better to continue but permissible to stop

Appendix B. List of Main Tajweed Rules

Condition	Pronunciation rule
Letters following نْ and *tanwīn*	
إظهار	No *ghunna*[8] if followed by throat letters
إدغام	Assimilation with and without *ghunna* depending on letter
إقلاب	نْ becomes مْ
إخفاء	With *ghunna*
Letters following مْ	
إظهار شفوى	Assimilate into following م
إدغام شفوى	With *ghunna* when followed by ب
إخفاء شفوى	No *ghunna* otherwise
Extended vowels (*madd)*	
المد المتصل	*Madd* followed by ء in the same word (duration of elongation: three beats)
المد المنفصل	*Madd* followed by ء in the next word (duration of elongation: three beats)
المد اللازم	*Madd* followed by ◌ْ or ◌ّ (duration of elongation: five beats)
The word الله	Recited with full mouth or empty mouth depending on preceding vowel
Rules of ر	
ر with ◌َ or ◌ُ or ◌ْ preceded by or ◌ُ	Full mouth
ر with ◌ِ or ◌ْ preceded by ◌ِ	Empty mouth
"Sun" letters	ل becomes silent and joined with preceding letter
Initiation and Stopping	
Any of ◌َ ◌ً ◌ٌ ◌ِ ◌ٍ before stop	Recited with◌ْ
◌ً before stop ◌ُ	Recited with ا
ة before stop	Pronounced as ه
Echo letters (ق ط ب ج د) with ◌ْ	Pronounced with a "bounce" on the letter

8 Ghunna: nasalisation of vowels

Appendix C. Online Questionnaire (Demographics, Language Background, Qur'an Memorisation and Recitation)

Demographics and Language Background Questionnaire

Information about You

Please write 'NA' for questions that do not apply to you.

What is your age? *

What is your gender? *

- Male
- Female

What is your ethnicity? *

- Malay
- Chinese
- Indian
- Eurasian
- Mixed
- Other:

What is your highest level of education? *

- Primary
- Secondary
- ITE
- Junior College
- Diploma
- Bachelor
- Master's
- PhD
- Other:

Are you a full-time madrasah student? *

- Yes
- No

Have you ever been diagnosed with a speech/hearing/reading disorder? *

- Yes
- No

If yes, please explain:

Your Language Background

Please write 'NA' for questions that do not apply to you.

English

Age you learned the language *

How/Where did you learn the language? (Please check all that apply.) *

- Parents
- Grandparents
- Relatives
- School
- Language Centre
- Other:

Please rate how fluent you are in READING in this language *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

Please rate how fluent you are in WRITING in this language *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

Please rate how fluent you are in SPEAKING this language *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

Malay

Age you learned the language *

How/Where did you learn the language? (Please check all that apply.) *

- Parents
- Grandparents
- Relatives
- School
- Language Centre
- Other:

Please rate how fluent you are in READING in this language *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

Please rate how fluent you are in WRITING in this language *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

Please rate how fluent you are in SPEAKING this language *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

Arabic

Age you learned the language *

How/Where did you learn the language? (Please check all that apply.) *

- ☐ Parents
- ☐ Grandparents
- ☐ Relatives
- ☐ School
- ☐ Language Centre
- ☐ Other:

Please rate how fluent you are in READING in this language *

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how fluent you are in WRITING in this language *

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how fluent you are in SPEAKING this language *

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Other

What other language did you learn?

Age you learned this language

How/Where did you learn this language? (Please check all that apply.)

- ☐ Parents
- ☐ Grandparents
- ☐ Relatives
- ☐ School
- ☐ Language Centre
- ☐ Other:

Please rate how fluent you are in READING in this language

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how fluent you are in WRITING in this language

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how fluent you are in SPEAKING this language

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Other

What other language did you learn?

Age you learned this language

How/Where did you learn this language? (Please check all that apply.)

- ☐ Parents
- ☐ Grandparents
- ☐ Relatives
- ☐ School
- ☐ Language Centre
- ☐ Other:

Please rate how fluent you are in READING in this language

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how fluent you are in WRITING in this language

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how fluent you are in SPEAKING this language

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Your Qur'an RECITATION Experience

Please write 'NA' for questions that do not apply to you.

At what age did you start to READ the Qur'an? *

How/Where did you learn to READ the Qur'an? (Please check all that apply.) *

- Parents
- Grandparents
- Relatives
- Religious Teacher
- Religious School
- Language Centre
- Other:

How often do you READ the Qur'an? *

- Daily
- Weekly
- Monthly
- Rarely

Based on your previous answer, how many times a day/week/month/year do you READ the Qur'an? *

Please provide an estimate if you are not sure of the exact number.

Please rate your fluency in READING the Qur'an: *

	1	2	3	4	5	6	7	8	9	
Very Poor										Excellent

How much of the Arabic in the Qur'an do you understand while READING it? *

- All of it
- Most of it
- Some of it
- A little of it
- None at all

Have you done a 'khatam' of the Qur'an? *
Khatam = Completed a recitation of the entire Qur'an.

- Yes
- No

If yes, please state how many times you have done a 'khatam' of the entire Qur'an. *
If you can't remember exactly, please provide an estimate.

Did you use a special book to learn how to read the Arabic in the Qur'an? *

- Yes
- No

If yes, which book(s) did you use? *
Please check all that apply.

- Iqra'
- Muqaddam
- Tilawati
- Qiraati
- Noorani Qaida
- Other:

If yes, please state the age at which you learned to read Arabic using the above book(s) *

If yes, how long did you take to finish learning using the above book(s)? *

What did you get for your latest Qur'an oral exam score? *
If you got separate scores for Qur'an recitation, memorisation (hafalan), etc., please report them separately and write "your mark/total marks" (e.g. bacaan: 75/100; hafalan: 70/100).

Have you learned Qur'anic Arabic? *
Qur'anic Arabic = Arabic related to the Qur'an specifically.

- Yes
- No

If yes, please state the age at which you started to learn Qur'anic Arabic: *

If yes, please state how long you have been learning Qur'anic Arabic: *

Please rate the proficiency of your Qur'anic Arabic: *

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Please rate how much you enjoy READING the Qur'an: *

	1	2	3	4	5	6	7	8	9	
Not at all	○	○	○	○	○	○	○	○	○	Very much

LISTENING to the Qur'an

Do you listen to Qur'anic recitation by a Qari? *

- ○ Yes
- ○ No

If yes, what do you use to listen to the Qur'anic recitation?
Please check all that apply.

- ☐ Qur'an App (Tablet/Smartphone)
- ☐ MP3
- ☐ CD/DVD
- ☐ YouTube videos
- ☐ Other: ______

If yes, how often do you listen to Qur'anic recitation?

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ Rarely

Based on your previous answer, how many times a day/week/month/year do you listen to Qur'anic recitation? *
Please provide an estimate if you are not sure of the exact number.

______

Do you listen to Qur'an recitation by a Qari while READING the Qur'an? *
E.g.: Using MP3, Qur'an App etc. together with the reading of the Qur'an

- ○ Yes
- ○ No

If yes, how often do you listen to Qur'an recitation by a Qari while READING the Qur'an?

- ○ All the time (while reading the Qur'an)
- ○ Most of the time (while reading the Qur'an)
- ○ Sometimes (while reading the Qur'an)
- ○ Rarely (while reading the Qur'an)

Please rate how much you enjoy LISTENING to Qur'an recitation: *

	1	2	3	4	5	6	7	8	9	
Not at all	○	○	○	○	○	○	○	○	○	Very much

****

Have you memorized any part of the Qur'an? *

- Yes
- No

Your Qur'an MEMORIZATION Experience

Please write 'NA' for questions that do not apply to you.

At what age did you start to memorize the Qur'an? *

Why did you want to memorize the Qur'an? *

Have you memorized the entire Qur'an? *

- Yes
- No

If yes, please state how long it took for you to memorize the entire Qur'an: *

How do you memorize the Qur'an? * (Please check all that apply.)

- Reading from the Qur'an
- Writing out the verses you are memorizing
- Listening to Qur'anic recitation by a Qari via mp3/Qur'an app
- Other:

How often do you practice your memorization of the Qur'an? *
Practice memorizing = Reciting without looking at the Qur'anic verses

- Daily
- Weekly
- Monthly
- Rarely

Based on your previous answer, how many times a day/week/month/year do you practice your memorization of the Qur'an? *

How much of the Arabic in the Qur'an did you understand while MEMORIZING? *

- All of it
- Most of it
- Some of it
- A little of it
- None at all

Please rate how much you enjoy MEMORIZING the Qur'an: *

	1	2	3	4	5	6	7	8	9	
Not at all										Very much

Your Qur'an Memorization

Please rate your fluency in reciting the following surahs from memory: *
1 = Very Poor, Many Errors, Need More Practice; 9 = Excellent, No Errors, Can Recite From Memory Very Easily

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
1. Al-Fātiĥah	○	○	○	○	○	○	○	○	○	○
2. Al-Baqarah	○	○	○	○	○	○	○	○	○	○
3. 'Āli `Imrān	○	○	○	○	○	○	○	○	○	○
4. An-Nisā'	○	○	○	○	○	○	○	○	○	○
5. Al-Mā'idah	○	○	○	○	○	○	○	○	○	○
6. Al-'An`ām	○	○	○	○	○	○	○	○	○	○
7. Al-'A`rāf	○	○	○	○	○	○	○	○	○	○
8. Al-'Anfāl	○	○	○	○	○	○	○	○	○	○
9. At-Tawbah	○	○	○	○	○	○	○	○	○	○
10. Yunus	○	○	○	○	○	○	○	○	○	○
11. Hūd	○	○	○	○	○	○	○	○	○	○
12. Yūsuf	○	○	○	○	○	○	○	○	○	○
13. Ar-Ra`d	○	○	○	○	○	○	○	○	○	○
14. 'Ibrāhīm	○	○	○	○	○	○	○	○	○	○
15. Al-Ĥijr	○	○	○	○	○	○	○	○	○	○

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
16. An-Naĥl										
17. Al-'Isrā'										
18. Al-Kahf										
19. Maryam										
20. Ţā Hā										
21. Al-'Anbiyā'										
22. Al-Ĥaj										
23. Al-Mu'minūn										
24. An-Nūr										
25. Al-Furqān										
26. Ash-Shu`arā'										
27. An-Naml										
28. Al-Qaşaş										
29. Al-`Ankabūt										
30. Ar-Rūm										
31. Luqmān										

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
32. As-Sajdah										
33. Al-'Aĥzāb										
34. Saba'										
35. Fāţir										
36. Yā Sīn										
37. Aş-Şaffāt										
38. Şād										
39. Az-Zumar										
40. Ghāfir										

Your Qur'an Memorization

Please rate your fluency in reciting the following surahs from memory: *
1 = Very Poor, Many Errors, Need More Practice; 9 = Excellent, No Errors, Can Recite From Memory Very Easily

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
41. Fuşşilat	○	○	○	○	○	○	○	○	○	○
42. Ash-Shūrā	○	○	○	○	○	○	○	○	○	○
43. Az-Zukhruf	○	○	○	○	○	○	○	○	○	○
44. Ad-Dukhan	○	○	○	○	○	○	○	○	○	○
45. Al-Jāthiyah	○	○	○	○	○	○	○	○	○	○
46. Al-'Aĥqāf	○	○	○	○	○	○	○	○	○	○
47. Muĥammad	○	○	○	○	○	○	○	○	○	○
48. Al-Fatĥ	○	○	○	○	○	○	○	○	○	○
49. Al-Ĥujurāt	○	○	○	○	○	○	○	○	○	○
50. Qāf	○	○	○	○	○	○	○	○	○	○
51. Adh-Dhāriyāt	○	○	○	○	○	○	○	○	○	○
52. Aţ-Ţūr	○	○	○	○	○	○	○	○	○	○
53. An-Najm	○	○	○	○	○	○	○	○	○	○
54. Al-Qamar	○	○	○	○	○	○	○	○	○	○
55. Ar-Raĥmān	○	○	○	○	○	○	○	○	○	○
56. Al-Wāqi`ah	○	○	○	○	○	○	○	○	○	○

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
57. Al-Ĥadīd										
58. Al-Mujādila										
59. Al-Ĥashr										
60. Al-Mumtaĥanah										
61. Aş-Şaf										
62. Al-Jumu`ah										
63. Al-Munāfiqūn										
64. At-Taghābun										
65. Aţ-Ţalāq										
66. At-Taĥrīm										
67. Al-Mulk										
68. Al-Qalam										
69. Al-Haqqah										
70. Al-Ma`ārij										
71. Nūĥ										
72. Al-Jinn										

73. Al-Muzzammil	○	○	○	○	○	○	○	○	○	○
74. Al-Muddaththir	○	○	○	○	○	○	○	○	○	○
75. Al-Qiyāmah	○	○	○	○	○	○	○	○	○	○
76. Al-'Insān	○	○	○	○	○	○	○	○	○	○
77. Al-Mursalāt	○	○	○	○	○	○	○	○	○	○
78. An-Naba'	○	○	○	○	○	○	○	○	○	○
79. An-Nāzi`āt	○	○	○	○	○	○	○	○	○	○
80. `Abasa	○	○	○	○	○	○	○	○	○	○

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
81. At-Takwīr	○	○	○	○	○	○	○	○	○	○
82. Al-'Infiţār	○	○	○	○	○	○	○	○	○	○
83. Al-Muţaffifīn	○	○	○	○	○	○	○	○	○	○
84. Al-'Inshiqāq	○	○	○	○	○	○	○	○	○	○
85. Al-Burūj	○	○	○	○	○	○	○	○	○	○
86. Aţ-Ţāriq	○	○	○	○	○	○	○	○	○	○
87. Al-'A`lā	○	○	○	○	○	○	○	○	○	○
88. Al-Ghāshiyah	○	○	○	○	○	○	○	○	○	○
89. Al-Fajr	○	○	○	○	○	○	○	○	○	○

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
90. Al-Balad										
91. Ash-Shams										
92. Al-Layl										
93. Ađ-Đuĥā										
94. Ash-Sharĥ										
95. At-Tīn										
96. Al-`Alaq										
97. Al-Qadr										
98. Al-Bayyinah										
99. Az-Zalzalah										
100. Al-`Ādiyāt										

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
101. Al-Qāri`ah										
102. At-Takāthur										
103. Al-`Aşr										

	N/A (Haven't memorized)	1 (Very Poor)	2	3	4	5	6	7	8	9 (Excellent)
104. Al-Humazah	○	○	○	○	○	○	○	○	○	○
105. Al-Fīl	○	○	○	○	○	○	○	○	○	○
106. Quraysh	○	○	○	○	○	○	○	○	○	○
107. Al-Mā`ūn	○	○	○	○	○	○	○	○	○	○
108. Al-Kawthar	○	○	○	○	○	○	○	○	○	○
109. Al-Kāfirūn	○	○	○	○	○	○	○	○	○	○
110. An-Naşr	○	○	○	○	○	○	○	○	○	○
111. Al-Masad	○	○	○	○	○	○	○	○	○	○
112. Al-'Ikhlāş	○	○	○	○	○	○	○	○	○	○
113. Al-Falaq	○	○	○	○	○	○	○	○	○	○
114. An-Nās	○	○	○	○	○	○	○	○	○	○

Appendix D. Qur’an Vocabulary Test

Instructions: In this test, the first word in each line is printed in Arabic. Opposite it are four other words in English. Circle the ONE WORD which means the SAME THING, or most nearly the same thing, as the first word. If you don’t know, guess. Be sure to choose the ONE WORD that means the same thing as the first word. There are 90 questions which you will have 25 minutes to complete.

EXAMPLE:

كَبِيرَةً **1)** red **2)** big **3)** silent **4)** wet

The correct response is to circle the response “**2)** big”.

1)	ءَامَنُواْ	**1) they rejected**	**2) they hunted**	**3) they interfered**	**4) they believed**
2)	ٱلدُّنْيَا	**1) the ocean**	**2) the hill**	**3) the dome**	**4) the world**
3)	كَفَرَ	**1) he understood**	**2) he disbelieved**	**3) he faked**	**4) he agreed**
4)	قَالَ	**1) he did**	**2) he said**	**3) he wrote**	**4) he stopped**
5)	جَمِيعًا	**1) alone**	**2) rarely**	**3) together**	**4) often**
6)	ثُمَّ	**1) first**	**2) sum**	**3) then**	**4) last**
7)	مُّسْتَقِيمٍ	**1) small**	**2) straight**	**3) grand**	**4) wrong**
8)	ٱلْمَوْتَ	**1) the life**	**2) the dawn**	**3) the death**	**4) the anchor**
9)	إِنَّ	**1) finally**	**2) firstly**	**3) newly**	**4) verily**
10)	يَعْلَمُونَ	**1) they know**	**2) they mould**	**3) they deny**	**4) they teach**
11)	ٱلْمُرْسَلِينَ	**1) the messengers**	**2) the poets**	**3) the kings**	**4) the soldiers**

12)	سِحْرٌ	1) magic	2) cloth	3) soul	4) disease
13)	ٱلْأَرْضِ	1) the sea	2) the earth	3) the sky	4) the mountain
14)	خَلَقَ	1) he chewed	2) he created	3) he launched	4) he ran
15)	ٱلْحَقُّ	1) the strength	2) the lie	3) the law	4) the truth
16)	عَزِيزٌ	1) weak	2) legendary	3) just	4) all-mighty
17)	حَتَّىٰ	1) until	2) over	3) on	4) from
18)	ٱلنَّاسِ	1) the forests	2) the omens	3) the animals	4) the people
19)	يُنصَرُونَ	1) they will be helped	2) they will be announced	3) they will be rejected	4) they will be loosened
20)	ٱلَّذِينَ	1) that who	2) the adulterer	3) those who	4) our fact
21)	أَنفُسَهُمْ	1) herself	2) themselves	3) himself	4) ourselves
22)	مُّبِينٌ	1) unseen	2) cloudy	3) clear	4) difficult
23)	ٱلْأَنْهَٰرُ	1) the skies	2) the boats	3) the rivers	4) the fields
24)	ٱلْمُفْسِدِينَ	1) the adulterers	2) the partners	3) the corrupters	4) the believers
25)	ٱلسَّمَٰوَٰتِ	1) the birds	2) the oceans	3) the heavens	4) the lands
26)	أَيْدِيهِمْ	1) their heads	2) their feet	3) their shoulders	4) their hands

27)	يُرِيدُ	1) he denies	2) he points	3) he wants	4) he tells
28)	تَوَلَّوْاْ	1) they take	2) they turn away	3) they understand	4) they fly away
29)	عَدُوٌّ	1) a friend	2) an angel	3) an enemy	4) an army
30)	أَضْعَفُ	1) is stronger	2) is smarter	3) is weaker	4) is slower
31)	أَكْثَرَ	1) enough	2) more	3) little	4) less
32)	مُّسَمًّى	1) opened	2) appointed	3) left	4) took
33)	تَابَ	1) he forgave	2) he asked	3) he repented	4) he needed
34)	شَيْءٍ	1) intention	2) thing	3) excuse	4) time
35)	كَذَّبَ	1) rejects	2) pardons	3) accepts	4) searches
36)	يَشْعُرُونَ	1) they realize	2) they learn	3) they like	4) they receive
37)	غَيْرَ	1) therefore	2) with	3) for	4) without
38)	شَدِيدٌ	1) severe	2) certain	3) fair	4) lenient
39)	رَيْبٍ	1) purpose	2) enlightenment	3) doubt	4) truth
40)	شُهَدَآءَ	1) soldiers	2) judges	3) lovers	4) witnesses
41)	خَٰلِدِينَ	1) they will help soon	2) they will stay now	3) they will abide forever	4) they will protect us

42)	وَجَدْنَا	1) we revealed	2) we arrived	3) we took	4) we found
43)	بَغْتَةً	1) suddenly	2) maybe	3) nearly	4) often
44)	ظُلَلٍ	1) sins	2) leftovers	3) coverings	4) households
45)	تُتْلَىٰ	1) is exclaimed	2) is animated	3) is recited	4) is expedited
46)	تَجْرِى	1) breed	2) leave	3) flow	4) help
47)	مُّعْرِضُونَ	1) those who accept	2) those who understand	3) those who turn away	4) those who weaken
48)	ٱلْإِبِلِ	1) the camels	2) the lions	3) the beasts	4) the ants
49)	بَلْ	1) thus	2) but	3) who	4) henceforth
50)	أَتْقَنَ	1) he succeeded	2) he failed	3) he warned	4) he perfected
51)	سَعِيرًا	1) a blaze	2) a storm	3) a flood	4) an earthquake
52)	دُونِ	1) excluding	2) perhaps	3) including	4) moreover
53)	سَوْفَ	1) never	2) must	3) often	4) will
54)	ٱلْقُرَىٰ	1) the months	2) the deserts	3) the cities	4) the countries
55)	فَرِيقٌ	1) a rock	2) a wrongdoing	3) a group	4) a business
56)	خَلَتْ	1) has permitted	2) has occurred	3) has died	4) has flown

57)	ظَلْتَ	1) you have remained	2) you have decided	3) you have appeared	4) you have left
58)	صُرِفَتْ	1) are turned	2) are connected	3) are covered	4) are expanded
59)	جُنَاحَ	1) deed	2) sin	3) necessity	4) wealth
60)	أَصْبُ	1) I might imply	2) I might incline	3) I might show	4) I might find
61)	ٱلرِّعَآءُ	1) the scribes	2) the wealthy	3) the shepherds	4) the advisers
62)	قَتَرَةٌ	1) brightness	2) coldness	3) darkness	4) happiness
63)	مِنسَأَتَهُۥ	1) his staff	2) his chain	3) his land	4) his garment
64)	وَزُورًا	1) and a tale	2) and a lie	3) and a moral	4) and a fact
65)	صَدِيدٍ	1) blood	2) flesh	3) mucus	4) pus
66)	مُّتَّكِئِينَ	1) reclining	2) swimming	3) standing	4) crossing
67)	يَنقُصُوكُمْ	1) they have let you	2) they have failed you	3) they have angered you	4) they have won you
68)	ٱلصَّيْحَةُ	1) the loud noise	2) the awful cry	3) the terrible buzz	4) the soft whisper
69)	ٱلشِّتَآءِ	1) the winter	2) the spring	3) the summer	4) the autumn
70)	مَّعَرَّةٌۢ	1) harm	2) peace	3) safety	4) freedom
71)	ٱلرَّعْدُ	1) the fog	2) the thunder	3) the rain	4) the lightning

72)	ٱلْأَفْـِٔدَةِ	1) the souls	2) the bodies	3) the minds	4) the hearts
73)	أَسْفَلَ	1) was similar	2) was higher	3) was different	4) was lower
74)	مَّدْحُورًا	1) accepted	2) escaped	3) abandoned	4) sought
75)	مَّحِيصٍ	1) place of abandonment	2) place of inspiration	3) place of refuge	4) place of atonement
76)	ٱلْأَصْفَادِ	1) chains	2) insects	3) risks	4) bottles
77)	لُغُوبٌ	1) energy	2) force	3) fuel	4) fatigue
78)	سَحَابٌ	1) storms	2) floods	3) tornadoes	4) clouds
79)	ٱلْقِطْرِ	1) molten iron	2) molten silver	3) molten gold	4) molten copper
80)	عُمْيٌ	1) blind	2) mute	3) deaf	4) dumb
81)	مَخْمَصَةٌ	1) hunger	2) poverty	3) thirst	4) illness
82)	مُعَقِّبَ	1) buyer	2) adjuster	3) seller	4) middleman
83)	كِسَفًا	1) boulders	2) spaces	3) fragments	4) ranges
84)	وَٱلصَّيْفِ	1) and spring	2) and winter	3) and summer	4) and autumn
85)	خَسِرَ	1) he has won	2) he has lost	3) he has gained	4) he has bought
86)	ٱللُّؤْلُؤُ	1) the diamond	2) the silver	3) the pearl	4) the gold

87)	بَخْسٍ	1) very different	2) very high	3) very similar	4) very low
88)	ٱلْفُلْكُ	1) the rowers	2) the caravans	3) the ports	4) the ships
89)	تَلْقَفُ	1) devoured	2) thrown	3) forbade	4) permitted
90)	فُطُورٍ	1) scar	2) stitch	3) break	4) crash

Information about You

Age

Email address (if you would like to receive your results for the test).

How many years have you been learning Qur'anic Arabic?

Please rate your proficiency in Qur'anic Arabic.

	1	2	3	4	5	6	7	8	9	
Very Poor	○	○	○	○	○	○	○	○	○	Excellent

Appendix E. List of Stimuli for Lexical Decision

Nonword Stimuli	Arabic Stimuli	IPA	English Gloss
وَاشًا	نَارًا	na:ran	(to) Fire
يَأْطِىَ	يَأْتِىَ	jaʔtija	comes
غَىْءٍ	شَىْءٍ	ʃajʔin	thing
بَعْةِ	بَعْدِ	baʕdi	after
أَكْطَرَ	أَكْثَرَ	ʔakθara	most
ثَلَّىٰ	وَلَّىٰ	walla:	he turns away
مِقِّيُّونَ	رِبِّيُّونَ	ribbijju:na	(were) religious scholars
أَرْفَابًا	أَرْبَابًا	ʔarba:ban	(as) Lords
عَغِيمًا	عَلِيمًا	ʕali:man	All-Knower
يَوْبِ	يَوْمِ	jawmi	(of the) Day
بَمِىٓ	بَنِىٓ	bani::	(from the) Children
لِشَانَ	لِسَانَ	lisa:na	a mention
تَتَوَّلَ	تَقَوَّلَ	taqawwala	he (had) fabricated
بُرْهَٰتَانِ	بُرْهَٰنَانِ	burha:na:ni	(are) two evidences
عَمَابٌ	عَذَابٌ	ʕaða:bun	(is) a punishment
سَجَٰوَٰتٍ	سَمَٰوَٰتٍ	sama:wa:tin	heavens
نَفُولُ	نَقُولُ	naqu:lu	We will say
عَشِيمًا	عَظِيمًا	ʕaðˤi:ma:	great
كُضِبَ	كُتِبَ	kutiba	Prescribed
شَآضَ	شَآءَ	ʃa::ʔa	wills
أَفَاشَ	أَرَادَ	ʔara:da	wishes
تٰقِبَةُ	عٰقِبَةُ	ʕa:qibatu	(in) the end
جَلِيعًا	جَمِيعًا	dʒami:ʕan	all
جَقًّا	حَقًّا	ħakkan	a duty
وٰحِخَةً	وٰحِدَةً	wa:ħidatan	(only) one

Nonword Stimuli	Arabic Stimuli	IPA	English Gloss
أَبَّامٍ	أَيَّامٍ	ʔajja:min	days
فِيِّنَٰتٍ	بَيِّنَٰتٍ	bajjina:tin	clear
قَبْخُ	قَبْلُ	qablu	before
شَلِيدًا	شَهِيدًا	ʃahi:dan	a witness
صُتُفِ	صُحُفِ	sˤuħufi	(the) Scriptures
كَشِيرًا	كَبِيرًا	kabi:ran	great
عَلِيزٌ	عَزِيزٌ	ʕazi:zun	grievous
صَبْدًا	صَبْرًا	sˤabran	patience
مُّضَمًّى	مُّسَمًّى	musamma:	specified
مُسْجَكْبِرِينَ	مُسْتَكْبِرِينَ	mustakbiri:na	(Being) arrogant
دَصَلَ	دَخَلَ	daxala	entered
فِلْدٍ	عِلْمٍ	ʕilmin	(any) knowledge
سَوَّبَتْ	سَوَّلَتْ	saẇalat	suggested
كَامَتْ	كَانَتْ	ka:nat	is
إِجَهَ	إِلَٰهَ	ʔila:ha	god
أَفِيمٌ	أَلِيمٌ	ʔali:mun	painful
ظَمْرُ	أَمْرُ	ʔamru	(the) Order of Allah
ظَمَّ	ظَنَّ	ðˤaṅa	he thought
خَلْضٍ	خَلْقٍ	xalqin	(the) creation
مُّسْلَضْعَفُونَ	مُّسْتَضْعَفُونَ	mustadˤʕafu:na	(and) deemed weak
عِنضَ	عِندَ	ʕinda	before
خَٰسِدِينَ	خَٰلِدِينَ	xa:lidi:na	abiding forever
وَبِيهًا	وَجِيهًا	wadʒi:han	honorable
دَآتَّةٍ	دَآبَّةٍ	da::ḃatin	any animal
شُنَدَآءَ	شُهَدَآءَ	ʃuhada::ʔa	witnesses
حَيْغٌ	زَيْغٌ	zajɣun	(is) perversity

Nonword Stimuli	Arabic Stimuli	IPA	English Gloss
مَّعْلُودَٰبٍ	مَّعْدُودَٰتٍ	maʕdu:da:tin	numbered
فَرِيبَةً	فَرِيضَةً	fari:dˤatan	an obligation (dower)
حَتِيلًا	قَلِيلًا	qali:lan	a few
طَكُن	يَكُن	jakun	is; will have
ضَجَلٍ	أَجَلٍ	ʔadʒalin	a term
ضِعْثَيْنِ	ضِعْفَيْنِ	dˤiʕfajni	two-fold
كُلَّجَا	كُلَّمَا	kuɭama:	Whenever
مُّسْبَقِيمٍ	مُّسْتَقِيمٍ	mustaqi:min	straight
بَيْرَ	غَيْرَ	ɣajra	other (than)
سُنعُلَٰتٍ	سُنۢبُلَٰتٍ	sumbula:tin	ears (of corn)
ظُمُّ	كُلُّ	kullu	every
وَفَالَ	وَبَالَ	waba:la	(the bad) consequence
طَوْمًا	طَوْعًا	tˤawʕan	willingly
رُل	قُل	qul	Say
ظَفَا	شَفَا	ʃafa:	edge; (the) brink
كَطَرَ	كَفَرَ	kafara	disbelieved
مَّقَاجٍ	مَّكَانٍ	maka:nin	a place
سَشِيلِ	سَبِيلِ	sabi:li	(the) way
رُلِّ	كُلِّ	kulli	every
ثَنَثُونَ	ثَلَٰثُونَ	θala:θu:na	(is) thirty
ءَاثِهَةٌ	ءَالِهَةٌ	ʔa:lihatun	gods
رَظُلٌ	رَجُلٌ	radʒulun	a man
زَوْكَيْنِ	زَوْجَيْنِ	zawdʒajni	pairs
سَقَتَ	سَكَتَ	sakata	was calmed
ذَفَّةٍ	ذَرَّةٍ	ðarratin	(of) an atom
قَوْشًا	قَوْمًا	qawman	a people

Nonword Stimuli	Arabic Stimuli	IPA	English Gloss
قِيثَ	قِيلَ	qiːla	it is said
ذَرْمًا	ذَرْعًا	ðarʕan	(and) uneasy
يَكْتُرُ	يَكْفُرُ	jakfuru	you will deny
أَظَىٰ	أَرَىٰ	ʔaraː	see
سَضِيعٌ	سَمِيعٌ	samiːʕun	(is) All-Hearing
مَنَلُ	مَثَلُ	maθalu	like (came to)
بَهْدِى	يَهْدِى	jahdiː	guides
ثَيْرٌ	خَيْرٌ	xajrun	(is) better
أَيَّبَ	أَوَّلَ	ʔaẇala	(the) first
مَفَكَتْ	مَلَكَتْ	malakat	you possess
أَضُونَ	أَكُونَ	ʔakuːna	I can be
قَآئِعَةً	قَآئِمَةً	qaːːʔimatan	will occur
تَاضَ	تَابَ	taːba	repented
مَفْسٍ	نَفْسٍ	nafsin	(another) soul
مَبْضُوطَتَانِ	مَبْسُوطَتَانِ	mabsuːtˤataːni	(are) stretched out
عَحَابًا	عَذَابًا	ʕaðaːban	a punishment
مُّسْبَخْلَفِينَ	مُّسْتَخْلَفِينَ	mustaxlafiːna	trustees
تُسَٰةً	تُقَٰةً	tuqaːtan	(as) a precaution
مَآئِفَةٌ	طَآئِفَةٌ	tˤaːːʔifatun	a group
وَذِيرٌ	نَذِيرٌ	naðiːrun	a warner
كَلِيرًا	كَثِيرًا	kaθiːran	abundant
يا حَ	قَالَ	qaːla	said; He said
مَّثَدَّةً	مَّوَدَّةً	mawaddatan	love
جَآةَ	جَآءَ	dʒaːːʔa	came
أَفْغَهَ	أَفْلَحَ	ʔaflaħa	he succeeds; (will be) successful
أَظَدًا	أَحَدًا	ʔaħadan	anyone

Nonword Stimuli	Arabic Stimuli	IPA	English Gloss
غَتُورٌ	غَفُورٌ	ɣafu:run	(is) Oft-Forgiving
طَوِيقًا	طَرِيقًا	tˤari:qan	a path; (to) a way
مَّغْظِرَةٌ	مَّغْفِرَةٌ	maɣfiratun	(is) forgiveness
مُتَطَٰكِسُونَ	مُتَشَٰكِسُونَ	mutaʃa:kisu:na	quarrelling
جُلْكُ	مُلْكُ	mulku	(is the) Kingdom
وَثَدَ	وَعَدَ	waʕada	Has promised
ءَافَةً	ءَايَةً	ʔa:jatan	a sign
تَرَلَ	تَرَكَ	taraka	he left
يَعْحَمُ	يَعْلَمُ	jaʕlamu	knows
قَوْنًا	قَوْلًا	qawlan	words
قَدِيثٌ	قَدِيرٌ	qadi:run	(is) All-Powerful
أَثَدًا	أَبَدًا	ʔabadan	forever
جُتَاحَ	جُنَاحَ	dʒuna:ħa	blame
مُسَٰعِحِينَ	مُسَٰفِحِينَ	musa:fiħi:na	being lewd; (to be) lustful.
مَبَّ	مَسَّ	massa	(has) touched
مُتَغَابِعَيْنِ	مُتَتَابِعَيْنِ	mutata:biʕajni	consecutively
جَنَّٰضٍ	جَنَّٰتٍ	dʒanna:tin	(to) Gardens
ثَشَنًا	ثَمَنًا	θamanan	a price
ذَقَا	عَلَا	ʕala:	exalted himself
أَمزَلَ	أَنزَلَ	ʔanzala	has revealed
ضَشْ	هَبْ	hab	grant
ظَمِّ	رَبِّ	rabbi	the Lord

Appendix F. List of Stimuli for Speeded Pronunciation

Arabic Stimulus	IPA	English Gloss
تُسْمِعُ	tusmiʕu	cause the deaf to hear
أَصْحَٰبُ	ʔasˤħa:bu	(are the) companions
رِسَٰلَٰتِ	risa:la:ti	Messages
كَلَٰلَةً	kala:latan	(has) no parent or child
زُيِّنَ	zuẏina	Beautified
مُتَّكِـِٔينَ	muttakiʔi:na	Reclining
طَرِيقَ	tˤari:qa	(the) way
أَكْبَرُ	ʔakbaru	(is) greater
أَزْوَٰجًا	ʔazwa:dʒan	wives
رَبِّ	raḃi	the Lord
عَلِيمٌ	ʕali:mun	(is) All-Knowing
شَيْـًٔا	ʃajʔan	anything
خَيْرًا	xajran	good
ثَقِيلًا	θaqi:lan	heavy
حَيْثُ	ħajθu	where
ثُبُورًا	θubu:ran	(for) destructions
جَعَلَ	dʒaʕala	made
قَرْيَةٍ	qarjatin	a city
خَمْطٍ	xamtˤin	bitter
بَشَرٌ	baʃarun	any man
أَعْلَمُ	ʔaʕlamu	better knowing
كَذِبًا	kaðiban	a lie
قُلْ	qul	Say
شَكٍّ	ʃakkin	doubt
مُسْتَـْٔنِسِينَ	mustaʔnisi:na	seeking to remain

Arabic Stimulus	IPA	English Gloss
كَيْفَ	kajfa	how
كَانَ	ka:na	is; it is; will
مُتَشَٰبِهَٰتٌ	mutaʃa:biha:tun	(are) allegorical
مَثَلًا	maθalan	an example
مَكَانٍ	maka:nin	place
وَازِرَةٌ	wa:ziratun	a bearer of burden,
كَوْكَبًا	kawkaban	stars; a star
ءَامَنَ	ʔa:mana	believed
أُوتِىَ	ʔu:tija	was given; he is granted; is given
كَذَّبَ	kaððaba	rejects
إِيمَٰنًا	ʔi:ma:nan	(in) faith
يُتَقَبَّلَ	jutaqabbala	will be accepted
بِيضٌ	bi:dˤun	white
يَوْمَ	jawma	(on the) Day
كِتَٰبُ	kita:bu	(was the) Scripture
زِدْ	zid	add
تَرَ	tara	you see
مَآءً	ma::ʔan	water
كَافِرَةٌ	ka:firatun	disbelievers
عِندِ	ʕindi	from
أَشَدُّ	ʔaʃaddu	stronger
رَحْمَةً	raħmatan	mercy
تَجْرِى	tadʒri:	flowing
يُحِبُّ	juħibbu	like
مُسْتَضْعَفِينَ	mustadˤʕafi:na	oppressed
مُّتَقَٰبِلِينَ	mutaqa:bili:na	facing each other

Arabic Stimulus	IPA	English Gloss
ضَلَٰلٍ	dˤala:lin	(the) error
مُّبَيِّنَةٍ	mubajjinatin	clear
فُصِّلَتْ	fusˤsˤilat	explained in detail
أُنزِلَ	ʔunzila	(is) sent down; was sent down
وَعْدُ	waʕdu	(the) promise
مُتَشَٰبِهًا	mutaʃa:bihan	similar; (things) in resemblance
وَقَعَ	waqaʕa	has fallen; fell; (became) incumbent
وَعْدًا	waʕdan	a promise
قِيَٰمًا	qija:man	standing
أَخَافُ	ʔaxa:fu	fear
حَبًّا	ħabban	grain
يُوَسْوِسُ	juwaswisu	whispers
يَتَذَكَّرُ	jataðakkaru	may take heed
مَكْرًا	makran	a plan; a plot; (in) planning
مُّتَجَٰوِرَٰتٌ	mutadʒa:wira:tun	neighbouring
أُمَّةٍ	ʔummatin	(of) people
لَيْسَ	lajsa	not
يَتَّقِى	jaṫaqi:	will shield
مُسَخَّرَٰتٍ	musaẋara:tin	controlled
ضَلَّ	dˤalla	he lost (the) way; he went astray (from); he strayed
حَكِيمٌ	ħaki:mun	(is) All-Wise
خَلَقَ	xalaqa	created
صَلَّىٰٓ	sˤalla::	he prayed; he prays
مُعَٰجِزِينَ	muʕa:dʒizi:na	(to) cause failure
هُدًى	hudan	Guidance
أَرْضًا	ʔardˤan	(to) a land

Arabic Stimulus	IPA	English Gloss
بَطَنَ	batˤana	is concealed
تَمَيَّزُ	tamajjazu	bursts
مُتَتَابِعَيْنِ	mutata:biʕajni	consecutively
أَخَا	ʔaxa:	(the) brother
أَنَّىٰ	ʔaṅa:	when; how; from where
يُرِيدُ	juri:du	intends
حَسَنًا	ħasanan	good
مُتَكَبِّرٍ	mutakabirin	arrogant one
إِلَٰهَيْنِ	ʔila:hajni	(as) two gods
رَقَبَةٍ	raqabatin	(of) a slave; (of) a believing slave; a neck
جَسَدًا	dʒasadan	an image; bodies; a body
قَبْلِ	qabli	before
دُونِ	du:ni	other than; excluding; besides
بَيْنَ	bajna	(in) front
يَقُولُ	jaqu:lu	say
عَدُوٌّ	ʕaduwwun	an enemy
قَوْمٌ	qawmun	a people
مَأْتِيًّا	maʔtijjan	sure to come
تَسْتَطِيعَ	tastatˤi:ʕa	will be able; you will be able
مَرَّ	marra	passed; he passes on
صَٰلِحًا	sˤa:liħan	righteous deeds; a righteous (child)
بَعْدَ	baʕda	after
حَرَّمَ	ħaṙama	He has forbidden
نَجْزِى	nadʒzi:	We reward
مُّؤْمِنِينَ	muʔmini:na	believers
تُتْلَىٰ	tutla:	is recited; are recited; were recited

Arabic Stimulus	IPA	English Gloss
تَلَظَّىٰ	talaŻa:	blazing
عَذَابَ	ʕaða:ba	(from the) punishment
أَمْرًا	ʔamran	a matter; something; a command
غَيْرُ	ɣajru	other than
ءَالِهَةً	ʔa:lihatan	(there are) gods; (as) gods
عَاقَبَ	ʕa:qaba	has retaliated
كُلَّ	kulla	every
طِينٍ	tˁi:nin	clay
ظُلَلٌ	ðˁulalun	coverings
كَسَبَتْ	kasabat	it earned
ظَٰهِرِينَ	ðˁa:hiri:na	dominant
لَعْنَةً	laʕnatan	(by) a curse; (with) a curse
يَشَآءُ	jaʃa::ʔu	He wills
وَدَّ	wadda	Wished
بَلَغَ	balaɣa	it reaches
قُتِلَ	qutila	is slain
أَوْلِيَآءَ	ʔawlija::ʔa	(the) friends; (as) allies
سَلْ	sal	Ask
ءَايَٰتِ	ʔa:ja:ti	(the) Verses; (the) Signs
أَجْرًا	ʔadʒran	a reward; a payment
ذِكْرَىٰ	ðikra:	remembrance; a reminder
ءَالَآءِ	ʔa:la::ʔi	the Favours; (of the) favours

Appendix G. List of Stimuli for Morphological Priming Task (With English Gloss and IPA)

Root Priming

	Prime		
Target	+R+P	-R+P	Baseline
أَهْوَآءَ	هَاوِيَةٌ	وَاهِيَةٌ	نَاظِرَةٌ
(the) desires	abyss; (will be the) Pit	frail; weak; infirm	looking
/ʔahwaːːʔa/	/haːwijatun/	/waːhijatun/	/naːðˤiratun/
تَحْمِلُ	حَمْلًا	لَحْمًا	ضَرْبًا
(she) bears; carries; conceives	burden	meat; (with) flesh	a blow; (to) move about
/taħmilu/	/Hamlan/	/laHman/	/dˤarban/
جَعَلَ	تَجْعَلْ	تَعْجَلْ	تَحْزَنْ
(he) has made	make	hasten; make haste	grieve
/dʒaʕala/	/tadʒʕal/	/taʕdʒal/	/taHzan/
دَآئِبَيْنِ	دَأَبًا	أَبَدًا	سَكَرًا
both constantly pursuing their courses	as usual	forever; ever	intoxicant
/daːːʔibajni/	/daʔaban/	/ʔabadan/	/sakaran/
رَجْمًا	رَّجِيمٍ	مَّرِيجٍ	يَبَسًا
guessing (n)	accursed	confused	dry
/radʒmam/	/radʒiːmin/	/mariːdʒin/	/jabasan/
سُورَةٌ	أَسَاوِرَ	رَوَٰسِىَ	مَنَازِلَ
a surah (chapter of the Qur'an)	bracelets	firm mountains	phases
/suːratun/	/ʔasaːwira/	/rawaːsija/	/manaːzila/
سِحْرٌ	مَّسْحُورًا	مَّحْسُورًا	تَأْثِيمًا
magic	bewitched	insolvent	sinful (speech)
/siħrun/	/masHuːran/	/maHsuːran/	/taʔθiːman/
عَقِيمًا	عَقِيمٍ	عَمِيقٍ	حَنِيذٍ
barren	barren	distant	roasted
/ʕaqiːman/	/ʕaqiːmin/	/ʕamiːqin/	/Haniːðin/
عَمَلًا	يَعْمَلُ	يَعْلَمُ	يَشْهَدُ
deed; work	(they) do	(he) knows	(he) bears witness
/ʕamalan/	/jaʕmalu/	/jaʕlamu/	/jaʃhadu/
عَمِلَ	يَعْمَلْ	يَعْلَمْ	تَغْفِرْ
(he) has done; does	(he) does	he knows	you forgive
/ʕamila/	/jaʕmal/	/jaʕlam/	/taɣfir/
عُسْرَةٍ	عَسِيرًا	سَعِيرًا	خَصِيمًا
in difficulty; in hardship	(a) difficult (Day)	(in) a Blazing Fire	a pleader; an advocate
/ʕusratin/	/ʕasiːran/	/saʕiːran/	/xasˤiːman/
عِلْمٌ	نَعْلَمُ	نَعْمَلُ	نَشْهَدُ
(any/some) knowledge	(we) know	(we are) doing	we testify
/ʕilmun/	/naʕlamu/	/naʕmalu/	/naʃhadu/

	Prime		
Target	+R+P	-R+P	Baseline
فُقَرَآءَ	فَقِيرٌ	فَرِيقٌ	شَفِيعٌ
poor	(is) poor; (in) need	a group; a party	(any) intercessor
/fuqara::ʔa/	/faqi:run/	/fari:qun/	/ʃafi:ʕun/
قُرْبَانًا	قَرِيبًا	رَقِيبًا	شَدِيدًا
a sacrifice; gods as a way of approach	near; close; soon	Ever-Watchful; an Observer	severe
/qurba:nan/	/qari:ban/	/raqi:ban/	/ʃadi:dan/
مَعَٰيِشَ	عِيشَةٍ	شِيعَةٍ	لِّينَةٍ
livelihood; means of living	life; way of life	sect	(the) the palm-trees
/maʕa:jiʃa/	/ʕi:ʃatin/	/ʃi:ʕatin/	/li:natin/
مُحَرَّمًا	حَرَمًا	مَرَحًا	سَكَنًا
(anything) forbidden	a sanctuary	(with) insolence; pride; exultantly	(for) rest; a resting place
/muħarraman/	/Haraman/	/maraHan/	/sakanan/
مُعْتَدٍ	تَعْدُ	تَدْعُ	أَخْذُ
transgressor; aggressor	pass beyond	invoke	(is) the seizure (of) your Lord
/muʕtadin/	/taʕdu/	/tadʕu/	/ʔaxðu/
مِعْشَارَ	عَشَرَ	شَرَعَ	سَبَقَ
a tenth	ten	he has ordained	it has preceded
/miʕʃa:ra/	/ʕaʃara/	/ʃaraʕa/	/sabaqa/
مُّقَرَّنِينَ	قَرِينًا	نَقِيرًا	وَجِيهًا
bound; bound together; bound in chains	(as) a companion	(even as much as the) speck on a date seed	honoured; distinguished; honourable
/muqarrani:na/	/qari:nan/	/naqi:ran/	/wadʒi:han/
نَتَقَبَّلُ	قَبْلِ	قَلْبِ	أَهْلِ
we will accept	before	heart	(the) people
/nataqabbalu/	/qabli/	/qalbi/	/ʔahli/
نُفَرِّقُ	فَرِيقًا	فَقِيرًا	أَلِيمًا
we make distinction	a group; a party; a portion	poor	(with) a painful punishment; painful
/nuqarriqu/	/fari:qan/	/faqi:ran/	/ʔali:man/
هُدًى	أَهْدَىٰ	أَدْهَىٰ	أَعْمَىٰ
guidance	(is) a better guide	(will be) more grievous	(is) blind
/hudan/	/ʔahda:/	/ʔadha:/	/ʔaʕma:/
يَتَرَقَّبُ	رَقِيبٌ	قَرِيبٌ	نَصِيبٌ
(and was/and) vigilant	(is) an observer; a watcher	near	a share; a portion; a chance;
/jataraqqabu/	/raqi:bun/	/qari:bun/	/nasˤi:bun/
يَسْعَىٰ	سَعَىٰ	عَسَىٰ	تَرَىٰ
running; striving; (light) will run	he strove (for)	(it) may be	you see
/jasʕa:/	/saʕa:/	/ʕasa:/	/tara:/

	Prime		
Target	+R+P	-R+P	Baseline
يَكْفُرْ	كَفَّرَ	فَكَّرَ	أَحَقَّ
(whoever) disbelieves	he will remove	he thought	(they were) more deserving
/jakfur/	/kaffara/	/fakkara/	/ʔaHaqqa/
يُدْخَلَ	دَٰخِلُونَ	خَٰلِدُونَ	كَٰفِرُونَ
he enters	(we will) enter (it)	(they will) abide forever	disbelievers
/judxala/	/da:xilu:na/	/xa:lidu:na/	/ka:firu:na/

Word Pattern Priming (Deverbal Nouns)

	Prime		
Target	+WP+P	-WP+P	-WP-P
ءَاسِنٍ polluted; unaltered (contextual) /ʔa:sinin/	طَاعِمٍ an eater /tˤa:ʕimin/	أُنَاسٌ (are) people; men; /ʔuna:sun/	وَالِدٌ a father /wa:lidun/
إِسْرَافًا extravagantly /ʔisra:fan/	إِصْلَٰحًا reconciliation /ʔisˤla:ħan/	أَسْفَارًا books /ʔasfa:ram/	مُخْتَالًا [a] proud /muxta:lan/
حِسَابًا account /ħisa:ban/	ضِرَارًا (for causing) harm; (to) hurt /dˤira:ran/	سَحَابًا clouds; rainclouds /saħa:ban/	حَلَٰلًا lawful /ħala:lan/
سَاحِرٌ a magician /sa:ħirun/	نَاصِحٌ an adviser /na:sˤiħun/	حَرَسًا guards /ħarasan/	رِحْلَةَ (with the) journey /riħlata/
سُجَّدًا prostrating; bowing humbly /sudʒdʒadan/	رُكَّعًا bowing /rukkaʕan/	جَسَدًا an image; bodies; forms; a body /dʒasadan/	حَمِيمٌ boiling fluid; scalding water; any devoted friend; a friend /ħami:mun/
شَاكِرٌ (is) All-Appreciative /ʃa:kirun/	ذَاهِبٌ going; I will go /ða:hibun/	شَرِيكٌ a partner /ʃari:kun/	نُزُلًا (as) accommodation; a hospitality; a hospitable gift /nuzulan/
صَابِرًا patient /sˤa:biran/	بَصِيرًا he will regain sight; (was once) seeing /basˤi:ran/	كَٰذِبًا a liar /ka:ðiban/	شَهِيدًا a witness; (was) present /ʃahi:dan/
صَادِقًا truthful /sˤa:diqan/	خَاسِئًا humbled /xa:siʔan/	قَاصِدًا easy /qa:sˤidan/	شُيُوخًا old /ʃuju:xan/
ضَامِرٍ lean camel /dˤa:mirin/	عَاصِفٍ stormy /ʕa:sˤifin/	مَرَضًا (in) disease /maradˤan/	غَوَاشٍ coverings /ɣawa:ʃin/
عَٰمِلُونَ (we are) working; (they are) doers /ʕamilu:na/	حَٰفِظُونَ (are) guardians /ħa:fiðˤu:n/	عَٰلِمِينَ Well-Knowing /ʕa:limi:n/	تَقْدِيرًا measure /taqdi:ra:/
عَابِدٌ a worshipper /ʕa:bidun/	عَارِضٌ (is) a cloud /ʕa:ridˤun/	بَعِيدٌ far /baʕi:dun/	طَاعَةٌ Obedience /tˤa:ʕatun/
عَامِلٌ a worker; (I am) working /ʕa:milun/	كَاتِبٌ a scribe /ka:tibun/	عَلِيمٌ (is) All-Knowing; Knowing of all things; All-Knower /ʕali:mun/	رُسُلًا [we sent] messengers; messengers /rusulan/

	Prime		
Target	+WP+P	-WP+P	-WP-P
غَالِبٌ	هَالِكٌ	بَلَٰغٌ	قَوِيًّا
(is) Predominant	(will be) destroyed	(is) a message; a notification	All-Strong; Powerful
/ɣaːlibun/	/haːlikun/	/balaːɣun/	/qawiyyan/
غَالِبَ	هَادِىَ	بَٰلِغُ	ثُلُثَا
(can) overcome	guide	(will) accomplish	two-thirds
/ɣaːliba/	/haːdija/	/baːliɣu/	/θuluθaː/
فَٰرِغًا	صَٰلِحًا	غَفُورًا	بُيُوتًا
empty	a righteous child/deed	Most Forgiving	homes
/faːriɣan/	/sˤaːliħan/	/ɣafuːran/	/bujuːtan/
فَاسِقٌۢ	تَارِكٌۢ	سُقُفًا	حَلَّافٍ
a wicked person; a disobedient person	(may) give up	roofs	habitual swearer
/faːsiqum/	/taːrikum/	/suqufam/	/ħaȽaːfim/
قَادِرٌ	ثَابِتٌ	رُقُودٌ	سَلَفًا
(is) Able	(is) firm; (is) firmly fixed;	(were) asleep	a precedent
/qaːdirun/	/θaːbitun/	/ruquːdun/	/salafan/
قَاضٍ	زَانٍ	ضَيْقٍ	رِيحٌ
(you are) decreeing; (you are) to decree	a fornicator	distress	a wind
/qaːdˤin/	/zaːnin/	/dˤajqin/	/riːħun/
كَامِلَةً	قَاطِعَةً	كَلِمَٰتٍ	دَآئِرَةٌ
(in) full	the one to decide a matter	words	a misfortune
/kaːlimatan/	/qaːtˤiʕatan/	/kalimaːtin/	/daːːʔiratun/
مُعْتَدٍ	مُفْتَرٍ	دَعْوَةً	أَرْجُلٌ
transgressor; aggressor	an inventor	(with) a call	feet
/muʕtadin/	/muftarin/	/daʕwatan/	/ʔardʒulun/

Word Pattern Priming (Verbs)

Target	Prime: +WP+P	Prime: -WP+P	Prime: -WP-P
أَشْكُرَ	أَبْلُغَ	أَشْرَكَ	نَبْعَثَ
I may thank You; (enable) me to be grateful	I reach	partners (were) associated (with Allah)	We sent; We have sent
/ʔaʃkura/	/ʔabluɣa/	/ʔaʃraka/	/nabʕaθa/
أُشْرِكُ	أُقْسِمُ	يَشْكُرُ	نَقْعُدُ
I associate	I swear	(whoever) is grateful; he is grateful	(we) sit
/ʔuʃriku/	/ʔuqsimu/	/jaʃkuru/	/naqʕudu/
بُشِّرَ	وُكِّلَ	شَرِبَ	عَمِيَ
(one of them) is informed of; is given good news	has been entrusted	(whoever) drinks	(whoever) is blind
/buʃʃira/	/wukkila/	/ʃariba/	/ʕamija/
تَدُورُ	تَكُونُ	تُرِيدُ	نُضِيعُ
(their eyes) revolving	is; will be	desiring; you want	(we) let go waste; allow to be lost
/taduːru/	/takuːnu/	/turiːdu/	/nudˤiːʕu/
تَرْجُفُ	تَسْقُطُ	فُجِّرَتْ	أُقِّتَتْ
will quake; will convulse	(not a leaf) falls	(the seas) are made to gush forth; are erupted	are gathered to their appointed time
/tardʒufu/	/tasqutˤu/	/fuĵirat/	/ʔukkitat/
تَسْقُطُ	أَقْسَطُ	تَغْرُبُ	أَعْظَمُ
(it) falls	(is) more just	setting	(are) greater
/tasqutˤu/	/ʔaqsatˤu/	/taɣrubu/	/ʔaʕðˤamu/
تَصِلُ	تَزِرُ	تُصَلِّ	نُوَفِّ
(their hands) reaching (for)	will bear; bears	(you) pray	we will repay in full; we fully repay
/tusˤilu/	/taziru/	/tusˤaḷi/	/nuwaffi/
تَعْرِفُ	تَصْبِرُ	رُفِعَتْ	مُلِئَتْ
you will recognize	you have patience	(how) it is raised	filled (with)
/taʕrifu/	/tasˤbiru/	/rufiʕat/	/muliʔat/
تُقَلَّبُ	تُفَتَّحُ	تُقُبِّلَ	نُسَوِّىَ
(their faces) will be turned about	(will) be opened	will be accepted	we can restore; able to proportion
/tuqallabu/	/tufattaħu/	/tuqubbila/	/nusawwija/
تَّعْبُدُ	تَحْكُمُ	بَعِدَتْ	حَصِرَتْ
(she was) worshipping	(you) will judge	was taken away	restraining; strained at [the prospect of]
/taʕbudu/	/taħkumu/	/baʕidat/	/ħasˤirat/
حَرَّمَ	صَدَّقَ	رَّحِمَ	تَبِعَ
He has forbidden	he accepted the truth; believed	He has mercy; has given mercy	(whoever) follows; he follows
/ħarrama/	/sˤaddaqa/	/raħima/	/tabiʕa/
حُشِرَ	سُقِطَ	شَرَحَ	تَقَعَ
(they) are gathered	(it was made to) fall; overcame	(who willingly) open; has expanded	it falls; (from) falling
/ħuʃira/	/suqitˤa/	/ʃaraħa/	/taqaʕa/

	Prime		
Target	+WP+P	-WP+P	-WP-P
خَسِرَ he (has) lost /xasira/	أَذِنَ permitted /ʔaðina/	سَخَّرَ (He) subjected /saxxara/	فَضَّلَ (has) bestowed; has given /faDDala/
رَحُبَتْ (in spite) of its vastness; it was vast /raħubat/	كَبُرَتْ grave (is) /kaburat/	رَبِحَتْ profited; prosperity /rabiħat/	يَنْعِقُ shouts /janʕiqu/
شَرَحَ Allah has expanded; (those who willingly) open /ʃaraħa/	فَصَلَ (he) set out; went forth /fasˤala/	حُشِرَ (people) are gathered /ħuʃira/	عُفِيَ is pardoned; (whoever) overlooks /ʕufija/
ضَاقَتْ (was) straitened /dˤaːqat/	زَاغَتْ has turned away /zaːɣat/	تَقْضِي you can decree /taqdˤiː/	نَدْرِي we know /nadriː/
عُطِّلَتْ (she-camels are) left untended; neglected /ʕutˤtˤilat/	سُعِّرَتْ (Hellfire) is set ablaze /suEEirat/	تَطْلُعُ rising /tatˤluʕu/	يَسْلُكُ makes to march; sends /jasluku/
فُرِجَتْ (the heaven) is cleft asunder; is opened /furidʒat/	نُصِبَتْ (how) they are erected; they are fixed /nusˤibat/	تَفْجُرَ you cause to gush forth; you break open /tafdʒura/	أَعْيُنَ (the) eyes /ʔaʕjuna/
يَرْجِعُ it (could) return; (they) will throw back /jardʒiʕu/	يَفْصِلُ He will judge /jafsˤilu/	يَعْرُجُ it will ascend; (what) ascends /jaʕrudʒu/	نَعْبُدُ we worship; we serve /naʕbudu/
يَطْمَعُ he desires /jatˤmaʕu/	يَرْهَقُ (will) cover /jarhaqu/	يُطْعِمُ (He) who feeds /jutˤʕimu/	تُكْرِهُ (you) compel /tukrihu/
يَعْرُجُ it will ascend /jaʕrudʒu/	يَقْدُمُ he will precede /jaqdumu/	يَرْجِعَ (he) returns /jardʒiʕa/	أَمْضِيَ I continue /ʔamdˤija/
يَقْنَطُ (who) despairs /jaqnatˤu/	يَرْغَبُ (who) would be averse; will turn away /jarɣabu/	يَنطِقُ he/this/(which) speaks /jantˤiqu/	تَكْسِبُ earns; it will earn /taksibu/
يُشْرَكْ (others) were associated /juʃrak/	يُغْفَرْ will be forgiven /juɣfar/	يَشْكُرْ (whoever) is grateful /jaʃkur/	تَقْعُدْ sit; remain /taqʕud/
يُطْعَمُ He is fed /jutˤʕamu/	يُحْشَرُ will be gathered /juħʃaru/	يَطْمَعُ he desires /jatˤmaʕu/	أَصْغَرُ smaller /ʔasˤɣaru/

Word Pattern Priming (Primitive Nouns)

	Prime		
Target	+WP+P	-WP+P	-WP-P
بَشَرًا	أَجَلًا	شَرَابٌ	خَشْيَةِ
(of) a man; a human being	a term	a drink	fear
/baʃaran/	/ʔadʒalan/	/ʃaraːbun/	/xaʃjati/
بَعْضَ	أَهْلَ	بِضْعِ	أَيْدٍ
some; a part (of)	(the) People	a few; three to nine (years)	hands
/baɣdˤa/	/ʔahla/	/bidˤʕi/	/ʔajdin/
بَعْضُ	أَهْلُ	بِضْعَ	حَامٍ
some; some (of)	(the) people; (is) worthy	several	a Hami
/baɣdˤu/	/ʔahlu/	/bidˤʕa/	/ħaːmin/
رُطَبًا	غُرَفًا	بَطَرًا	جَنَفًا
fresh dates	lofty dwellings; (elevated) chambers	boastfully; indolently	(any/some) error
/rutˤaban/	/ɣurafan/	/batˤaran/	/dʒanafan/
رِزْقًا	حِمْلًا	زُرْقًا	طَيْرًا
a provision	(as) a load	blue-eyed	birds
/rizqan/	/ħimlan/	/zurqan/	/tˤajran/
سَبِيلًا	حَدِيثًا	لِبَاسًا	فِرَارًا
a way; (to a right) way	a narration; a statement	clothing	(in) flight; to flee
/sabiːlan/	/ħadiːθan/	/libaːsan/	/firaːran/
سَنَةٍ	ذَهَبٍ	سِنَةٌ	فِئَةٌ
years	gold	slumber; sleep	a/one group; company
/sanatin/	/ðahabin/	/sinatun/	/fiʔatun/
عَرْشَ	بَأْسَ	عَشْرُ	صُمًّا
(the) Throne	(the military) might; violence;	ten times; (is) ten (times)	deaf
/ʕarʃa/	/baʔsa/	/ʕaʃru/	/sˤumman/
قُبُلًا	عُمُرًا	قُلُوبٍ	أَضْعَفُ
face to face; before (them)	a lifetime	(their) hearts	(is) weaker
/qubulan/	/ʕumuran/	/quluːbin/	/ʔadˤʕafu/
كَفِيلًا	فَلَكٍ	عَقِيمًا	لَهَبٍ
a surety; a witness	an orbit	barren	blazing flames
/kafiːlan/	/falakin/	/ʕaqiːman/	/lahabin/
كِبْرٌ	دِفْءٌ	كَرْبٍ	ضِعْفٌ
greatness	warmth; warm clothing	distress	a double
/kibrun/	/difʔun/	/karbin/	/dˤiʕfun/
لَحْمَ	نَصْرَ	حِمْلُ	أَبًا
(the) flesh	help; (to) help	(is) a load	a father
/laħam/	/nasˤra/	/ħimlu/	/ʔaban/
مِيقَٰتُ	مِّيعَادُ	مُّقِيتًا	مُّحِيطًا
(the) set term	(is the) appointment	a Keeper	All-Encompassing
/miːqaːtu/	/miːʕaːdu/	/muqiːtaː/	/muħiːtˤaː/

	Prime		
Target	+WP+P	-WP+P	-WP-P
وَجِلَةٌ	كَلِمَةٌ	وَلِيجَةً	مَعِيشَةً
(are) fearful	a word	(as) intimates	a life
/wadʒilatun/	/kalimatun/	/wali:dʒatan/	/maʕi:ʃatan/

Appendix H. Supplementary Analyses

Table 8-1. *Full model showing the fixed effects with standardised RT regression coefficients from a linear mixed effects regression analysis for lexical decision in word targets for both cleaned and all data with inverse transformation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = $p < .1$, * = $p < .05$, ** = $p < .01$, *** = $p < .001$.*

	Cleaned Data (*N* = 20557)				All Data >200ms (*N* = 23892)			
	β	*SE*	$\chi^2(1)$	*p*	*β*	*SE*	$\chi^2(1)$	*p*
(Intercept)	1.230	.019			1.232	.020		
Onsets (combined; df = 27)			40.915	*	-	-	-	-
Trial Order Number	.008	.003	18.963	***	.013	.003	20.294	***
Display Refresh Rate	-.054	.016	10.045	**	-.073	.018	15.562	***
Sex	.046	.016	7.532	**	.079	.018	17.010	***
Age	-.068	.018	13.506	***	-.078	.019	15.212	***
MemScore	-.037	.017	4.939	*	-.079	.019	18.964	***
QVT	.128	.018	44.455	***	.079	.020	18.023	***
Length	-.084	.009	62.386	***	-.083	.008	87.114	***
Frequency	.055	.009	33.212	***	.074	.007	76.988	***
N	.030	.007	15.530	***	.038	.007	24.508	***
LD	-.047	.008	29.773	***	-.051	.008	39.392	***
PP	.018	.009	3.856	*	.016	.007	5.078	*
Root	.009	.009	1.145		.025	.007	10.586	**
MemScore:QVT	.032	.016	6.712	**	.084	.017	23.740	***
MemScore:Length	.004	.003	1.412		-.001	.004	.056	
MemScore:Frequency	.003	.003	1.177		.005	.003	5.120	*
MemScore:N	.000	.002	.027		.000	.003	.002	
MemScore:PP	-.004	.002	.106		-.003	.003	1.372	
MemScore:LD	-.003	.003	1.178		-.003	.004	.899	
MemScore:Root	.002	.003	.760		-.001	.003	2.659	
QVT:Length	.005	.004	2.279		-.005	.004	1.772	
QVT:Freq	.006	.003	3.955	*	.015	.003	20.035	***
QVT:N	-.002	.002	.843		.000	.003	2.631	
QVT:PP	-.004	.002	2.591		.000	.003	2.653	
QVT:LD	-.008	.003	7.100	**	-.018	.004	23.977	***
QVT:Root	.005	.003	3.493	.	.011	.003	11.212	***
MemScore:QVT:Length	.003	.003	.904		.009	.003	9.804	**
MemScore:QVT:Frequency	-.007	.003	5.969	*	-.009	.003	9.273	**
MemScore:QVT:N	-.002	.002	.558		-.003	.003	1.662	
MemScore:QVT:PP	.001	.002	.244		-.001	.003	2.674	
MemScore:QVT:LD	.002	.003	.318		.004	.003	1.498	
MemScore:QVT:Root	-.002	.003	.467		.000	.003	.023	

Table 8-2. *Full model showing the fixed effects with standardised RT regression coefficients from a linear mixed effects regression analysis for lexical decision in word (LDTRW) and nonword (LDTNW) targets for both cleaned and all data with inverse transformation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each likelihood-ratio test is represented by asterisks at the following levels: * = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 38725)				All Data >200ms (*N* = 43997)			
	β	*SE*	$\chi^2(1)$	*p*	*β*	*SE*	$\chi^2(1)$	*p*
(Intercept)	1.048	.018			1.055	.024		
Trial Order Number	.016	.002	101.580	***	.021	.002	132.120	***
Display Refresh Rate	-.039	.016	5.775	*	-.064	.019	11.267	***
Sex	.029	.016	3.055	.	.070	.019	12.195	***
Age	-.069	.017	15.885	***	-.074	.020	13.308	***
MemScore	-.036	.016	5.150	*	-.086	.022	15.091	***
QVT	.107	.017	35.523	***	.018	.022	.686	
TargetTypeLDTRW	.201	.007	327.570	***	.177	.010	194.960	***
MemScore:QVT	.042	.015	8.930	*	.121	.019	37.983	***
MemScore:TargetTypeLDTRW	.002	.007	.044		.011	.010	1.397	
QVT:TargetTypeLDTRW	.027	.007	13.018	***	.061	.010	37.143	***
MemScore:QVT:TargetTypeLDTRW	-.010	.007	2.118		-.034	.009	14.912	***

Table 8-3. *Full model showing the fixed effects with standardised RT regression coefficients from a linear mixed effects regression analysis for speeded pronunciation for both cleaned and all data with log transformation. χ^2 and p-values are from likelihood-ratio tests of model comparisons between a model without the effect and the full model. The p-value for each coefficient is represented by asterisks at the following levels: . = p < .1,* = p < .05, ** = p < .01, *** = p < .001.*

	Cleaned Data (*N* = 6944)				All Data > 200ms (*N* = 7357)			
	β	*SE*	$\chi^2(1)$	*p*	*β*	*SE*	$\chi^2(1)$	*p*
(Intercept)	-.360	.035			-.349	.042		
Onsets (combined: df =27)			69.751	***			62.028	***
Trial Order Number	-.031	.006	30.746	***	-.037	.006	36.248	***
Age	.074	.028	4.741	*	-	-	-	-
MemScore	-.079	.035	7.710	**	-.135	.042	9.775	**
QVT	-.090	.034	9.484	**	-.131	.041	10.230	**
Length_LD	.079	.011	49.515	***	.078	.013	32.549	***
Frequency	-.041	.007	30.281	***	-.045	.008	31.899	***
N	-.038	.006	31.013	***	-.039	.007	27.368	***
PP	-.023	.008	8.822	**	-.026	.008	9.048	**
Root	-.023	.007	10.194	**	-.024	.007	9.760	**
MemScore:QVT	.058	.032	3.173	.	.147	.034	17.046	***
MemScore:Length_LD	.004	.008	.297		.004	.010	6.779	**
MemScore:Frequency	.003	.004	.710		.001	.004	6.774	**
MemScore:N	.001	.003	.068		.001	.004	.106	
MemScore:PP	.012	.004	9.482	**	.014	.004	11.283	***
MemScore:Root	.005	.004	2.057		.006	.004	8.650	**
QVT:Length_LD	.004	.008	.265		.002	.010	.059	
QVT:Frequency	.008	.004	3.967	*	.008	.004	3.823	.
QVT:N	.003	.003	.798		.001	.004	.074	
QVT:PP	.002	.004	3.340	.	.006	.004	2.420	
QVT:Root	.002	.004	.222		.002	.004	.190	
MemScore:QVT:Length_LD	.004	.007	.319		.008	.008	.872	
MemScore:QVT:Frequency	.001	.004	.123		.006	.004	2.362	
MemScore:QVT:N	.003	.003	1.074		.006	.003	3.834	.
MemScore:QVT:PP	-.004	.003	4.620	*	-.009	.003	6.269	*
MemScore:QVT:Root	.000	.003	.002		-.001	.003	.150	

Appendix I. Participant Information Sheet

1. **Project title:** Qur'anic Memorizing in Singapore

2. **Principal Investigator and co-investigator(s):**

Siti Syuhada Binte Faizal (PI) Speech and Language Sciences Dept., Newcastle University Tel: 98578134 Email: s.s.binte-faizal@ncl.ac.uk	Dr. Ghada Khattab (Co-investigator) Speech and Language Sciences Dept., Newcastle University Tel: +44 191 222 6583 Email: ghada.khattab@ncl.ac.uk

3. **What is the purpose of this research?**
The purpose of this study is to examine the knowledge of words acquired by Qur'anic memorizers who are not native speakers of Arabic.

You are invited to participate in a research. This information sheet provides you with information about the research. The Principal Investigator (the research doctor or person in charge of this research) or his/her representative will also describe this research to you and answer all of your questions. Read the information below and ask questions about anything you don't understand before deciding whether or not to take part.

4. **Who can participate in the research? What is the expected duration of my participation? What is the duration of this research?**

We are looking for people who have memorized the entire Qur'an, are currently memorizing the Qur'an, or are not memorizing the Qur'an. You should be at least 18 years of age, have normal or corrected-to-normal vision, no reading/hearing disabilities, and have Malay as one of your languages. If you are less than 18 years old, your parent/guardian will be asked to sign a consent form.

You are expected to participate in an hour-long experiment. The full duration of this research is approximately 1 year but we plan to collect data in the next five months.

5. **What is the approximate number of participants involved?**
About 100 participants will be involved.

6. **What will be done if I take part in this research?**
In this study, you will be asked to complete several tasks which include listening to recorded speech and either repeating them aloud or deciding if they are real words. You will also be completing a questionnaire about yourself and your language background as well as standardized memory and general intelligence tests. The entire session will take about an hour and you will be given an opportunity to take a short break in between the tasks.

7. **How will my privacy and the confidentiality of my research records be protected?**

We will do everything we can to protect your (or your child's) privacy. No identifiable information will be collected during the study. The only demographic information collected will be age, ethnicity, gender, and language background. Moreover, only the Principal Investigator will have access to this information and this will not be released to any other person, including members of the research team. The data you provide will be electronically archived on a secured computer for at least 5 years after the publication of this research, in line with the publication requirements of the American Psychological Association. Should no publication arise from this research within 5 years, the data will be discarded.

8. What are the possible discomforts and risks for participants?

There are no known risks associated with this research other than the potential for mild boredom or fatigue. You will be given the opportunity to take short breaks regularly.

9. What is the compensation for any injury?

No injury is expected. You will only be doing simple writing and speech production tasks.

10. Will there be reimbursement for participation?

You will be given a small token of appreciation for your participation. If you are interested, we will also email you your standardized memory and cognitive ability test scores.

11. What are the possible benefits to me and to others?

There is no direct benefit to you by participating in this research except that you will learn about psycholinguistic experimentation. However, the data you provide may help to advance our understanding of the knowledge gained by non-Arabic-speakers who memorize the Qur'an, which could have possible educational implications.

12. Can I refuse to participate in this research?

Yes, you can. Your decision to participate in this research is voluntary and completely up to you. You can also withdraw from the research at any time without giving any reasons, by informing the Principal Investigator and all your data collected will be discarded.

13. Whom should I call if I have any questions or problems?

Please contact the Principal Investigator, Siti Syuhada Binte Faizal at **98578134 (tel)** / **s.s.binte-faizal@ncl.ac.uk (email)** or Dr. Ghada Khattab at **+44 191 222 6583 (tel) / ghada.khattab@ncl.ac.uk (email)** for all research-related matters and in the event of research-related injuries.

In the event of any complaints arising concerning this research, please address them to Dr Carolyn Letts (email: carolyn.letts@ncl.ac.uk), Head of Section, Speech and Language Sciences, King George VI Building, Newcastle upon Tyne, NE1 7RU.

PLEASE KEEP THIS INFORMATION SHEET AND A COPY OF THE SIGNED CONSENT FORM FOR YOUR RECORD.

Appendix J. Consent Form (Adult)

Title of Study	Qur'anic Memorizing in Singapore
Investigators	Siti Syuhada Binte Faizal, PhD Student, Speech and Language Sciences Dr. Ghada Khattab, Lecturer, Speech and Language Sciences

I, the undersigned, confirm that (please tick box as appropriate):

1.	I have read and understood the information about the project, as provided in the Information Sheet dated _________________.	☐
2.	I have been given the opportunity to ask questions about the project and my participation.	☐
3.	I voluntarily agree to participate in the project.	☐
4.	I understand I can withdraw at any time without giving reasons and that I will not be penalised for withdrawing nor will I be questioned on why I have withdrawn.	☐
5.	The procedures regarding confidentiality have been clearly explained (e.g. use of names, pseudonyms, anonymisation of data, etc.) to me.	☐
6.	If applicable, separate terms of consent for interviews, audio, video or other forms of data collection have been explained and provided to me.	☐
7.	The use of the data in research, publications, sharing and archiving has been explained to me.	☐
8.	I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of the data and if they agree to the terms I have specified in this form.	☐
9.	Select only **one** of the following: • I would like my name used and understand what I have said or written as part of this study will be used in reports, publications and other research outputs so that anything I have contributed to this project can be recognised.	☐
	• I do not want my name used in this project.	☐
10.	I, along with the Researcher, agree to sign and date this informed consent form.	☐

Participant:

________________________	___________________________	________________
Name of Participant	Signature	Date

Researcher:

________________________	___________________________	________________
Name of Researcher	Signature	Date

Appendix K. Consent Form (Minor)

Speech and Language Sciences
King George VI building
Newcastle upon Tyne NE1 7RU
Enquiries: (65) 98578134

CONSENT FORM

Title of Study	**Qur'anic Memorizing in Singapore**
Investigators:	Siti Syuhada Binte Faizal, PhD Student, Speech and Language Sciences Dr. Ghada Khattab, Lecturer, Speech and Language Sciences

Please check box where applicable.

1. I confirm that I have read and understand the information sheet dated .... for the above study and have had the opportunity to ask questions. **O**

2. I understand that my/my child's participation is voluntary and that I/my child am/is free to withdraw at any time, without giving any reason. **O**

3. I agree to take part in the above study. **O**

4. For parent/guardian: I agree for my child to take part in the above study. **O**

________________________	________________	_______________
Name of Participant/Parent/ Guardian	Date	Signature
________________________	________________	_______________
Researcher	Date	Signature

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