# Visual Word Recognition in Deaf Readers: The interplay between orthographic, semantic and phonological information

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# Declaration

I, Katherine Elizabeth Rowley, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

K E Rowley

# Dedication

I dedicate this thesis to my husband, Duncan Rowley, who has been with me every step of the way on this incredibly challenging journey. There are no words for how grateful I am for the love and support you have given me over the years to help me achieve my dreams.  I could not have done this without you.

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# Abstract

Poor literacy is prevalent in the deaf population. This thesis assesses levels of literacy in the deaf population by investigating visual word recognition in deaf readers. For hearing readers, several studies have demonstrated that good visual word recognition skills are crucial for successful literacy attainment and poor readers are likely to have poor word recognition skills. In particular, phonology is known to play an important role in visual word recognition in hearing individuals. The role of phonology in deaf readers has also been addressed extensively. However, these have generated mixed results, which may be partly due to different methodological approaches and lack of control for reading level of participants.

Studies reported in this thesis explore the role of orthography, semantics and phonology in deaf skilled readers during visual word recognition and also sentence reading using various methodologies and controlling carefully for reading level. The methodologies used include: lexical decision, masked priming, the visual world and the invisible boundary paradigm.

The results from the various tasks described in this thesis show that there are similarities in the way deaf skilled and hearing readers process semantic and orthographic information. However, I found differences in how they process phonological information: deaf and hearing readers show similar effects of phonology in tasks that do not require semantic activation, however, deaf readers do not show phonological activation in tasks that require semantics while hearing readers do. This suggests qualitative differences in reading strategies for the two populations. These differences do not account for differences in literacy attainment across deaf and hearing groups (as our participants where matched for reading levels). Implications for theories of visual word recognition are discussed and in the final chapter, I introduce a proposed model of visual word recognition for deaf readers based on findings reported in this thesis.

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# 1 Introduction

In the deaf population there is a high prevalence of poor literacy. Although many studies have assessed different factors that might explain this phenomenon, thus far none have investigated the interplay between orthography, semantics and phonology during word recognition in deaf readers. For hearing readers, word recognition is the foundation of reading and it has been claimed that this involves the activation of orthography, semantics and phonology (Cortese & Balota, 2012; Rastle, 2007). Individuals with poor word recognition skills are also likely to be poor at reading comprehension (Nation & Snowling, 1998; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001), . This highlights the importance of good word recognition skills for successful literacy attainment.

While it is intuitively clear that orthographic and semantic processing are both essential to word recognition, the literature also clearly indicates that phonology is critical (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Cortese & Balota, 2012; Harm & Seidenberg, 1999; Rastle, 2007; Rastle & Brysbaert, 2006; Rayner et al., 2001). Much of the literature suggests that developmental reading deficits have at their core poor phonological processing skills (i.e. the inability to decode efficiently) (Gough & Tunmer, 1986; Hoover & Gough, 1990; Rack, Snowling, & Olson, 1992; Rayner et al., 2001; Rayner, Pollatsek, & Schotter, 2013), Therefore, many scholars have focused on phonological processing when investigating literacy attainment in the deaf population (Chamberlain, 2002; Cripps, McBride, & Forster, 2005; Hanson & Fowler, 1987; Leybaert, 1993; Mayberry, del Giudice, & Lieberman, 2011; Mayer & Trezek, 2014; Waters & Doehring, 1990) obtaining, however, mixed results. There may be several reasons for the variability in studies that have investigated whether deaf people apply phonological processing during reading, which will be discussed in depth in Chapter 3 of this thesis. Before I go on to discuss the scope of this thesis, it is important to be clear in what I mean by the application of phonological processing to reading. In alphabetic languages such as English, Italian and Russian, graphemes are associated with phonemes, that is graphemes such as ‘p’ can be directly mapped onto the phoneme /p/ (Rayner et al., 2001). In such languages, there are strong spelling-to-sound associations that readers often utilise or activate upon viewing words. Here I ask whether deaf readers utilise or activate such correspondences upon viewing words.

The goal of the present thesis is to further our understanding of word processing by deaf skilled readers. In particular the two main aims are (1) to provide a comprehensive investigation of orthographic, semantic and phonological processing as well as the time-course of their activation during word recognition in deaf skilled readers and (2) to further explore the role of phonology during word recognition and reading in this population.

Before I go on to discuss the scope of this thesis, I explain below the nature of deafness and why it has an impact on literacy attainment in the deaf population.

## 1.1 Levels of deafness and age of onset of deafness

Individuals who are considered to be deaf have a hearing loss, which can range from partial to complete. Hearing loss is measured in decibels (dBHL) and the table below describes each level of deafness.

**Table 1-1. Levels of deafness (taken from www.actiononhearingloss.org.uk)**

| Level of Deafness | Decibels (dBHL) | Description |
|---|---|---|
| **Normal** | 0 - 24dBHL | Full hearing, no loss. |
| **Mild** | 25 – 39 dBHL | Can sometimes struggle to hear speech especially in noisy environments |
| **Moderate** | 40 – 69 dBHL | May need hearing aids to follow speech |
| **Severe** | 70 – 94 dBHL | Difficulty in following speech without hearing aids. Usually relies on lipreading or sign language. |
| **Profound** | 95+ dBHL | Usually relies on lipreading or sign language. |

In order to access speech, individuals need to be able to hear sounds between 45 and 55 dB. Once fitted with hearing aids, those with moderate hearing loss will be able to access speech sounds. For the purpose of this study, **only those with severe to profound hearing loss are included** as these individuals have the most difficulty in accessing spoken language without amplification (Moore, 1998; Peters, Moore, & Baer, 1998). Individuals who took part in this study were either deaf from birth or became deaf before they fully acquired spoken language (before the age of 3). However, the majority of deaf participants in this study were born deaf.

## 1.2 Early language experience

The majority of deaf children are born to hearing parents (90-95%) (Mitchell & Karchmer, 2004) and many do not have full access to a natural language whether signed or spoken. Due to the nature of deafness, severely to profoundly deaf children of hearing parents will not have full access to the language their parents speak. Many of those parents who have deaf children will not know sign language initially and some may never choose to learn. There is a minority group of deaf children that are born to deaf parents (5-10%) and these children are typically exposed to a sign language from birth (Humphries et al., 2014; Lu, Jones, & Morgan, 2016; Mitchell & Karchmer, 2004). These children are known as 'native signers'. Many studies have shown that early language experience is crucial for the development of cognitive, social, emotional and educational attainment (Humphries et al., 2014, 2017). It is important to note that some deaf children of hearing parents do learn a signed language, because their parents have decided that this is the best route for them to develop linguistic skills and therefore they attend a nursery or school where the language of instruction is a signed language. These children are known as 'near native' signers. **Native and near native signers are included in the studies reported in this thesis.**

## 1.3 Deafness and Literacy Attainment

Deafness has an impact on the normal acquisition of spoken language. Deaf children cannot pick up spoken language through incidental learning and must be explicitly taught but even then, many struggle to fully acquire spoken language. One of the most important factors for successful literacy acquisition is good oral language skills (Gough & Tunmer, 1986; Hoover & Gough, 1990; Nation & Snowling, 1998; Rayner et al., 2001) thus many deaf children and adults do not become successful readers (Chamberlain, 2002; Goldin-Meadow & Mayberry, 2001; Mayberry et al., 2011; Mayer & Trezek, 2014; Ormel, 2008). Nevertheless, a small portion of the deaf population do indeed become successful readers and can read at a rate that is on par with their hearing peers (Bélanger, Slattery, Mayberry, & Rayner, 2012; Humphries et al., 2014). In this thesis, I will be examining word recognition processes in a group of deaf skilled readers, comparing them to a group of carefully matched hearing readers.

## 1.4 Organisation of Thesis

Chapters 2 and 3 will provide an introduction to the current literature on word recognition in deaf and hearing readers. In Chapter 2, I will discuss visual word recognition in hearing readers focusing on factors that influence word processing in this group. This, will include a discussion about current models of word recognition and what predictions they make about these processes. Different methodologies that test those processes will also be discussed in this chapter. In Chapter 3, I review previous studies of visual word recognition in deaf readers. I will highlight the gaps in the current literature and discuss whether or not models of word recognition can be applied to deaf readers.

From Chapters 4 to 9, I describe the different paradigms used in this study in order to explore word recognition in deaf and hearing readers. In Chapter 4, I describe and discuss a lexical decision experiment where I explore the influence of many lexical and semantic variables on visual word recognition in deaf and hearing readers. In Chapters 5 and 6, I explore and compare phonological effects during single word reading in deaf and hearing readers using pseudohomophones and masked phonological priming in two separate lexical decision tasks. In Chapters 7 and 8, I introduce a novel adaptation of the visual world paradigm used to explore the interplay between orthography, semantics and phonology during single word recognition in deaf and hearing readers. In Chapter 7, two visual world experiments are described; in the first, both words and nonwords are presented and in the second, I focus on pseudohomophones only to further explore the role of phonology in both groups. In Chapter 8, I describe another visual world experiment where deaf and hearing readers were presented with words and amongst the distracter items, there were homophonic and orthographic distracters to further investigate the role of phonology and orthography in both groups. In Chapter 9, I explore word recognition in the context of sentence reading using the invisible boundary paradigm, a replication of Belanger and Rayner’s (2013) study, in deaf and hearing readers. In particular I examine whether or not there are orthographic or phonological preview benefits, comparing these effects in deaf and hearing readers.

Finally, in Chapter 10, the conclusions of the experiments and a proposed model of word recognition for deaf readers will be presented. The limitations of this study and suggestions for future research will also be discussed in this chapter.

# 2 Word Recognition Processes in Hearing Readers

In the introduction, I discussed briefly the nature of deafness and how this can have an impact on literacy attainment. I explained that the focus of my thesis is to explore in more depth what word recognition processes skilled deaf readers undertake during single word reading and when reading sentences. However, it is essential at this point to discuss theories of word recognition for hearing readers and the predictions they make with respect to what, how and when orthographic, phonological and semantic information is activated and used in reading in order to assess how these predictions can be applied to skilled deaf readers. It is also important to discuss the hypotheses that have been put forward to account for poor reading in hearing individuals, as this may be informative for understanding why poor literacy is prevalent in the deaf population.

In this chapter, I will first discuss visual word recognition in the hearing population, the methods that have been used in the past to explore orthographic, semantic and phonological processes that occur during single word recognition and sentence reading. Second, I will discuss what factors may influence word recognition and why it is important to consider them when carrying out new investigations into word recognition processes. I will then present different models of word recognition and outline what predictions these models make about the roles of orthographic, semantic and phonological information. Last, I will explain how young children learn to read and where reading deficits may stem from.

In modern societies, the ability to read is of paramount importance as it impacts educational, vocational and social development (Rayner et al., 2001). Additionally, much information is presented via written words and as Rayner et al (2001:31) point out, ‘a literate population is a key to the functioning of these societies’. Reading is somewhat paradoxical as for most adults reading is an effortless process but learning to read is difficult to master for many young children. There is a general consensus that successful reading involves interplay between orthographic, semantic and phonological processing. One of the first steps to investigate such processes is to look at what is involved in single word recognition, as the ability to learn to recognise words is central to learning to comprehend text.

## 2.1 Visual Word Recognition

Visual word recognition is the ability to read and recognise a word rapidly, accurately and effortlessly and is said to be ‘the foundation of reading’ (Cortese & Balota, 2012). Individuals with poor visual word recognition skills also have poor literacy (Nation & Snowling, 1998), which demonstrates that fast and accurate word identification is crucial for successful reading. Researchers have adopted different methods to explore word recognition and these methods have become more sophisticated over time. Below I describe some of the classic methods for studying visual word recognition.

### 2.1.1 Lexical decision and word naming tasks

To examine the processes involved in word recognition, many have used response time and accuracy measures in word naming and lexical decision tasks (Rayner, Pollatsek, & Schotter, 2013). In these tasks, the stimuli can be manipulated in various ways to provide an insight into psychological and neural processes (Balota et al., 2007) underscoring orthographic, phonological and semantic processing. For example, to examine the role of phonology in word naming, readers are usually presented with a mixture of words and nonwords and amongst the nonwords there could be both homophonic (e.g., brane) and nonhomophonic (e.g., brone) nonwords. Homophonic words are words that sound the same but are spelt differently and have different meanings e.g. bare/bear or rose/rows. Homophonic nonwords are known as 'pseudohomophones', which are nonwords that sound like real words e.g. taughn/torn. Participants are asked to pronounce each letter string that is presented to them. It has been demonstrated in past studies that pseudohomophones are named faster and more accurately compared to nonhomophonic nonwords such as 'gand' (Seidenberg, Petersen, Macdonald, & Plaut, 1996). This is because they sound like real words thus participants already have a phonological representation, which they can activate upon reading the pseudohomophone.

In lexical decision tasks participants are asked to quickly and accurately decide whether a letter string is a real word or not. Here for example, it has been found that participants are slower and less accurate to reject pseudohomophones as real words, which has been taken as evidence that the word's phonological information interferes with the decision-making (Seidenberg et al., 1996). This doesn't happen for a nonhomophonic nonword (e.g. brone) as there is less activation upon seeing the nonword (as there is no competing phonological equivalent). However, when exploring the role of phonology in word recognition it is important to think about the influence that orthography may have. As mentioned earlier, pseudohomophones are often used in word naming and lexical decision tasks but some have pointed out that some pseudohomophones are visually similar to the words they are derived from e.g. klip/clip, brane/brain. This could mean that any phonological effects detected in those tasks are actually an effect of similarity in orthography (Rastle & Brysbaert, 2006).

Some studies have used pseudohomophones that are not visually similar to the words they are derived from e.g. taughn/torn, brooze/bruise, koack/coke (Rastle & Brysbaert, 2006), thus reducing the possibility of a confound between orthography and phonology. In these studies, there was still an effect of phonology on lexical decision, although smaller than in previous studies (Rastle & Brysbaert, 2006).

Word naming and lexical decision tasks in which the target word is manipulated have been criticised in the past as participants are making explicit judgments about the word or nonword (Harley, 1995; Leinenger, 2014). It is not clear whether the processes are pre or post lexical (before or after the word is recognised) and whether these tasks reveal automatic processes that occur during word recognition and reading. Alternative methods such as priming provide researchers with the opportunity to tap into more automatic and online processing during experimental tasks.

### 2.1.2 Priming

In priming studies, prime words are usually displayed to participants prior to the presentation of the target word. Upon seeing the target word, participants are expected to make a decision as to whether the letter string displayed is a word or not. Priming studies have shown that participants' decision latencies and accuracy rates are influenced by the prime (Harley, 1995; Rastle, 2007; Rastle & Brysbaert, 2006). Primes can be orthographically (e.g. couch-TOUCH), semantically (e.g. feel-TOUCH) or phonologically (e.g. much-TOUCH) related to a target word(Cortese & Balota, 2012). Semantic effects have been found in priming studies e.g. when the target word, 'doctor' is preceded by a semantically related word such as, 'nurse' decision latencies are shorter in comparison to unrelated items such as, 'bread'

(Meyer & Schvaneveldt, 1971; Rastle, 2007). However, in such tasks, participants are aware of the primes thus this method, although informative, does not assess implicit lexical processing (Leinenger, 2014).

To test implicit lexical processing, masked priming is used and again, participants' are asked to quickly and accurately decide whether the letter string presented to them is a word or not. Prior to the presentation of the target (either a word or nonword), another letter string (the prime) is presented for a very short duration (e.g., 30-60ms) followed (and sometimes also preceded) by a mask (usually a series of hash tags that match the length of the prime). As the prime is presented for a very short duration of time and has a mask following it, participants' are generally unaware of it. If the prime influences the decision latencies or accuracy in any way, this gives us insights into the 'automatic' processes that occur during word recognition. Several studies exploring phonological processing have shown that when a letter string (e.g. moan) is preceded by a pseudohomophone prime (e.g. mone), decision latencies are faster and more accurate in comparison to primes that are orthographically similar (e.g. moin) to the target word (Rastle & Brysbaert, 2006). Although phonological primes seem to have more of an effect on decision latencies and error rates in masked priming studies, several studies have found that orthographic primes also influence decision latencies and error rates (Ferrand & Grainger, 1994). Primes that have an orthographic overlap with target words (e.g. nonword primes that are highly similar to target words (e.g. bontrast-CONTRAST) speed up decisions and reduce error rates even when there is no phonological overlap between the target and prime word (Ferrand & Grainger, 1994; Rastle, 2007). Additionally, several studies have reported that orthographic coding (around 40ms SOA) seems to occur earlier than phonological coding (around 60ms SOA) (Pollatsek, Perea, & Carreiras, 2005). Furthermore, primes that have a semantic association with target words have also been found to facilitate decision latencies, however the effect depends on how the prime and target are semantically associated (Hutchison, 2003). Although masked priming taps into automatic processes during word identification, it does not show us how these processes unfold over time.

## 2.2 Visual word recognition: the impact of lexical variables

The literature shows that there are many sublexical, lexical and semantic factors that influence visual word recognition. These are: bigram frequency (how frequent the same two letters appear together in words), word frequency (how frequent a word occurs in a given text), orthographic and phonological neighbourhood (how many other words that can be derived from a target word by changing one letter or phoneme, whilst preserving the other letters/phonemes), familiarity (the subjective familiarity of words, usually rated by participants on a scale of 1-7 (no familiarity to high familiarity), length (number of letters, number of syllables), age of acquisition (the average age from which a given word is acquired), concreteness (the degree in which a given word can be experienced through the senses), imageability (the degree in which a given word can be visualised) and valence (the degree of emotion (whether positive, negative or neutral) that can be triggered upon seeing a given word) (e.g. Rastle, 2007; Vinson, Ponari, & Vigliocco, 2014). The influences of (sub) lexical and semantic factors on word recognition are often explored using lexical decision tasks. Response latencies and accuracy rates have been shown to differ depending on a number of variables e.g. word length, word frequency, age that a given word is usually acquired etc. For example, past studies have demonstrated that participants respond faster and more accurately if they are presented with a high frequency word compared to a low frequency word and response times seem to increase as the length of a word increases (accuracy also decreases). Other studies have shown that words that are highly imageable lead to faster response times (Cortese & Balota, 2012). However, when exploring the effects of various lexical and semantic variables on word recognition, it is important to separate out each of the various effects. For example, when comparing words such as ‘table’ and ‘exclaim’, there is not only a frequency difference but also a length difference so when measuring word frequency, you also need to control for length (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004). Other factors such as word familiarity and the age at which words are acquired can also be confounded with word frequency effects, which need to be considered and controlled for (Brysbaert, Lange, & Van Wijnendaele, 2000). In terms of the relative importance of these variables, some megastudies have used RT and accuracy data from a large number of subjects (taken from the English Lexicon Project (Balota et al., 2007) or the British Lexicon Project (Keuleers, Lacey, Rastle, & Brysbaert, 2012)) and a regression approach to the data. For example, several studies have reported that some variables such as length, frequency, orthographic neighbourhood size etc. will account for almost half of the variance in behavioural data (Balota et al., 2007). Some studies have shown that word frequency can account for up to 40% of the variance in lexical decision (e.g. Ferrand et al., 2011), thus showing the impact of these variables on decision latencies.

So far, I have discussed the different methods used to explore the processes involved in single word recognition as well as described some of the properties that have been found to influence these processes. Although studies on single word recognition has given us valuable insights into many of the processes involved during reading, it is relatively rare to read words in isolation. Most of the time, we read text thus it is important to consider word recognition in the context of sentences. I will now move on to describe some of the methods that have been used to investigate word recognition processes during sentence reading.

## 2.3 Word recognition processes during sentence reading

Several studies have investigated orthographic, semantic and phonological influences on word processing in the context of sentences as this is considered to be closer to natural reading in comparison to single word reading (Leinenger, 2014). Here I will focus on tracking eye movements during sentence reading in experimental situations and discuss the invisible boundary paradigm.

### 2.3.1 Tracking Eye-Movements.

Tracking readers' eye movements whilst presented with sentences or a section of text has enabled us to gain insights on how people read sentences or text as well as seeing what influences or impacts reading. It is common for people to think that when people read, the eyes glide from one end of the sentence to the other and then move on to the next sentence but this is not the case (Rayner et al., 2001). When reading, the eyes move at an extraordinary pace from left to right repeatedly (known as saccades) and there are also moments where the eyes are relatively still (fixations). Saccades last about 20-40 milliseconds (ms) and fixations generally last about 200-250ms. Most of the information is gained when the eyes are fixating on a given word. Skilled readers will often 'regress' back onto text that they have read already (this occurs at around 10-15% of the time). Readers can see letter spaces that are 3-4 letters to the left of the fixation point and also up to 15 letter spaces to the right of the fixation point. This is known as the perceptual span and it indicates that readers can process information that is outside of the fixation point. The fixation point is where our central vision is, also known as the fovea. The area outside the foveal region is known as the parafoveal region. It has been shown that readers often 'skip' words – usually high frequency, highly predictable and function words – but this does not mean that these words have not been processed. It merely means that readers have not fixated on those words directly and extracted information about them from the parafoveal region. Readers typically fixate on two thirds of the text they read (Rayner et al., 2001).

There are several important measurements used in eye tracking research and these are; first fixation duration (how long a target word is fixated upon in the first instance); gaze duration (the total time spent on fixating on a target word); number of regressions made on the text; word skipping probability (the likelihood of a letter string being skipped completely) (Rayner et al., 2013). These measurements give us an indication on the complexity of the words that are being read. For example, it has been found that low frequency words are fixated on for longer in comparison to high frequency words. When readers are looking at text that includes a lot of low frequency words, there are more regressions on to the text, longer fixations and shorter saccades. Beginning readers are more likely to have longer fixations on words (between 300 and 400ms), more regressions (up to 50% more) and shorter saccades compared to fluent, skilled readers (Rayner, 2009). Beginning readers' perceptual span is also shorter compared to skilled readers.

As it is possible for readers to extract information from the parafoveal region during reading, studies have manipulated information in this region in order to understand more about the processes involved in reading. For example, phonological and orthographic information in the parafoveal region can be manipulated using the invisible boundary paradigm. This is used in Experiment 6 (described in Chapter 9) in the current thesis and is described in detail below.

#### 2.3.1.1 The Invisible Boundary Paradigm.

In the invisible boundary paradigm, the relationship between the target and prime word is manipulated. The manipulation could be phonological, orthographic or semantic. The figure below shows an example of the invisible boundary paradigm.

| *Condition* | *Sentence* | |
|---|---|---|
| Identical | She decided to cut her | hair before the wedding. |
| Phonologically Similar | She decided to cut her | hare before the wedding. |
| Orthographically Similar | She decided to cut her | hail before the wedding. |
| Unrelated | She decided to cut her | vest before the wedding. |

**Figure 2-1. The invisible boundary paradigm, examples of sentences before display change. The dashed line represents the invisible boundary. When the boundary change is triggered, the target sentence reads, 'she decided to cut her hair before the wedding'.**

Subjects are presented with a series of sentences and in the sentences there is an invisible boundary that participants are not aware of. As the participant begins to read the sentence, the prime word sits just outside the invisible boundary. Once their eyes cross the invisible boundary the prime word will turn into the target word. In the above example, there are four conditions; identical (hair), phonologically similar (hare), orthographically similar (hail) and unrelated (vest). The prime varies across conditions. Studies have demonstrated that there is a preview benefit i.e. readers will process the sentence faster, regress less on the text and fixate for shorter periods of time when the prime is phonologically or orthographically related to the target compared to when the target and prime are unrelated (Rayner, 2009). Past studies have also investigated semantic preview benefits using this paradigm, but there is no evidence of a semantic preview benefit, e.g. ‘cat’ will not facilitate processing of ‘dog’ (Rayner, 2009).

In summary, looking at single words and sentences, the paradigms described above have been used to explore what factors influence word recognition when words are presented in isolation or in sentences. As there are advantages and disadvantages in the use of any of these paradigms it is likely that using converging methods bears the promise of better insights of the processes involved in word recognition.

### 2.4 Models of Word Recognition

It is generally agreed that visual word recognition entails processing orthography (spelling), semantics (meaning) and phonology (pronunciation) (Coltheart et al., 2001; Harm & Seidenberg, 2004). In the “reading triangle” these three components are interconnected with bidirectional links (Rastle, 2007). Models of word recognition such as Dual Route Cascaded (DRC) and single route models include each of those three components (Coltheart et al, 2001; Harm & Seidenburg, 2004). It is important to note that sometimes models of word recognition are mistakenly called ‘models of reading’ when only describing one part of the process involved in reading (Rayner & Reichle, 2010). To date there is no complete model of reading, only models of some of the processes involved in reading such as eye movement control and word recognition (Rayner & Reichle, 2010). The dominant models of word recognition in the field are reviewed below.

### 2.4.1 Dual route models of word recognition

In dual route models, there are two ways readers can recognize words, either via the lexical (orthographical) route or the non-lexical (phonological) route (Coltheart et al., 2001). In the lexical route, readers access the word meaning directly from print and subsequently, the pronunciation (spelling to meaning to sound). This route is used for highly familiar words. In the non-lexical route, readers first access the pronunciation by applying grapheme-phoneme correspondence (GPC) rules and then, access the meaning (spelling to sound to meaning). It is thought that this route is used for novel, irregular and infrequent words, as well as nonwords (Treiman & Kessler, 2007). The two routes operate in parallel to one another and pronunciations of words are determined jointly by the two routes (Rayner & Reichle, 2010). Frequent and regular words are activated more rapidly and accurately compared to irregular and infrequent words. This is because the activation does not spread quickly along the routes, as it takes longer to map between phonemes and graphemes in unfamiliar and less frequent words.

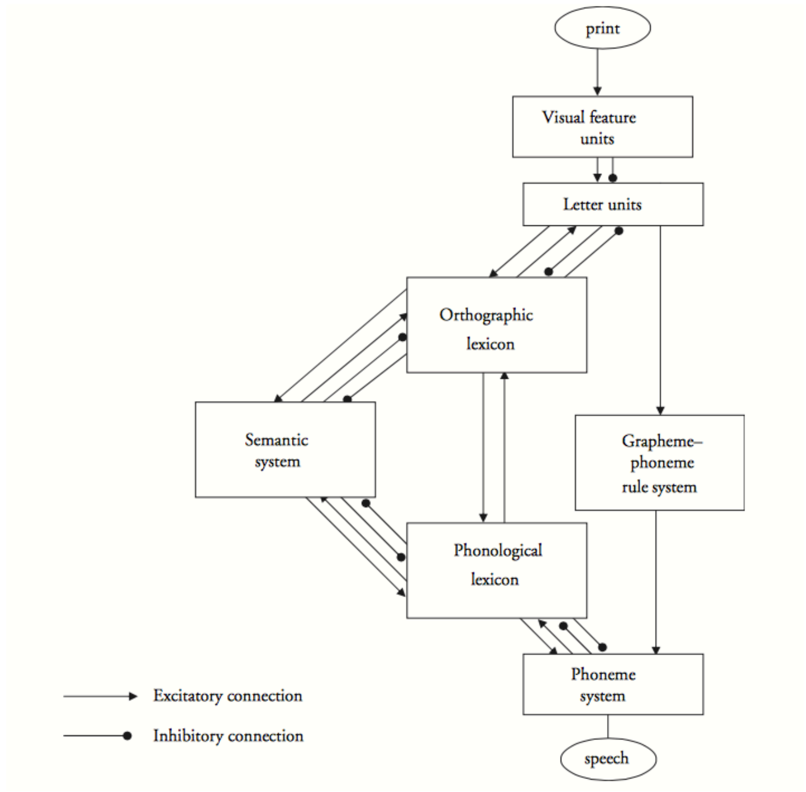

**Figure 2-2 The Dual Route Model of Word Recognition (taken from Coltheart et al, 2001)**

Proponents of dual route models posit that both routes are necessary for successful word recognition. It would not be possible to recognise exception words such as ‘one’ (which sounds like ‘won’) by applying the grapheme to phoneme correspondence rules, which is why the direct route (orthography to semantic pathway) is needed. But if word recognition depended on the direct route alone, we would need to have a lexical entry for every single possible pronounceable word and especially nonword (Rayner et al., 2013) and the cognitive load would be too great. It is possible to read out nonwords and this provides evidence in support of the phonological route. Additionally, there is a ‘regularity effect’, which means that regular words (gave, hint) are named faster in comparison to irregular words (have, pint). This effect shows that there is a possible conflict between the two routes in generating an appropriate pronunciation for irregular words. However, the effect disappears with high frequency irregular words such as ‘one’ suggesting that the two routes work together in parallel to generate the right pronunciation (Rayner et al., 2001).

Individuals with reading deficits such as dyslexia can also provide evidence in support of dual route models of reading. Among the different types of dyslexia that have been described (pure alexia, phonological, surface and deep dyslexia) the deficit of some patients can be parsimoniously accounted for in terms of deficit to the phonological route and others as a deficit of the orthographic route. Surface dyslexics are able to read both words and nonwords but will make mistakes with the pronunciation of irregular words by trying to apply the grapheme to phoneme correspondence rules to those words e.g. /iz-land/ for island (Bishop & Snowling, 2004; Frost, 1998; Rayner et al., 2013). The tendency to try and apply the grapheme to phoneme correspondence rules for all words suggests that surface dyslexics rely on the phonological route. Phonological dyslexics can pronounce both regular and irregular words but they are unable to pronounce nonwords, which suggest that they are more reliant on the direct route to identify words (Rayner et al., 2013). A similar impairment in the ability to read nonwords, however accompanied by errors (especially semantic errors) in reading of real words is typical of deep dyslexia. The traits of surface and phonological dyslexics provide evidence to support that there are two distinct routes used by skilled adult readers and that they operate independently of one another (Rack et al., 1992; Rayner et al., 2013).

### 2.4.2 Single route models of word recognition (Connectionist models)

Single route models of word recognition (e.g. Harm & Seidenburg, 2004) use connectionist architectures in which input nodes represent the printed word letters and the order of the letters in that printed word, and the output nodes are the word's pronunciation. In between input and output nodes, there are hidden units that learn mappings between input and output (Treiman & Kessler, 2007). Phonological and orthographical information are interconnected together at the hidden level. It is proposed that the more a person reads, the stronger these connections become leading to skilled reading (Cortese & Balota, 2012). In such models, there is no mental lexicon where words are stored but rather patterns that relate to the phonological, semantic and orthographic features of a given language. Upon reading a word, these patterns are activated leading to word identification (Rayner et al., 2001). As patterns in irregular and less frequent words are less familiar, it will take longer for those patterns to activate and thus word identification is slower and less accurate.

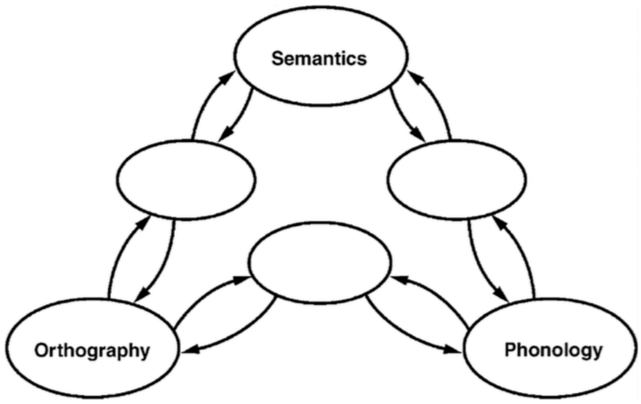

**Figure 2-3 Connectionist Model of Reading (Seidenberg, 2005)**

Harm and Seidenburg (1989, 2004) implemented a computational model of the single route pathway to word recognition and this has provided useful insights into the processes involved in word recognition. These models are said to imitate human behaviour during reading and can explain what occurs when children learn to read and where the deficits are in reading.

Computational models have demonstrated that readers can derive phonological and semantic information from words (orthographic stimuli) simultaneously which provides support for connectionist models of reading (Rayner et al., 2001). Furthermore, in the past it was argued that phonological recoding was not possible as there are many irregular words but computational models have demonstrated otherwise and can learn such words with relatively little training (250 trials maximum) (Rayner et al., 2001).

Although these models of word recognition are different they do seem to be able to account for many different phenomena that influence word recognition but in different ways (Rayner et al., 2001). In both models, the ability to process phonological information also seems to be crucial for skilled reading. However, it is important to note that the extent of the role of phonology in word recognition is still under debate (Rayner et al., 2013). Some support a 'weak phonological theory' where phonology is not always essential for word recognition (Rastle & Brysbaert, 2006; Rayner et al., 2013). Brysbaert (2001) proposed that it is possible that readers may adopt strategies during word recognition that do not always involve phonological processing. In a study by Brysbaert and Praet (1992), three different experiments investigating the role of phonology in visual word recognition were carried out and a pseudohomophone effect was only found in one experiment. In the first experiment (a backwards masked lexical decision task) a pseudohomophone effect was detected but as the authors note, the masks were orthographically similar to target items. In Experiments 2 and 3 (also backwards masked lexical decision tasks), there was no pseudohomophone effect and the authors conclude that this is due to high numbers of pseudohomophones and nonwords (non-homophones) used in the experiment. A high number of masked words were not related in any way to the target items and this influenced word processing (Brysbaert & Praet, 1992). Masks in the latter two experiments were less visually similar to target items, ruling out any orthographic effects. Some studies show evidence that readers may directly connect written words to their meanings, mapping between orthographic and semantic information. This is considered to be more advantageous than the orthographic to phonological to semantic pathway as there are less stages of processing (Harm & Seidenberg, 2004). It is also argued that fluent readers read at a much faster pace than they speak so phonological processes may be bypassed (Harm & Seidenberg, 2004; Wagner & Torgesen, 1987). Furthermore, English is considered to have a relatively ‘deep’ orthography compared to languages such as Italian, as there are many spelling-to-sound inconsistencies in words such as ‘pint’ (compared to ‘hint’, ‘tint’). There are also many homophones in English that are spelt differently e.g. ‘their’ and ‘there’. These inconsistencies may mean that relying on phonological processing alone would be inefficient (Harm & Seidenberg, 2004; Snowling & Caravolas, 2007). These accounts demonstrate that there are likely to be multiple pathways to word recognition and that both orthographic and phonological information provide access to meaning. Readers are likely to use the most efficient route to word recognition (Brysbaert, 2001; Coltheart et al., 2001; Harm & Seidenberg, 2004).

As both models of word recognition emphasise the importance of phonological information for word recognition, a central question concerns the implications for deaf readers. According to both models, deaf readers would struggle to recognise words, as they may not be able to access phonological information. However, this is not the case for many deaf readers. Thus, a central question is how deaf readers process written words. This will be discussed further in the next chapter. Below, I review the literature concerning how children learn to read, as this is important in understanding similarities and differences between hearing and deaf readers.

## 2.5 Learning to read

Prior to learning to read, most children are already highly skilled in mapping phonology and semantic representations for words. One of the first stages in reading acquisition is to teach children the connections between phonemes and graphemes and by learning a small set of symbols; children are then able to read an infinite number of words (Frith, 1985; Treiman & Kessler, 2007). This method is known as the 'alphabetic principle' and this method is said to be crucial for successful reading acquisition (Rayner et al., 2001). For example, if a child is able to map between four letters and their phonemes /t/, /e/, /a/ and /m/, they are then able to read 'team', 'meat', 'eat', 'tea' and so on even if they have never encountered them before (Rayner et al., 2001).

Numerous studies have shown a strong correlation between phonological awareness and literacy achievement. Children who display good phonological awareness when learning to read go on to read more successfully compared to those who do not (Castles & Coltheart, 2004; Snowling & Caravolas, 2007). Children with developmental dyslexia (those with lower reading standards compared to their peers) have been shown to have problems with phonological processing, which suggest that problems with reading are due to poor phonological processing (e.g. reading nonwords) (Harm & Seidenberg, 1999; Rack et al., 1992; Snowling & Caravolas, 2007). Children who have problems with learning to read generally show some improvement after phonological training (Harm & Seidenberg, 1999; Rack et al., 1992; Rayner et al., 2001).

Some argue that children can be taught using whole word approach rather than via the alphabetic principle. This approach means that initially children are taught 50-100 words and their subsequent meanings and from this set of words, they are then able to learn to read many more words. They are able to do this as their phonological awareness is said to develop naturally as their reading experience increases, they do not need to be explicitly taught phonics (Weaver, 1994). Supporters of the whole word approach feel it is more important to focus on the whole word and their meanings – words should not be broken down into smaller units as this is not how we read words naturally. Additionally, they believe that children can learn grapheme to phoneme correspondences without being explicitly taught to do so. It has been shown that children can learn to read via the whole-word approach but this is less successful in comparison to learning via the alphabetic principle (Adams, 1990; Rayner et al., 2001). This is supported by several laboratory studies, which demonstrate that if you teach participants a finite set of grapheme to phoneme correspondences, they are able to read novel words by applying their knowledge of grapheme to phoneme correspondences. Those who were taught a finite set of words (as in the whole-word approach), were less likely to be able to read novel words (Adams, 1990; Rayner et al., 2001).

Learning to read via the alphabetic principle is said to be quite complex in languages with deep orthographies such as English. There are many irregularities with grapheme to phoneme correspondences in deep orthographies, which can make learning to read using the alphabetic principle a challenge. These irregularities cause confusion for many beginning readers e.g. ‘pint’, ‘one’. Consonants can also different pronunciations depending on what vowels come before or after it, creating more confusion for beginning readers of English. As for vowels, not every vowel is associated with a symbol. Although there are 5 vowels represented in the alphabet, there are more than 5 vowels in spoken English e.g. /y/ can sometimes represent a vowel in words such as ‘sky’ or ‘fly’. However, it has been argued that English is not as irregular as many studies make it out to be as in words such as ‘car’ or ‘care’, the presence or absence of the /e/ gives the reader an indication of how to pronounce the word (Rayner et al., 2001). It has also been found that many of the irregularities in English will occur in high frequency words, which children and adults will see so often and thus bypass the phonological processes in reading such words (Harm & Seidenberg, 2004).

Models of word recognition also attempt to explain what occurs when children are learning to read. Supporters of dual-route models posit that children will rely heavily on the orthography to phonology to semantic (phonological) route when they first learn to read. They are mapping between graphemes and phonemes in order to recognise the word and then extract the meaning based on their knowledge of spoken language (Coltheart et al., 2001). As their word identification improves, because of increasing familiarity of words through experience of reading, they become less reliant on the phonological route and will use the orthography to semantic (direct) route more frequently (Frith, 1985). Supporters of the connectionist model of word recognition give a similar account of what occurs when children are learning to read but instead of two separate routes, there is a single pathway. As explained earlier, in the connectionist model, there are units that represent orthographic, semantic and phonological information and they are all interconnected (Harm & Seidenberg, 2004). When children are young, the connections between orthography and semantics are weak thus semantic activation largely depends on their phonological knowledge. Over time, with more reading experience, the connections between orthography and semantics become stronger and children become less reliant on phonology (Harm & Seidenberg, 2004). Although both models posit that phonological processing becomes less important with increased experience and skill with word identification, this does not mean that it is no longer used. Readers will encounter many novel words during their life span and thus use phonology to process them.

As mentioned before, reading is a complex skill and there are many elements involved in becoming successful readers. Although phonological skills/awareness is crucial for successful reading, it is also important to have other skills such as cognitive, linguistic and social skills. Early language is an important factor in learning to read as children use their knowledge of spoken language to learn to read. Rayner et al (2001) point out that competence in language is the most important factor for literacy attainment. Prior to starting school, children will have extensive knowledge of the phonology, grammar, vocabulary, semantics etc. of their language and this will assist them in learning to read. It is important to note that despite the many factors contributing to learning to read successfully, general intelligence does not seem to be a factor. Studies have shown a weak correlation between IQ and reading skills. Those who read early do not necessarily have high IQs and some who have reading disabilities have been found to have higher than average IQs (Castles & Coltheart, 2004; Wagner & Torgesen, 1987). Comprehension is also an important factor and studies have shown strong correlations between spoken and written language comprehension. This shows that the more fluent and competent the child is at spoken language; this skill will transfer onto written language. This provides support to the simple view of reading, which posits that two crucial elements are needed for successful reading, linguistic comprehension and the ability to decode information (Gough & Tunmer, 1986).

Linguistic comprehension is 'the ability to take lexical information (i.e. semantic information at the word level) and derive sentence and discourse interpretation' (Hoover & Gough, 1990, pp 131). To test linguistic comprehension, hearing readers are asked to listen to a narrative and then they are asked questions about the narrative. Linguistic comprehension is measured verbally as the ability to comprehend written narratives could be influenced by the reader's ability to decode written information. The ability to decode is to be able to 'rapidly derive a representation from printed input that allows access to the appropriate entry in the mental lexicon and thus, the retrieval of semantic information at the word level' (Hoover & Gough, 1990, pp130). The ability to decode words is measured by a nonword naming task where readers utter novel letter strings. To be able to work out the pronunciation of those novel letter strings, readers need to be able to make connections between orthography and phonology by mapping phonological information onto orthographical information. It is argued that to become a successful reader, you need to master both linguistic comprehension and decoding skills.

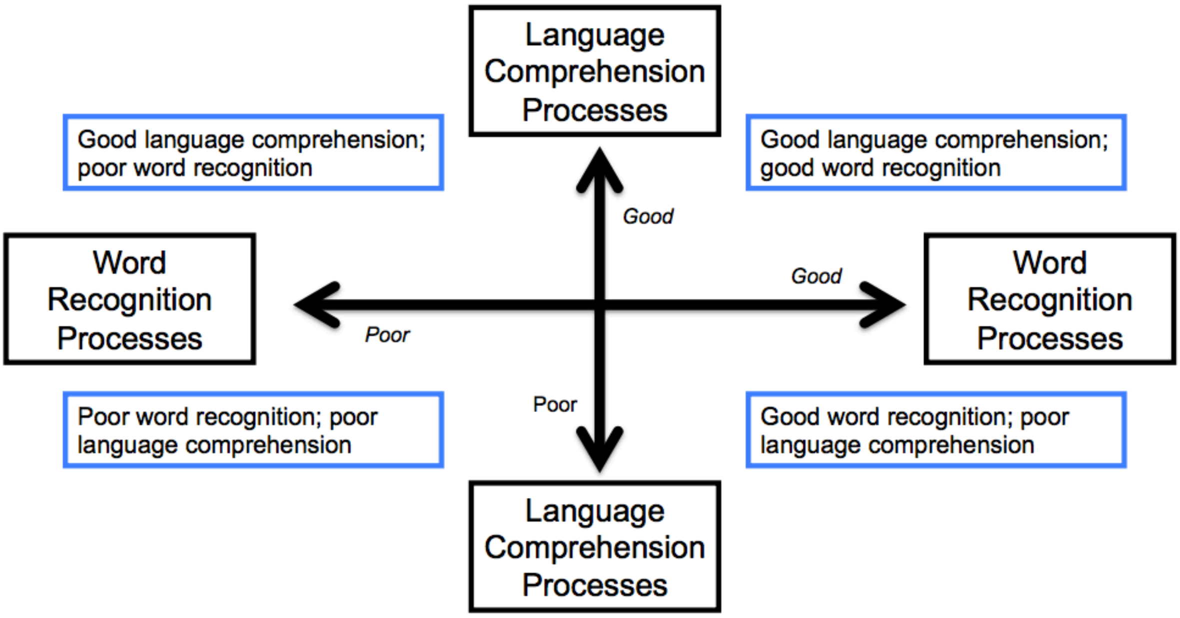

**Figure 2-4 The simple view of reading (Hoover & Gough, 1990)**

Poor readers can fall into one of three quadrants; they can have poor language comprehension but have adequate decoding abilities (poor comprehenders, hyperlexics), have poor decoding skills with good language comprehension (poor decoders, dyslexics) or have weaknesses in both areas ('Garden Variety' poor readers). Supporters of the simple view of reading believe that the main deficit in reading lies with the inability to decode letter strings, which involves the mapping of phonological information onto orthographical information. As mentioned earlier, support for this comes from studies looking at poor readers such as those who have dyslexia (Snowling & Caravolas, 2007; Swan & Goswami, 1997a) as they perform poorly on non-word reading tasks (Rack, Snowling & Olson, 1992) and a range of other phonological tasks.

To summarise, word recognition is an important element in skilled reading and there are many factors that will influence word recognition that will need to be taken into account when exploring this phenomenon. Furthermore, there are various methods that can be used to explore word recognition and each will elicit different aspects of the processes that occur during word recognition. Considering this, it is important to employ various methods when exploring word recognition to gain better understanding of the strategies used in different tasks. Different models of word recognition such as the dual-route and connectionist models have different accounts of how individuals may process the written word but despite their differences, they can account for much of the same phenomena and posit that orthographic, semantic and phonological information are all interconnected and crucial for word recognition. However, the role of phonology is a crucial element in those models. In particular, poor phonological skills underlie the reading deficit observed in developmental dyslexics. Moreover, in those models, learning to read requires different processes to skilled reading and skilled reading takes time and experience to develop. Finally, good understanding of language prior to learning to read seems to be an important factor for successful reading.

In the next chapter, I will focus on the literacy attainment in the deaf population and the many reasons outlined by different studies for the prevalence of poor literacy in this population. I will look into studies that explored reading and word recognition in skilled deaf readers and discuss the factors that contributed to good reading achievements in this population. I will discuss the literature on word recognition processes in deaf adults and children and whether current models of word recognition can be applied to this population.

# 3 Word Recognition in Deaf Readers

The focus of Chapter 2 was word recognition and reading processes in hearing readers to help us understand what is important for reading attainment in hearing readers (both children and adults). The various methods used to explore these processes were described and models of word recognition were introduced. In this chapter, the focus will be on deaf readers and studies that have explored word recognition and reading processes in deaf adults and children.

I will first review studies that have reported literacy levels in the deaf population. These studies are predominantly from the UK and the USA. I will then discuss studies that have looked into visual word recognition and reading processes in deaf readers, focusing on how adult deaf readers process orthographic, semantic and phonological information. I will also describe factors that have been found to be predictors of reading attainment in adult deaf readers. Next, I will discuss reading acquisition in deaf children and outline what factors predict reading skills in deaf children, comparing them to hearing readers. Additionally, I will discuss models of word recognition and reading and discuss how they can be modified to account for visual word recognition and reading processes in deaf readers.

## 3.1 Literacy in the deaf population

In the deaf population, the majority of deaf children and adults have poor literacy skills (Conrad, 1979; Kyle, Campbell, & MacSweeney, 2016; Kyle & Harris, 2010; Qi & Mitchell, 2012). For example, Harris, Terlektsi, & Kyle (2017) report that around half of severe to profoundly deaf children in their study were not reading at age appropriate levels. Several studies looking into literacy processes in severe to profoundly deaf adults also report that deaf, poor readers in their sample had a mean reading age of 8 to 11 years (e.g. Bélanger, Slattery, Mayberry, & Rayner, 2012; Chamberlain, 2002). Hearing readers in the same studies were reading at post high school levels (Bélanger, Mayberry, & Rayner, 2013; Chamberlain, 2002). However, there are also some studies that have found that some deaf readers do read successfully and at age appropriate levels despite impoverished access to spoken language (Bélanger, Baum, & Mayberry, 2012; Chamberlain, 2002). Different reasons have been given for this variability in reading attainment amongst deaf individuals such as the inability to fully access spoken language due to hearing loss (Perfetti & Sandak, 2000), delays in acquiring a first language whether signed or spoken (Humphries et al., 2014), difficulties in processing phonological information (Harris & Moreno, 2006). Although the relative importance of each of those factors is not clear, it is likely that all play a role in explaining why deaf individuals are not always successful readers.

In Chapter 2, I explained that word recognition and reading in hearing individuals involves orthography, semantics and phonology and bidirectional connections among them. Is the same true for deaf readers? For hearing readers, many have argued that phonology is essential for successful word recognition and reading. As deaf readers have reduced access to the phonology of spoken language, many studies have investigated phonological processing in deaf individuals as a potentially critical factor underlying poor literacy attainment in the deaf population (Bélanger, Baum, et al., 2012; Chamberlain, 2002; Hanson & Fowler, 1987; Mayberry et al., 2011; Mayer & Trezek, 2014; Perfetti & Sandak, 2000).

## 3.2 The role of phonology for adult deaf readers

Despite numerous studies investigating the role of phonology in deaf readers, the evidence is mixed with some studies suggesting that deaf readers make use of phonological information and other studies suggesting that they do not. Table 3-1 summarises a range of studies that have investigated the use of phonology in adult deaf readers, whether reading level was controlled for, what tasks were used, whether implicit or explicit phonological processing was tested and the findings of each study.

**Table 3-1 - Results from previous studies looking into phonological processing in deaf adult readers** [1]

| Study | Reading Level matched? | Experiment/Task | Implicit or Explicit? | Evidence of phonological processing? |
|---|---|---|---|---|
| Belanger, Mayberry & Rayner, 2013 | Yes | Parafoveal preview benefits (invisible boundary paradigm) | Implicit | No |
| Belanger, Baum & Mayberry, 2012 (Experiment 1) | No | Masked Phonological Priming Lexical Decision Task | Implicit | No |
| Belanger, Baum & Mayberry, 2012 (Experiment 2) | No | Serial Recall Task | Implicit | No |
| Chamberlain, 2002 (Experiment 1) | No | Spelling-to-sound correspondences | Implicit | No |
| Chamberlain, 2002 (Experiment 2) | No | Lexical decision using pseudohomophones | Implicit | No |
| Cripps, McBride & Forster, 2005 | No | Masked Phonological Priming Lexical Decision Task | Implicit | No |
| Emmorey, Weisberg, McCullough & Petrich, 2013 | Yes | Phonemic Awareness Task | Explicit | Yes |
| Hanson & Fowler, 1987 | No | Paired lexical decision task (rhyming/non-rhyming) | Implicit | Yes |
| Hanson, Goodell & Perfetti (1991) | No | Semantic acceptability judgment task | Implicit | Yes |
| MacSweeney, Brammers, Waters & Goswami, 2009 | Yes | Phonemic Awareness Task | Explicit | Yes |
| MacSweeney, Goswami & Neville (2013 | No | Rhyme judgment task | Explicit | Yes |

As is clear from the table, the results are mixed and this may be largely due to the use of different tasks and whether implicit or explicit use of phonology was tested. For example,

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[1] Please note that this is not a systematic review of previous literature.

some of the studies test explicit phonological awareness using tasks such as rhyme judgment, phonemic awareness. Other tasks give insights into the automatic activation of phonological information during single word reading e.g. masked phonological priming lexical decision task, which tests the implicit use of phonology. Additionally, not all of the studies controlled for reading level (i.e. ensuring that deaf and hearing readers in their studies were matched on age, gender and reading skill) and this may be a reason for the differences. Importantly, of the studies reviewed above that did find evidence of phonological awareness/processing in deaf adult readers, only one found a positive correlation between phonological awareness/skills and reading level (MacSweeney, Brammer, Waters, & Goswami, 2009). This may be different for deaf children learning to read, which I will discuss later in this chapter. In two of the three studies, deaf readers could carry out a phonemic awareness task but, as would be expected, their performance was much poorer on this task compared to hearing readers (Emmorey, Weisberg, McCullough, & Petrich, 2013a; MacSweeney et al., 2009). In Emmorey et al's (2013) study, in the phonemic awareness task, deaf readers had 52% accuracy whereas the hearing readers achieved 87% accuracy. In MacSweeney et al's study (2009), deaf readers achieved 75% accuracy, similar to dyslexic individuals who achieved 78% accuracy. Whereas, hearing readers in the same study achieved 90% accuracy on the phonemic task (MacSweeney et al., 2009). In MacSweeney, Goswami, & Neville (2013), deaf readers were able to perform a rhyme judgment task, however their performance was far below hearing readers with only 9/15 deaf participants performing above chance levels. Below, I discuss in more detail some of studies outlined in Table 3-1.

Several studies have used lexical decision tasks in order to explore the role of phonology in deaf readers, e.g. Chamberlain (2002) used pseudohomophones in a lexical decision task and found little evidence of phonological processing in both skilled and less skilled deaf readers compared to hearing readers. In that study, there were three groups; deaf good readers (10.3 grade average), deaf poor readers (3.7 grade average) and hearing readers (reading levels were post high school) and groups were matched for age (±2 years), gender and educational level. Monosyllabic pseudohomophone and non-pseudohomophone stimuli were used (e.g., pseudohomophones such as 'hoap' and 'joak' and nonwords such as 'hoak' and 'joap') (Chamberlain, 2002). The only difference between the two sets of nonwords was that one set were pseudohomophonic (e.g. hoap, joak) and the other set were nonhomophonic nonwords (e.g. hoak, joap), both sets were highly similar visually. Hearing readers responded slower and made more errors with pseudohomophones compared to other nonwords. Deaf good readers were equally fast and had similar error rates in both conditions. Deaf poor readers were equally slow in both conditions but had a similar error pattern to the hearing readers in the rejection of pseudohomophones. The author concluded that deaf skilled readers do not use phonological information to support their judgments in lexical decision and was able to reject pseudohomophones as nonwords based on orthographic information alone. There are some issues with the conclusions from this study, which are; deaf skilled and hearing readers were not matched on reading level (10.3 grade level compared to 12+ grade), which could explain group differences with regards to phonological processing; less skilled deaf readers showed a similar error pattern as hearing readers when rejecting pseudohomophones, which the author attributes to the pseudohomophones being 'wordlike'. This suggests that there may be a confound between orthographic and phonological effects in this study. Chamberlain (2002) found that the main difference between the two groups was the age of ASL acquisition, skilled deaf readers acquired ASL at a much earlier age and this seems to be vital for successful reading attainment. Although this study did not find an effect of phonology in deaf readers, other studies have done so using a lexical decision task (e.g. Hanson & Fowler, 1987).

In Hanson & Fowler's (1987) study, participants were presented with pairs of words and word/nonword pairs in a lexical decision task. These word pairs were all orthographically similar, however in half of the trials the pairs rhymed (e.g. beach, teach) and in the other half of trials, they did not rhyme (e.g. couch, touch). There were also word/nonword pairs. Half of the word/nonword pairs were orthographically and phonologically similar (e.g. mark, wark) and half of the word/nonword pairs were orthographically and phonologically dissimilar (e.g. rown, toad). Participants were instructed to respond, 'yes' if word pairs were both English words and to respond, 'no' if they were not. Deaf and hearing participants had faster decision latencies for rhyming pairs compared to non-rhyming pairs even with word/nonword pairs (e.g. mark, wark). However, in this same study, both deaf and hearing readers were asked to complete a rhyme judgement task and deaf readers achieved a far lower score in comparison to hearing readers (64.1% compared to 99.6%), which seems to be in contradiction to the findings from the lexical decision task. However, the authors report that 64.1% is significantly above chance levels, and argue that this awareness of rhyme may have been enough to facilitate deaf readers' responses in the lexical decision task. Furthermore, as mentioned in Chapter 2, it has been argued that unmasked lexical decision tasks do not test implicit phonological processing as participants' are making explicit meta-linguistic judgments (Leinenger, 2014). To test implicit and 'automatic' activation of phonology in deaf readers, some have used masked phonological priming in lexical decision tasks (e.g. Bélanger et al., 2012; Cripps, McBride, & Forster, 2005).

Cripps et al. (2005) administered a masked priming lexical decision task to deaf and hearing readers and found an effect of phonology for the hearing readers not for the deaf readers. In this study, there were four different prime types; 12 pseudohomophone primes e.g. bloo, blue, 12 repetition primes e.g. highway, highway, 12 unrelated nonword primes e.g. caft, blue and 12 unrelated word primes e.g. victory, highway. There were 2 lists for counterbalancing purposes and all target/prime pairs were presented only once. All primes were presented for 67ms, which came straight after a mask (hash marks) that remained onscreen for 606ms and then word target was presented directly after presentation of prime until response. There was a strong effect of repetition priming for both the deaf and hearing readers, replicating previous findings for hearing readers, however phonological primes facilitated the response times of hearing readers only. For deaf readers, phonological primes had an inhibitory effect and the authors concluded that this must be an effect of orthography, as deaf readers cannot access phonology. The authors argue that this inhibition shows that deaf readers only processed the conflicting orthographic code (Cripps et al., 2005). This seems to suggest that the stimuli used in this study were not carefully controlled to ensure there was no confound between orthographic and phonological effects. Additionally, reading levels were not controlled for. The authors recruited deaf participants who were either currently attending college or college graduates and claim that all have mastered English as their L2, thus they did not test for reading level (Cripps et al., 2005). This does not mean there is no variability in the reading levels in this group or that they are matched to the hearing readers on reading level, which could be a reason for the differences between the two groups.

Belanger et al, (2012) argued previous findings did not properly distinguish between orthographic and phonological processing because phonological information was clearly represented in the orthography (e.g. Hanson & Fowler, 1987). In Belanger et al’s (2012) study, effects of phonological and orthographical coding on visual word recognition were investigated independently of one another. A masked priming lexical decision task was used, as this is believed to tap into very early processes. Participants are unaware of primes as they appear briefly and then are masked thus any effect of prime on reaction times is argued to be 'automatic' (Rastle & Brysbaert, 2006). Participants were deaf adults, bilingual in written French and Langue des Signes Quebecoise (LSQ). There were three groups, skilled and less skilled deaf readers and hearing readers (control group). Two prime durations (40 and 60 ms) and four non-word primes types were used: orthographically similar pseudohomophones (e.g., bore-BORD), orthographically dissimilar pseudohomophones (baur-BORD), orthographically dissimilar nonhomophonic nonwords (boin-BORD) and unrelated non-words (clat-BORD) (Belanger et al, 2012). The study found hearing readers used both orthographic and phonological information, skilled and less skilled deaf readers used only orthographic information. The authors concluded that deaf readers do not make use of phonological information during single word reading and that this did not have an impact on reading level. However, skilled deaf readers' group had a mean reading level equivalent to 9.5 grade whereas all hearing readers had reading levels beyond 12th grade thus participants were not matched on reading level, which could be a reason for the differences in phonological processing and could explain the lower levels of reading achievement in the deaf groups. It is important to note that neither group of deaf readers – skilled or less skilled deaf readers used phonological information, yet the reading attainment of the less skilled deaf readers were much lower (mean reading level, 4.6 grade), which could indicate that the ability to process phonological information may not be the crucial factor in reading attainment for deaf readers. Belanger et al (2012) found that the key difference between the two deaf groups was the age of ASL acquisition, deaf skilled readers learnt ASL at a much earlier age than less skilled deaf readers. This shows that early language exposure is important for successful literacy attainment for deaf readers. Interestingly, this study also found that both deaf and hearing readers made use of orthographic codes during the 60ms prime duration but deaf readers also made use of orthographic codes in the 40ms prime duration. The data suggest that deaf readers process orthographic information quicker in comparison to the hearing readers, which may compensate for reduced or lack of ability to process phonological information.

One potential problem of the above tasks is that they all focused on single word reading, which may not give a true indication of what processes are used during sentence or text reading (Leinenger, 2014). These studies also required participants to make meta-linguistic judgments (lexical decision), which is not something that occurs during normal reading. Additionally, the aim of reading text is to comprehend it, which means that readers need to access meaning and in lexical decision tasks it may be possible that readers do not need to access meaning to reject nonwords. In summary, these tasks may not tap into processes that occur during normal reading comprehension (Leinenger, 2014).

Few studies have examined sentence reading by deaf readers. One such study looked at phonological processing during sentence reading in deaf and hearing readers (Bélanger et al., 2013), exploring whether or not there were any phonological or orthographic preview benefits. Belanger and colleagues used the invisible boundary paradigm and the relationship between targets and primes were manipulated (either phonologically or orthographically). When the sentences are first presented, the prime is present until the eyes cross the invisible boundary and turns into the target word. Participants are unaware of the change as it usually occurs during saccades (visual processing is suppressed during this time). There were 4 conditions, in the first condition; primes were identical to the target (bare, bare). In the second condition, primes were phonologically identical to the target (bare, bear). In the third condition, primes were orthographically similar to the target (bare, bore) and finally, in the unrelated condition, primes were unrelated to the target (bare, golf). Again, three groups of readers were compared; deaf skilled readers (10th grade), less skilled deaf readers (6th grade) and hearing readers (11th grade) and there were differences in how deaf and hearing readers utilised orthographic and phonological information. For hearing readers, there were parafoveal preview benefits when primes were phonologically related to the target words. There was no such effect for either group of deaf readers, which indicates that they did not benefit from phonologically related previews. However, both groups of deaf readers showed an orthographic preview benefit i.e. orthographic primes enhanced processing for deaf readers, whereas there was no such effect for hearing readers (Bélanger et al., 2013). These findings indicate that deaf readers may rely more on orthographic codes in comparison to phonological codes.

Hanson and colleagues (1991) also examined the use of phonology in deaf readers during sentence reading. Deaf readers and hearing controls were tested on their performance on a semantic acceptability judgment task, where they were presented with tongue-twister and control sentences and instructed to judge whether these sentences were semantically acceptable or not (Hanson, Goodell, & Perfetti, 1991). Both deaf and hearing readers made more acceptability errors with tongue-twister sentences compared to the control sentences, which indicates that deaf readers utilise phonological codes during silent reading (Hanson et al., 1991). Crucially, in this study, all of the deaf participants were native signers of American Sign Language (ASL) (i.e. all had deaf parents) and the majority had unintelligible speech. Despite these factors, deaf readers were influenced by phonological information, which suggests that phonological information can be accessed via other sources. However, reading attainment amongst deaf individuals in this study was extremely variable and ranged from 3.3

to 12+ grade levels (median 8.7 grade level). It may be possible that there were differences in how good and poor readers were influenced by phonological information in this task.

It is possible that the role of phonology is less of a critical factor in reading attainment for deaf readers compared to hearing readers. For example, some of the studies mentioned in this chapter show that although it is possible to match deaf and hearing people on reading level even though their performance on phonological tasks do not always match (Bélanger et al., 2013; Emmorey et al., 2013a; MacSweeney et al., 2009). This indicates that phonology must not be as crucial for deaf readers like it is for hearing readers.

In several of the studies mentioned in this chapter, age of sign language acquisition had the largest impact on literacy attainment (those who were exposed to sign language later had poorer literacy skills) (Bélanger, Baum, et al., 2012; Bélanger et al., 2013; Chamberlain, 2002). This is in line with findings from a meta-analysis study carried out by Mayberry et al (2011) where they reviewed 57 different studies (which included studies with both children and adults) and found that language ability contributed to 35% of the variance in reading achievement (from 8/57 studies where it was measured). In this meta-analysis, a wide range of assessments including vocabulary and comprehension assessments was used to measure language ability in both signed and spoken languages (Mayberry et al., 2011). In the same meta-analysis study Mayberry and colleagues found that phonological awareness/skills only contributed to 11% of the variance in reading achievement. However, it has been argued that phonological skills also only contribute 12% of the variance for hearing readers but this does not mean that it is not an important component of word recognition or reading skills (Mayer & Trezek, 2014).

Although there are different findings from the various studies described above about the role of phonology in deaf adult readers, it seems clear that some deaf readers are able to use phonological information (Emmorey et al., 2013a; Hanson & Fowler, 1987; Hanson et al., 1991; MacSweeney et al., 2009). If this is the case, how are these deaf readers able to access or use phonological information if they do not have full access to the sounds of spoken language? There are several ways in which deaf readers can gain access to the phonology of spoken language, one of which is via speechreading (Kelly & Barac-Cikoja, 2007; Kyle, Campbell, Mohammed, & Coleman, 2013; Kyle, MacSweeney, Mohammed, & Campbell, 2009; Mohammed, Campbell, MacSweeney, Barry, & Coleman, 2006). However, it is important to note that speechreading does not provide full access to spoken language, as some words are virtually indistinguishable visually e.g. mat, bat. Dyer et al (2003:215) point out that, 'speechreading alone does not offer a full rage of minimal meaningful contrasts at the phonological level' and that the 'segmental structure of the spoken language is only partially accessible by speechreading alone'. Deaf individuals are also very rarely totally deaf and many use amplification aids that will give them some access to the sounds of spoken language and thus some understanding/awareness of phonology. Finally, the written word also provides information about the phonology of spoken language especially in many alphabetic languages where letters (graphemes) and sounds (phonemes) have a very close relationship. Despite the various ways that deaf individuals can access the phonology of spoken language, levels of access will greatly vary for each individual thus it is likely that the role of phonology will be qualitatively different for deaf and hearing readers (Chamberlain & Mayberry, 2008).

Overall, we have seen mixed results with regards to phonological processing in adult deaf readers, where it is clear that phonology seems to play a role for some deaf adult readers and not others. However, the variability in results could be down to varying methodologies, lack of control for reading level and using tasks that may not reflect normal reading. Future research is needed to determine the characteristics of the deaf readers that tend to use phonological processing to support their reading and how these characteristics differ to readers who do not.

## 3.3 Orthographic and semantic processing in deaf readers

Many studies have focused on phonological processing in deaf readers, as this aspect is believed to be the most crucial aspect for successful word recognition. As access to phonology is problematic for deaf readers for several reasons, does this mean that they will rely more on orthographic and semantic information in comparison to hearing readers? Some of the studies mentioned so far in this chapter have demonstrated that deaf readers have exhibited a tendency to make use of orthographic information (more so compared to hearing readers), (e.g. Bélanger et al., 2012, 2013; Cripps et al., 2005). Hearing readers, additionally, use semantic processing during word recognition. It is currently unclear whether deaf readers use semantic information in the same way as hearing readers. Many of the studies of phonological processing reviewed earlier meant participants did not necessarily need to access meaning in order to complete the task (e.g. lexical decision) but for some tasks, participants did need to access meaning. For example, in one study, a picture rhyme judgment task was used to investigate phonology in deaf readers (MacSweeney et al., 2009). This meant that deaf participants had to decide whether or not the English labels for two pictures rhymed. To do this, they needed to be able to silently label the pictures and they were able to successfully carry out the task demonstrating that they can make connections between semantics and phonology.

Morford and colleagues (2011) asked deaf and hearing readers to make judgments on semantic relatedness of word pairs and found that both groups of readers responded faster to semantically related word pairs compared to semantically unrelated word pairs. In addition, deaf readers were found to have faster decision latencies in comparison to hearing readers, which indicates that deaf readers are highly efficient in deriving semantic information from orthography (Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011). These results have also been replicated in another study (Kubus, Villwock, & Morford, 2014) providing further support that deaf readers are efficient at extracting semantic information from orthography. However, it is not clear from those studies whether semantic processing is the same for deaf and hearing readers as the aim of these studies was to see if deaf readers who are bilingual in a written and a sign language activated sign representations during reading (Morford et al, 2011; Kubus et al, 2014). Amongst the semantically related and unrelated word pairs were also pairs that were either phonologically related or unrelated in their respective sign languages. In the Morford et al (2011) study, participants were ASL/English bilinguals and in the Kubus et al (2014) study, participants were German Sign Language (DGS)/German bilinguals. In both studies, word pairs that were phonologically related in their respective sign languages influenced deaf bilinguals' responses thus showing that sign equivalents are being activated. This indicates that deaf readers may link up words to their L1 equivalent (i.e. ASL or DGS signs) and then access meaning. Similar patterns have been found in hearing bilinguals who are reading in their L2 and are still activating their L1 (Dijkstra, 2005; Thierry & Wu, 2007).

In summary, the studies reviewed here suggest that, in some instances deaf readers rely more on orthographic information in comparison to hearing readers, which may compensate for lack of or impoverished phonological processing (Bélanger, Baum, et al., 2012; Bélanger et al., 2013; Cripps et al., 2005). Some studies have also demonstrated that deaf readers are skilled in extracting semantic information when it is a necessary requirement of the task (Hanson et al., 1991; Kubus et al., 2014; MacSweeney et al., 2009; Morford et al., 2011). However, very little is known about the interplay between all three elements in word recognition and reading for adult deaf readers. This is the focus of the current thesis. However to gain a fuller picture of the role these factors play in reading in deaf people, the contribution of these factors during *learning* to read will now be reviewed in studies of young deaf children.

## 3.4 The role of phonology for young deaf readers

When hearing children learn to read an alphabetic language, they rely heavily on their knowledge of spoken language and the ability to map phonological information onto orthographic information (on a phoneme to grapheme level). As phonology has been found to be important for hearing children learning to read, many studies have explored the role of phonology in young deaf readers. (See Table 3-2).

**Table 3-2 - Results from a selection of studies looking into phonological processing in deaf children**

| Study | Reading Level matched? | Language | Task | Evidence of phonology? |
|---|---|---|---|---|
| McQuarrie & Parrila (2009) | No hearing control group | American Sign Language | Phonological judgment task | No |
| Harris & Moreno (2006) | Yes | Total Communication | Spellings test (analysis of phonetic errors) | Yes |
| Kyle & Harris (2006) | Yes* | Varied | Phonological awareness task | Yes |
| Dyer, MacSweeney, Szczerbinski, Green & Campbell (2003) | Yes* | Total Communication | Picture rhyme judgment task, pseudohomophone picture matching | Yes |
| Harris & Beech (1998) | Prereaders | Various | Phonological awareness task | Yes |
| Leybaert (1993)** | No | Oral | Word/nonword naming and regularity effects | Yes |
| Waters & Doehring (1990)*** | No | Oral | Paired lexical decision task (rhyming and non-rhyming) | No |

*Subjects were matched for reading age but differed in chronological age

**Tested both teenagers and young adults

***Tested children and adults (age range, 7-21 years)

In contrast to studies that have explored the role of phonology in adult deaf readers, the results seem more consistent with deaf children. Most studies found evidence of phonological processing and/or awareness in deaf children. However, it is important to note that most of the studies used tasks to tap into explicit phonological awareness rather than implicit phonological processing. The fact that deaf children may be successful on a phonological a task is one thing, whether this has any functional implications is another. That is, we need to consider whether phonological awareness/skills correlate positively with reading ability in deaf children, as they do in hearing children, In the above studies, phonological awareness/skills correlated positively with reading skill in 4/7 studies (Dyer, MacSweeney, Szczerbinski, Green, & Campbell, 2003; Harris & Beech, 1998; Harris & Moreno, 2006; Leybaert, 1993). It is important to note that in the study by Dyer et al (2003), deaf children were matched to hearing children for reading age rather than chronological age thus they were not reading at a level expected for their age. The remaining studies did not find a positive correlation between phonological awareness/skills and reading level (Kyle & Harris, 2006; McQuarrie & Parrila, 2009; Waters & Doehring, 1990) and of those studies, two found that orthographic awareness/skill was a better correlate of reading level. Additionally, Harris & Moreno (2006) also found that good readers in their study also had better orthographic awareness/skills than poor readers. In some of those studies, speechreading, language comprehension (whether signed or spoken) and vocabulary were found to be better correlates of reading achievement in deaf children (Harris & Moreno, 2006; Harris, Terlektsi, & Kyle, 2017a; Kyle et al., 2013; Kyle & Harris, 2006).

Overall, although we know that phonological awareness/skill is a critical factor for successful reading attainment for hearing children, it is unclear whether it is as crucial for deaf children learning to read. Additionally, as the deaf population is extremely heterogeneous, we are likely to see differences with some young deaf readers using phonological information during reading to a greater extent than others. If deaf children do not have full access to spoken language, how do they learn to read?

### 3.4.1 How do deaf children learn to read?

When hearing children learn to read, they are already fluent speakers of that language. This is not, however, the case for many deaf children whether they use sign language or not. For those children who already sign, learning to read in English involves learning a second language as BSL is typologically different from English and there is no (widely accepted) written form of BSL. As Dyer et al (2003) point out: ‘signed languages bear no systematic relationship to orthographic systems, which reflect the structure of speech within the speaking hearing community’. Thus deaf children who sign may start learning to read by making a connection between signs and written words (Hoffmeister & Caldwell-Harris, 2014) and then later develop phonological representations of those written words via speechreading (Harris & Moreno, 2004). Kyle & Harris (2011) carried out a longitudinal study looking at reading development of deaf children and found that earlier reading ability was directly correlated to later phonological awareness supporting the above hypothesis. This finding is also supported by a recent longitudinal study where it seemed that deaf readers were developing phonological awareness while learning to read (Harris et al., 2017a).

There are also deaf children who do not learn sign language as their first language and who are primarily exposed to a spoken language. This does not mean they have greater access to phonological information compared to deaf children who sign. The nature of deafness, means that many of those deaf children have impoverished access to spoken language and thus have poorer phonological skills and poorer general language ability compared to their hearing counterparts, which in turn affects literacy attainment (Goldin-Meadow & Mayberry, 2001; Humphries et al., 2014; Musselman, 2000).

Several studies have found a correlation between speechreading and reading in deaf children (Kyle et al., 2016, 2013; Kyle & Harris, 2011). Longitudinal studies have also shown that speechreading ability is a good predictor of later reading achievement in deaf children (Kyle et al., 2016; Kyle & Harris, 2011). It is interesting to note that hearing children had similar speechreading abilities as deaf children and that it also predicted reading abilities in hearing children (Kyle et al., 2016; Kyle & Harris, 2011). Although, deaf children were found to have similar levels of accuracy as hearing peers when tested on speechreading at a young age, they later outperformed hearing peers as they got older (Mohammed et al., 2006). These studies also found that vocabulary knowledge was a significant predictor of successful reading attainment in deaf children (Kyle et al., 2016; Kyle & Harris, 2011). However, speechreading and vocabulary knowledge are not the only factors that have been found to correlate with reading ability in deaf children.

Several studies have found that age of sign language acquisition is an important factor in the literacy attainment of deaf children (Chamberlain & Mayberry, 2008; Goldin-Meadow & Mayberry, 2001; Humphries et al., 2014; McQuarrie & Parrila, 2014). Authors from these studies argue that the early acquisition of sign language provides deaf children with a platform from which they can use to learn to read and write, as once you have acquired a first language in full, you can then go on to learn a second language (Hoffmeister & Caldwell-Harris, 2014; Humphries et al., 2014). This is in contrast to deaf children who have not been exposed to a sign language, and who have struggled to acquire spoken language. As these children have not acquired a first language in full, their ability to learn to read and write will be seriously hindered (Humphries et al., 2014). It is, however, important to note that very few deaf children have the opportunity to acquire sign language as their first language as only 10% of deaf children are born to deaf parents (Mitchell & Karchmer, 2004). Additionally, although several studies have shown a correlation between age of sign language acquisition and literacy attainment in deaf children, age of spoken language acquisition is also a predictor of successful literacy in deaf children (Chamberlain, 2002). This suggests that it does not matter what language deaf children acquire, as long as they acquire it early. This provides them with the foundation that they need to learn to read and write.

To summarise, from the previous adult and developmental literature, whether deaf individuals read using the same strategies used by hearing individuals remains an open question. Overall, for hearing readers, the processes of word recognition are extremely complex and there isn't a single factor that determines reading success. This is also true for deaf readers, there is no single factor that explains how deaf people recognise words especially in an extremely heterogeneous population with various language experiences, degrees of deafness, educational backgrounds etc.

While on the one hand it is obvious that some deaf readers do utilise spoken language phonology, especially in childhood during reading development, it remains to be established whether the task demands encourage the use of phonology in deaf adult skilled readers and the extent to which deaf readers rely on direct connections between orthography and semantics. As models of word recognition posit that orthography, semantics and phonology are all important components of word recognition, we need to explore the extent of the role that these components play in deaf readers and determine whether or not models of word recognition can be applied to deaf readers.

### 3.4.2 Can models of word recognition and reading be applied to deaf readers?

As described in Chapter 2, all models of word recognition and reading posit that the ability to process phonological information is crucial for successful word recognition and reading (Coltheart et al., 2001; Harm & Seidenberg, 2004; Hoover & Gough, 1990). However, can these models explain word recognition and reading processes in deaf readers, who, by definition have reduced access to spoken language phonology and may not recruit this information during visual word recognition?

#### 3.4.2.1 Dual-route models

If deaf readers do not use phonology, they will rely solely on the direct route. However, if they do make use of phonological information, they will also use the indirect route when reading novel or less frequent words, as hearing readers do. As explained in Chapter 2, supporters of dual-route models (e.g. Coltheart et al., 2001) argue that readers will use grapheme to phoneme correspondence (GPC) rules when encountering novel or infrequent words. However, this may not always be possible for deaf readers especially if they have impoverished access to spoken language. Even if some deaf readers do make use of phonological information during word recognition or reading, the phonological representations that deaf readers have are likely to be qualitatively different to that of hearing readers due to the differences in the way phonology is accessed, i.e. primarily visually (Goldin-Meadow & Mayberry, 2001).

Elliott and colleagues provided an account of how the dual-route model can be adapted for deaf readers who access phonology via speechreading (Elliott, Braun, Kuhlmann, & Jacobs, 2012) (See Figure 3-1).

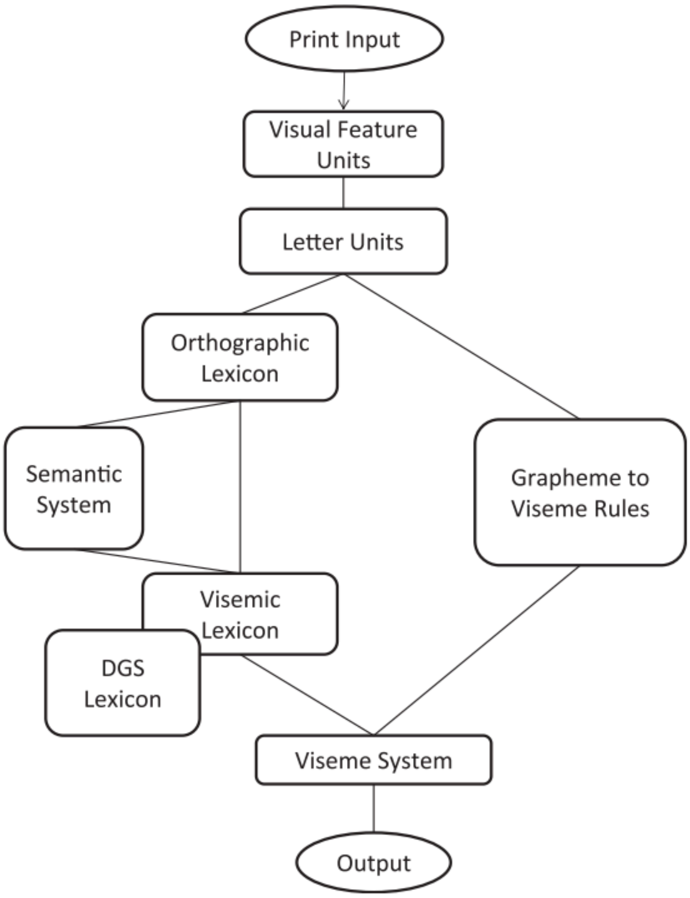

**Figure 3-1 - The proposed dual route cascaded model of word recognition for deaf adults (taken from Elliott et al, 2012) *DGS - German Sign Language**

As explained earlier, many deaf people access spoken language via speechreading thus Elliott and colleagues (2012) incorporated a ‘visemic lexicon’ into the dual route model of word recognition. The ‘visemic lexicon’ replaces the ‘phonological output lexicon’ described by Coltheart and colleagues (2001). ‘Visemes’ are described as the ‘phonemes’ of deaf readers where phonological information is represented by different mouth patterns that are distinguishable from one another. Elliott et al (2012) tested this model by carrying out an experiment to explore whether or not there was a ‘pseudohomovisemy’ effect (equivalent to the pseudohomophone effect) in deaf readers. To do this they identified 11 German 'visemes' and incorporated words and nonwords in a lexical decision task (some of the nonwords were pseudohomovisemes in German). They found an overall effect of pseudohomovisemy amongst deaf readers demonstrating that deaf readers make use of phonological information accessible via speechreading. Elliott et al (2012) also incorporated the lexicon of German Sign Language (DGS) into the model. As can be seen in Figure 3-1, the DGS lexicon overlaps with the German Visemic Lexicon and the authors state that the DGS lexicon can also contribute to word recognition processes (Elliott et al., 2012). This theory is supported by two studies that show signs are activated during single word reading in Deaf German and Deaf American bilinguals as explained earlier in this chapter (Kubus et al., 2014; Morford et al., 2011).

Although the proposed adaptation of the DRC model for deaf readers can provide an account for how some deaf readers recognise words, it may not be applicable to all deaf readers. In their study, Elliott et al (2011) found that six of their deaf participants did not display a pseudohomovisemy effect, thus showing that not all deaf readers will make use of phonological information that can be accessed by speechreading.

Dual-route models of word recognition also provides an account of how children learn to read, explaining that children will use the indirect route more frequently to begin with (Coltheart et al., 2001; Nation, 2017). As reading experience increases, they rely on the direct route more frequently (Harm & Seidenberg, 1999; Nation, 2017). If some deaf children do not make use of phonological information during learning to read, this model suggests that all words will have to be learnt via orthographic to semantic mappings even for novel and infrequent words. This would be a very laborious task and this model does not give alternative strategies for when deaf readers encounter novel and infrequent words, especially for deaf children who sign. Some studies have found that deaf children will first map between signs and print (Hoffmeister & Caldwell-Harris, 2014) and then possibly develop phonological awareness at a later stage. This study suggests that first deaf children will rely on direct mappings between orthography and semantics and increased reading experience will help them develop their phonological skills. As they develop phonological skills, they will then use that as a strategy when they encounter novel or infrequent words. The model proposed by Elliott and colleagues (2012), suggests that some deaf children could map between visemes and graphemes when they encounter novel and infrequent words. The model also supports the notion that deaf children who sign could use their knowledge of sign language to support their reading (Elliott et al., 2012).

#### 3.4.2.2 Single route models

In single route models of reading there is only one pathway to word recognition (see Chapter 2) and this process relies on the connections between orthographic, semantic and phonological information. In between those connections there are hidden units that contain information about a word's orthography, semantics and phonology (Harm & Seidenberg, 2004) and upon reading words all of those units are activated in order to extract word meanings. If we assume that deaf readers do not use phonology during word recognition, there will be little or no information in the hidden units about a word's phonology and deaf readers will rely almost exclusively on orthography and semantics. But if we assume that deaf readers have some access to phonology, then there will be some information about this in the hidden units that will be activated upon viewing words. Supporters of the single route model of reading posit that phonology is important for word recognition thus this model would not be able to account for deaf readers who do not use phonology. However, this model could be adapted to account for deaf readers who DO use phonological information during word recognition, they would perhaps have less phonological information or different phonological representations in those hidden units. For example, if they access phonological information via speechreading, they may have 'visemic' information as described by Elliott et al (2012). Furthermore, as deaf readers have demonstrated stronger orthographic processing in some studies in comparison to hearing readers (Bélanger, Baum, et al., 2012; Bélanger et al., 2013), this indicates that they may rely more heavily on the connections between orthography and semantics for successful word recognition. With regards to learning to read, supporters of single route models stress that phonological awareness and processing facilitates reading acquisition (Harm & Seidenberg, 1999) thus single route models also cannot provide an account of how deaf children who sign learn to read.

## 3.5 Chapter summary

To summarise, it is clear that poor literacy in the deaf population is largely due to reduced access to the spoken language to be read and the delay in the acquisition of a first language, in any modality. However, the skills that underlie successful reading in this population are not yet entirely clear. The roles of orthography, semantics and phonology for deaf readers need further exploration and care taken to ensure that deaf and hearing readers are matched for reading levels (which wasn't the case for several studies mentioned in this chapter). Additionally, when exploring the role of phonology in deaf readers, care must also be taken to ensure there is minimal confound between phonology and orthography. To date, there has been very little investigation into the timing of orthographic and semantic processing in deaf readers and it is important to consider those elements, as they are vital for successful reading. Furthermore, different tasks will elicit different processes. Therefore to understand in more detail interplay between orthography, semantics and phonology in deaf readers, it is important to employ various methodologies. In Chapter 4, I will present the first of six experimental tasks employed in this study to investigate the role of orthography, semantics and phonology in deaf skilled readers.

# 4 What lexical and semantic variables influence visual word recognition in deaf readers?

In Chapter 2, I explained that there is extensive evidence that lexical and semantic variables (e.g., frequency, concreteness) have an impact on word recognition in hearing readers. However, to date, very little is known about how the same lexical and semantic variables influence word recognition processes in deaf readers. Word recognition skills are considered to be the foundation of reading (Cortese & Balota, 2012). If readers struggle to extract meaning at the word level, they will almost certainly struggle to decipher sentences or text. Previous studies on hearing individuals report that those with poor visual word recognition skills struggle to achieve good literacy (Nation & Snowling, 1998; Seidenberg & McClelland, 1989), therefore it is important to establish if these factors are linked to poor literacy in deaf readers too.

Any effect of lexical variables is strongly associated with language experience. These effects may differ for deaf readers who typically acquire written English relatively late compared to their hearing counterparts (Humphries et al., 2014). Studies also show that hearing children develop connections between phonology and semantics prior to learning to read (Harm & Seidenberg, 1999; Nation & Snowling, 2004; Rayner et al., 2001), whereas for deaf children, studies have shown that these connections develop while learning to read (Harris & Moreno, 2006; Kyle & Harris, 2011). Additionally, deaf readers who acquired a sign language as their first language may learn to read by first mapping lexical signs onto print (Hoffmeister & Caldwell-Harris, 2014). These differences in language experience may reflect on how lexical variables, such as word length, frequency, concreteness etc., impact on word recognition because the connections between orthographic, semantic and phonological information may differ for deaf and hearing readers. For example, word frequency norms are an estimate of an individual's exposure to words, and more frequent exposure facilitates word recognition.  It is likely that frequency in written English is modulated by exposure to spoken English, as increased exposure to spoken language will have an effect on how written language is processed. As deaf readers do not have experience of spoken English, they will not be able to benefit from frequency as their hearing peers, or in other words, current word frequency norms, based on ratings by hearing individuals, may not be such a good estimate of frequency at the individual level for deaf readers.

In addition to lexical variables, semantic variables such as valence, arousal, concreteness and imageability also have an influence on word recognition, as established by looking at differences in response latencies in lexical decision. The effects of these variables demonstrate that readers are accessing meaning during single word recognition. For emotional variables, it is well established that valence has an impact on word recognition in hearing readers, although there is debate about the direction of those effects (see Hinojosa et al., 2015; Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011; Kuperman, Estes, Brysbaert, & Warriner, 2014; Vinson, Ponari, & Vigliocco, 2014). Generally, the more emotionally valenced words have a facilitatory effect, i.e. yield faster decision latencies (Kousta, Vinson, & Vigliocco, 2009; Vinson et al., 2014). Again, although there is consensus in the literature that concreteness and imageability influence decision latencies, the nature of those effects are still under debate (see Cortese & Fugett, 2004; Kousta et al., 2011; Soares, Costa, Machado, Comesaña, & Oliveira, 2016). In general, concrete and highly imageable words yield faster decision latencies, however this is modulated by valence (Kousta et al., 2011). Some of the semantic effects (like valence/concreteness/imageability) are attributed to body-related experiences (whether sensory, motoric or emotional, Vigliocco, Meteyard, Andrews, & Kousta, 2009). For deaf individuals, if semantic activation from print is less effective/efficient, such "embodied" effects might be reduced.

It is also the case that, however, although deaf and hearing readers' everyday communication may differ (i.e. deaf people use sign language and hearing people use spoken language), this does not mean that deaf readers are less exposed to written English. In fact, deaf readers may rely more heavily on print, as this is their main access to English (e.g., the use of subtitles). Thus, one could speculate that the connections between orthography and semantics may be more robust for deaf compared to hearing readers as they rely on this channel more frequently.

In the present study, we explore how lexical and semantic variables (e.g. word length, word frequency, valence, concreteness) that have been shown to play a role in skilled reading by hearing individuals affect skilled deaf readers who use BSL as their main form of communication.  We test the impact of the following lexical and semantic variables: valence, arousal, concreteness, age of acquisition, familiarity, number of letters in a word, word frequency, how many orthographic neighbours a word has and bigram frequency-by-position. In particular, we are interested in exploring interactions, if any, between group and word properties.

On the basis of the fact that deaf and hearing individuals have different language experience, we predict that frequency effects will differ for the two groups, with hearing readers showing a stronger effect of frequency due to increased exposure to spoken language. Additionally, we hypothesise that semantic effects may be less strong for the deaf readers compared to the hearing readers due to differences in reading and language experience.

## 4.1 Methods

### 4.1.1 Participants

A total of 38 participants took part in this study, 19 deaf, native BSL users and 19 hearing, native English speakers. Deaf participants were either severely or profoundly deaf. Participants from each group were matched as closely as possible for age, gender, education and reading level. All participants completed a questionnaire in which they provided information about their age, gender, education and language history (see Appendix 1). This information was collected to ensure that hearing participants were native speakers of English and that deaf participants were fluent in both written English and BSL and that both deaf and hearing participants matched on age, gender and educational levels. Deaf participants were asked to fill in an additional questionnaire, which asked about their deafness, hearing status of parents and siblings, language experience and educational background (see Appendix 2).

Reading level was assessed using the Vernon-Warden Reading Test (Hedderly, 1996). This is a timed (10minutes) reading test in which participants choose the missing word in a sentence from five options provided (max score = 42).

In addition, deaf readers were asked to carry out also a task assessing their BSL skills. We used the BSL Sentence Repetition Task (SRT), which is a non-standardised assessment of global BSL fluency (adapted from the American Sign Language (ASL) SRT (Hauser, Paludneviciene, Supalla, & Bavelier, 2008)). A small subset of data has been collected on BSL users showing that there are clear differences between native and non-native signers (Cormier, Adam, Rowley, Woll, & Atkinson, 2012; Rowley, Johal, & Woll, 2013). 40 BSL sentences, varying in complexity, were presented to deaf participants and participants were instructed to recall the sentences verbatim. Participants were given a score of 1 if repeated sentences were judged to be exactly as the original and a score of 0 if they were not (max. score 40). Participants' responses were filmed and scored at a later date by the author who has been trained to administer and score this test.

One deaf participant achieved a low score on the reading test (more than 2.5 standard deviations below the group mean) and was subsequently removed from data analysis. One hearing participant achieved accuracy scores that were more than 2.5 standard deviations below the group mean (79%) on the lexical decision task and were therefore excluded from data analysis. One hearing participant had reaction times that were more than 2.5 standard deviations above the group mean and thus was removed from data analysis. Any matched participants (matched to the excluded participants) were also excluded from any further data analyses. Thus, a total of 32 participants (16 in each group) were included in data analysis. Participants were given monetary compensation for taking part in this study. See Table 4-1 for participant demographics and see Table 4-2 for further information about the deaf participants' use of language and amplification aids.

**Table 4-1 - Participants' age, gender and education level**

| Participants | Deaf | Hearing |
|---|---|---|
| Male | 8 | 8 |
| Female | 8 | 8 |
| Age | 30.69 | 30.5 |
| Age Range | 19-41 | 18-42 |
| Education level | | |
| College | 3 | 2 |
| HND | 2 | 1 |
| Bachelors | 7 | 7 |
| Masters | 4 | 6 |

**Table 4-2 - Deaf participants' degree of deafness, language experience and use of amplification aids**

| | |
|---|---|
| **Degree of Deafness** | Severe or profound - 16 |
| **Amplification aids** | Hearing aids – 8<br>None used - 8 |
| **Sign language background** | Native – 8<br>*Near native – 6<br>**Late learner – 2 |

*Near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

** Late learners used BSL as their main language for more than 10 years

#### 4.1.1.1 Reading measures

The Vernon-Warden Reading Test was administered to all participants to ensure both groups were matched as closely as possible on reading level. A pairwise comparison of the reading level of hearing readers *(n = 16, m = 30.25, SD = 5.74, range = 18 - 42)* and deaf readers *(n = 16, m = 29.63, SD = 6.15, range = 19 - 41)* showed no significant differences *(t (15) = -.275, p = .787 (two-tailed)).*

#### 4.1.1.2 Sign language measures

The BSL SRT was administered to all participants to test for global BSL fluency and to see if there are any correlations between scores on the BSL SRT and reading scores as several studies have reported correlations between sign language fluency and reading achievement (Hauser et al., 2008). Additionally, we wanted to see if there were any correlations between scores on the BSL SRT and performance on the lexical decision task. On average, deaf participants achieved a score of *27.25 out of 42 (SD = 3.99, range = 19 – 34).*

### 4.1.2 Stimuli

480 words and 481 nonwords were selected (see Appendices 3 and 4 for the full list of items). The 480 English words were obtained from a previous study (Kousta et al., 2011) and most of the nonwords were obtained from the English Lexicon Project (ELP) Database (Balota et al., 2007). 80 of the nonwords used in this study were pseudohomophones, 59 of which were taken from Twomey, Keith, Price, & Devlin's (2011)study. A further 21 pseudohomophones were derived from the words included in this study. Results from the pseudohomophone data will not be reported in this chapter. To ensure that words and nonwords were similar, they were exactly matched (pairwise) for length and for orthographic neighbourhood. Past studies

have shown that orthographic neighbourhood size influence decision latencies, i.e. words with many orthographic neighbours slow down decision latencies (Cortese & Balota, 2012). They were also closely matched for bigram frequency by position (to ensure that words and nonwords were visually similar) using data from the English Lexicon Project (ELP, Balota et al 2007). A pairwise comparison of the bigram frequencies-by-position of the words and nonwords revealed no significant differences *(t (479) = 1.226, p = .221, two-tailed)*. By controlling for the visual similarity of the words and nonwords, any significant effects cannot be attributed to differences between the words and nonwords. All of the words and nonwords were merged into a single word list and entered into E Prime version 2.0 (Schneider, Eschman, & Zuccolotto, 2002).

### 4.1.3 Procedure

All participants were tested individually using a Lenovo ThinkPad laptop with a 13-inch screen. All words and nonwords were presented randomly using E Prime version 2.0 (Schneider et al., 2002). A fixation cross was presented at the centre of a PC computer screen for 400ms followed by a stimulus that remained visible until subjects responded. Reaction times (RTs) and accuracy were recorded. Participants were instructed to decide whether the stimulus presented was a word or not by pressing the ‘j’ button to indicate ‘yes’ if the word presented is an English word and the ‘f’ button to indicate ‘no’ if it was not as quickly and as accurately as possible. A deaf, native signer administered the tests to deaf participants and instructions were delivered in BSL. Instructions to hearing participants were delivered in English via a BSL/English interpreter.

### 4.1.4 Analyses

For RT analysis, we only considered correct responses from the word trials. Variables of interest included in the analysis were orthographic neighbourhood, length, frequency, familiarity, imageability, concreteness, arousal, valence, hedonic valence, age of acquisition (AOA) and bigram frequency-by-position (See Table 4-3 for descriptive statistics). Responses by group (hearing and deaf readers) were compared for all variables.

**Table 4-3 – Variables included in this study along with means, standard deviation (SD) and range for each variable.**

| Variable tested | Mean | SD | Range |
|---|---|---|---|
| AOA | 387.58 | 111.44 | 152 – 694 (months) |
| Arousal | 4.85 | 0.94 | 2.67 – 7.67 |
| Bigram frequency-by-position | 1787.39 | 1076.85 | 59 – 6359 |
| Concreteness | 459.50 | 115.29 | 219 – 634 |
| Familiarity | 507.93 | 64.82 | 351 – 645 |
| Frequency | 8.89 | 1.58 | 1.58 – 12.47 |
| Hedonic Valence* | 1.14 | 0.95 | 0.00 – 3.44 |
| Imageability | 488.35 | 93.01 | 213 – 637 |
| Length | 6.29 | 2.31 | 3 – 14 |
| Orthographic Neighbourhood Size | 3.19 | 4.60 | 0 – 23 |
| Valence* | 5.21 | 1.47 | 1.56 – 8.44 |

*Note, hedonic valence measures the effect of either positively or negatively valenced words on decision latencies/accuracy rates. Valence measures the effects of valence on decision latencies/accuracy rates on a continuum basis ranging from negatively to positively valenced words, including neutrally valenced words.

We analysed the effects of these variables on reaction times and accuracy. In order to do so, mixed-effects modelling with crossed random effects for participants and items along with restricted maximum likelihood estimation[2] was used. Interactions were tested using separate models and compared directly to one another. Initially, as we hypothesised that there may be different effects of frequency in deaf and hearing readers due to language experience, we tested for all possible interactions involving group and frequency, as well as main effects of all the other variables such as length, valence etc. (interaction effects were not tested for the other variables, only for group and frequency). We fit a series of models by eliminating terms that did not improve model fit, after each step performing model comparisons between the reduced model and the previous one (see Appendices 5 and 6). We first eliminated three-way interactions that did not improve model fit, followed by removal of two-way interactions involving variables that did not improve model fit and did not participate in three-way interactions, followed by removal of variables that did not contribute at all. Here, we report results from the final refitted models (for both RTs and accuracy). As the final models showed significant interactions between group and some variables, we analysed each group (deaf and hearing) separately to determine the extent and directions of those interactions. The package used for this analysis was the lme4 package v.1.1-12 (Bates, Mächler, Bolker, & Walker, 2015), which was run using R version 3.3.3 (R Core Team, 2017). In addition to random intercepts for participants and items, we started with an initial model that also included random slopes of the linguistic variables by participant, and of group by items. As these models failed to converge we removed the random slopes during model selection. We added frequency as a random slope by participants in the final model, with comparable results.

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[2] Restricted maximum likelihood estimates were used as it only focuses on the variance components and there is less bias, which is more appropriate for a small sample size.

For the deaf participants, correlation analyses (Pearson's *r*) were carried out for reading and BSL SRT scores. Correlations (Pearson's *r*) between reading scores and performance on the lexical decision task were also tested for both groups.

## 4.2 Results

**Reaction Times.** Prior to data analysis, items with an error rate of more than 35% were removed (these were 'anecdote' and 'receptacle', 0.4% of all data). Responses below 250ms and above 2000ms were also excluded from data analysis. Main effects are reported in Table 4-4. There was no main effect of bigram frequency-by-position or valence, thus this was dropped from the model early on in the analyses.

**Table 4-4 - Terms included in the final model**

| | Estimate | Std. Err. | t value | p value |
|---|---|---|---|---|
| Intercept | 1.12 | 2.12 | 5.29 | <0.01 |
| Group | -2.49 | 1.39 | -1.80 | 0.07 |
| AOA | 5.85 | 1.50 | 3.89 | <0.01 |
| Frequency | -5.99 | 2.34 | -2.56 | 0.01 |
| Hedonic Valence | -1.15 | 3.00 | -3.82 | <0.01 |
| Familiarity | -9.12 | 2.17 | -4.19 | <0.01 |
| Length | 1.22 | 1.54 | 6.88 | <0.01 |
| Orthographic Neighbourhood | 2.35 | 5.42 | 4.33 | <0.01 |
| No. of morphemes | -1.72 | 5.98 | -2.87 | <0.01 |
| Arousal | -3.97 | 1.62 | -2.45 | 0.01 |
| Concreteness | -1.53 | 1.40 | -1.09 | 0.27 |
| AOA x Frequency | -4.81 | 1.67 | -2.88 | <0.01 |
| Frequency x Familiarity | 8.13 | 2.45 | 3.31 | <0.01 |
| Group x Hedonic Valence | 7.71 | 3.48 | 2.22 | 0.03 |
| Group x Arousal | 4.55 | 1.88 | 2.42 | 0.02 |
| Group x Concreteness | 3.37 | 1.48 | 2.28 | 0.02 |
| Group x Length | -8.30 | 1.32 | -6.28 | <0.01 |
| Group x Arousal x Frequency | -4.90 | 2.04 | -2.40 | 0.02 |
| Group x Arousal x Concreteness | -3.61 | 1.62 | -2.23 | 0.03 |

There were main effects, but no interactions, involving orthographic neighbourhood size and number of morphemes. As orthographic neighbourhood size increased, decision latencies also increased and participants were faster to respond to monomorphemic words in comparison to polymorphemic words. There were main effects of length and hedonic valence, however these effects were qualified by a 2-way interaction with group. There were also main effects of frequency, familiarity and AOA, however there were also interactions between frequency and familiarity as well as frequency and AOA, which are explored further below. There was not a significant main effect of group, but there were significant 3-way interactions between group, arousal and concreteness.

To follow up the significant 2-way interactions between group and length and between group and hedonic valence, we first fit separate models for deaf and hearing participants (which directly allowed us to test the 2-way interactions involving length and hedonic valence). These models were the same as the "final" model described above, with the exception that the group term was removed (see Table 4-5 for results from the separate models).

**Table 4-5 - Simple main effects of variables that were involved in interactions with Group, when analysed separately for deaf and hearing participants (See Appendix 7 for full results for each group)**

| | Estimate | Std. Error | T value | P value |
|---|---|---|---|---|
| Deaf | | | | |
| Intercept | 816.12 | 83.62 | 9.76 | <0.01 |
| Hedonic Valence | -11.80 | 3.17 | -3.73 | <0.01 |
| Arousal | -1.97 | 3.27 | -0.60 | 0.55 |
| Concreteness | -0.28 | 0.13 | -2.10 | 0.04 |
| Frequency | -25.89 | 7.04 | -3.68 | <0.01 |
| Length | 11.78 | 1.80 | 6.53 | <0.01 |
| Concreteness x Frequency | 0.02 | 0.01 | 1.86 | 0.06 |
| Hearing | | | | |
| Intercept | 831.72 | 81.23 | 10.24 | <0.01 |
| Hedonic Valence | -4.06 | 3.11 | -1.31 | 0.19 |
| Arousal | -1.50 | 3.21 | -0.47 | 0.64 |
| Concreteness | 0.00 | 0.13 | 0.01 | 0.99 |
| Frequency | -14.45 | 6.95 | -2.08 | 0.04 |
| Length | 5.11 | 1.77 | 2.89 | <0.01 |
| Concreteness x Frequency | 0.00 | 0.01 | -0.31 | 0.75 |

These analyses show that deaf participants were more affected by hedonic valence in comparison to hearing participants for whom there was no effect of hedonic valence. Deaf participants were also more affected by word length in comparison to hearing participants. For each letter increase, deaf participants were 11ms slower, whereas hearing participants were 5ms slower for each letter increase, especially for longer words (See Figure 4-1). Further analyses show that the effect was still significant even after removing words that were 12 letters or longer (19 words in total). Moreover, we also tested for quadratic effects of length (including group in the model), given that recent studies have shown such a quadratic effect of length in addition to linear effects (e.g. Ferrand et al., 2011). However there were no significant effects on the quadratic term for length or an interaction effect between group and length on the quadratic term.

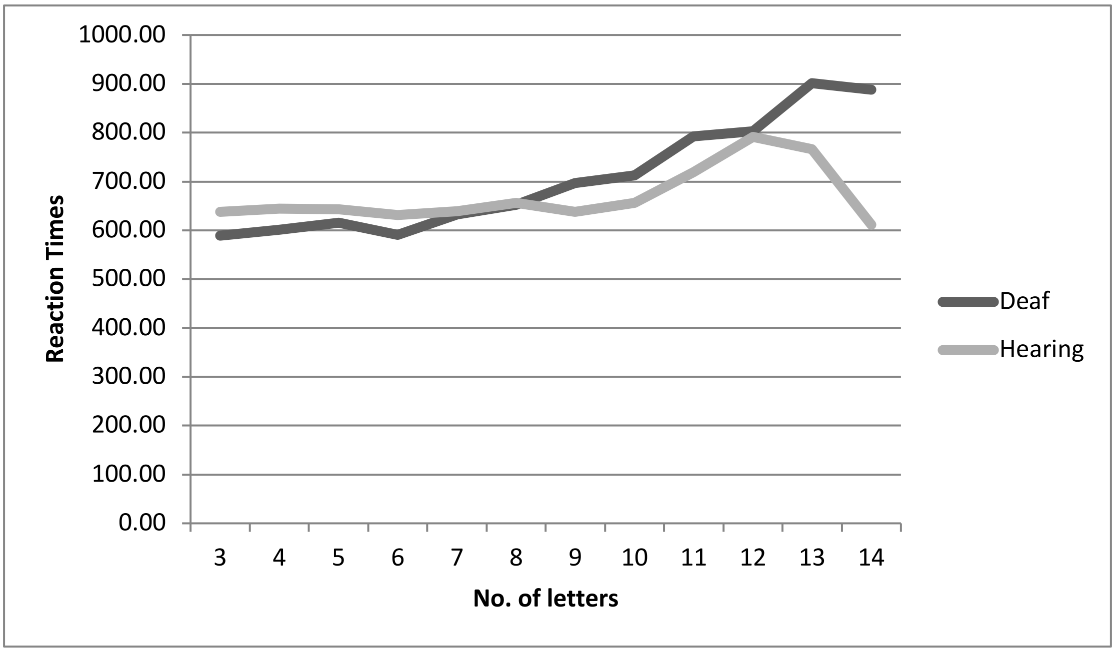

**Figure 4-1 - The above figure depicts length effects in deaf and hearing readers.**

Further analyses were carried out to investigate the three-way interactions involving group x frequency x concreteness, as well as group x frequency x arousal. Initially, we subdivided the items into high vs. low frequency (median split) and ran four different models testing the effects of concreteness and arousal for each group (i.e. the four models compared high vs. low frequency items and how this interacted with concreteness for each group. The same four models were also carried out with arousal). As those separate models did not indicate obvious differences driving the interactions (see Appendix 8 for results), we carried out analyses, for the deaf and hearing groups separately, discretizing the other variables involved in the interaction (median split) one at a time. For concreteness, there is an effect of frequency; participants were faster to respond as word frequency increased with the exception of abstract words for the hearing readers (see Figure 4-2).

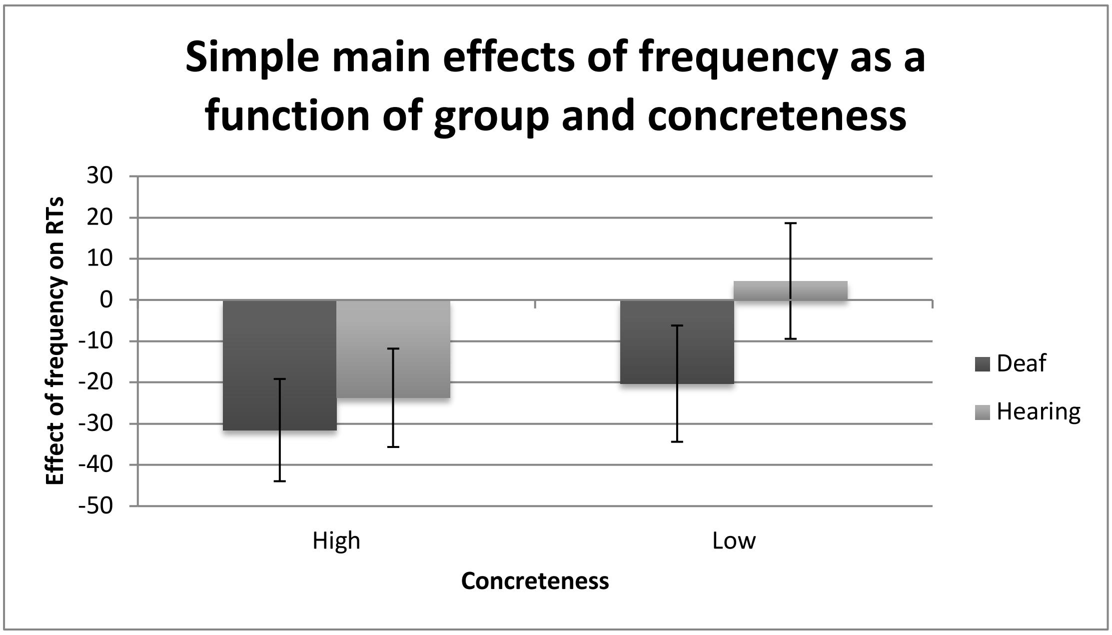

**Figure 4-2 - The X axis represents concreteness (high vs low) and the Y axis shows the parameter estimates from the separate models. The error bars show the standard errors for each parameter estimate. Parameter estimates show the differences in the effect of frequency between highly concrete words and words that are low in concreteness.**

Finally, we fit a set of models discretizing arousal within deaf/hearing groups separately and found that the effect of frequency seems to be larger for low arousing words for deaf readers.

As word frequency increased, deaf participants responded faster to low arousing words (15ms faster). There were no effects for hearing readers (see Figure 4-3).

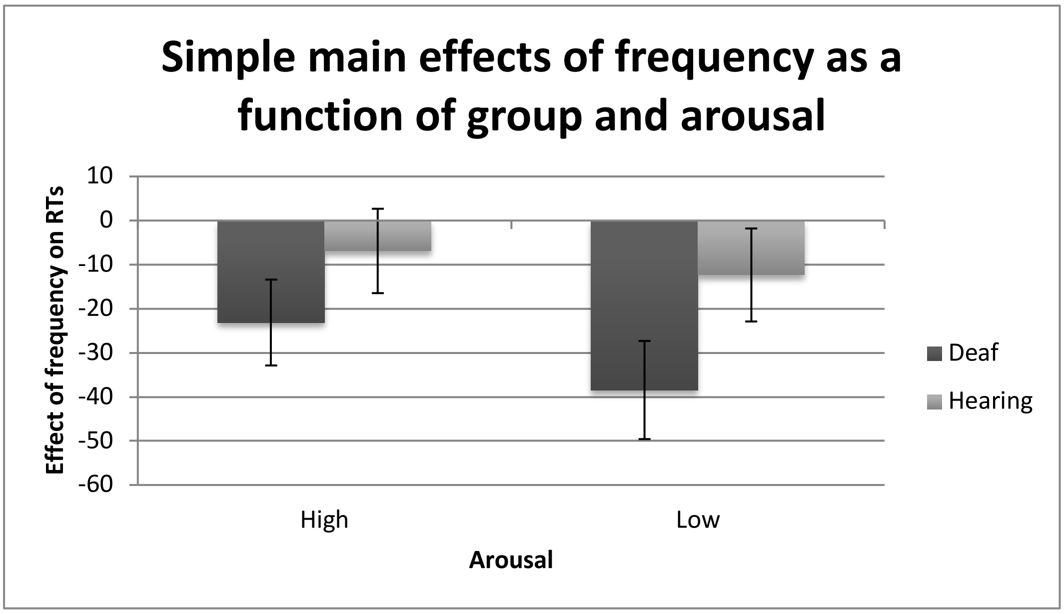

**Figure 4-3 - The X axis represents words' arousal and the Y axis show the parameter estimates from the separate models. The error bars show the standard errors for each parameter estimate. Parameter estimates show the differences in the effect of frequency between high and low arousing words.**

To explore further why there was very little evidence of semantic effects (hedonic valence, arousal and concreteness) for the hearing group (frequency effects for highly concrete words), these variables were removed from the model. This was to test whether or not the combined semantic effect from these three variables had a significant effect. Model comparisons showed no improvement when the semantic variables were added *($\chi2 = 4.91$, $p = 0.30$).* This lack of semantic effects for hearing readers in the current study may be due to our small sample size. Effect sizes were calculated for each of the three variables (valence (r

= .05), arousal (r = .03) and concreteness *(r = -.05)*) for the hearing group, and all revealed a very small effect size.

To rule out effects of multicollinearity, correlation analyses were carried out on all of the variables included in the model. Results revealed that concreteness and imageability highly correlated with one another, at r = .83 (see Table 4-6). Follow-up models were carried out, removing imageability from the model, with comparable results.

**Table 4-6 Correlation coefficients for different variables included in the model.**

| Variable | AOA | Arousal | Bigram Frequency | Concreteness | Familiarity | Frequency | Hedonic Valence | Imageability | Length | ONS* | Valence |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOA | 1.00 | .12 | .34 | -.50 | -.58 | -.27 | .74 | -.59 | .49 | -.40 | -.15 |
| Arousal | .12 | 1.00 | .01 | -.26 | -.49 | .07 | .56 | -.06 | .06 | -.38 | .08 |
| Bigram frequency | .34 | .01 | 1.00 | -.02 | -.15 | -.08 | .30 | -.29 | .73 | -.35 | -.04 |
| Concreteness | -.50 | -.26 | -.02 | 1.00 | .10 | -.11 | -.21 | **.83** | -.32 | .22 | .06 |
| Familiarity | -.58 | -.58 | -.15 | .10 | 1.00 | .06 | .27 | .19 | -.24 | .23 | .15 |
| Frequency | -.27 | .07 | -.08 | -.11 | .06 | 1.00 | .26 | -.11 | -.22 | .22 | .15 |
| Hedonic Valence | .74 | .56 | .30 | -.21 | .27 | .26 | 1.00 | .03 | .03 | -.08 | .01 |
| Imageability | -.59 | -.06 | -.29 | **.83** | .19 | -.11 | .03 | 1.00 | -.34 | .23 | .08 |
| Length | .49 | .06 | .73 | -.32 | -.24 | -.22 | .03 | -.34 | 1.00 | -.64 | -.01 |
| Orthographic Neighbourhood Size | -.40 | -.38 | -.35 | .22 | .23 | .22 | -.08 | .23 | -.64 | 1.00 | .02 |
| Valence | -.15 | .08 | -.04 | .06 | .15 | .15 | .01 | .08 | -.01 | .02 | 1.00 |

*Note.* Figures in bold face indicate significant correlations between variables. *Orthographic Neighbourhood Size

**Accuracy.** Responses below 250ms and above 2000ms were excluded from the data analysis. Main effects are shown in Table 4-7.

**Table 4-7 – Terms included in the final model for accuracy analyses**

| Main Effects for both groups | Estimate | Std. Error | t value | p |
|---|---|---|---|---|
| Intercept | 9.83 | 2.35 | 41.78 | <0.01 |
| Group | -1.33 | 2.19 | -6.06 | <0.01 |
| Familiarity | -4.34 | 4.35 | -0.10 | 0.92 |
| AOA | -5.42 | 1.82 | -2.99 | <0.01 |
| Frequency | 3.53 | 1.77 | 2.00 | 0.05 |
| Group x Familiarity | 2.10 | 4.77 | 4.41 | <0.01 |
| Group x Frequency | 1.25 | 2.16 | 0.58 | 0.56 |
| Group x Orthographic Neighbourhood Size | -8.49 | 3.44 | -2.47 | 0.01 |
| Frequency x Orthographic Neighbourhood Size | 2.71 | 2.88 | 0.94 | 0.35 |
| Group x Frequency x Orthographic Neighbourhood Size | 7.39 | 3.55 | 2.08 | 0.04 |

Analyses revealed that there are main effects of age of acquisition, familiarity, group and frequency and interaction effects between group and familiarity, as well as between group and orthographic neighbourhood size. Additionally, there was also a 3-way interaction between group, frequency and orthographic neighbourhood size.

To follow up the significant interactions between group and frequency and between group and familiarity, we first fit separate models for deaf and hearing participants (which allowed us to assess the main effect of frequency and familiarity for each group separately). These models were the same as the "final" model described above, with the exception that the group term was removed (see Table 4-8 for results from the separate models)

**Table 4-8 - Simple main effects of variables that were involved in interactions with Group, when analysed separately for deaf and hearing participants.**

| | Estimate | Std. Error | t value | p |
|---|---|---|---|---|
| Deaf | | | | |
| Intercept | 9.63 | 2.11 | 45.64 | <0.01 |
| Familiarity | 2.13 | 3.72 | 0.57 | 0.57 |
| Frequency | 3.23 | 1.43 | 2.26 | 0.02 |
| Orthographic Neighbourhood Size | -3.56 | 2.26 | -1.58 | 0.12 |
| Frequency x Orthographic Neighbourhood Size | 2.57 | 2.32 | 1.11 | 0.26 |
| Hearing | | | | |
| Intercept | 8.71 | 3.19 | 27.27 | <0.01 |
| Familiarity | 1.81 | 5.51 | 3.28 | <0.01 |
| Frequency | 5.03 | 2.11 | 2.39 | 0.02 |
| Orthographic Neighbourhood Size | -1.27 | 3.35 | -3.78 | <0.01 |
| Frequency x Orthographic Neighbourhood Size | 1.02 | 3.43 | 2.98 | <0.01 |

The results from the separate group analyses show that larger effects in the hearing group (compared to the deaf group) drove the interaction effects with group. Namely, hearing readers' were more accurate with words that were acquired earlier in life and highly familiar words. No such effects were found for deaf readers. This is likely to be because deaf readers had higher accuracy rates overall compared to the hearing group (ceiling effects), which make any influence of lexical variables on accuracy rates in the deaf group hard to detect. There was a simple main effect of frequency for both groups. For the hearing readers there were interaction effects between frequency and orthographic neighbourhood size. There was an effect of familiarity and age of acquisition on accuracy rates for the hearing group only.

Further analyses were carried out to investigate the 2-way interactions involving frequency x orthographic neighbourhood size for the hearing group only. We carried out separate analyses for high and low frequency items (median split). See Table 4-9 for results.

**Table 4-9 – Simple main effects of variables for high and low frequency items for the hearing group**

| | Estimate | Std. Error | t value | p |
|---|---|---|---|---|
| High | | | | |
| Intercept | 9.37 | 3.48 | 26.92 | <0.01 |
| Orthographic Neighbourhood Size | -1.03 | 4.39 | -2.35 | 0.02 |
| Low | | | | |
| Intercept | 8.64 | 5.24 | 16.48 | <0.01 |
| Orthographic Neighbourhood Size | -5.87 | 1.21 | -4.86 | <0.01 |

Analysing high and low frequency items separately showed that there is still a simple main effect of orthographic neighbourhood size for both high and low frequency items. Hearing readers are affected by orthographic neighbourhood size (larger neighbourhoods = less accurate overall: simple main effect of orthographic neighbourhood size is significant in both models with negative sign) but this effect is stronger for less frequent words (See Figure 4-4). Orthographic neighbourhood size did not influence deaf readers' accuracy rates, which explains the interaction effects detected earlier between group, frequency and orthographic neighbourhood size.

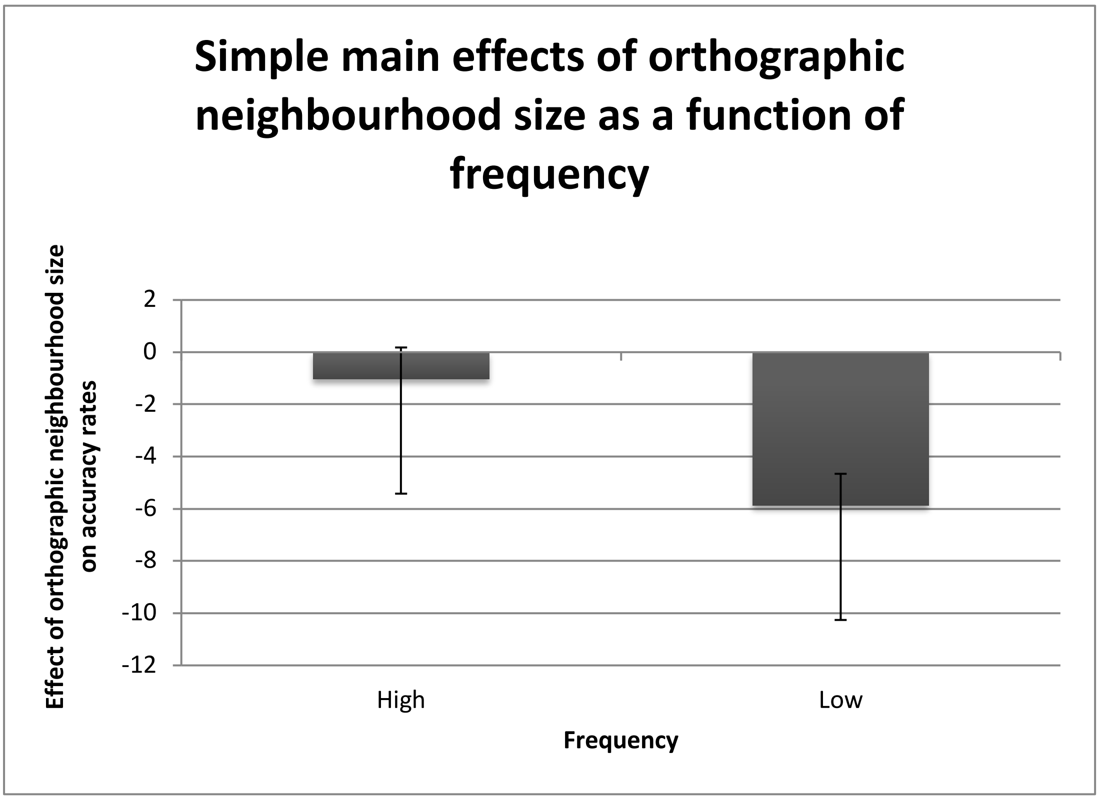

**Figure 4-4 - The X axis represents word frequency and the Y axis show the parameter estimates from the separate models. The error bars show the standard errors for each parameter estimate. Parameter estimates show the differences in the effect of orthographic neighbourhood size between high and low frequency words.**

As with the reaction time analyses, to rule out effects of multicollinearity, correlation analyses were carried out on all of the variables included in the model. Results revealed that imageability highly correlated with both concreteness ($r = .84$) and valence ($r = .88$) (See Table 4-11). Valence and hedonic valence were also highly correlated ($r = .93$) (See Table 4-11). Follow up models were carried out leaving out imageability and valence. Note, in the models where imageability was left out, valence was kept in and vice versa. Results show that there are reliable main effects of group (deaf readers were more accurate), AOA and frequency across all three final models (for both groups), see Appendix 9. Additionally, follow up models also showed that there were no main effects of bigram frequency-by-position, concreteness, length or orthographic neighbourhood size, which is in line with the results from the model reported in this section (see Appendix 9). For the hearing group, both final follow up models also showed an effect of orthographic neighbourhood size on accuracy rates (see Table 4-10).

**Table 4-10 - Orthographic Neighbourhood Size effects for the hearing group in the follow up models**

| | Estimate | Std. Error | t value | p |
|---|---|---|---|---|
| No imageability model | | | | |
| Orthographic Neighbourhood Size | 13.13 | 4.41 | 2.98 | <0.01 |
| No valence model | | | | |
| Orthographic Neighbourhood Size | 9.87 | 4.66 | 2.11 | 0.03 |

**Table 4-11. Correlation coefficients for different variables included in the model.**

| Variable | AOA | Arousal | Bigram Frequency | Concreteness | Familiarity | Frequency | Hedonic Valence | Imageability | Length | ONS* | Valence |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOA | 1.00 | .12 | .40 | -.51 | -.59 | -.30 | .01 | -.61 | .54 | -.41 | -.15 |
| Arousal | .12 | 1.00 | .51 | -.26 | -.54 | .62 | .55 | -.58 | .43 | -.36 | .77 |
| Bigram frequency | .40 | .51 | 1.00 | -.29 | -.18 | -.12 | .04 | -33 | .76 | -.36 | -.44 |
| Concreteness | -.51 | -.26 | -.29 | 1.00 | .12 | -.08 | -.21 | **.84** | -.35 | .24 | .61 |
| Familiarity | -.59 | -.54 | -.18 | .12 | 1.00 | .64 | .03 | .21 | -.27 | .23 | .16 |
| Frequency | -.30 | .62 | -.12 | -.08 | .64 | 1.00 | .04 | -73 | -.27 | .23 | .14 |
| Hedonic Valence | .01 | .55 | .04 | -.21 | .03 | .04 | 1.00 | .25 | .03 | -.07 | **.93** |
| Imageability | -.61 | -.58 | -33 | **.84** | .21 | -.07 | .25 | 1.00 | -.39 | .24 | **.88** |
| Length | .54 | .43 | .76 | -.35 | -.27 | -.27 | .03 | -.39 | 1.00 | -.60 | -.21 |
| Orthographic Neighbourhood Size | -.41 | -.36 | -.36 | .24 | .23 | .23 | -.07 | .24 | -.60 | 1.00 | .29 |
| Valence | -.15 | **.77** | -.44 | .61 | .16 | .14 | **.93** | **.88** | -.21 | .29 | 1.00 |

*Note.* Figures in bold face indicate significant correlations between variables. *Orthographic Neighbourhood Size

**Correlation analyses.** There were no correlations between reading and BSL SRT scores for deaf participants *(r = .101, n = 16, p = .710 (two tailed))*. There were also no correlations between reading scores and performance (RTs and accuracy) on the lexical decision task (See Table 4-12).

**Table 4-12 – Results from the correlation analyses carried out between reading scores and performance on the lexical decision task (both RTs and accuracy) for each group**

| Group | N | Accuracy | RT |
|---|---|---|---|
| **Overall** | 32 | *r = -.197, p = .279* | *r = .129, p = .483* |
| **Deaf** | 16 | *r = .245, p = .360* | *r = .282, p = .289* |
| **Hearing** | 16 | *r = -.419, p = .106* | *r = -.016, p = .953* |

## 4.3 General Discussion

The present experiment explored how different lexical and semantic variables influenced visual word recognition in skilled deaf readers, whilst comparing this group to a group of carefully matched hearing readers using a lexical decision task. Hearing readers' performance was affected by the lexical variables in similar ways as previously reported in the literature (Balota et al., 2004; Brysbaert & Cortese, 2011; Ferrand et al., 2011; New, Ferrand, Pallier, & Brysbaert, 2006). However, some of the semantic variables (concreteness, valence and arousal) that have previously been shown to show effects in hearing readers (Balota et al., 2007; Brysbaert et al., 2000; Keuleers et al., 2012; Kousta et al., 2011; Vinson et al., 2014), were not significant in the current study, despite testing for combined semantic effects. The lack of effects for the semantic variables is in contradiction with past studies that have shown semantic effects during single word recognition (e.g., Kousta et al., 2011), however it is important to note that there were only 16 hearing participants in this study, which is likely to be due to low statistical power (Effect sizes were very small for arousal, concreteness and valence for the hearing group).

Performance of the deaf readers in this study also largely replicates findings from hearing readers. This is a crucial finding as it demonstrates that skilled deaf readers' word recognition processes are influenced by lexical and semantic variables in the same ways as in hearing readers. Importantly the deaf readers in this study were matched to the hearing readers for age, gender, educational level and overall reading level. This has not typically been the case in many previous study of reading in deaf adults (Bélanger et al., 2013). This finding has important implications, as it demonstrates that deaf readers are able to develop robust connections between orthographic and semantic codes despite differences in early language experience.

However, there were some interesting differences between the two groups of readers. First, deaf readers were more affected by word-length in comparison to hearing readers; an increase of one letter meant decision latencies increased by 11ms. This effect remained even after removing a small subset of long words (12+ letters). Second, there were semantic effects for deaf readers and not for hearing readers: deaf RTs were influenced by valence, arousal and concreteness and no such effects were found for hearing readers. Deaf readers were faster to respond to highly valenced words (11.8ms), low arousing words (compared to high arousing words) and concrete words, however arousal and concreteness effects were modulated by frequency. Deaf readers were quicker to respond to low arousing words as frequency increased, which explains the 3-way interaction effect between group, frequency and arousal. Both deaf and hearing readers were faster to respond as word frequency increased, except for hearing readers with abstract words, which explains the 3-way interaction between group, frequency and concreteness. Third, deaf readers were more accurate overall compared to the hearing readers, which indicates that deaf readers are highly efficient readers, as has been reported in numerous studies (Bélanger, Slattery, et al., 2012; Dye, Hauser, & Bavelier, 2009). Additionally, for the deaf readers there was only an effect of frequency on accuracy rates whereas frequency, age of acquisition, familiarity and orthographic neighbourhood influenced hearing readers' accuracy rates. This is likely to be because deaf readers achieved accuracy rates that were at ceiling levels. For hearing readers, there were interaction effects between frequency and orthographic neighbourhood size, i.e. they were less accurate with words that have large orthographic neighbourhood sizes. However, this effect is stronger for less frequent words. Deaf readers' accuracy rates were unaffected by orthographic neighbourhood size.

We raised the possibility in the introduction that semantic effects would be less strong for deaf readers, as they may have less overall exposure to English and that semantic effects may be influenced by the amount of exposure to spoken language. The findings of this study suggest otherwise, as semantic effects were stronger for deaf readers. This suggests that deaf readers may have stronger connections between orthography and semantics than hearing individuals, which is also supported by the fact that their accuracy rates were also higher compared to the hearing readers. This may be a consequence of their relying on written information to a larger extent than hearing counterparts for example in watching TV with subtitles, texting, email and the use of textphones to make phone calls etc. These findings are also in line with studies where it has been found that young deaf readers develop stronger orthographic representations compared to their hearing counterparts (Harris & Moreno, 2004), even though reading development in young deaf children is generally slower compared to hearing children (Harris et al., 2017a; Kyle & Harris, 2011). The increased exposure to print enables deaf children and adults to develop strong connections between orthography and semantics. For hearing children, reading experience has been found to be one of the strongest predictors for successful reading attainment (Nation, 2017), which could explain why these connections between orthography and semantics seem to be stronger for deaf readers.

Additionally, deaf readers' decision latencies are sensitive to frequency effects across semantic domains, as indicated by the results from splitting arousal and concreteness into two groups; high and low arousal/concreteness (median split). Frequency effects were present for deaf readers for both high and low arousing words as well as both concrete and abstract words, while this was not the case for hearing readers. Additionally, for deaf readers the effects of these semantic variables were more pronounced for low frequency words. For the hearing readers, frequency effects were only present for concrete words. These results might have come about as a consequence of greater exposure to English in print for deaf readers. Effects from increased exposure to print may not occur for high frequency words, as there may be a point where frequency no longer has an effect. Previous studies have shown that skilled deaf readers are highly efficient at extracting information from print (Bélanger et al., 2013) and are more accurate in lexical decision tasks than hearing readers (Bélanger, Baum, et al., 2012). Both studies found that deaf readers relied more on orthography than phonology during single word recognition and were extremely efficient in doing so, which may be an explanation for why semantic variables led to faster decision latencies for deaf than hearing readers in this study. Overall, the differences in semantic and frequency effects on decision latencies in the two groups indicate that deaf readers are more efficient readers, which should lead to better reading comprehension.

Frequency effects have also been found in deaf skilled and less skilled readers in a sentence-processing task where low frequency words were fixated upon for longer compared to high frequency words. Low frequency target words were also less likely to be skipped in comparison to high frequency words (Bélanger & Rayner, 2013). Deaf readers' performance on this task was very similar to hearing readers, whether skilled or less skilled (Bélanger & Rayner, 2013, 2015). It is unsurprising that frequency effects is evident in both deaf and hearing readers, based on this study's findings and that of past studies, as frequency is a powerful predictor of performance in many psycholinguistic tasks (Cortese & Balota, 2012). Frequency effects show strong support for the importance of reading experience when accessing semantic information via orthographic codes. Importantly, Nation (2017) points out that print exposure does not only predict successful reading in young readers but also how skilled adult readers process the written word. Deaf readers' eye movements follow a similar pattern to hearing readers where their fixation durations on target words are modulated by reading level and word frequency and this is also true for young deaf readers between the ages of 8 and 12 (Bélanger & Rayner, 2015). This lends further support to the notion that print exposure is crucial for both deaf and hearing readers.

Although it is widely known that word frequency is important for visual word recognition, being exposed to the same words in different contexts will also enrich reading experience (Nation, 2017; Perfetti, 2007). Psycholinguistic tasks have demonstrated that words that are likely to appear in different contexts are processed faster in comparison to words that are used in fewer contexts despite similar levels of frequency (Nation, 2017). As deaf readers are more likely to have increased exposure to print (this would need to be confirmed in a future study), it is possible that they experience words in more various contexts compared to hearing readers, which could also explain why semantic effects seem to be stronger for deaf readers. This fits in with both the lexical quality hypothesis (Perfetti, 2007) and the lexical legacy hypothesis (Nation, 2017), both of which support the notion that reading experience is crucial for successful reading. According to the lexical quality hypothesis, there are words that are high in quality (i.e. that have tight mappings between orthography, semantics and phonology) and words that are under-specified (i.e. less clear mappings between orthography, semantics and phonology) (Perfetti, 2007). High quality words are more easily recognized and less reliant on contextual information. Reading experience increases an individual's mean lexical quality (i.e. experienced readers have more knowledge of a given word's orthography, semantics and phonology, which in turn enables them to recognize words more efficiently) (Nation, 2017; Perfetti, 2007). The lexical legacy hypothesis posits that experiencing words in many different contexts is important for reading skill, as opposed to reading the same words in similar contexts. Readers' who are exposed to rich and diverse texts more frequently are likely to be more skilled at reading compared to those who have limited exposure (Nation, 2017). However, both hypotheses suggest that early literacy acquisition requires the ability to decode phonological information, i.e. map phonological information onto orthographic information, which may not be the case for deaf readers and this will be investigated and reported on in subsequent chapters.

Deaf readers included in this study mainly consisted of native or near native signers (14/16) and most are fluent signers (average score 27 on the BSL SRT). Additionally, all 16 participants reported they were severely or profoundly deaf. Contrary to the majority of the deaf population, most of the deaf readers in this study had early access to language via sign language and had reading levels that matched their hearing counterparts despite limited access to spoken language. Early access to sign language might have allowed this group of deaf readers to develop connections between form (signs) and meaning (concepts), which they can then apply to print when they first learn to read. For example, young signers know the sign for ‘cat’ and also the concept linked to the sign and when they learn the word ‘cat’, they already have a semantic representation of ‘cat’. This may help them develop robust connections between orthography and semantics. This is likely to be very different for deaf children who acquire language late, whether signed or spoken.

It is unclear why deaf readers were more affected by length compared to the hearing readers. There are several possible accounts for this difference, one of which is that deaf readers are fully reliant on orthographic codes due to impoverished access to spoken language, which may slow down the processing of longer words. Activation of phonological codes may help speed up processing of longer words for hearing readers. As hearing readers have full access to spoken language, phonological processing may enable hearing readers to quickly distinguish between words and nonwords even if they have never seen it in print (they may have heard it). Another explanation could be that deaf readers are less exposed to long English words in their everyday communication (i.e. deaf readers in this study use BSL as their main form of communication), which could affect their processing of long words. Future research will need to explore alternative accounts for this difference.

There were no correlations between scores from the reading test and BSL SRT scores for the deaf readers. There were also no correlations between reading scores and performance on the task for either group. This is likely to be due to little variability in the language proficiency of the participants included in this study.

To summarise, results from this study show that there are no major differences in how skilled deaf and hearing readers process words that differ in length, frequency etc. This similarity in processing of orthographic codes show that skilled reading does not always stem from spoken language skills. There were differences in how the two groups were influenced by semantic variables but, crucially, this did not have an impact on reading level as both groups were matched on this aspect. These findings have important implications for theory and practice; first, models of word recognition and reading (e.g. dual-route or connectionist models of word recognition, simple models of reading, lexical quality hypothesis) posit that access to phonological codes is crucial for achieving good reading proficiency (Coltheart et al., 2001; Harm & Seidenberg, 1999; Nation, 2017; Perfetti, 2007). However, as deaf readers do not have full access to spoken language, our results suggest that access to spoken language may not be necessary. Secondly, if the pathway to achieving high levels of reading proficiency is different for deaf readers, then we need to rethink reading instruction for young deaf readers, perhaps focusing more on connections between form (orthography) and meaning (semantics). In the next chapter, I compare phonological processing in deaf and hearing readers using pseudohomophones in a lexical decision task that will inform us what role phonology plays in word recognition processes in deaf readers.

# 5 Experiment 2 - Pseudohomophone effects in deaf readers

The previous chapter examined how different lexical and semantic variables influence word recognition processes in deaf readers and found that these processes were very similar for deaf and hearing skilled readers. However, as mentioned in Chapter 2, the activation of phonological information is one of the most important factors for successful word recognition for hearing readers. This will be the focus of this chapter.

To explore the role of phonology in hearing readers, many have used pseudohomophones in lexical decision tasks as a way to determine whether or not phonological information is activated during word recognition. Using pseudohomophones in lexical decision tasks allow us to tap into the 'automatic' activation of phonological information in hearing and deaf readers as participants are asked to decide whether or not the letter string presented to them is an English word. This is in contrast to other tasks used to assess phonological processing where participants are asked to make explicit judgments about phonological structure, such as whether words rhyme or count the number of syllables in a word. As explained in Chapter 3, it is clear that many deaf readers are able to complete phonological judgment tasks, however whether or not they automatically **recruit phonological information** during word recognition and reading is a separate question.

Models of word recognition provide accounts of how the pseudohomophone effect comes about in lexical decision tasks. Dual-route models suggest that upon seeing a pseudohomophone, a lexical representation is activated due to feedback from the indirect route (phonological route) and this activation hinders performance on the lexical decision task. When non-homophonic nonwords are presented, there is no lexical representation to be activated. In single route models, where orthography, semantics and phonology are all interconnected, lexical decision is hindered upon seeing pseudohomophones as semantic representations are activated via phonological activation, whereas for non-homophonic nonwords, there are no such activations.

As outlined in Chapter 3, findings regarding the role of phonology information in reading by deaf adults have been variable, due to different methodologies and lack of control for reading level that could explain the differences in phonological processing of deaf and hearing readers in those studies. Importantly, some of these studies have found that deaf readers do not make use of phonological information yet are successful readers and suggest that poor phonological processing is not at the root of poor literacy in the deaf population (Bélanger, Baum, et al., 2012; Chamberlain, 2002; Mayberry et al., 2011). Here we explore this claim further with a group of deaf and hearing readers using a lexical decision task in which participants were presented with words, nonwords and pseudohomophones. Crucially, we compared deaf and hearing readers who were matched for age, gender and overall reading level, which have not been well controlled for in past studies investigating the role of phonology in deaf readers.

## 5.1 Method

### 5.1.1 Participants

See section 4.1.1 for participant criteria and description of how background information was elicited. 38 participants took part in the study, 19 deaf, native BSL users and 19 hearing, native English speakers. One hearing participant achieved accuracy scores on the lexical decision task that were more than 2.5 standard deviations below the group mean on the task (79%) and were therefore excluded from data analysis. The matched deaf participant was also excluded from analyses, leaving a total of 36 participants (18 in each group). See Table 5-1 for participant demographics and see Table 5-2 for further information about the deaf participants' use of language and amplification aids.

**Table 5-1. Participants' age, gender and educational level**

| Participants | Deaf | Hearing |
|---|---|---|
| Male | 10 | 10 |
| Female | 8 | 8 |
| Age | 30.69 | 30.5 |
| Age Range | 19-41 | 18-42 |
| Education level | | |
| College | 4 | 3 |
| HND* | 2 | 1 |
| Bachelors | 8 | 8 |
| Masters | 4 | 6 |

*Higher National Diploma

**Table 5-2. Deaf participants' degree of deafness, use of amplification aids and sign language background**

| | |
|---|---|
| **Degree of Deafness** | Profound – 16<br>Severe – 2 |
| **Amplification aids** | Hearing aids – 8<br>None used - 10 |
| **Sign language background** | Native – 9<br>*Near native – 7<br>**Late learner – 2 |

*Near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

**Late learners used BSL as their main language for more than 10 years

#### 5.1.1.1 Reading measures

See section 4.1.1 for information about the reading test administered to participants. A pairwise comparison of the reading level of hearing readers *(n = 18, m = 30.72 (17 years), SD = 5.59, range = 18 – 38 (13 years to 21 years))* and deaf readers *(n = 18, m = 29.22 (16 years 8 months), SD = 5.99, range = 17-38 (12 years 6 months to 21 years))* showed no significant differences *(t (17) = -.669, p = .513 (two tailed)).*

### 5.1.2 Stimuli

480 words (obtained from a previous study (Kousta et al., 2011) and 481 nonwords (including pseudohomophones) were used (see Appendices 5 (words) and 6 (nonwords) for list of items). Amongst the 481 nonwords, there were 80 pseudohomophones. Of the 80 pseudohomophones, 59 pseudohomophones were taken from (Twomey et al., 2011) and a

further 21 pseudohomophones were derived from 21 of the English words used in this experiment (Kousta et al., 2011). Care was taken to ensure all pseudohomophones selected were matched pairwise to words and non-homophonic nonwords for length, orthographic neighbourhood and closely matched for bigram frequency by position using data from the English Lexicon Project (ELP, Balota et al 2007). It was not possible to match pairwise for word length and orthographic neighbourhood for all 80 pseudohomophones, thus there were 54 matched words, nonwords and pseudohomophones. Pairwise comparisons of the bigram frequencies of the pseudohomophones and words *(t (53) = .208, p = .836 (two tailed))* and pseudohomophones and nonwords *(t (53) = .544, p = .589 (two tailed))* showed no significant differences. See Appendix 10 for list of matched words, nonwords and pseudohomophones. The remaining words and nonwords were treated as fillers.

### 5.1.3 Procedure

All participants were tested individually using a Lenovo ThinkPad laptop with a 13-inch screen. All words and nonwords were presented randomly using E Prime version 2.0 (Schneider et al., 2002). A fixation cross was presented at the centre of the computer screen for 400ms followed by a stimulus letter string that remained visible until participants responded. Reaction times (RTs) and accuracy rates were recorded. Participants were instructed to decide whether the stimulus presented was a word or not by pressing the ‘j’ button to indicate ‘yes’ if the word presented is an English word and the ‘f’ button to indicate ‘no’ if it was not as quickly and as accurately as possible. A deaf, native signer administered the tests to deaf participants and instructions were delivered in BSL. Instructions to hearing participants were delivered in English via a BSL/English interpreter. Prior to the main experiment, participants undertook 20 practice trials to ensure they understood the task and were familiar with the buttons they needed to press.

### 5.1.4 Data Analyses

Response times and error rates were analysed for the 54 words, nonwords and pseudohomophones that were matched pairwise. Reaction times and accuracy rates of target items that elicited a ‘no’ response were analysed using a 2 (Condition: nonwords/pseudohomophone) x 2 (group: deaf/ hearing) mixed analysis of variance (ANOVA), by-subjects and by-items. Condition was a within subjects factor, Group was a between subjects factor. Reaction times below 250ms and above 2000ms were trimmed and not included in the analyses (1.6% of the data).

Correlation analyses (Pearson’s *r)* were carried out between reading scores and performance on the lexical decision task (both accuracy and RTs).

## 5.2 Results

**Reaction times.** There was a significant effect of condition on decision latencies *(F1 (1, 34) = 15.990, p = .000; F2 (1, 106) = 10.948, p = .001).* Participants were 27ms slower to reject pseudohomophones than non-homophonic as nonwords (by-items). There was no main effect of group and no interaction *(F1 (1, 34) = .035, p = .853; F2 (1, 106) = .000, p = .994).*

**Accuracy.** There was a significant main effect of condition on accuracy *(F1 (1, 34) = 9.013, p = .005; F2 (1, 106) = 5.479, p = .021). P*articipants were more accurate when rejecting non-homophonic nonwords (96%) in comparison to pseudohomophones (94%). There was no main effect of group and no interaction *(F1, (1, 34) = .940, p = .339; F2, (1, 106) = .151, p = .699).*

Table 5-3 provides a summary of the results.

**Table 5-3. Reaction times and accuracy (means and standard deviations)**

| Condition | Group | Mean Accuracy | Std. Dev. Accuracy | Mean RT | Std. Dev. RT | N |
|---|---|---|---|---|---|---|
| Nonword | Deaf | .96 | .05 | 669.23 | 69.08 | 54 |
| Pseudohomophone | Deaf | .94 | .07 | 696.76 | 56.67 | 54 |
| Nonword | Hearing | .96 | .05 | 677.74 | 52.59 | 54 |
| Pseudohomophone | Hearing | .94 | .08 | 705.16 | 57.44 | 54 |

**Correlations.** Correlation analyses revealed that there was a significant relationship between reading score and accuracy rates in the pseudohomophone condition *(r = .403, n = 36, p = .015 (two tailed)).* The scattergraph below shows that those with higher reading proficiency have higher accuracy rates (See Figure 5-1).

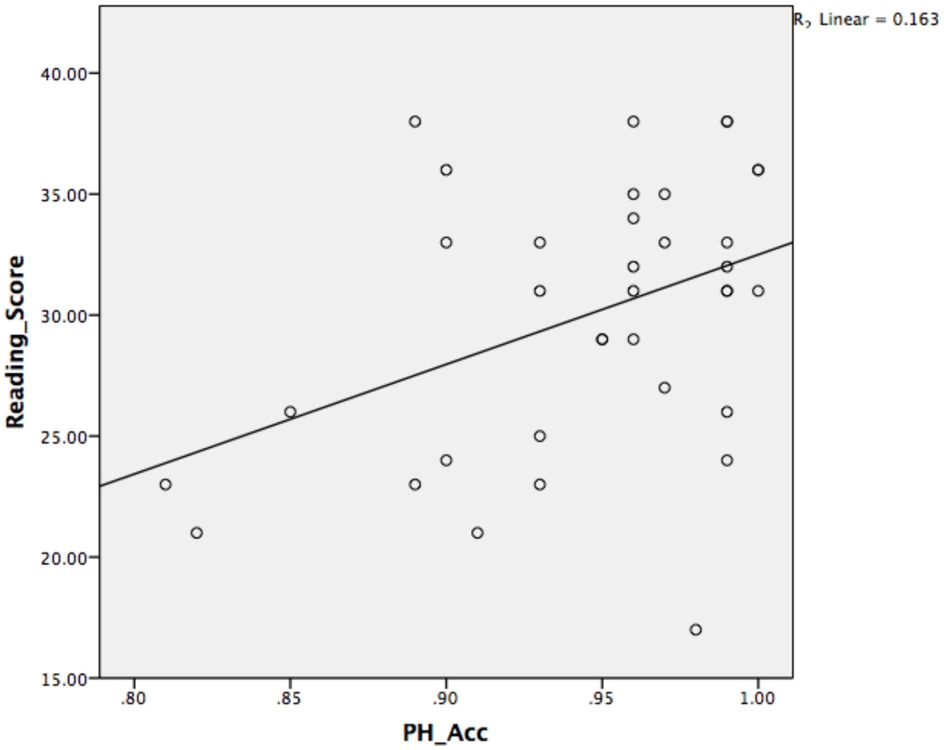

**Figure 5-1 - The above scattergraph depicts the relationship between reading scores (Y axis) and accuracy rates in the pseudohomphone condition (X axis).**

Correlations between reading score and nonword accuracy were not significant *(r = .304, n = 36, p = .071 (two tailed))*. There were no correlations between reading score and RTs in the pseudohomophone condition *(r = -.176, n = 36, p = .305 (two tailed))* or in the nonword condition *(r = -.180, n = 36, p = .295 (two tailed))*. Further correlation analyses were carried out, separating out each group to determine if one or both groups displayed a correlation between reading scores and performance on the lexical decision task. For the hearing readers, there was a significant correlation between reading scores and nonword accuracy *(r = .489, n = 18, p = .040)*, and pseudohomophone accuracy *(r = .645, n = 18, p = .004)*. In both cases, those with high reading proficiencies responded more accurately (See Figures 5-2 and 5-3).

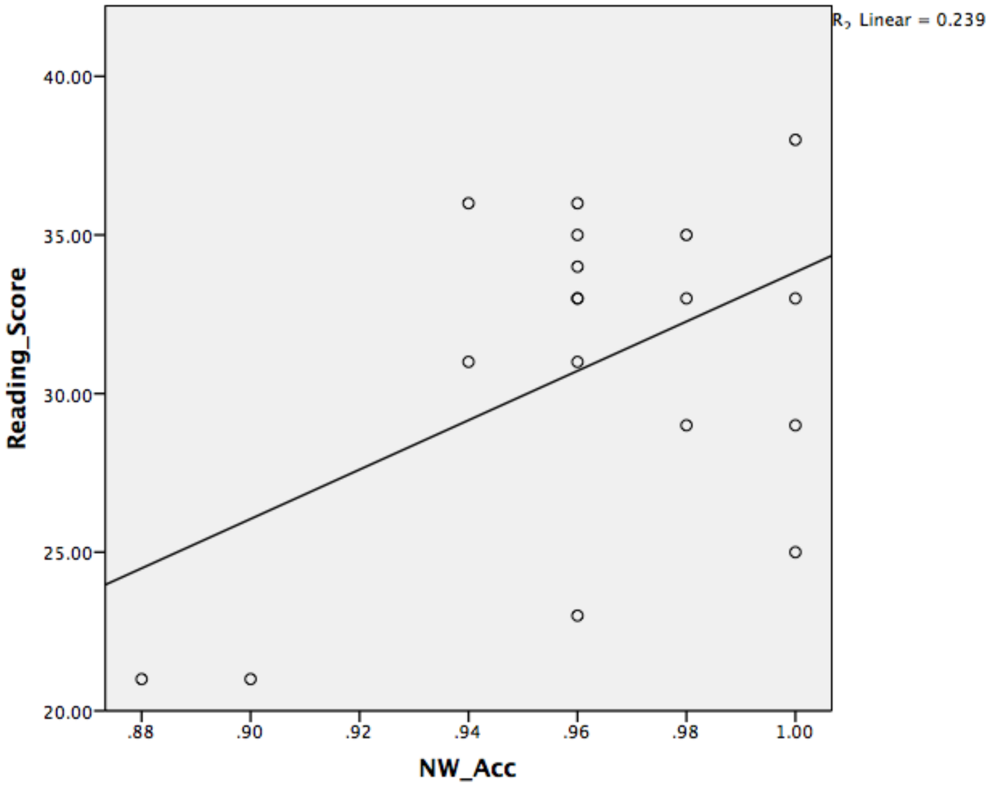

**Figure 5-2 - The above scattergraph depicts the relationship between reading score (Y axis) and nonword accuracy (X axis) for hearing readers.**

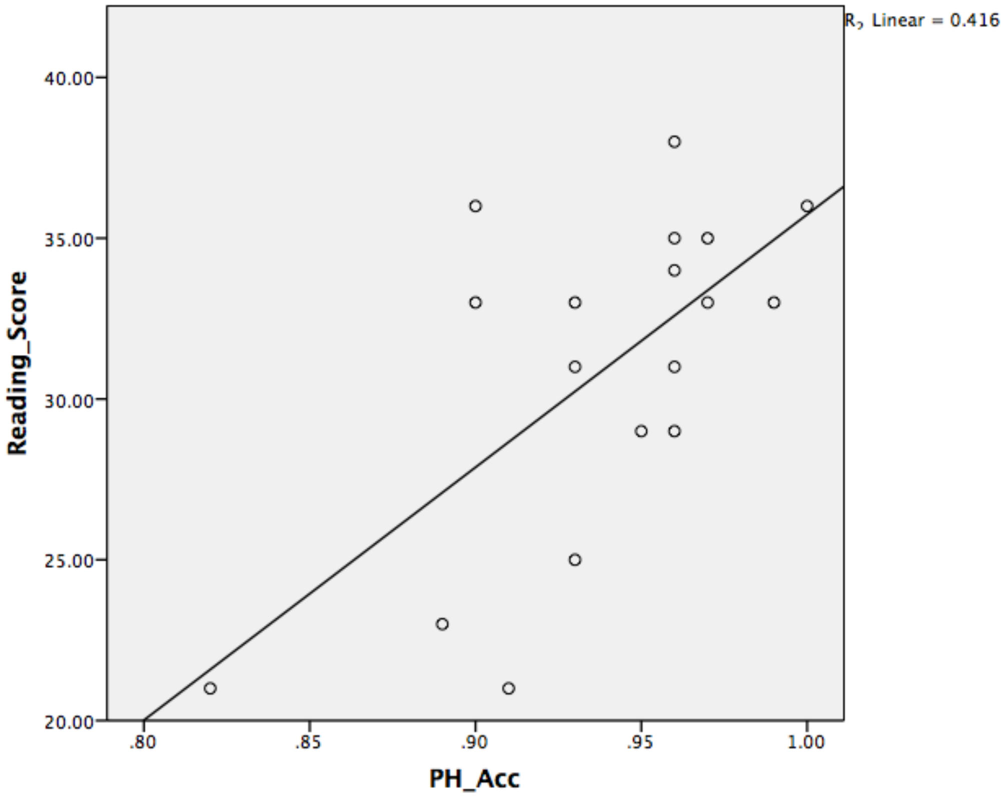

**Figure 5-3 - The above scattergraph depicts the relationship between reading score (Y axis) and pseudohomophone accuracy (X axis) for the hearing readers.**

There were no correlations between reading scores and RTs in either condition for the hearing readers (nonword condition, *r = -.064, n = 18, p = .800*; pseudohomophone condition, *r = -.083, n = 18, p = .744).* There were no correlations between reading scores and performance (both accuracy and RTs) for the deaf readers (See Table 5-4).

**Table 5-4 - Results from the correlation analyses for the nonword and pseudohomophone conditions for deaf readers.**

| | Condition | N | r | p |
|---|---|---|---|---|
| Reading score/accuracy | Nonword | 18 | .219 | .382 |
| Reading score/RTs | Nonword | 18 | -.297 | .231 |
| Reading score/accuracy | Pseudohomophone | 18 | .301 | .226 |
| Reading score/RTs | Pseudohomophone | 18 | -.273 | .272 |

## 5.3 General Discussion

Our findings with hearing readers, replicate results from many previous studies where decision latencies were quicker and more accurate for non-homophonic nonwords in comparison to pseudohomophones (Brysbaert, 2001; Seidenberg et al., 1996; Ziegler, Jacobs, & Klüppel, 2001). The same pattern was found for the deaf readers who took part in this study, they also had quicker decision latencies and higher accuracy rates when rejecting non-homophonic nonwords in comparison to pseudohomophones. As outlined in Chapter 3, the findings as to whether or not there is a pseudohomophone effect amongst deaf readers are largely mixed, the results of the current study are supported by some studies (Cripps et al., 2005; Hanson & Fowler, 1987) but in contradiction of others (Bélanger, Baum, et al., 2012; Chamberlain, 2002).

As mentioned in Chapter 3, many studies did not match carefully for reading level in deaf and hearing readers, which may have been the reason for the differences in how deaf and hearing readers process phonological information. In this study, deaf and hearing readers were carefully matched for reading level and statistically, there were no significant differences between the two groups of readers and this may explain why there were no differences in how the two groups responded to non-homophonic nonwords and pseudohomophones.

However, lexical decision has been criticised in the past for using pseudohomphone stimuli that are very similar to the words from which they are derived (Leinenger, 2014; Martin, 1982), which means that a positive pseudohomophone effect could be an effect of orthography rather than phonology. To assess whether there was a possible confound between orthography and phonology in this experiment, the degree of orthographic similarity between pseudohomophones and the words they were derived from was calculated. The orthographic similarity of the 54 matched pseudohomophones included in this study were compared to the English words they were derived from using an online match calculator (Davis, 2007). The results show that pseudohomophones and words were 74% orthographically similar to one another, This is a high percentage, which indicates that the effect of phonology detected in this study could be an effect of orthography (see Appendix 11 for full tabulation of the percentages of similarity between pseudohomophones and words from which they were derived). There was only 10% similarity between the words and matched nonwords. This confound may be especially important when comparing deaf and hearing readers as several studies have shown that deaf readers are highly efficient readers and are able to process written words and sentences rapidly (Bélanger et al., 2013; Bélanger, Slattery, et al., 2012). Deaf readers are likely to be more sensitive to visual information in comparison to hearing readers to compensate for reduced access to auditory information.

Correlation analyses revealed a significant relationship between reading scores and accuracy rates in both conditions for the hearing readers only. Participants with higher reading proficiency achieved higher accuracy rates. This finding is in line with the current literature; individuals with poor word recognition skills are usually less proficient at reading compared to individuals who are skilled at recognising words (Hoover & Gough, 1990; Rayner et al., 2001). As no such effects were found for deaf readers, this suggests that reading proficiency has more of an impact on word recognition skills in hearing readers. Several studies have reported that deaf readers are efficient at extracting information from print even if they are not good readers (Bélanger et al., 2013; Bélanger, Slattery, et al., 2012).

In summary, here we found that deaf and hearing readers had similar response and accuracy rates despite differences in their language experiences. However, from the current study we cannot clearly tell whether the similarity between groups comes about because of similar phonological processes or because of similar orthographic processes. In Experiment 3, I will tease phonology and orthography apart using a masked priming lexical decision task where stimuli are carefully controlled to reduce orthography effects.

# 6 Masked Phonological Priming Effects in Deaf Readers

In the previous chapter, I discussed pseudohomophone effects in deaf readers. An effect was detected amongst deaf readers and there was no difference in the magnitude of the effect for deaf and hearing readers. However, there were a number of methodological issues, which limit the interpretation of these data. First and foremost, there was an important confound between orthography and phonology as pseudohomophones were visually similar to the words they were derived from (e.g kyte-KITE, steem-STEAM), which wasn't the case for matched words and non-homophonic nonwords. Second, lexical decision has been criticised with respect to whether it really taps into the processes occurring before lexical access because participants are making explicit judgments based on what they see in print and they are fully aware of the decisions they are making (Leinenger, 2014). The experiment reported in this chapter attempts to respond to both of these criticisms: we use masked priming in order to tap into the automatic processes leading to word recognition and we carefully controlled for orthographic overlap between words.

Masked phonological priming (within a lexical decision task) has been used to explore the automatic activation of phonological codes during word recognition in a number of published papers (e.g., Brysbaert, 2001; Rastle & Brysbaert, 2006). In such experiments, participants make a lexical decision on targets preceded by 'primes', presented for an extremely short duration of time (around 40-60ms, on average) and followed by a series of hash marks in order to 'mask' the prime (Bélanger, Baum, & Mayberry, 2012; Rastle & Brysbaert, 2006). Rastle and Brysbaert (2006) showed that pseudohomophonic primes lead to faster and more accurate decision latencies in comparison to orthographic controls even when both prime types are equally visually similar (Rastle & Brysbaert, 2006). As participants are unaware of the primes, any influence on decision latencies and accuracy rates are interpreted as reflecting 'automatic' processes during word recognition.

In Chapter 3, I described a study where a masked phonological priming lexical decision task was used to explore phonological processing in deaf readers (Bélanger, Baum, et al., 2012). Although the stimuli in that study seemed to be well controlled to reduce influence from orthography, skilled deaf readers did not match the hearing readers for reading level, which could be a reason for the differences between those two groups. Thus in this study, the 'automatic' activation of phonological codes is explored using masked phonological priming in two groups of carefully matched hearing and deaf readers.

We use the same stimuli and masked priming procedure as Rastle & Brysbaert (2006), which have been carefully selected to ensure they were not visually similar to the words from which they were derived. (e.g. torn-TAUGHN, bruise-BROOZE). Thus our study further provides a replication of the Rastle and Brysbaert's study.

## 6.1 Experiment 3.1

### 6.1.1 Method

#### 6.4.1.1 Participants

See section 4.1.1 for participant selection criteria and description of how background information was elicited. 23 severely to profoundly deaf adults and 25 hearing English native speakers took part in this study. One deaf and 1 hearing participant were not included, as they could not be matched to another deaf/hearing participant following the set criteria. Two deaf and 3 hearing participants achieved low scores (more than 2.5 standard deviations below the group mean) on the reading test and were subsequently removed from data analysis. Data from 1 hearing participant could not be used as data recorded was corrupted. Thus, 20 participants from each group (40 in total) were included in this study. Table 6-1 provides demographic information about the participants. Table 6-2 provides relevant background information about the deaf participants e.g. what amplification aids are used.

**Table 6-1. Participants' age, gender, educational level and reading level**

| | Deaf | Hearing |
|---|---|---|
| Average Age | 31.5 | 30.75 |
| Male | 8 | 8 |
| Female | 12 | 12 |
| College | 7 | 2 |
| HND* | 4 | 0 |
| Bachelor’s degree | 6 | 6 |
| Master’s degree | 3 | 9 |
| PhD | 0 | 3 |
| Mean Reading Raw Score (max score 42) | 32.5 | 31.55 |

*HND = Higher National Diploma

**Table 6-2. Deaf participants' degree of deafness (based on self report), use of amplification aids and sign language background.**

| | |
|---|---|
| **Degree of Deafness** | Profound – 15<br>Severe to profound – 3<br>Severe - 2 |
| **Amplification aids** | Hearing aids – 9<br>Cochlear Implants – 3<br>None used - 8 |
| **Sign language background** | Native – 11<br>*Near native – 6<br>**Late learners – 3 |

*near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

**Late learners used BSL as their main language for more than 10 years

#### 6.4.1.1.1 Reading measures

A pairwise comparison of the reading level of hearing readers *(n = 20, m = 31.55 (17 years 8 months), SD = 4.55, range = 24 – 41 (15 years 4 months to 23+ years))* and deaf readers *(n = 20, m = 32.5 (18 years 4 months), SD = 5.26, range = 24 – 42 (15 years 4 months to 23+ years))* showed no significant differences *(t (40) = 1.229, p = 0.234).*

### 6.4.1.2 Stimuli

Stimuli were taken from Rastle and Brysbaert (2006). There were a total of 224 target letter strings (112 words and nonwords) and a total of 224 primes.

**Word targets.** First, 112 pseudohomophone primes were selected (each with 3 phonemes) from the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002). From these pseudohomophones, 112 phonologically identical English words were derived to be used as word targets. Primes and targets could differ by either one, two or three graphemes e.g. the target RAISE was derived by changing all three graphemes in the pseudohomophone WRAZE (WR→R, A.E→AI.E and Z→S), whereas the target FARM was derived by changing only one of the graphemes in the pseudohomophone PHARM (PH→F). In total, there were 16 English word targets that differed by three graphemes, 48 English words that differed by two graphemes and a further 48 English words that differed by one grapheme. The position of the grapheme change varied where word targets differed by one or two graphemes. Graphemic controls were also created for each prime-target pair. Whenever prime-target pairs had shared letters in the same position, this was also preserved in graphemic controls (e.g. the pair groe-GROW shares the GRO component, and this was preserved in the graphemic control, groy).

**Nonword targets.** 112 nonwords were obtained from the ARC Nonword Database (Rastle et al., 2002) and used as targets. Nonword targets selected were similar in length and orthography to word targets. Each nonword target also had 3 phonemes. Phonological primes and orthographical control primes were created for each of those nonword targets in the same way as the word targets. For 56 of the nonword targets, a phonologically identical nonword prime was generated that differed by one (e.g. sig-CIG), two (e.g. deck-DEAK), or three (e.g. wreese-REACE) graphemes. Again the grapheme change position varied. The other 56 nonword targets were phonologically dissimilar e.g. cheve-BEVE, dack-LECK and bleigh-FREW.

Two counterbalanced lists (lists A and B) were created, each consisting of 112 target English words, 56 pseudohomophones and fifty-six control words. As in Rastle and Brysbaert (2006), 112 target non-words were also used. For 56 of those non-words targets, there were pseudohomophone primes and for the latter 56 target non-words there were graphemic controls. Target non-words were not counterbalanced and were included in both lists A and B. See Appendix 12 for list of items used in this experiment.

Response and error rates were analysed for the word targets only. There were two conditions, word targets preceded by a pseudohomophone prime and word targets preceded by a graphemic control prime.

### 6.1.2 Procedure

All participants were tested individually using a Lenovo ThinkPad laptop with a 13-inch screen. The experiment was run using E Prime (version 2.0, Schneider, Eschman & Zuccolotto, 2002). Participants were informed they would see a series of words and non-words, preceded by a string of hash marks. Participants were not informed about primes and were instructed to quickly decide whether the words/non-words presented were English words or not. Hash marks were presented for 500ms and following that, primes were displayed in lower case for 58ms. Target words/non-words were presented in upper case immediately after primes and remained on screen until participants responded. Before the main experiment, there were 20 practice trials to ensure participants understood the task and were familiar with the buttons they needed to press.

### 6.1.3 Data Analyses

Reaction times (RTs) and accuracy of word targets were analysed using a 2x2x2 analysis of variance (ANOVA), both by-subjects and by-items. For prime type there were 2 factors (graphemic and phonological), treated as within-subjects repeated factors. Group and list version were treated as between-subjects unrepeated factors. Prior to data analysis, words with error rates more than 35%, across both groups, were eliminated. The words eliminated were BADE, DUES, FOB, NORSE, VAT and WAIF (as in Rastle and Brysbaert, 2006). Secondly, any participant with average reaction times and error rates > 2.5 SD above the mean of all participants were removed from subsequent analysis. In this experiment, 4 participants (1 deaf and 1 hearing as well as their matched counterparts) were removed. Thus, analyses were carried out on 18 deaf and 18 hearing participants.

Correlations (Pearson's *r)* between reading scores and performance on the task were tested for all participants.

### 6.1.4 Results

**Table 6-3. RTs and accuracy (means and standard deviations)**

| Prime Type | Group | N | Mean Accuracy | Std. Dev. Accuracy | Mean RT | Std. Dev. RT |
|---|---|---|---|---|---|---|
| Graphemic | Deaf | 18 | .972 | .026 | 628.69 | 35.56 |
| Phonological | Deaf | 18 | .987 | .017 | 622.02 | 28.11 |
| Graphemic | Hearing | 18 | .951 | .035 | 639.72 | 49.98 |
| Phonological | Hearing | 18 | .961 | .032 | 636.89 | 55.06 |

**Reaction Times**. There was no significant effect of prime type on decision latencies *(F1 (1, 32) = 353.146, p = .231; F2 (1, 408) = .608, p = .410).* Effect size calculations were carried out in the same way as Rastle & Brysbaert (2006), which revealed *r* values of *.96 (by-subjects)* and *.04 (by-items).* Item analyses showed that the deaf group were 16ms faster overall in comparison to the hearing group *(F2 (1, 408) = 7.009, p = .008)* and that there were significant differences between the 2 lists *(F2 (1, 408) = 9.848, p = .002).* Participants were 3ms slower when target words were preceded by a phonological prime compared to graphemic primes when viewing list A but for list B, they were 13ms faster when target words were preceded by a phonological prime compared to graphemic primes (by-items).

**Accuracy**. There was a significant effect of prime type *(F1 (1, 32) = 4.847, p = .035; F2 (1, 408) = .2.837, p = .093)* participants were 1% more accurate when target words were preceded by a phonological prime in comparison to graphemic primes. However, analyses by-items did not reach significance levels. Effect size revealed *r* values of *.36 (by-subjects)* and *.08 (by-items).* Deaf participants were 2% more accurate overall in comparison to hearing participants *(F1, (1, 33) = 11.243, p = .002; F2 (1, 408) = 11.094, p = .001).* There were no interaction effects for group and prime type. There were no significant differences between lists.

We replicated the effect of prime-type on accuracy observed in Rastle and Brysbaert (2006), however this did not reach significance in the by-items analyses. Effect size calculations show a very small effect (*r* was below .1). We did not replicate the effect of prime type on RTs. Again the effect size was very small by-items (*r* = below .1). Additionally, analyses revealed significant differences between the two lists used, which could also explain the lack of effect overall. However, we did find that the deaf group had faster decision latencies overall.

**Correlations.** There were no correlations between reading scores and performance on the task *(r = -.038, n = 36, p = .828 to r = -.149, n = 36, p = .385).* See Appendix 13 for results from all correlation analyses.

### 6.1.5 Discussion

Accuracy results from hearing participants replicated results reported by Rastle and Brysbaert (2006) with greater lexical decision accuracy when a target word was preceded by a pseudohomophone prime. Deaf readers showed the same pattern: greater accuracy when target words were preceded by a pseudohomophone prime. Crucially, there was no interaction between prime type and group. The data therefore suggest that both hearing and deaf readers access phonological information even during brief exposure to the pseudohomophone prime and this information subsequently influences lexical decision. However, it is important to note that there was only a significant effect of accuracy in the by-subjects analysis, which is possibly due to the small group size (Effect size calculations revealed a very small effect). Further investigations need to be carried out before we can safely conclude that deaf readers do access phonology during word recognition. It is possible that we need to carry out this study with a larger group of participants to see if results found by Rastle & Brysbaert (2006) CAN be replicated.

Additionally, we found that deaf readers were more accurate and had faster decision latencies than hearing readers. Such a difference has also been reported previously (Bélanger et al., 2013) and may be linked to increased use of visual attention to compensate for a lack of hearing (Bélanger et al., 2013; Bélanger, Slattery, et al., 2012; Dye et al., 2009). Similar findings have been found for early blind people who seemingly have enhanced hearing to compensate for a lack of vision, e.g. they seem to be more efficient at localising sounds and also are found to have better speech perception (Gougoux, Zatorre, Lassonde, Voss, & Lepore, 2005).

The reaction time advantage for pseudohomophone primes found in Rastle & Brysbaert's (2006) study was not replicated which we suggest is related to lack of power of our experiment to detect small to medium effects in RTs. Thus to establish if the RT and accuracy effects can be replicated with a larger sample, we carried out the study again with a larger sample of hearing English speaking participants. Additionally, there were significant differences in how participants responded to graphemic and phonological primes depending on which list was used, which needed to be further investigated.

## 6.2 Experiment 3.2: Replication of phonological masked priming study with hearing individuals

### 6.2.1 Method

#### 6.2.1.1 Participants, Stimuli, Procedure and Analyses

52 (40 females) hearing English speakers participated as part of an undergraduate psychology lab class (mean age = 19.04, SD = 0.83, age range = 18-22). Stimuli, Procedure, Analyses were the same as in Experiment 3.1, with exception that we did not include a group factor.

### 6.2.2 Results

Data were trimmed as in Experiment 3.1. The words: BADE, DUES, FOB, NORSE, VAT and WAIF were removed from analyses. Four participants were also excluded, for reasons outlined in Experiment 3.1. Thus, 48 participants were included in the data analyses.

Priming effects on RTs and accuracy were explored using a 2x2 analysis of variance (ANOVA), both by-subjects and by-items. For prime type, there were 2 levels (phonological and graphemic), treated as repeated factors. For the list factor, there were also 2 levels (list A, list B), treated as unrepeated factors. Table 6-4 provides a summary of the results.

**Table 6-4 - RTs and accuracy for each list version**

| Prime Type | List Version | N | Mean Accuracy | Std. Dev. Accuracy | Mean RT | Std. Dev. RT |
|---|---|---|---|---|---|---|
| Graphemic | A | 54 | .926 | .080 | 678.10 | 67.65 |
| Phonological | A | 52 | .943 | .090 | 684.43 | 73.63 |
| Graphemic | B | 52 | .889 | .117 | 663.54 | 63.62 |
| Phonological | B | 54 | .925 | .065 | 642.24 | 62.38 |

**Reaction Times**. Analyses revealed that there was not a significant effect of prime type on reaction times *(F1 (1, 46) = 2.728, p = .105; F2 (1,212 = .673, p = .413).* Effect size calculations revealed *r* values of *.24 (by-subjects)* and *.07 (by-items)*. By-subjects analyses showed that there was a significant interaction between prime type and list version *(F1 (1, 46) = 5.134, p = .028)* but this was not significant in the by-items analyses *(F2 (1, 212) = 2.249, p = .135)*. In the by-items analyses, there were significant differences between the reaction times in the two lists for phonological and graphemic primes *(F2 (1, 212) = 9.580, p*

= *.002)*. The average reaction time was higher for list A (681.25ms) compared to list B (652.69ms). Participants were 6ms slower when target words were preceded by a phonological prime compared to graphemic primes when viewing list A but for list B, they were 21ms faster when target words were preceded by a phonological prime compared to graphemic primes (by-items).

**Accuracy**. Analyses revealed that there was a significant effect of prime type on accuracy *(F1 (1, 46) = 17.677, p = .000; F2 (1, 212) = 4.652, p = .000).* Participants' responses were 3% more accurate when target words were preceded by a phonological prime (*by-items*). Effect size calculations revealed *r* values of *.53 (by-subjects)* and *.21 (by-items).* There were no interaction effects between prime type and list version *(F1 (1, 46) = 2.911, p = .095; F2 (1, 212) = .574, p = .450).* However, by-items analyses revealed that there were significant differences in accuracy rates between the 2 lists used *(F2 (1, 212) = 4.914, p = .032).* Overall, participants were 3% more accurate with list A (93%) in comparison to list B (90%).

### 6.2.3 Discussion

To establish whether the lack of effects in Experiment 3.1 was due to a lack of power, here we tested a large group of hearing participants on the same masked priming paradigm. There was a significant effect of prime type on task accuracy. Participants were more accurate when targets were preceded by a phonological prime, which replicates results found by Rastle & Brysbaert (2006). This suggests that the lack of effect in the by-items analysis when comparing deaf and hearing readers was likely to be due to a lack of power.

For RTs, we did not replicate results found by Rastle & Brysbaert (2006): there was no significant effect of prime type. Results revealed significant differences between lists (by-items) as well as a significant interaction between prime type and list version (by-subjects), suggesting that readers were influenced by other nuisance differences across items not relevant to the experimental manipulation raising question about the validity of the previously reported results.

## 6.3 General Discussion

For hearing readers, we were able to replicate results from Rastle & Brysbaert's (2006) study where hearing readers displayed higher accuracy rates when target words were preceded by a phonological prime in comparison to orthographic controls in both Experiments 3.1 and 3.2. However, we were not able to replicate results from Rastle & Brysbaert's (2006) study for decision latencies in Experiments 3.1 or 3.2. As we were still unable to replicate this effect in a larger sample of hearing readers (Experiment 3.2), there may lack of effect may not be due to lack of power. Analyses show that there were differences in participants' decision latencies depending on which list was presented to participants and this could explain the null result.

For deaf readers, we were also able to replicate results from Rastle & Brysbaert's (2006) study, which means that deaf readers in this study responded more accurately when target words were preceded by a phonological prime in comparison to orthographic controls. This is an important finding as the deaf and hearing readers in this study were matched individually on a number of important dimensions, age, gender and most crucially of all, reading level, which shows that skilled deaf readers can automatically activate phonological codes during word recognition. Although levels did not reach significance in the by-items analyses, it did approach significance at .09 and this was also true for the hearing readers. The strong effect of accuracy for hearing readers in Experiment 3.2 supports the conclusion that accuracy levels did not reach significance levels by-items in Experiment 3.1 due to a lack of power. Again, for deaf readers, we were unable to replicate results from Rastle & Brysbaert (2006) for decision latencies and suspect that this could be for the same reasons outlined earlier for hearing readers. There were differences in the decision latencies of participants depending on which list were presented to them.

Although there were no differences in how the two groups of readers responded to target words depending on prime type, there was a significant difference between the accuracy rates of deaf and hearing participants in Experiment 3.1. Deaf participants were more accurate in comparison to hearing participants and this shows that these deaf readers are highly efficient readers. This effect has been demonstrated in numerous studies where deaf readers have been shown to read text faster (Bélanger et al., 2013) and have a wider perceptual span (Bélanger, Slattery, et al., 2012) in comparison to their hearing counterparts.

There were no correlations between reading scores and performance on the task, which is unsurprising as all participants had similar reading proficiency as indicated by reading scores. If there were greater variability in reading proficiency, there would be more chance of detecting the impact of reading proficiency on task performance.

Using a masked phonological priming lexical decision task where orthography was well controlled for has enabled the exploration of the automatic activation of phonological codes in deaf readers with minimal influence from orthography. This addresses the main concerns with the lexical decision experiment described in the previous chapter.

Although masked phonological priming lexical decision tasks can tap into automatic processes by using primes, participants are still required to make explicit judgments. This is not something that occurs during normal reading and this could have an impact on performance in lexical decision (Leinenger, 2014). It has been argued that the use of pseudohomophones are important in lexical decision tasks as it shows that meaning has been accessed via phonology (Cortese & Balota, 2012) but is it necessary to access meaning in order to accept or reject words in a lexical decision task? In lexical decision tasks, it is possible that readers are only making connections between orthography and phonology in order to complete the task in the most efficient way possible. Furthermore, as mentioned in Chapter 2, the aim of reading is to comprehend the text at hand, which involves semantic processing and this is not something that is required during lexical decision tasks.

Importantly, as mentioned in Chapter 2, successful word recognition and reading involves the interplay of three important elements, orthography, semantics and phonology. The above task only allows us to explore two of those three elements, orthography and phonology. Additionally, lexical decision tasks does not allow us to explore the dynamics of the activations of phonological codes i.e. are phonological codes activated following a similar time course for deaf and hearing readers? In the next chapter, I introduce a novel adaptation of the visual world paradigm where written targets are presented along with four pictures in order to explore the time course of the interplay between orthographic, semantic and phonological information in deaf and hearing readers.

# 7 Introducing a novel adaptation of the visual world paradigm to explore semantic and phonological processing

In the last chapter, I described an experiment that showed deaf skilled and hearing readers are influenced in their lexical decisions in the same way by pseudohomophone primes. This experiment did not provide information regarding whether the dynamics of activation of phonological codes by deaf and hearing readers are also similar. Although effects of semantic variables are well documented during lexical decision tasks (Kousta et al., 2011) lexical decision does not necessarily require access to semantics (Leinenger, 2014). Therefore, it does not allow us to assess whether the activation of phonological codes by deaf readers we have observed in the masked phonological priming lexical decision task would boost semantic activation as well as orthographic activation. In this chapter, I introduce a novel adaptation of the "visual world paradigm" developed to investigate the moment-by-moment processing in spoken word recognition (Allopenna, Magnuson, & Tanenhaus, 1998) to visual word recognition.

A paradigm that allows for the investigation of automatic activation of phonological and semantic information as it unfolds is the visual world paradigm (Huettig, Rommers, & Meyer, 2011).  This paradigm has been fruitfully used previously to investigate the time course of phonological and semantic activation during spoken word recognition (Huettig & McQueen, 2007; Huettig et al., 2011).  In visual world experiments, participants are typically presented with an auditory target sentence (e.g., 'click on the fly') whilst simultaneously being presented with an array of pictures including the target ('fly') and distracter pictures, which can be semantically (e.g., 'moth') and/or phonologically (e.g., 'sky') related to the target, or unrelated to the target (e.g., ‘chair’). The eye movements of participants from the onset of the visual display onward are recorded (Huettig et al., 2011) and provide information about the time course of activation.

Studies show that listeners, not surprisingly, fixate more on target objects than distracters (Allopenna et al., 1998; Dahan, Magnuson, & Tanenhaus, 2001; Huettig et al., 2011). They also show that, if distracter objects are semantically or phonologically related to the target, participants are more likely to fixate on them than unrelated objects during a time window between 200-500ms from word onset (Allopenna et al., 1998; Dahan et al., 2001; Huettig & Altmann, 2005). Allopenna et al. (1998) showed that participants, upon hearing a target word, fixated on target items (e.g. ‘beaker’) and looks towards target items peaked at around 1000ms. Participants also fixated more on phonological distracters compared to unrelated items e.g. looks towards any cohort competitors (words with the same onset as the target item e.g. beetle) peaks at the 450ms time window. Rhyme competitor effects were also found in the same study. Participants looked at rhyming words such as, ‘speaker’ after hearing ‘beaker’ at the 600ms time window. Throughout the trial, fixations on target items continually increase, and fixations on the distracters decline. Another study also demonstrated that listeners were also drawn to distracters that were orthographically similar to the target item and these fixations peaked at around 500ms (Salverda & Tanenhaus, 2010). In this study, participants were presented with four written words on a computer screen (target, orthographic and phonological competitors, and an unrelated item) and a spoken word (target). This shows that written stimuli in the visual world paradigm can be used fruitfully to investigate processes involved in word recognition.

To our knowledge, no previous study has used the visual world paradigm to investigate visual word recognition. This is challenging because with visual presentation of the word, participants' visual attention needs to be divided between the written words and the object displays and therefore the number of looks to the objects may be greatly reduced. However, this paradigm has been used successfully previously with British Sign Language (BSL) stimuli, which suggests that while this is the case, at least for dynamic stimuli such as signs, effects are nonetheless robust (Thompson, Vinson, Fox, & Vigliocco, 2013). In Thompson et al's (2013) study, video recordings of BSL signs were presented in the centre of the screen along with four pictures (one in each corner) including semantic, phonological and unrelated items. The study showed clear effects of semantics and phonology in BSL[3].

Here, we presented deaf and hearing readers with written targets (words, pseudohomophones and control nonwords) in the centre of a screen and four surrounding pictures, which were phonologically related, semantically related or unrelated to the target (see Figure 7-1). The participant's task was to click on the target picture if the target was a real word. If the target was not a real word they were instructed to simply wait for the next word (trial). Of interest was to establish similarities and differences between deaf and hearing readers in the activation of phonological and semantic information in the word and pseudohomophone conditions, with the nonword condition serving as a baseline. As the nonwords are not orthographically or phonologically related to any of the pictures presented, we do not expect to observe any differences between deaf and hearing participants in this condition.

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[3] Single signs in sign languages have an internal structure, which can be broken down into smaller segments. The three main components of a single sign are handshape (the form that the hands take on), location (the place where the sign is produced) and movement (how the articulators i.e. hands or arms move). These components are the phonological features of sign languages (Johnston & Schembri, 2007).

**Figure 7-1. An example of a single experimental trial**

## 1.1 Experiment 4.1

### 7.1.1 Method

#### 7.1.1.1 Participants

See section 4.1.1 for participant criteria and description of how background information was elicited. Twenty-three severely to profoundly deaf adults and 25 hearing English native speakers took part in this study. One deaf and one hearing participant were not included, as they could not be matched following the set criteria. Two deaf and three hearing participants achieved low scores (23/42 or below) on the reading test and were subsequently removed from data analysis. Data from one hearing participant could not be used as the data recorded were corrupted. Thus, 20 participants from each group (40 in total) were included in this study. Table 7-1 provides demographic information about the participants. Table 7-2 provides relevant background information about the deaf participants e.g. what amplification aids are used.

**Table 7-1. Participants' age, gender, education and reading level**

| | Deaf | Hearing |
|---|---|---|
| Average Age | 31.5 | 30.75 |
| Male | 8 | 8 |
| Female | 12 | 12 |
| College | 7 | 2 |
| HND* | 4 | 0 |
| Bachelor’s degree | 6 | 6 |
| Master’s degree | 3 | 9 |
| PhD | 0 | 3 |
| Mean Reading Raw Score (max score 42) | 32.5 | 31.55 |

*HND = Higher National Diploma

**Table 7-2. Deaf participants' degree of deafness, language background and use of amplification aids**

| | |
|---|---|
| **Degree of Deafness** | Profound – 15<br>Severe to profound – 3<br>Severe - 2 |
| **Amplification aids** | Hearing aids – 9<br>Cochlear Implants – 3<br>None used - 8 |
| **Sign language background** | Native – 11<br>*Near native – 6<br>**Late learners – 3 |

*near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

**Late learners used BSL as their main language for more than 10 years

#### 7.1.1.1.1 Reading measures

See section 4.1.1 for description of assessment. A pairwise comparison of the reading level of hearing readers *(n = 20, m = 31.55 (17 years 8 months), SD = 4.55, range = 24 – 41 (15* *years 6 months to 23+ years))* and deaf readers *(n = 20, m = 32.5 (18 years 4 months), SD = 5.26, range = 24 – 42 (15 years 6 months to 23+ years))* showed no significant differences *(t (40) = 1.229, p = 0.234).*

#### 7.1.1.2 Stimuli

There were two sets of written target items: words and pseudohomophones.

**Pseudohomophone items:** Twenty-eight pseudohomophone items were selected from Rastle and Brysbaert's (2006) and Twomey, Keith, Price & Devlin's (2011) studies. Items were selected on the basis that they were easily matched to a picture e.g. snale (snail). Some pseudohomophones were selected from Rastle & Brysbaert (2006)'s study, as they were carefully assembled to ensure that they were not highly visually similar to words they sounded like to reduce the chances of a confound between orthography and phonology. An additional set of pseudohomophones was taken from Twomey et al's (2011) set, and care was taken to ensure that the orthographic similarity among the chosen pseudohomophones was low (e.g. brooze/bruise and taughn/torn).

**Word items:** Twenty-eight words that matched the pseudohomophones for length and orthographic neighbourhood (on the basis of ELP database, Balota et al, 2007) were included as targets. They were also closely matched on bigram frequency-by-position *(t = 0.785, df (31), p = 0.439).* An additional 28 words comprised all the words from which the pseudohomophones were derived e.g. 'snail' from 'snale'. The two sets of words and nonwords did not differ in frequency *(t = 0.978, df (31), p = 0.336) as measured using* SUBLEX-UK (Van Heuven, Mandera, Keuleers, & Brysbaert, 2014)).

A set of 28 non-homophonic nonwords were also included as filler items. These were created by changing one letter from the matched words (e.g., “swog”, from “smog”) in order to obtain the same number of “yes” and “no” trials.

Each word and pseudohomophone target was displayed to participants with four pictures (see Figure 7-1). One picture corresponded to the target word /pseudohomophone (displayed visually via print). The other three pictures included a semantic distracter, a phonological distracter and an unrelated picture. Thus, for example given “coat” (word) or “kote” (pseudohomophone) as target, the pictures presented included: a coat (target), a boat (phonological distracter), a shirt (semantic distracter) and a swing (unrelated). For nonwords (e.g. ‘chisk’ for ‘whisk’), the pictures included: a whisk (target), a disc (phonological distracter), a bowl (semantic distracter) and a dog bone (unrelated).

The same pictures were used across the word, pseudohomophone and nonword conditions. We created two lists for counterbalancing purposes; each participant was only shown half of each type of items (e.g., participant 1 would see the pseudohomophone “KOTE” and the pictures: coat, boat, shirt and swing; participant 2 would see the word “COAT” presented with the same pictures). Additionally for the nonhomophonic nonwords and the words from which they were derived, participant 1 would also see half of the nonwords e.g. chisk and participant 2 would see ‘whisk’, target and distracter pictures would remain the same in each condition (word and nonhomophonic nonword).

To ensure that the pictures we used elicited the labels we expected, we asked 3 additional participants (who were hearing, native speakers of English and did not take part in the main experiment) to name them. From 32 pseudohomophone items, four were removed, as responses did not match the intended target. The pseudohomophones’ corresponding matched words were also removed leaving 28 pseudohomophones, 28 corresponding English words, 28 matched words and 28 control nonwords. See Appendix 14 for full stimuli and distracter list.

#### 7.1.1.3 Procedure

Participants were tested individually in a dark and acoustically adapted room to reduce distractions. Participants’ eye movements were recorded using an SR Research Eyelink 2 © system and Experiment Builder Software (SR Research ©). Participants’ eyes were 20 to 25 inches away from the display. Prior to practice trials, camera setup, calibration and validation of the eye tracker took place. If needed, re-calibration was carried out between trials. There were practice and experimental trials. Each trial began with a fixation cross at the centre of the screen, as soon as participants’ gaze was on fixation, the letter string was presented at the centre of the screen for 500ms along with the four pictures, which remained on the screen for five seconds. Participants were instructed to click on the corresponding picture, if the stimulus was a word, or to simply wait for the beginning of the next trial if the stimulus was a non-word. Participants’ were also instructed to keep their hands on the mouse to ensure they could respond as quickly as possible. The display remained on screen until participants responded, or five seconds elapsed. There were eight practice trials (four words and four non-words/pseudohomophones) and 56 experimental trials.

We chose to use different instructions and tasks for words and nonwords because of the difficulty in finding a task that could be equally applied across conditions. Although the difference in task might affect viewing strategies, the trials were intermixed and presented randomly therefore this should reduce this possibility. Moreover, we do not carry out any direct statistical comparison across word and nonword conditions. Finally, there is no a priori reason to expect that even if different viewing strategies were to be used, these would differentially affect deaf and hearing readers.

#### 7.1.1.4 Data Analyses

Reaction times and accuracy data from the word condition were analysed using a paired sample t-test. Reaction times and accuracy of each group were directly compared.

Additionally, data from each participant's right eye were analysed and the proportion of fixation samples for each quadrant (see Figure 7-2) were coded for analysis in 100ms bins starting from 400ms and ending at 2000ms. Prior to 400ms there were not enough observations as participants fixated on the written word, which was presented for 500ms. Analyses ended at 2000ms as any looks beyond this time window would plausibly reflect only post-recognition processes as response times averaged around 2300ms (i.e., participants check pictures again to make sure they did not miss anything after having decided whether to respond or not).

Separate analyses were carried out for word and pseudohomophone items. The dependent variable in each analysis was proportion of fixations (in each time bin of 100ms) for each of the four quadrants of the screen corresponding to location of presentation of different picture types (see Figure 7-2).

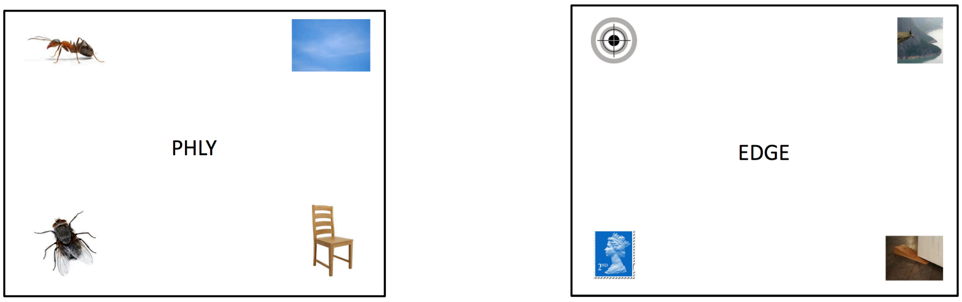


**Figure 7-2. The layout of the stimuli presented to participants and the four quadrants used for analysis.**

For each target condition, to assess differences between the different conditions, non-parametric analyses (Wilcoxon sign-rank test) were carried out, corrected for multiple comparisons by adjusting p levels for significance to .005. First, we carried out Wilcoxon signed-rank tests (by subjects and by items) for hearing and deaf participants separately. In these analyses, in the <u>word condition</u>, semantic and phonological distracters were compared to unrelated items. In the <u>pseudohomophone</u> condition, looks to the "pseudotarget" (i.e., the picture corresponding to the word from which the pseudohomophone was derived), "pseudosemantic" and "pseudophonological" (i.e., semantically or phonologically related to the word from which the pseudohomophone was derived) distracters were compared to "unrelated" items. Next, we carried out comparisons between groups (deaf vs. hearing) using the Mann-Whitney test on difference scores (difference in proportion of fixations in each comparison listed above).

Finally, to compare the time-course activations of the two groups, Growth Curve Analyses (Mirman, Dixon, & Magnuson, 2008) were carried out using the statistical software program R v.3.3.3 (R Development Core Team, 2017) and the lme4 package v.1.1-12 (Bates et al., 2015). P-values for fixed effects were obtained using the lmerTest package. Growth Curve Analyses were used, as this method was designed with the aim to compare differences in the proportion of looks towards specified interest areas at both the group and individual level in time-course data (Bates et al., 2015).

Initially, the overall target, semantic, phonological and unrelated effects (separately for words and pseudohomphones) were calculated by averaging out the proportion of fixation samples for all of the items for each subject for each 100ms time bin. Next, the difference between target, semantic, phonological items/distracters and unrelated items were calculated, thus creating an average target, semantic and phonological effect for each participant at each 100ms time bin. Like in prior analyses (Wilcoxon and Mann-Whitney) analyses were only carried out for time bins between 400ms and 2000ms from trial onset, for reasons outlined earlier. The time profile of target, semantic and phonological effects were analysed separately using growth curve analyses.

We modelled the proportion of fixations for each condition (target, semantically or phonologically related) using orthogonal polynomials (first, second, third and fourth order terms). To determine if fixations changed over time as a function of participants and condition, the model included a fixed effect of a particular condition (target, semantically or phonologically related distracters), adopting a maximal random effect structure (if the model converges; if not, then the random effect structure was reduced one at a time until the all models converged on a random effect structure) (Barr, Levy, Scheepers, & Tily, 2013). Once the random effect structure was determined, it was held constant in model comparisons that tested the fixed effects of each time term. Initially, the models included all the correlations but if the models failed to converge, correlations were then removed to reduce the model. Once this was done, group was included as a factor to examine whether the two groups differ in the time profile of each effect (target, semantic or phonological).

Correlation analyses (Pearson's *r*) between reading scores and performance in the word condition were carried out.

### 7.1.2 Results

#### 7.1.2.1 Word Condition

Reaction times and accuracy rates were similar for both deaf and hearing readers (see Table 7-3).

**Table 7-3 - Reaction times and accuracy rates for deaf and hearing participants in the word condition**

| Group | Mean RT | Std. Dev. RT | Mean Accuracy | Std. Dev. Accuracy | N |
|---|---|---|---|---|---|
| Deaf | 2471.53 | 210.31 | .978 | .034 | 20 |
| Hearing | 2559.49 | 426.00 | .983 | .021 | 20 |

**Reaction Times.** There were no significant differences between deaf and hearing readers *(t1 (19) = -.820, p = .422; t2 (55) = -3.095, p = .003).*

**Accuracy.** There were no significant differences between deaf and hearing readers *(t1 (19) = -.534, p = .599; t2 (55) = -.126, p = .900).*

Word trials with incorrect responses (i.e. the wrong target item was selected) were not included in data analysis (5% of total data). Figures 7-3 and 7-4 depicts the proportions of fixations by deaf and hearing participants, respectively. As it can be seen, both groups looked more often to the target picture than any other distracters and looks to semantic distracters were also more frequent than to unrelated distracters. See Appendix 15 for full tabulation of results from the Wilcoxon and Mann-Whitney analyses.

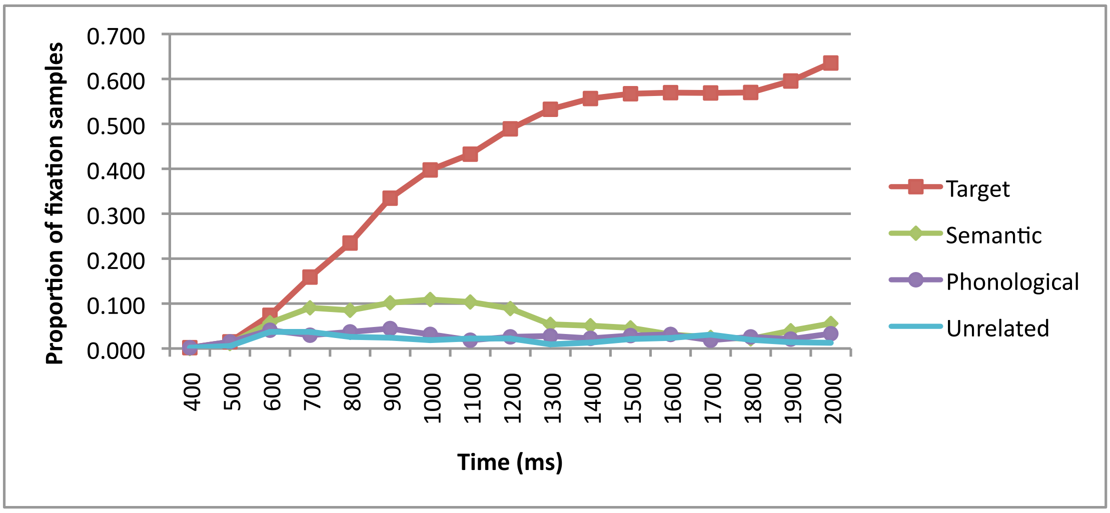


**Figure 7-3. Proportion of fixation samples in the word condition for deaf participants**

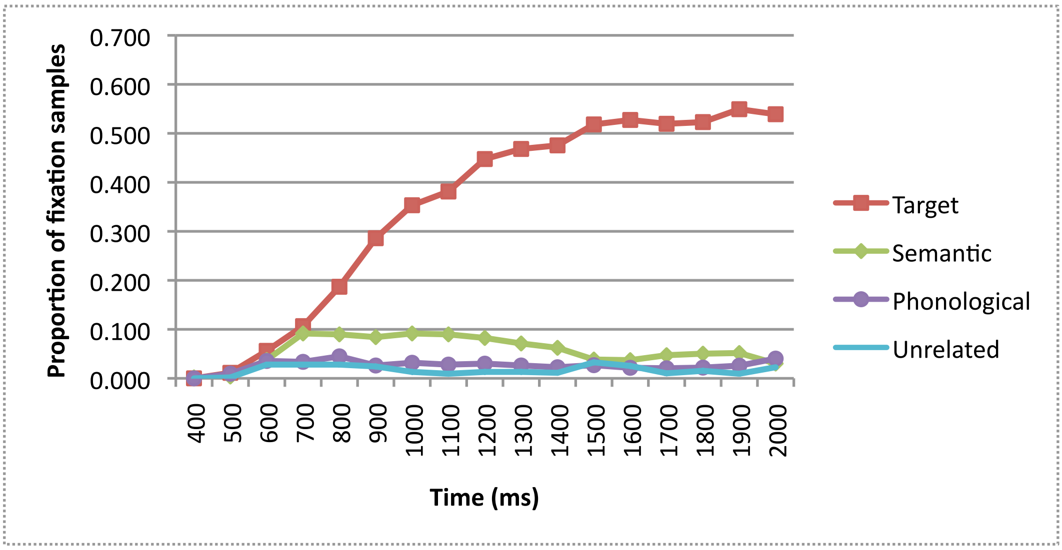


**Figure 7-4. Proportion of fixation samples in the word condition for hearing participants**

**Looks to targets.** Bin-by-bin Wilcoxon analyses revealed that both deaf and hearing participants looked at target items significantly more than unrelated items in all time windows from 400-2000ms (by-subjects and by-items). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.238, p > .024; U2 > -2.106, p > .035).*

In the growth curve analyses, the most complex model with all of the correlations and the most complex random effects structure converged and was found to be significantly better than other models, thus results from this model are reported here. Overall, there was a significant effect of target on the intercept term (Estimate = .40, SE = .01, p < 0.00). There was no significant effect of group (Estimate = .05, SE = .02, p = 0.07). There were also no interactions between group and any of the time polynomials, which strongly suggest that the temporal profile of the target effect did not differ for deaf and hearing readers (See Table 7-4). This provides converging statistical evidence to the non-parametric analyses reported earlier.

**Table 7-4 - Parameter estimates for each time term, group and interactions between each time term and group for target items from the growth curve analyses**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.40 | 0.01 | 32.50 | <0.00 |
| Time term 1 | 4.38 | 0.20 | 21.74 | <0.00 |
| Time term 2 | -1.77 | 0.16 | -10.76 | <0.00 |
| Time term 3 | 0.19 | 0.12 | 1.56 | 0.13 |
| Time term 4 | 0.26 | 0.10 | 2.67 | 0.01 |
| Group | -0.05 | 0.02 | -1.83 | 0.07 |
| Time term 1 x Group | -0.12 | 0.40 | -0.29 | 0.77 |
| Time term 2 x Group | 0.35 | 0.33 | 1.07 | 0.29 |
| Time term 3 x Group | 0.06 | 0.24 | 0.27 | 0.79 |
| Time term 4 x Group | 0.25 | 0.20 | 1.25 | 0.21 |

**Looks to semantically-related distracters.** Table 7-5 reports the Z (by-subjects and by-items) statistics for the comparison between semantic distracter vs. unrelated items, separately for deaf and hearing participants.

**Table 7-5. Comparison between proportion of fixation samples of the semantic distracters vs. unrelated items in the word condition.**

| Time Window | Deaf (by-subjects) | Deaf (by-items) | Hearing (by-subjects) | Hearing (by-items) |
|---|---|---|---|---|
| 600 | Z = -.882, p = .378 | **Z = -2.974, p = .003** | Z = -1.487, p = .137 | **Z = -3.374, p = .001** |
| 700 | **Z = -3.185, p = .001** | **Z = -3.936, p = .000** | **Z = -3.364, p = .001** | **Z = -3.661, p = .000** |
| 800 | **Z = -3.323, p = .001** | **Z = -4.182, p = .000** | **Z = -3.411, p = .001** | **Z = -3.333, p = .001** |
| 900 | **Z = -3.140, p = .002** | **Z = -4.006, p = .000** | **Z = -3.084, p = .002** | **Z = -4.667, p = .000** |
| 1000 | **Z = -3.826, p = .000** | **Z = -3.781, p = .000** | **Z = -3.456, p = .001** | **Z = -4.384, p = .000** |
| 1100 | **Z = -3.466, p = .001** | **Z = -3.266, p = .001** | **Z = -3.628, p = .000** | **Z = -4.455, p = .000** |
| 1200 | **Z = -2.898, p = .004** | **Z = -3.256, p = .001** | **Z = -3.231, p = .001** | **Z = -3.047, p = .002** |
| 1300 | **Z = -3.019, p = .003** | **Z = -2.981, p = .003** | **Z = -3.296, p = .001** | **Z = -3.285, p = .001** |
| 1400 | **Z = -2.923, p = .003** | Z = -2.202, p = .028 | **Z = -3.263, p = .001** | Z = -.397, p = .691 |
| 1500 | Z = -2.280, p = .023 | Z = 1.433, p = .152 | Z = -.312, p = .755 | Z = -.946, p = .344 |
| 1600 | Z = -.597, p = .550 | Z = -.472, p = .637 | Z = -.934, p = .350 | **Z = -3.007, p = .003** |
| 1700 | Z = -.311, p = .756 | Z = -.031, p = .975 | **Z = -2.829, p = .005** | Z = -1.760, p = .078 |
| 1800 | Z = -.401, p = .689 | Z = -2.401, p = .016 | Z = -2.668, p = .008 | **Z = -2.814, p = .005** |
| 1900 | Z = -1.958, p = .050 | Z = -2.315, p = .021 | **Z = -3.065, p = .002** | Z = -1.091, p = .275 |

*Note.* Numbers in boldface indicate significant effects, after Bonferroni correction.

Deaf and hearing participants performed similarly for semantically related distracters as the proportion of fixations to the semantic distracter picture were significantly higher compared to unrelated items for both groups between 700ms and 1400ms (see Table 7-5). Hearing participants also looked at semantic distracters significantly more between the 1700-1900ms time windows, while this was not the case for the deaf participants. No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.704, p > .007; U2 > -2.640, p > .008).*

The most complex model did not converge, thus correlations were removed and random effects reduced. The results from the reduced model are reported here. Overall, there was a significant effect of semantics on the intercept term (Estimate = 6.53, SE = 3.43, p < 0.00). There was no significant effect of group (Estimate = -1.84, SE = 6.86, p = 0.98). However, there was an interaction between group and one of the time polynomials, which indicates that the temporal profile of the semantic effect differed for deaf and hearing readers (See Table 7-6).

**Table 7-6 - Parameter estimates for each time term, group and interactions between each time term and group for semantic distracters from the growth curve analyses**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 6.53 | 3.43 | 19.04 | <0.00 |
| Time term 1 | -2.01 | 7.61 | -2.64 | 0.01 |
| Time term 2 | -3.61 | 5.93 | -6.08 | <0.00 |
| Time term 3 | 5.21 | 4.43 | 11.75 | <0.00 |
| Time term 4 | -1.57 | 4.44 | -3.53 | 0.00 |
| Group | -1.84 | 6.86 | -0.0.3 | 0.97 |
| Time term 1 x Group | 1.10 | 1.52 | 3.80 | 0.48 |
| Time term 2 x Group | -1.27 | 1.18 | 3.80 | 0.29 |
| Time term 3 x Group | -1.85 | 8.88 | 5.56 | 0.03 |
| Time term 4 x Group | -9.39 | 8.88 | 5.56 | 0.29 |

From the model, we cannot tell where the significant time-course differences are between the groups. However, earlier analyses using the Wilcoxon and Mann-Whitney non-parametric tests showed the proportion of looks towards semantic distracters was significantly different only during the late 1700 and 1800ms time window compared to unrelated items for the hearing readers (see Table 7-5). This was not the case for deaf readers. Results from the group comparisons (Mann-Whitney) showed that there were significant differences between the two groups at the .05 level during the 1700ms time window in the by-subjects analysis *(Z1 = -2.502, p = .014; Z2 = -1.625, p = .104)*. This is likely to be where the growth curve model is identifying temporal differences between deaf and hearing readers for semantic distracters.

**Looks to phonologically-related distracters.** Neither group looked to phonological distracters significantly more than unrelated items during any time window. No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.704, p > .007; U2 > -1.803, p > .071.*

The random effect structure where all models converged included only the random intercept. Overall, there was a significant effect of phonology on the intercept term (Estimate = 6.53, SE = 3.43, p < 0.00). When group was included as a factor, there was no significant effect of group (Estimate = -1.84, SE = 6.86, p = 0.98). However, there was an interaction between group and one of the time polynomials, which indicates that the temporal profile of the phonological effect differed for deaf and hearing readers (see Table 7-7).

**Table 7-7 - Parameter estimates for each time term, group and interactions between each time term and group for phonological distracters from the growth curve analyses**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 6.53 | 3.43 | 19.04 | <0.00 |
| Time term 1 | -2.01 | 7.61 | -2.64 | 0.01 |
| Time term 2 | -3.61 | 4.55 | -7.93 | <0.00 |
| Time term 3 | 5.21 | 4.55 | 11.46 | <0.00 |
| Time term 4 | -1.57 | 4.55 | -3.44 | 0.00 |
| Group | -1.84 | 6.85 | -0.03 | 0.98 |
| Time term 1 x Group | 1.10 | 1.52 | 0.72 | 0.48 |
| Time term 2 x Group | -1.27 | 9.10 | -1.40 | 0.16 |
| Time term 3 x Group | -1.85 | 9.10 | -2.04 | 0.04 |
| Time term 4 x Group | -9.39 | 9.10 | -1.03 | 0.30 |

Again, in order to understand where the differences arise, we looked back to our non-parametric analyses. Wilcoxon analyses showed a significant difference in the proportion of looks to phonological distracters during the 1000 *(Z1 = -1.930, p = .054; Z2 = -1.912, p = .056)* and 1100ms *(Z1 = -1.906, p = .057; Z2 = -1.832, p = .067)* time windows at the .05 level for hearing readers. No such effects were detected for deaf readers. The different pattern for hearing and deaf readers was, however, not confirmed in the formal comparison using the Mann-Whitney test.

There were no correlations between reading scores and RTs *(r = .263, n = 40, p = .101)* or between reading scores and accuracy *(r = -.118, n = 40, p = .469)*. Further analyses separating out the two groups also revealed no significant correlations between reading scores and performance (both RTs and accuracy) in the word condition (See Table 7-8).

**Table 7-8 - Results from the correlation analyses for deaf and hearing readers.**

| Group | Correlations | N | *r* | p |
|---|---|---|---|---|
| Deaf | Reading score/RTs | 20 | .030 | .898 |
| Deaf | Reading score/accuracy | 20 | -.150 | .527 |
| Hearing | Reading score/RTs | 20 | .408 | .074 |
| Hearing | Reading score/accuracy | 20 | -.075 | .752 |

#### 7.1.2.2 Pseudohomophone Condition

Figures 7-5 and 7-6 shows the proportions of fixations for deaf and hearing participants, respectively, in the pseudohomophone condition, in which participants were instructed not to respond. Here the labels "pseudotarget", "pseudosemantic" and "pseudophonological" refer to the relationship of the picture to the word from which the pseudohomophone is derived. (E.g. kote (from coat), shirt (semantic), and boat (phonological). In contrast to the word condition, the pattern of fixations looks much more variable for deaf readers. See Appendix 16 for full tabulation of results from the Wilcoxon and Mann-Whitney analyses.

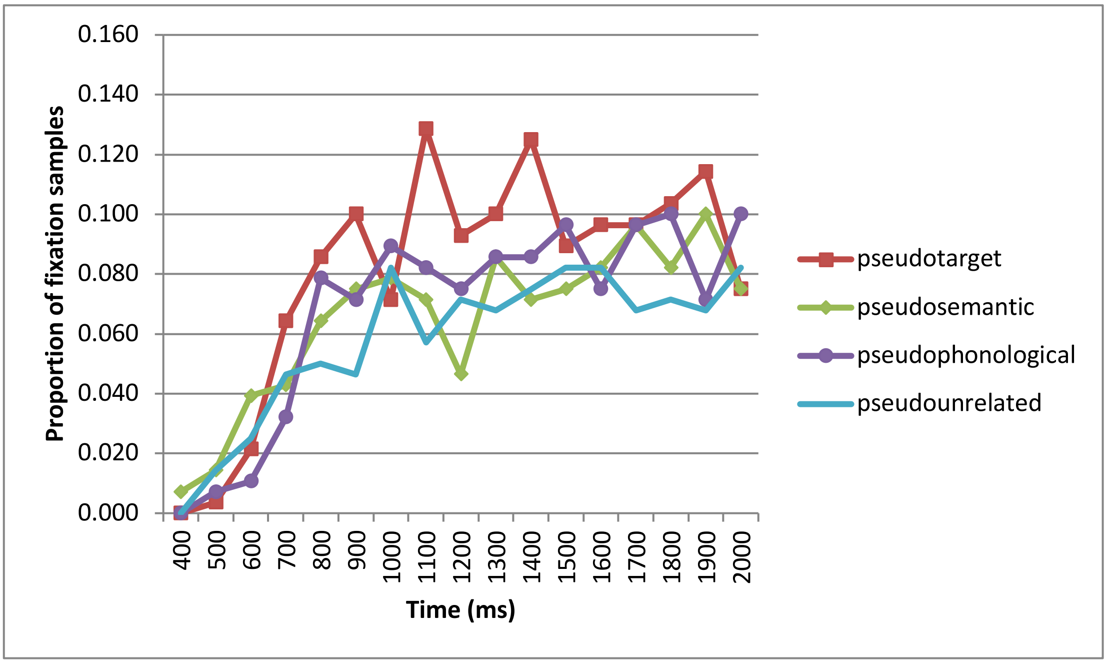


**Figure 7-5. Proportion of fixation samples in the pseudohomophone condition for deaf participants**

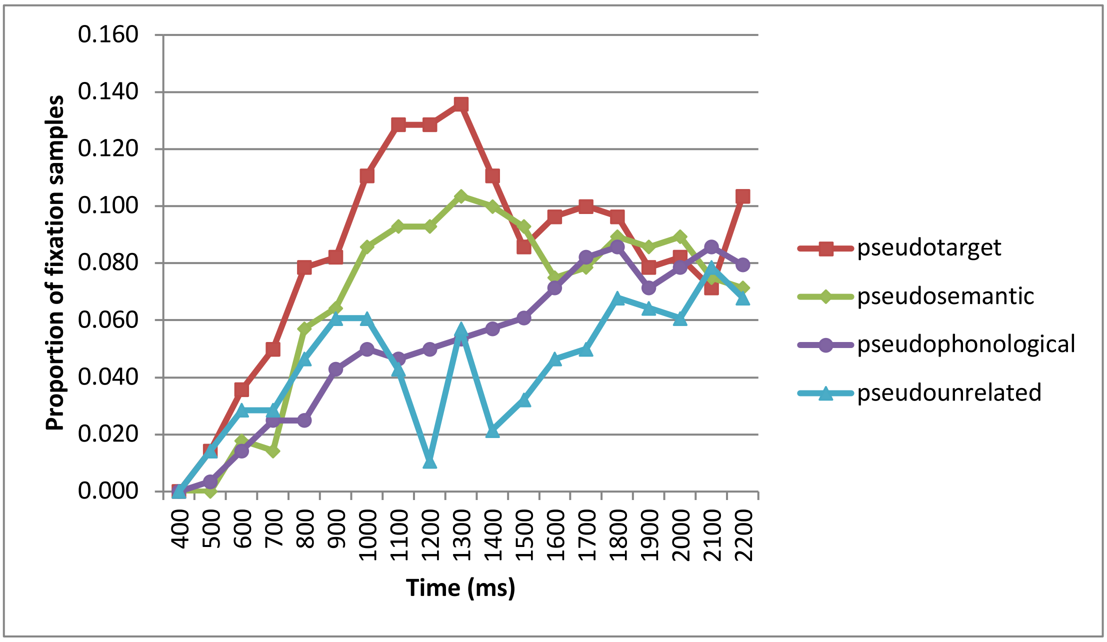


**Figure 7-6. Proportion of fixation samples in the pseudohomophone condition for hearing participants**

Hearing readers appear to have been mostly drawn to pseudotargets in comparison to the other distracter items. There does not seem to be a clear pattern for deaf readers. Tables 7-9 and 7-10 below report the Z (by-subjects and by-items) statistics for those comparisons (pseudotarget vs. pseudounrelated and pseudosemantic distracter vs. pseudounrelated) that was significant in at least some time-windows, for deaf and hearing participants.

**Looks to pseudotarget items.** Table 7-9 reports the Z (by-subjects and by-items) statistics for the comparison between pseudotarget vs. unrelated items, separately for deaf and hearing participants.

**Table 7-9. Comparison between proportion of fixation samples of pseudotarget vs. unrelated items in the pseudohomophone condition.**

| Time Window | Deaf (by-subjects) | Deaf (by-items) | Hearing (by-subjects) | Hearing (by-items) |
|---|---|---|---|---|
| 1000 | **Z = -2.787, p = .005** | Z = -.319, p = .750 | Z = -1.575, p = .115 | Z = -2.034, p = .042 |
| 1100 | Z = -.861, p = .389 | Z = -2.451, p = .014 | Z = -2.630, p = .009 | Z = -2.404, p = .016 |
| 1200 | Z = -2.086, p = .037 | Z = -.594, p = .553 | **Z = -3.314, p = .001** | **Z = -6.746, p = .000** |
| 1300 | Z = -.926, p = .354 | **Z = -3.853, p = .000** | Z = 2.312, p = .021 | **Z = -4.049, p = .000** |
| 1400 | Z = -1.752, p = .080 | **Z = -3.935, p = .000** | **Z = -3.406, p = .001** | **Z = -3.573, p = .000** |
| 1500 | Z = -1.482, p = .138 | **Z = -3.746, p = .000** | Z = -2.392, p = .017 | **Z = -3.684, p = .000** |
| 1600 | Z = -.154, p = .877 | **Z = -3.843, p = .000** | Z = -1.605, p = .109 | **Z = -3.853, p = .000** |

*Note.* Numbers in boldface indicate significant effects after Bonferroni correction.

Hearing participants looked at pseudotarget pictures significantly more compared to pseudounrelated pictures during the 1200 to 1500ms time window (See Table 7-9). There was a significant difference between the two groups during the 1100ms time window *(U1 = -2.878, p = .004, by-subjects)* and close to significance during the 1000ms time window *(U2 = -2.611, p = .009, by-items) for pseudotarget items.*

The most complex model did not converge, thus correlations were removed and random effects were reduced. The results from the reduced model are reported here. Overall, there was a significant effect of pseudotarget item on the intercept term (Estimate = 0.03, SE = 0.01, p < 0.00). There was no significant effect of group (Estimate = 0.02, SE = 0.01, p = 0.13). There were no interactions between group and any of the time polynomials, which indicate that the temporal profile of the pseudotarget effect did not differ for deaf and hearing readers (See Table 7-10).

**Table 7-10 - Parameter estimates for each time term, group and interactions between each time term and group for pseudotarget items from the growth curve analyses**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.03 | 0.01 | 5.09 | 0.00 |
| Time term 1 | 0.09 | 0.11 | 0.80 | 0.43 |
| Time term 2 | -0.52 | 0.14 | -3.65 | 0.00 |
| Group | 0.02 | 0.01 | 1.56 | 0.13 |
| Time term 1 x Group | -0.17 | 0.22 | -0.73 | 0.46 |
| Time term 2 x Group | -0.47 | 0.29 | -1.64 | 0.11 |

**Looks to (pseudo)semantically-related distracters.** Table 7-11 reports the Z (by-subjects and by-items) statistics for the comparison between pseudosemantic distracters vs. unrelated items, separately for deaf and hearing participants.

**Table 7-11. Comparison between proportion of fixation samples to pseudosemantic distracters vs. unrelated items in the pseudohomophone condition.**

| Time Window | Deaf (by-subjects) | Deaf (by-items) | Hearing (by-subjects) | Hearing (by-items) |
|---|---|---|---|---|
| 1200 | Z = -.673, p = .501 | Z = -.946, p = 344 | **Z = -3.334, p = .001** | **Z = -6.912, p = .000** |
| 1300 | Z = -1.359, p = .174 | Z = .000, p = 1.000 | Z = -1.419, p = .156 | Z = .000, p = 1.000 |
| 1400 | Z = -.712, p = .477 | Z = .000, p = 1.000 | **Z = -2.852, p = .004** | Z = .000, p = 1.000 |
| 1500 | Z = -.127, p = .899 | Z = .000, p = 1.000 | Z = -2.357, p = .018 | Z = .000, p = 1.000 |

*Note.* Numbers in bold indicate significant effects after Bonferroni correction.

Hearing readers' looks towards pseudosemantic distracters were significantly greater than unrelated items during the 1200ms time window (See Table 7-11). For deaf readers there were no significant effects. However, no significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.542, p > .012; U2 > -2.442, p > .015).*

The most complex model did not converge, thus correlations were removed and random effects were reduced. The results from the reduced model are reported here. Overall, there was a significant effect of pseudosemantics on the intercept term (Estimate = 0.02, SE = 0.00, p = 0.00). There was not a significant effect of group, however it was very close to significant (Estimate = 0.02, SE = 0.01, p = 0.06). There was an interaction between group and one of the time polynomials, which means that the temporal trajectory of the pseudosemantic effect seems to differ for deaf and hearing readers (See Table 7-12).

**Table 7-12 - Parameter estimates for each time term, group and interactions between each time term and group for pseudosemantic distracters from the growth curve analyses**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.02 | 0.00 | 3.31 | 0.00 |
| Time term 1 | 0.13 | 0.11 | 1.21 | 0.23 |
| Time term 2 | -0.27 | 0.09 | -3.17 | 0.00 |
| Group | 0.02 | 0.01 | 1.92 | 0.06 |
| Time term 1 x Group | 0.21 | 0.22 | 0.96 | 0.34 |
| Time term 2 x Group | -064 | 0.17 | -3.76 | 0.00 |

Going back to our non-parametric analyses, Table 7-11 shows that hearing readers looked to pseudosemantic distracters more frequently than unrelated items during the 1200ms time window. No such effect was found for deaf readers and this is likely to be where the model is identifying temporal differences in deaf and hearing readers for pseudosemantic distracters.

**Looks to pseudophonological related distracters.** Hearing readers' gazes towards pseudophonological distracters were close to significant during the 1200ms time window *(Z1 = -2.567, p = .010: Z2 = -7.142, p < .000).* There were no significant effects for deaf readers. No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.023, p > .046; U2 > -1.392, p > .164).*

The most complex model did not converge, thus correlations were removed and random effects were reduced. There was a significant effect of pseudophonological distracters on the intercept term, however it was only just significant (Estimate = 0.01, SE = 0.00, p = 0.05). There was not a significant effect of group (Estimate = -0.02, SE = 0.01, p = 0.81). There were no interactions between group and any of the time polynomials. There was a small effect of pseudophonological distracters on the intercept term but no interaction effects, which suggests that neither group looked to pseudophonological distracters very much at all throughout the experimental trials (See Table 7-13).

**Table 7-13 - Parameter estimates of each time term, group and interactions between each time term and group for pseudophonological distracters from the growth curve analyses**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.01 | 0.00 | 2.01 | 0.05 |
| Time term 1 | 0.23 | 0.12 | 1.98 | 0.06 |
| Time term 2 | -0.4 | 0.08 | -1.80 | 0.07 |
| Group | -0.00 | 0.01 | -0.24 | 0.81 |
| Time term 1 x Group | 0.15 | 0.24 | 0.61 | 0.54 |
| Time term 2 x Group | -0.09 | 0.16 | -0.56 | 0.58 |

### 7.1.3 Discussion

We recorded eye movements from a group of carefully matched deaf and hearing adults to investigate semantic and phonological activation during single word reading using a modification of the visual world paradigm. The aim was to determine whether deaf skilled readers automatically activate semantic and phonological information when the task focuses on meaning, and to identify the timing of these activations for each group. In one condition, we used real words as stimuli and in the other we used pseudohomophones. When the target was a real word, there was very little difference in looking patterns of deaf and hearing participants to target and semantically related items. Both groups looked to target items significantly more than unrelated items in most time windows throughout the experimental trials. Both groups also looked at semantic distracters significantly more when compared to unrelated items in the time window between 700ms and 1400ms. These results are important for two reasons. First, we show that our novel modification of the visual world paradigm can tap into activation of competitors during visual word recognition. Second, it shows that deaf and hearing readers activate semantic information from written words following a similar time-course.

In the pseudohomophone condition, hearing participants looked at the picture (coat) related to the pseudohomophone presented (“pseudotarget”, e.g. kote) and the semantic distracter (“pseudosemantic”, e.g., shirt) more frequently compared to unrelated items. For pseudotargets, we found significant differences in the 1200-1500ms time window; for pseudosemantic distracters, we found differences during the 1200ms time window. For deaf participants, there were no significant effects in any time window.

For pseudotargets, conservative group comparisons (U statistics) showed differences in the 1000ms and 1100ms time windows: hearing readers were more drawn to pseudotargets in comparison to deaf readers. However, the growth curve analysis did not find reliable differences between groups for pseudotargets. For pseudosemantic distracters, all analyses converged in indicating group differences.

Thus while we show that semantic information upon viewing words is activated following a similar time course in both groups, we also show that hearing readers may be more reliant on phonological processes than deaf readers, at least when reading pseudohomophones. More precisely, this experiment suggests that there are differences between deaf and hearing readers in whether they access phonology during a single word reading task and, especially whether they can activate semantics from phonology, since deaf readers looked less at pseudotargets in the pseudohomophone condition compared to the hearing readers.

These results however need to be interpreted with caution because of the following reasons. First, we had two different tasks for word and nonword stimuli. Participants were instructed to click on the target picture upon seeing a word and to do nothing upon viewing a nonword. This task difference might have induced the use of different strategies in carrying out the task and these strategies might have been different for the deaf and hearing readers. Second (and likely a consequence of the difference in task), there were hardly any looks to the pictures before 400ms, which is much later than we expected on the basis of results from the use of the visual world paradigm with spoken stimuli (Huettig & McQueen, 2007). Moreover, some of our effects of interest do not appear before 1000-1200ms. In order to assess the role of the switch in task, a follow up experiment was carried out in which only pseudohomophones were presented to a group of deaf and hearing readers.

## 7.2 Experiment 4.2

In this experiment we investigate semantic and phonological processing in deaf and hearing readers by replicating and modifying a part of the previous visual world experiment (Experiment 4.1). Specifically, printed pseudohomophone targets were presented to participants in the centre of the screen along with four pictures (one in each corner of the screen). Participants were asked to click on the picture that they felt was the closest match to the nonword presented to them. In the previous experiment, participants were presented with both words and nonwords, however if they saw any nonwords they were instructed to do nothing i.e. there was no response and for deaf readers there was no evidence of phonological processing when presented with pseudohomophones. In this study, there were only pseudohomophones and participants were forced to make a selection, which may show deaf participants adopting a different strategy to that observed in Experiment 4.1. Of particular interest in this experiment was to observe the similarities/differences in the processing of semantic and phonological information in deaf and hearing readers.

### 7.2.1 Method

#### 7.2.1.1 Participants

See section 4.1.1 for participant criteria and description of how background information was elicited. Twenty-one deaf adults (with moderate to profound hearing loss, 12 of these participants also took part in Experiment 4.1) and 24 hearing English native speakers took part in this study. One deaf participant was excluded from analyses as they had a moderate hearing loss and also achieved a low score on the reading test (more than 2.5 SDs below the group mean). Two hearing participants were excluded, as they did not match any of the deaf readers on the criteria set. Data from 2 hearing participants could not be used in the analyses as data recorded was corrupted. Thus, 20 participants from each group (40 in total) were included in this study. Table 7-14 provides demographic information about the participants. Table 7-15 provides information about deaf participants' degree of deafness, use of amplification aids and sign language background.

**Table 7-14. Participants' age, gender, educational level and reading level**

| | Deaf | Hearing |
|---|---|---|
| Average age | 33.85 | 34.05 |
| Male | 8 | 8 |
| Female | 12 | 12 |
| College | 5 | 3 |
| Bachelors | 9 | 5 |
| Masters | 3 | 11 |
| Postgraduate Diploma | 2 | 0 |
| PhD | 1 | 1 |
| Reading level (mean) | 32.35 | 31.6 |

**Table 7-15. Deaf participants' degree of deafness, use of amplification aids and language background**

| | |
|---|---|
| **Degree of Deafness** | Profound – 17 |
| | Severe to profound – 3 |
| **Amplification aids** | Hearing aids – 7 |
| | Cochlear Implants – 4 |
| | None used - 9 |
| **Sign language background** | Native – 11 |
| | *Near native – 6 |
| | **Late learner – 3 |

*Near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

**Late learners used BSL as their main language for more than 10 years

In addition to the reading and BSL measures, a test of adult speechreading (TAS) was also included. This is a measure of silent speechreading in adults (suitable for both deaf and hearing adults) and tests three levels of speechreading ability: words, sentences and short stories. This measure was carried out to see if there were any correlations between speechreading skill and reading as well as performance on the experimental tasks (Mohammed, Macsweeney, & Campbell, 2003).

#### 7.2.1.1.1 Reading measures

See section 4.1.1 for description of the reading assessment used. A pairwise comparison of the reading level of hearing readers *(n = 20, m = 31.60 (17 years 8 months)), SD = 4.19, range = 24 – 42 (15 years 4 months to 23+ years))* and deaf readers *(n = 20, m = 32.35, SD = 4.94, range = 23 – 42 (15 years to 23+ years))* showed no significant differences *(t (40) = 1.543, p = 0.139).*

#### 7.2.1.1.2 BSL Measures

See section 4.1.1 for description of the BSL assessment used. On average, deaf participants scored *27.72 out of 42 (n = 18, SD = 5.72, range = 11 – 31).* BSL SRT scores were not available for two participants due to corrupted video files.

### 7.2.1.1.3 Speechreading Measures

See end of section 7.2.1.1 for description of speechreading measures. Deaf participants scored an average of *32.45 out of 45 (n = 20, SD = 3.33, range = 27 – 38).* Average scores were around the 52nd percentile and percentiles ranged from the 25th to the 90th percentile.

### 7.2.1.2 Stimuli

The same 28 pseudohomophones used in Experiment 4.1 were used for this experiment, however in this instance there was no counterbalancing thus all participants saw all 28 pseudohomophones. There were no non-homophonic nonwords in this experiment. See Appendix 17 for full stimuli list.

### 7.2.1.3 Procedure

See section 7.1.1.3 for description of experiment set up. There were four practice trials and 28 experimental trials. Participants were instructed to click on the picture that they felt was the closest match to the nonword presented to them. Participants were not told that the nonwords were pseudohomophones.

### 7.2.1.4 Data Analyses

Reaction times and accuracy data were analysed using a paired sample t-test. Reaction times and accuracy of each group were directly compared.

Fixation data was analysed as in Experiment 4.1 using non-parametric tests and growth curve analyses. Fixation samples for each quadrant (see Figure 7-2) were coded for analysis in 100ms bins starting from 0ms and ending at 2500ms. Analyses ended at 2500ms as any looks beyond this time window would plausibly reflect only post-recognition processes as response times averaged around 2700ms (i.e., participants check pictures again to make sure they did not miss anything after having decided whether to respond or not). Trials with incorrect responses (i.e. the wrong target item was selected) were not included in data analysis (21% of total data).

Correlations (Pearson's *r)* between reading, speechreading and BSL SRT scores were tested for deaf participants. Correlations (Pearson's *r)* between reading scores and performance on the task were tested for all participants.

### 7.2.2 Results

**Table 7-16 - Reaction times and accuracy rates for deaf and hearing participants**

| Group | N | Mean RT | Std. Dev. RT | Mean Accuracy | Std. Dev. Accuracy |
|---|---|---|---|---|---|
| Deaf | 20 | 2689.40 | 344.21 | .817 | .099 |
| Hearing | 20 | 2625.69 | 477.42 | .854 | .096 |

**Reaction Times.** There were no significant differences between deaf and hearing readers *(t1 (19) = .513, p = .614; t2 (27) = .162, p = .873).*

**Accuracy.** There were no significant differences between deaf and hearing readers *(t1 (19) = -1.302, p = .209; t2 (27) = -1.469, p = .153).*

Figures 7-7 and 7-8 show the proportion of fixation samples for deaf and hearing participants.

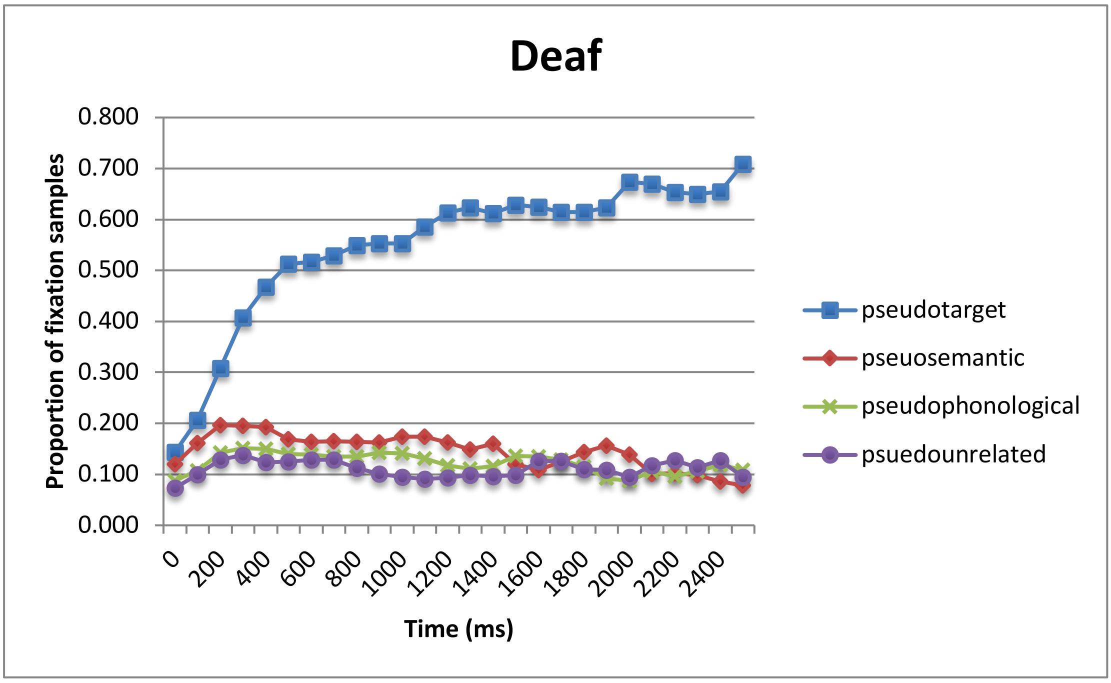


**Figure 7-7. Proportion of fixation samples for deaf participants**

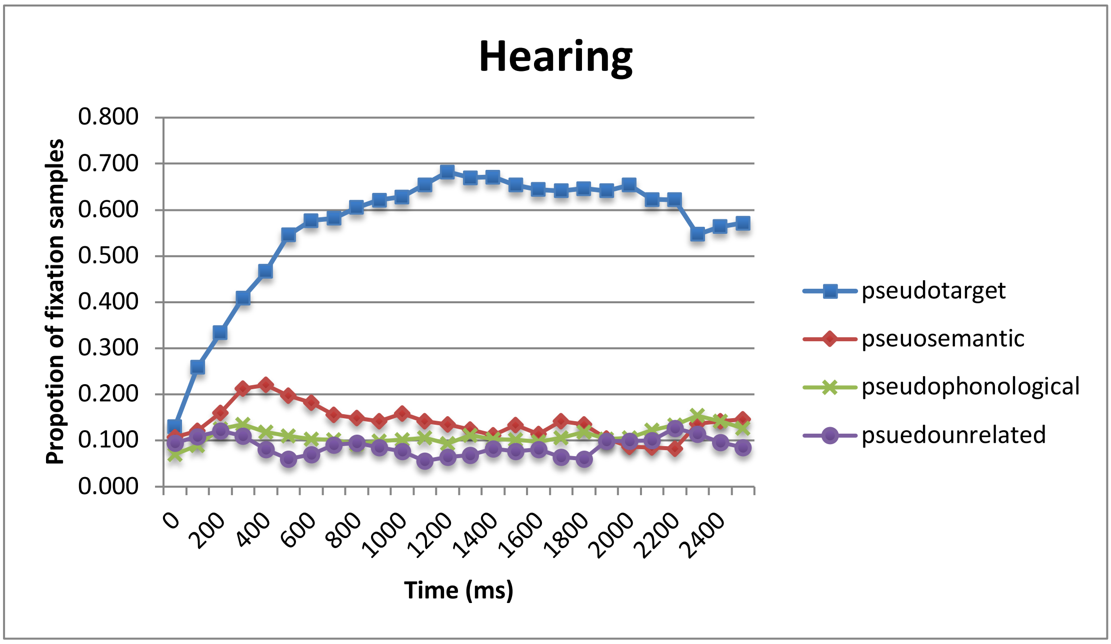


**Figure 7-8. Proportion of fixation samples for hearing participants**

**Looks to pseudotarget items.** As it can be seen from Figures 7-7 and 7-8, both deaf and hearing participants looked at pseudotarget pictures in all time windows from 100 to 2500ms (by-subjects and by-items). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -1.760, p > .081; U2 > -2.174, p > .045.* See Appendix 18 for full tabulation of results.

The most complex model did not converge, thus correlations were removed from the model and random effects reduced. Results from the reduced model are reported here. Overall, there was a significant effect of target on the intercept term (Estimate = .47, SE = .02, p < 0.00), which indicates that proportion of looks towards pseudotarget items changed over the time course of the trial between 0 and 2500ms. There was no significant effect of group (Estimate = .03, SE = .04, p = 0.35). There were also no interactions between group and any of the time polynomials, which strongly suggest that the temporal profile of the pseudotarget effect did not differ for deaf and hearing readers (See Table 7-17). This converges with the results of the earlier non-parametric analyses.

**Table 7-17 - Parameter estimates for each time term, group and interactions between each time term and group for pseudotarget items**

| Fixed Effects | Estimate | Std. Error | T value | P value |
|---|---|---|---|---|
| Intercept | 0.47 | 0.02 | 23.86 | <0.00 |
| Time term 1 | 3.66 | 0.61 | 5.58 | <0.00 |
| Time term 2 | -2.68 | 0.39 | -6.94 | <0.00 |
| Time term 3 | 0.99 | 0.17 | 5.81 | <0.00 |
| Group | 0.04 | 0.04 | 0.09 | 0.35 |
| Time term 1 x Group | -0.71 | 1.22 | -0.58 | 0.56 |
| Time term 2 x Group | -1.23 | 0.77 | -1.59 | 0.12 |
| Time term 3 x Group | 0.10 | 0.34 | 0.28 | 0.78 |

**Looks to pseudosemantic items.** Figures 7-7 and 7-8 shows that there were more looks towards pseudosemantic distracters compared to unrelated items for both groups, but more so for the hearing group. Wilcoxon analyses show that deaf participants were drawn to pseudosemantic items significantly more than unrelated items during the 1000ms *(Z1 = -2.834, p = .005, Z2 = -1.982, p = .048)* and 1100ms *(Z1 = -2.768, p = .006, Z2 = -2.355, p = .019)* time windows. For the hearing participants, looks towards pseudosemantic pictures were significantly more than unrelated items in several time windows starting at 300ms (see Table 7-18 below). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.262, p > .023; U2 > -2.863, p > .004).*

**Table 7-18. Comparison between proportion of fixation samples to pseudosemantic distracters vs. unrelated items.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items |
|---|---|---|---|---|
| **300** | **Z = -2.820, p = .005** | **Z = -2.997, p = .003** | Z = -2.430, p = .015 | Z = -1.715, p = .086 |
| **400** | **Z = -3.716, p = .000** | **Z = -4.078, p = .000** | Z = -2.232, p = .020 | Z = -2.430, p = .015 |
| **500** | **Z = -3.754, p = .000** | **Z = -4.304, p = .000** | Z = -1.831, p = .067 | Z = -1.658, p = .097 |
| **600** | **Z = -3.173, p = .002** | **Z = -3.886, p = .000** | Z = -1.233, p = .218 | Z = -.80, p = .419 |
| **700** | Z = -2.638, p = .008 | Z = -2.618, p = .009 | Z = -1.657, p = .097 | Z = -1.058, p = .290 |
| **800** | Z = -2.297, p = .022 | Z = -1.801, p = .072 | Z = -2.198, p = .028 | Z = -1.811, p = .070 |
| **900** | Z = -2.595, p = .009 | Z = -2,331, p = .020 | Z = -2.236, p = .025 | Z = -1.715, p = .046 |
| **1000** | Z = -2.738, p = .006 | **Z = -3.114, p = .002** | **Z = -2.834, p = .005** | Z = -1.982, p = .048 |
| **1100** | **Z = -2.942, p = .003** | **Z = -3.127, p = .002** | Z = -2.768, p = .006 | Z = -2.355, p = .019 |
| **1200** | Z = -2.711, p = .007 | Z = -2.725, p = .006 | Z = -2.108, p = .035 | Z = -1.745, p = .081 |

*Note.* Figures in boldface indicate significant effects.

The most complex model converged. Overall, there was a significant effect of pseudosemantic distracters on the intercept term (Estimate = .04, SE = .01, p < 0.00). When group was included as a factor, there was no significant effect of group (Estimate = .01, SE = .01, p = 0.43). There were no interactions between group and any of the time polynomials, which suggest that the temporal trajectory of the pseudosemantic effect did not differ for deaf and hearing readers (See Table 7-19).

**Table 7-19 - Parameter estimates for each time term, group and interactions between each time term and group for pseudosemantic distracters**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.04 | 0.01 | 5.70 | <0.00 |
| Time term 1 | -0.86 | 0.23 | -3.74 | <0.00 |
| Time term 2 | -0.59 | 0.18 | -3.23 | <0.00 |
| Group | 0.01 | 0.01 | 0.79 | 0.43 |
| Time term 1 x Group | -0.01 | 0.46 | -0.02 | 0.99 |
| Time term 2 x Group | -0.44 | 0.37 | -1.19 | 0.24 |

**Looks to pseudophonological items.** Wilcoxon analyses show that there were no significant differences in looks towards pseudophonological distracters and unrelated items across all time windows (by-subjects and by-items) for either group (see Figures 7-7 and 7-8). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -1.557, p > .121; U2 > -1.258, p > .208).*

The most complex model did not converge, thus correlations were removed from the model, random effects were reduced. The results from that reduced model are reported here. Overall, there was a significant effect of pseudophonological distracters on the intercept term (Estimate = .02, SE = .01, p = 0.01). There was no significant effect of group (Estimate = .02, SE = .01, p = 0.15). There were also no interactions between group and time polynomials, which suggests that the temporal trajectory of the pseudophonological effect did not differ for deaf and hearing readers (See Table 7-20), which supports earlier analyses carried out.

**Table 7-20 - Parameter estimates for each time term, group and interactions between time term and group for pseudophonological distracters**

| Fixed Effects | Estimate | Std. Error | T value | P value |
|---|---|---|---|---|
| Intercept | 0.02 | 0.01 | 2.67 | 0.01 |
| Time term 1 | 0.12 | 0.35 | 0.35 | 0.72 |
| Time term 2 | -0.06 | 0.32 | -0.19 | 0.85 |
| Time term 3 | 0.41 | 0.14 | 2.94 | 0.00 |
| Time term 4 | 0.32 | 0.01 | 1.46 | 0.02 |
| Group | 0.02 | 0.01 | 1.46 | 0.15 |
| Time term 1 x Group | 0.90 | 0.71 | 1.27 | 0.21 |
| Time term 2 x Group | 0.38 | 0.64 | 0.61 | 0.55 |
| Time term 3 x Group | 0.42 | 0.28 | 1.49 | 0.14 |

**Correlations.** For deaf readers, correlations between reading scores and the scores from the BSL SRT were not significant *(r = .059, n = 18, p = .815 (2 tailed)).* For deaf readers, correlations between reading and speechreading scores were not significant *(r = -.154, n = 20, p = .517 (2 tailed)*. For deaf readers, correlations between scores from the BSL SRT and speechreading measures were not significant *(r = -.050, n = 18, p = .845 (2 tailed))*. For both deaf and hearing readers, correlations between reading scores and performance on the pseudohomophone task were not significant (*r = -.295, n = 18, p = .064 (2 tailed))*. Correlations between reading scores and pseudohomophone accuracy were also not significant *(r = -.254, n = 20, p = .114 (2 tailed))*. Further analyses separating out the deaf and hearing readers revealed there were no significant correlations between reading scores and task performance (both accuracy and RTs).

**Table 7-21 - Results from the correlation analyses for deaf and hearing readers.**

| Group | Correlation Analyses | N | *r* | p |
|---|---|---|---|---|
| Deaf | Reading score/RTs | 20 | -.212 | .369 |
| Deaf | Reading score/accuracy | 20 | .285 | .222 |
| Hearing | Reading score/RTs | 20 | -.401 | .080 |
| Hearing | Reading score/accuracy | 20 | .268 | .254 |

## 7.3 Discussion

Like in Experiment 4.1 we recorded the eye movements of deaf and hearing readers who were carefully matched on age, gender and reading level. In this study, participants were presented with pseudohomophones only and asked to click on the picture that they felt was the best match to the nonword presented to them (participants were not told that items would be pseudohomophones).

In the previous study, we found some interesting differences in processing pseudohomophones between deaf and hearing readers, however, not only were the differences not very large but also the difference in task precluded us from drawing definitive conclusions from those results. Here, we wanted to see if there are any differences between deaf and hearing readers when both groups are forced to make a selection based on phonological information.

In this experiment, both deaf and hearing readers looked to pseudotarget pictures significantly more than unrelated items across most time windows from as early as 100ms from stimulus onset. There were no differences between the two groups and this shows that both deaf and hearing participants were able to process the pseudohomophone, extracting both phonological and semantic information to select the correct pictures. However, when comparing pseudosemantic distracters to pseudounrelated items, the two groups differed.

There are two main conclusions that we can draw from this study. First, the time course of eye movements toward target or distracter pictures is clearly variable and highly task dependent, such that, for example, while in Experiment 4.1, looks to semantic distracters were only observed from 700ms, these looks are present already at 300ms in Experiment 4.2. This difference between the two experiments, although important, should not compromise the interpretation of group differences. Second, both analyses indicated differences between deaf and hearing readers in the processing of phonological information. In particular, hearing readers appear to access semantic information from the pseudohomophones (as indicated by the frequency of looks towards pseudosemantic distracters across several time windows), while this is not the case for deaf readers. Crucially, although pseudohomophones do not automatically activate semantics in deaf readers, their decision latencies and accuracy rates did not differ to hearing readers. Additionally, the time course of looks to pseudotarget items were almost identical in both groups and taken together this shows that although the connections between phonology and semantics may differ between the two groups, it does not affect the pseudohomophone processing speed or accuracy for deaf readers.

## 7.4 General Discussion

In Experiment 4.1, at both deaf and hearing readers processed word targets similarly, looking to both target items and semantic distracters during similar time windows. Group comparisons show no differences between deaf and hearing readers except for phonological distracters: while hearing readers showed significantly more looks to these than unrelated distracters, this was not the case for deaf readers (though the groups did not differ significantly). With pseudohomophones, we discovered that hearing readers looked at pseudotargets and pseudosemantic distracters significantly more than unrelated items. For deaf readers, while they also looked at pseudotargets more often than unrelated, they did not show an effect for pseudosemantic distracters. These findings suggest differences in the processing of phonological information for the two groups. However, not only were the effects small, but they also occurred late (about 1000ms). We speculated that this might be due to the task: participants were instructed to click on the picture if the stimuli were real words, or not to do anything if the stimuli were nonwords. Experiment 4.2 addressed this concern and focused specifically on pseudohomophones. Here participants were asked to click on the picture that was best fit to the nonword. In this experiment, differences in looks to related vs. unrelated distracters started much earlier, suggesting that indeed, the specific task used in Experiment 4.1 led to delayed processing, at least as indexed by eye movements. In this experiment, while both deaf and hearing readers showed similar patterns for pseudohomophones, they differ with respect to pseudosemantic distracters. Hearing readers looked to pseudosemantic distracters significantly more than unrelated items over several time windows, starting from 300ms. Looks to pseudosemantic distracters occurred much later for the deaf readers, at 1000 and 1100ms and only occurred during those time windows. This suggests that the connections between phonology and semantics are stronger for hearing readers.

Together, the results of these two experiments seem to suggest that deaf readers can process phonological information when explicitly asked to do so, as evident in Experiment 4.2. However, they may not process it in the same way. In particular they may not automatically activate semantic information from phonology. This is evidenced by the following findings: (a) hearing but not deaf readers look at phonological distracters when stimuli are real words; (b) hearing but not deaf readers look at pseudosemantic distracters when processing pseudohomophones.

The above findings may help to reconcile the extremely mixed results reported in the previous literature with regards to phonological processing in deaf readers (Bélanger, Baum, et al., 2012; Hanson & Fowler, 1987; Mayberry et al., 2011; Mayer & Trezek, 2014). Many studies have shown that deaf readers can activate phonological information representations in tasks that do not involve retrieving semantics from phonology in an automatic fashion, for example, in a lexical decision task. It is unsurprising that the connections between semantics and phonology are less robust for deaf readers as hearing children are exposed to phonology and semantics prior to learning to read. The majority of participants in this study are native or near native signers of BSL, thus it is likely that they were exposed to English phonology at a later stage or developed phonological awareness after learning to read (Harris & Moreno, 2004). I will explore these ideas in more detail in the discussion chapter (Chapter Ten).

Correlations between the reading, speechreading and BSL measures were not significant. This is unsurprising as the deaf readers included in this group were all skilled readers, thus at similar levels of language proficiency. Several studies have shown correlations between different language measures such as reading proficiency and sign language proficiency (e.g. Chamberlain & Mayberry, 2008). If deaf, less skilled readers were included in this study, it may have been possible to detect correlations between those language measures. Correlation analyses show that there is no significant relationship between reading proficiency and performance in each task and this is likely to be because readers in these studies were at similar levels of proficiency.

Although the above results are compelling, there are some issues that will need to be addressed in future studies. In both experiments, phonological distracters were included along with semantic distracters yet there was very little or no looks towards phonological distracters in either experiment by either deaf or hearing participants. Differences were only detected in the word condition of Experiment 4.1, where hearing readers looked to phonological distracters more frequently during a single time window.  This may be because the phonological distracters were rhymes of the target items and past visual world studies have demonstrated that rhyming effects are very small (Huettig et al., 2011). Typically, there are larger effects when phonological distracters have the same or similar onset to the target item (Huettig et al., 2011). This will need to be addressed in future studies.

Overall, Experiments 4.1 and 4.2 demonstrate that the visual world paradigm can be used fruitfully to investigate visual word recognition in different populations. Experiment 4.1 shows that deaf and hearing readers activate orthographic and semantic information in a similar fashion following a similar time course. Experiments 4.1 and 4.2 highlight important differences between deaf and hearing readers when presented with pseudohomophones. Crucially, despite having weaker connections between phonology and semantics, reading skill was not impacted as deaf and hearing readers were matched for reading level.

As several studies have demonstrated that deaf readers make more use of orthographic information in comparison to phonological information (Bélanger et al., 2013), this will be explored further in the next study. In Chapter 8, I will describe and report results from another visual world study where written words were presented as targets. Only this time, distracter items included homophones of the target words as well as items that were orthographically similar to the target words, which will allow us to explore further whether or not deaf readers make more use of orthographic information in comparison to phonological information.

# 8 Experiment 5: Investigating orthographic, semantic and phonological processing in deaf and hearing readers using the visual world paradigm

In the Chapter 7, I introduced a novel adaptation of the visual world paradigm to investigate the interplay between orthography, semantic and phonological information. Instead of presenting auditory words as target stimuli, as in the traditional visual world paradigm design, I presented written word targets with picture options for responses that included the target item, as well as distracter items. Distracter items included were semantically or phonologically related to the target item, there were also unrelated items included to provide a baseline. I demonstrated that the visual world paradigm could be used fruitfully to show activation of semantic and phonological information during single visual word recognition. Findings from the previous experiments demonstrates that there are many similarities between deaf and hearing skilled readers especially when targets are words, showing that the connections between orthography and semantics are robust for both deaf and hearing readers. However, there were important differences when pseudohomophones were presented to both populations. In Experiment 4.1, hearing participants looked towards pseudotarget items significantly more than unrelated distracters. In Experiment 4.2, hearing participants looked to pseudosemantic items significantly more than unrelated items. On both occasions deaf participants did not, which indicates that connections between semantics and phonology are less robust for deaf readers compared to hearing readers.

Previous studies have reported that deaf readers use and rely more on orthographic information in comparison to phonological information (Bélanger, Baum, et al., 2012; Bélanger et al., 2013). In the previous chapter we did not include orthographically similar distracters therefore we could not draw conclusions. Including orthographic distracters would demonstrate the extent to which deaf and hearing readers make use of orthographic information during single visual word recognition. In this chapter, I investigate orthographic, semantic and phonological processing in a group of carefully matched deaf and hearing readers (matched on age, gender, education and reading level) using our adaptation of the visual world paradigm. Here we compare phonological and orthographic processing using homophonic and orthographically similar distracters.

As discussed in Chapter 3, several studies have demonstrated that deaf readers make more use of orthographic information in comparison to hearing readers (e.g. Bélanger et al., 2012, 2013). It is likely that increased efficiency in orthographic processing is because deaf readers have reduced access to phonological information compared to their hearing peers. The increased use of orthographic information compensates for reduced access to phonology. It is possible that the robust connections between orthography and phonology in deaf readers (as demonstrated by the lexical decision tasks described in Chapter 5) help to stabilise the input code even when connections between phonology and semantics are weak. Several studies investigating word recognition in hearing readers have demonstrated that it is not always necessary to activate phonological information in order to access meaning (Brysbaert, 2001) and that hearing readers do make use of different strategies during word recognition (Brysbaert & Praet, 1992; Harm & Seidenberg, 2004). However, asking whether phonological or orthographic information is accessed or not only gives us partial insight into visual word processing. Much richer information can be gained from eye-tracking studies by exploring time course activations of orthographic and/or phonological information in deaf skilled and hearing readers.

Although the experiments described in previous chapters show that deaf and hearing readers extract information from orthography, there were no manipulations based on orthographic similarity (i.e. distracter items that were orthographically similar to target items). One of the purposes of the experiment described in this chapter is to further explore the similarities/differences between deaf and hearing skilled readers, with the inclusion of distracters similar in orthography to target words.

Additionally, the role of phonology in deaf readers will be further explored, as although the previous experiments highlight important similarities and differences between phonological processing in deaf and hearing readers, pseudohomophones were used to explore this aspect. It is possible that seeing pseudohomophones elicits different processes as they are not real words, thus in this experiment, homophones are used. Importantly, the use of homophones allows us to administer the same task across different conditions, which differs from Experiment 4.1 described in Chapter 7 where participants needed to respond when targets were words and to do nothing when presented with nonwords.

If participants look towards orthographic distracters more frequently in comparison to unrelated items, this will suggest that they are activating orthographic information during single visual word recognition. If participants look towards homophonic distracters more frequently compared to unrelated items, this indicates that they may be activating phonological information during single visual word recognition. If there are differences between deaf and hearing readers in each of these conditions, the differences cannot be attributed to a difference in task.

## 8.1 Method

### 8.1.1 Participants

See section 4.1.1 for participant criteria and description of how background information was elicited. Twenty-one deaf adults (with moderate to profound hearing loss) and 24 hearing English native speakers took part in this study. One deaf participant was excluded from analyses as they had a moderate hearing loss and also achieved a low score (23/42) on the reading test. Two hearing participants were excluded, as they did not match any of the deaf readers on the set criteria. Data from 2 hearing participants could not be used in the analyses as data recorded was corrupted. Thus, 20 participants from each group (40 in total) were included in this study. Table 8-1 provides demographic information about the participants. Table 8-2 provides information about deaf participants' degree of deafness, use of amplification aids and sign language background.

**Table 8-1. Participants' age, gender, education and reading level**

| | Deaf | Hearing |
|---|---|---|
| Average age | 33.85 | 34.05 |
| Male | 8 | 8 |
| Female | 12 | 12 |
| College | 5 | 3 |
| Bachelors | 9 | 5 |
| Masters | 3 | 11 |
| Postgraduate Diploma | 2 | 0 |
| PhD | 1 | 1 |
| Reading level (mean) | 32.35 | 31.6 |

**Table 8-2. Deaf participants' degree of deafness, use of amplification aids and sign language background**

| | |
|---|---|
| **Degree of Deafness** | Profound – 17 |
| | Severe to profound – 3 |
| **Amplification aids** | Hearing aids – 7 |
| | Cochlear Implants – 4 |
| | None used - 9 |
| **Sign language background** | Native – 11 |
| | *Near native – 6 |
| | **Late learners |

*Near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

**Late learners used BSL as their main language for more than 10 years

#### 8.1.1.1 Reading measures

See section 4.1.1 for participant criteria and a description of how background information was elicited. A pairwise comparison of the reading level of hearing readers *(n = 20, m = 31.60, SD = 4.19, range = 24 – 42)* and deaf readers *(n = 20, m = 32.35, SD = 4.94, range = 23 – 42)* showed no significant differences *(t (40) = 1.543, p = 0.139).*

#### 8.1.1.2 BSL Measures

See section 4.1.1 for description of the BSL assessment used. On average, deaf participants scored *27.72 out of 42 (n = 18, SD = 5.72, range = 11 – 31).* BSL SRT scores were not available for two participants due to corrupted video files.

#### 8.1.1.3 Speechreading Measures

See end of section 7.2.1.1 for description of speechreading measures. Deaf participants scored an average of *32.45 out of 45 (n = 20, SD = 3.33, range = 27 – 38).* Average scores were around the 52nd percentile and percentiles ranged from the 25th to the 90th percentile.

### 8.1.2 Stimuli

There were two conditions, homophone and orthographic conditions. For each condition, homophonic and orthographic similar pairs were created. Prior to commencing the study we asked 3 additional participants (who did not take part in the main experiment) to name them to ensure that the pictures we used elicited the labels we expected.  From 19 homophonic pairs, 3 pairs were removed as responses did not match the intended target e.g. tied/tide (participants would say ‘tie’ instead of ‘tied’ and beach/sea/ocean instead of ‘tide’. From 22 orthographically similar pairs, 2 pairs were removed as responses did not match the intended target e.g. inch/itch (participants would say ‘scratch’ instead of ‘itch’ and ‘ruler’ instead of ‘inch’.

**Homophones.** Participants were presented with a target homophone word (e.g. night) along with four pictures (see Figure 8-1), one of which was a homophonic distracter (e.g. knight). In this condition there was also a distracter that was semantically related to the target item (e.g. day) and an unrelated item (e.g. chocolate). In total, there were 16 sets of homophones. Although every effort was made to try and ensure that word frequencies between homophone pairs did not differ greatly, there was still a significant difference in word frequency *(t (15) = 2.321, p = .035*). However, for counterbalancing purposes, two lists were created – in the first list, participants saw ‘night’ as the target and ‘knight’ as the homophone and in the second list participants saw ‘knight’ as the target and ‘night’ as the homophone. This also alleviates issues related to differences in frequency between homophonic pairs. Semantic distractors were also changed to match the new target. In the example above, the semantic distracter was also changed from ‘day’ to ‘castle’ whereas the unrelated item remained as ‘chocolate’. Participants were only shown one list during the experimental trials.

**Figure 8-1 - Layout of the stimuli presented to participants in the homophone condition (Description of stimuli from top left to bottom right; chocolate (unrelated), day (semantic), knight (homophonic) and night (target).**

**Orthographically similar items.** As with the homophones, participants were presented with a target written word in the centre of the screen along with four pictures only this time distracter items included an orthographically similar item, a semantically related item and an unrelated item (See Figure 8-2). There were 20 sets of orthographically similar items. A paired sample t-test showed that there was not a significant difference in word frequency between orthographically similar pairs *(t = 1.539, df (19), p = .140)*. Items in this condition were also matched for word length and only differed by a single letter.

**Figure 8-2 - Layout of the stimuli presented to participants in the orthographic condition. (Description of stimuli from top left to bottom right; anchor (semantic), boat (target), boot (orthographically similar) and mug (unrelated).**

Presentation of words and pictures in the orthographic condition was identical to the homophone condition (see earlier for description), only this time for the target word ‘boat’, an orthographically similar distracter was also presented which was ‘boot’ in this case (see Figure 8-2). In addition, a semantic distractor (e.g. anchor) and an unrelated distracter (e.g. mug) were presented. Again, for counterbalancing purposes two lists were created and participants either saw ‘boat’ or ‘boot’ as the target item depending on which list was presented to them. As in the homophonic condition, semantic distracters were also adapted when the target item was swapped.

For the experimental trials, 16 homophones and 20 orthographically similar items were included. There were two lists of items for counterbalancing purposes as outlined earlier (each with 16 homophones and 20 orthographically similar targets). See Appendix 19 for full stimuli list.

### 8.1.3 Procedure

See section 7.1.1.3 for description of experimental set up. There were a total of 4 practice trials and a total of 36 experimental trials (16 homophones and 20 orthographically similar items). On all trials participants were presented with real words in the centre of the screen, along with 4 pictures. Trials were presented in random order and participants only saw items from one list. Pictures were also presented at different locations for each participant. Each trial began with a fixation cross at the centre of the screen, as soon as participants' gaze was on fixation, the letter string was presented at the centre of the screen for 500ms along with the four pictures, which remained on the screen until participants clicked on a picture or when 5 seconds elapsed. Participants were instructed to click on the picture that the word presented corresponded to and were also asked to keep their hand on the mouse to ensure rapid responses.

### 8.1.4 Data analyses

Reaction times and accuracy of clicks on target items in the orthographic and homophonic condition were compared and analysed using a 2 x 2 analysis of variance (ANOVA). Both subjects and items analyses had a mixed design with condition (within subjects and target items, homophone vs. orthographically similar) and group (between subjects and within items, deaf vs. hearing).

Data from each participant's right eye were analysed and the proportion of fixation samples for each quadrant were coded for analysis in 100ms bins starting from 0ms and ending at

2000ms. Analyses ended at 2000ms, as any looks beyond this time window would plausibly reflect only reanalysis as response times averaged around 2300ms (i.e., participants check pictures again to make sure they did not miss anything after having decided whether to respond or not). Separate analyses were carried out for each condition, i.e. the homophone condition and the orthographic condition. In the analyses for the homophone condition, target items, semantic and phonological (homophones of the target word) distracters were compared to unrelated items. For the orthographic condition, target items, semantic and orthographically similar distracters were compared to unrelated items. The proportion of fixation samples for each of those was compared to unrelated items. For each, to assess differences between the types of pictures and for each group, non-parametric analyses (Wilcoxon sign-rank test) were carried out, corrected for multiple comparisons by adjusting p levels for significance to .005. First, we carried out Wilcoxon signed-rank tests (by subjects and by items) for hearing and deaf participants separately. Secondly, we carried out comparisons between groups (deaf vs. hearing) using the Mann-Whitney test on difference scores (difference in proportion of fixations in each comparison listed above). Trials with incorrect responses (i.e. the wrong target item was selected) were not included in data analysis.

To compare the time-course activations of the two groups, Growth Curve Analyses (Mirman et al., 2008) were carried out using the statistical software program R v.3.3.3 (R Development Core Team, 2017) and the lme4 package v.1.1-12 (Bates et al., 2015). P-values for fixed effects were obtained using the lmerTest package. Growth Curve Analyses were used, as this method was designed with the aim to compare differences in the proportion of looks towards specified interest areas at both the group and individual level in time-course data (Bates et al., 2015).

Correlations (Pearson's *r)* between reading scores, speechreading scores and BSL SRT scores were tested for deaf participants. Correlations between reading scores and performance on the task were tested for all participants.

## 8.2 Results

### 8.2.1 Reaction Times and Accuracy

Table 8-3 provides a summary of the reaction times and accuracy for each group and condition. When analyzing reaction times, incorrect responses were not included (8% of trials in the homophone condition and 3% of trials in the orthographic condition).

**Table 8-3. RTs and accuracy (means and standard deviations)**

| Condition | Group | N | Mean Accuracy | Std. Dev. Accuracy | Mean RT | Std. Dev. RT |
|---|---|---|---|---|---|---|
| Homophone | Deaf | 20 | .97 | .08 | 1869.89 | 35.60 |
| Orthosim* | Deaf | 20 | .97 | .05 | 1807.65 | 28.10 |
| Homophone | Hearing | 20 | .90 | .11 | 2074.26 | 49.98 |
| Orthosim* | Hearing | 20 | .97 | .05 | 1857.68 | 55.06 |

*orthosim = orthographically similar

**Reaction times.** There was a significant effect of condition on reaction times; overall participants were slower to respond in the homophone condition *(F1 (1, 38) = 7.112, p = 0.11; F2 (1, 62) = 6.369, p = .014)*. There was no main effect of group and no interaction.

**Accuracy.** There was a significant effect of condition on accuracy *(F1 (1, 38) = 7.218, p = 0.11; F2 (1, 62) = 2.577, p = .000)*. There was also an interaction effect *(F1 (1, 38) = 5.303, p = 0.27; F2 (1, 62) = 6.675, p = .012)*, deaf participants responded more accurately (97% accuracy) in the homophone condition in comparison to the hearing participants (90% accuracy).

### 8.2.2 Homophone condition

Word trials with incorrect responses (i.e. the wrong target item was selected) were not included in data analysis (8% of total data). Figures 8-3 and 8-4 reports the proportions of fixations by deaf and hearing participants, respectively. See Appendix 20 for full tabulation of results from the Wilcoxon and Mann-Whitney analyses.

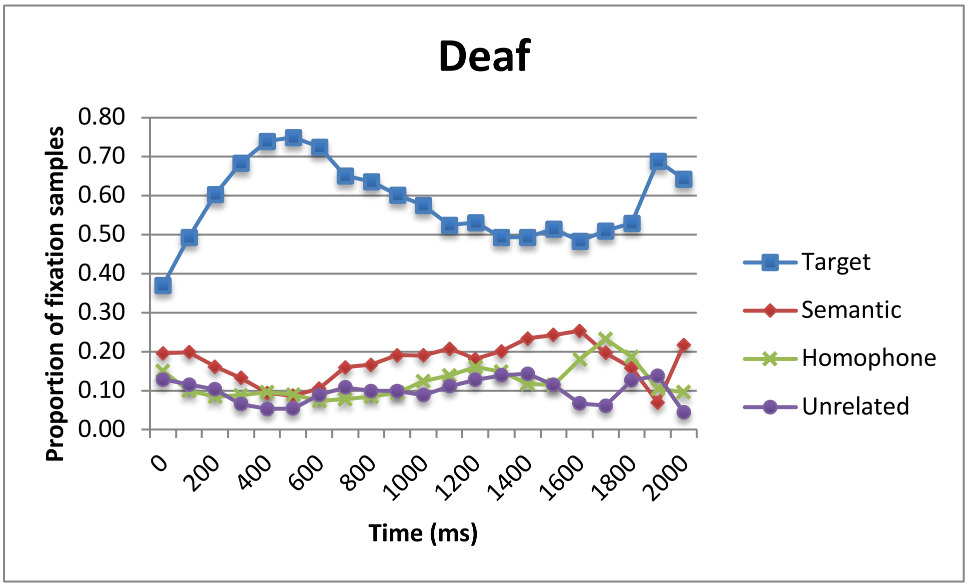


**Figure 8-3 - Proportion of fixation samples in the homophone condition for deaf participants.**

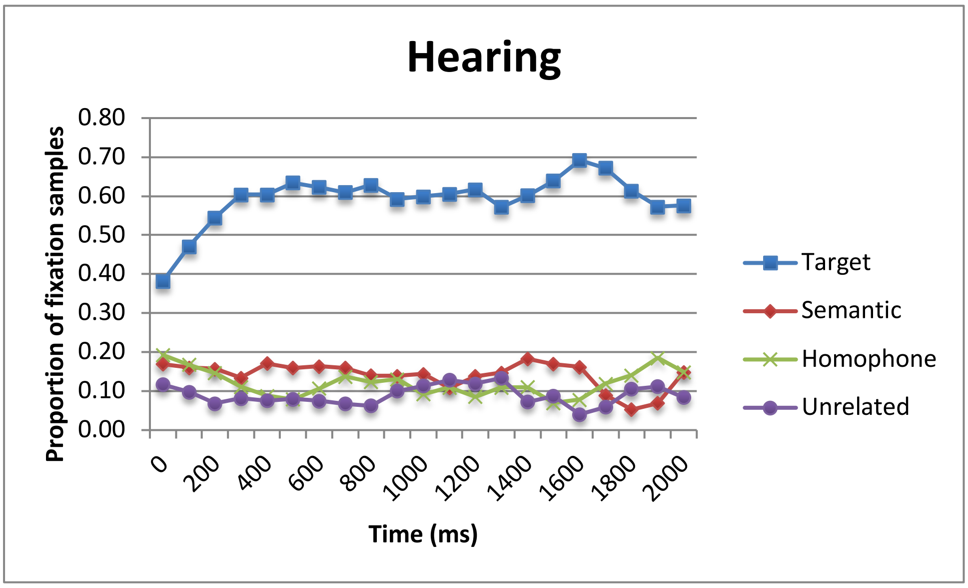


**Figure 8-4 - Proportion of fixation samples in the homphone condition for hearing participants.**

**Looks to target items.** As can be seen in Figures 8-3 and 8-4, both groups looked more frequently to the target picture than any other distracters. Analyses show that deaf and hearing participants performed similarly when comparing target and unrelated items in the homophone condition, with looks towards target items being significant in almost all time windows from 0 to 2000ms (by-subjects and by-items). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -1.751, p > .088; U2 > -2.600, p > .009).*

The most complex model converged and was found to be significantly better than other models, thus results from this model are reported here. Overall, there was a significant effect of target on the intercept term *(Estimate = .55, SE = .03, p < 0.00)*. There was no significant effect of group *(Estimate = .00, SE = .05, p = 0.96)*. There were also no interactions between group or any of the time polynomials, which strongly suggests that the temporal trajectory of looks towards the target did not differ for deaf and hearing readers (See Table 8-4).

**Table 8-4 - Parameter estimates for each time term, group and interactions between each time term and group for target items**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.56 | 0.03 | 21.14 | <0.00 |
| Time term 1 | 1.29 | 0.56 | 2.32 | 0.03 |
| Time term 2 | -1.30 | 0.45 | -2.83 | 0.01 |
| Time term 3 | 1.93 | 0.55 | 3.54 | 0.00 |
| Time term 4 | -0.91 | 0.37 | -2.46 | 0.02 |
| Group | 0.00 | 0.05 | 0.05 | 0.96 |
| Time term 1 x Group | 1.13 | 1.11 | 1.01 | 0.32 |
| Time term 2 x Group | -0.19 | 0.92 | -0.21 | 0.83 |
| Time term 3 x Group | -1.71 | 1.09 | -1.57 | 0.12 |
| Time term 4 x Group | -0.98 | 0.74 | -1.33 | 0.19 |

**Looks to semantic distracters.** Table 8-5 reports the Z (by-subjects and by-items) statistics for those comparisons (semantic distracter vs. unrelated items) that were significant or close to significant in at least some time-windows, for deaf and hearing participants.

**Table 8-5. Comparison between proportions of fixation samples for semantic distracters vs. unrelated items in the homophone condition.**

| Time Window | Deaf (by-subjects) | Deaf (by-items) | Hearing (by-subjects) | Hearing (by-items) |
|---|---|---|---|---|
| 200 | Z = -2.138, p = .032 | Z = -.758, p = .448 | Z = -2.549, p = .011 | Z = -2.659, p = .008 |
| 300 | Z = -2.749, p = .006 | Z = -2.309, p = .021 | Z = -1.872, p = .061 | Z = -1.846, p = .065 |
| 400 | Z = -1.670, p = .095 | Z = -1.800, p = .072 | **Z = -2.811, p = .005** | Z = -2.403, p = .016 |
| 500 | Z = -1.517, p = .129 | Z = -.888, p = .375 | Z = -2.416, p = .016 | Z = -2.084, p = .037 |

*Note.* Numbers in bold indicate signifcant effects after Bonferroni correction.

Looks towards semantically related items were significant for the hearing group at 400ms *(Z1 = -2.811, p = .005, Z2 = -2.403, p = .016)* and approached significance for the deaf group at 300ms *(Z1 = -2.749, p = .006, Z2 = -2.309, p = .021).* No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.626, p > .008; U2 > -2.092, p > .036).*

The most complex model did not converge, thus correlations were removed and random effects were reduced. The results from the reduced model are reported here. Overall, there was a significant effect of semantics on the intercept term *(Estimate = 0.04, SE = 0.01, p < 0.00)*. There was no significant effect of group *(Estimate = -0.01, SE = 0.02, p = 0.59)*. There were no interactions between group or any of the time polynomials, which indicates that the temporal trajectory of looks towards semantic distracters did not differ for deaf and hearing readers (See Table 8-6).

**Table 8-6 - Parameter estimates for each time term, group and interactions between time terms and group for semantic distracters.**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.05 | 0.01 | 5.01 | <0.00 |
| Time term 1 | -0.91 | 0.31 | -2.98 | 0.00 |
| Time term 2 | -0.01 | 0.17 | -0.04 | 0.97 |
| Time term 3 | 0.15 | 0.17 | 0.91 | 0.36 |
| Time term 4 | 0.04 | 0.17 | 0.23 | 0.82 |
| Group | -0.01 | 0.02 | -0.54 | 0.59 |
| Time term 1 x Group | -0.11 | 0.61 | -0.19 | 0.85 |
| Time term 2 x Group | 0.36 | 0.33 | 1.06 | 0.29 |
| Time term 3 x Group | 0.33 | 0.33 | 1.00 | 0.32 |
| Time term 4 x Group | -0.54 | 0.33 | -1.621 | 0.10 |

**Looks to homophonic distracters.** Table 8-7 below reports the Z (by-subjects and by-items) statistics for those comparisons (semantic distracter vs. unrelated items) that were significant in at least some time-windows, for hearing participants.

**Table 8-7. Comparison between proportions of fixation samples of homophonic distracters vs. unrelated items in the homophone condition.**

| Time Window | Deaf (by-subjects) | Deaf (by-items) | Hearing (by-subjects) | Hearing (by-items) |
|---|---|---|---|---|
| **0** | Z = -.521, p = .602 | Z = -.848, p = .396 | Z = -2.476, p = .013 | Z = -1.959, p = .050 |
| **100** | Z = -.256, p = .798 | Z = -.685, p = .494 | Z = -2.436, p = .015 | Z = -1.166, p = .244 |
| **200** | Z = -.819, p = .413 | Z = -1.112, p = .266 | **Z = -2.961, p = .003** | Z = -1.981, p = .048 |

*Note.* Numbers in bold indicate significant effects after Bonferroni correction.

Looks towards items that were homophones of the target item were significant during the 200ms time window for hearing participants *(Z1 = -2.961, p = .003, Z2 = -1.981, p = .048).* Looks towards homophones were also close to significant during the 0 *(Z1 = -2.476, p = .013, Z2 = -1.959, p = .050)* and 100ms *(Z1 = -2.436, p = .015, Z2 = -1.166, p = .244)* time windows for the hearing participants. Deaf participants did not look at homophones significantly more than unrelated items during any time window throughout all trials. No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -2.613, p > .008; U2 > -2.227, p > .026).*

Again, the most complex model did not converge, thus results from the reduced models are reported here. Overall, there was a significant effect of phonology on the intercept term *(Estimate = 1.61, SE = 6.39, p = 0.02).* There was no significant effect of group *(Estimate = -6.46, SE = 1.28, p = 0.99).* There were no interactions between group or any of the time polynomials, which indicates that the temporal trajectory of the homophonic distracter effect did not seem to differ for deaf and hearing readers (See Table 8-8).

**Table 8-8 - Parameter estimates for each time term, group and interactions between each time term and group.**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 1.61 | 6.39 | 2.52 | 0.02 |
| Time term 1 | -5.29 | 2.34 | -0.23 | 0.82 |
| Time term 2 | 1.86 | 2.30 | 0.81 | 0.42 |
| Time term 3 | -4.71 | 1.64 | -0.29 | 0.77 |
| Time term 4 | 1.08 | 1.62 | 0.67 | 0.51 |
| Group | -6.46 | 1.28 | -0.01 | 1.00 |
| Time term 1 x Group | -1.11 | 4.68 | -0.237 | 0.81 |
| Time term 2 x Group | 6.15 | 4.59 | 1.34 | 0.19 |
| Time term 3 x Group | 5.38 | 3.27 | 1.65 | 0.10 |
| Time term 4 x Group | -6.38 | 3.25 | -0.20 | 0.84 |

### 8.2.3 Orthographic condition

Again, word trials with incorrect responses (i.e. the wrong target item was selected) were not included in data analysis (3% of total data). Figures 8-5 and 8-6 reports the proportions of fixations by deaf and hearing participants, respectively. As can be seen, both groups looked more often to the target picture than any other distracters and analyses show no significant differences between deaf and hearing participants. Both groups also seem to be more drawn to semantic distracters in comparison to unrelated items up to about 700ms. See Appendix 21 for full tabulation of results from the Wilcoxon and Mann-Whitney analyses.

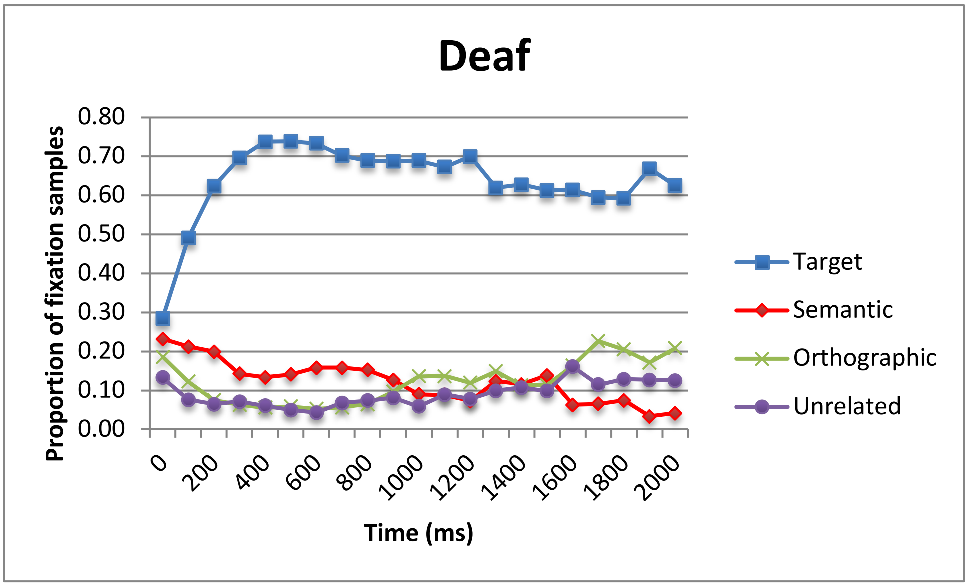


Figure 8-5 - Proportion of fixation samples in the orthographic condition for deaf participants.

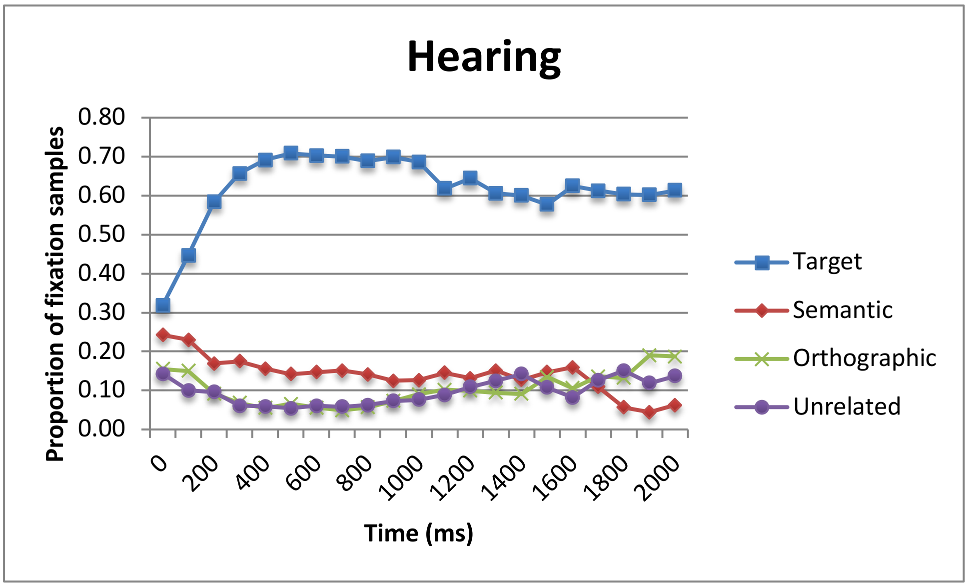


Figure 8-6 - Proportion of fixation samples in the orthographic condition for hearing participants.

**Looks to target items.** Figures 8-5 and 8-6 demonstrate that deaf and hearing participants looked to target items more frequently than unrelated items. Analyses show that deaf and hearing participants performed similarly when comparing target and unrelated items in the orthographic condition, with looks towards target items being significant in almost all time windows from 0 to 2000ms (by-subjects and by-items). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -1.692, p > .091; U2 > -1.429, p > .153).*

The most complex model converged and was found to be significantly better than other models, thus results from this model are reported here. Overall, there was a significant effect of target on the intercept term *(Estimate = .58, SE = .03, p < 0.00).* There was no significant effect of group *(Estimate = .05, SE = .05, p = 0.35).* There were also no interactions between group and any of the time polynomials, which strongly suggest that the temporal trajectory of the target effect did not differ for deaf and hearing readers (See Table 8-9).

**Table 8-9 - Parameter estimates for time terms, group and interactions between time terms and group for target effects in the orthographic condition**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.58 | 0.03 | 22.96 | <0.00 |
| Time term 1 | 1.54 | 0.54 | 2.83 | 0.01 |
| Time term 2 | -1.36 | 0.46 | -2.98 | 0.01 |
| Time term 3 | 1.95 | 0.53 | 3.67 | 0.00 |
| Time term 4 | -0.87 | 0.36 | -2.38 | 0.02 |
| Group | 0.05 | 0.05 | 0.93 | 0.36 |
| Time term 1 x Group | 1.62 | 1.09 | 1.49 | 0.15 |
| Time term 2 x Group | -0.31 | 0.91 | -0.34 | 0.74 |
| Time term 3 x Group | -1.68 | 1.06 | -1.58 | 0.12 |
| Time term 4 x Group | -0.90 | 0.73 | -1.24 | 0.22 |

**Looks to semantic distracters.** Table 8-10 below reports the Z (by-subjects and by-items) statistics for those comparisons (semantic distracter vs. unrelated items) that was significant in at least some time-windows, for deaf and hearing participants.

**Table 8-10. Comparison between proportion of fixation samples of semantics distracters vs. unrelated items in the orthographic condition.**

| | **Deaf (by-subjects)** | **Deaf (by-items)** | **Hearing (by-subjects)** | **Hearing (by-items)** |
|---|---|---|---|---|
| 0 | **Z = -2.824, p = .005** | Z = -2.539, p = .011 | Z = -2.279, p = .023 | Z = -2.704, p = .007 |
| 100 | **Z = -3.699, p = .000** | **Z = -3.713, p = .000** | **Z = -2.901, p = .004** | **Z = -3.015, p = .003** |
| 200 | **Z = -3.622, p = .000** | **Z = -3.814, p = .000** | Z = -2.225, p = .026 | **Z = -2.899, p = .004** |
| 300 | Z = -2.750, p = .006 | **Z = -2.704, p = .007** | **Z = -3.314, p = .001** | **Z = -3.281, p = .001** |
| 400 | **Z = -2.949, p = .003** | Z = -2.189, p = .029 | **Z = -3.050, p = .002** | **Z = -3.124, p = .002** |
| 500 | **Z = -2.797, p = .005** | Z = -2.588, p = .010 | **Z = -3.101, p = .002** | **Z = -2.928, p = .003** |
| 600 | **Z = -3.056, p = .002** | **Z = -3.632, p = .000** | **Z = -3.102, p = .002** | **Z = -2.816, p = .005** |
| 700 | Z = -2.557, p = .011 | **Z = -3.138, p = .002** | **Z = -2.842, p = .004** | **Z = -2.843, p = .004** |

*Note.* Numbers in bold indicate significant effects after Bonferroni correction.

Looks towards semantically related distracters were significant from 0-700ms for both deaf and hearing participants (by-subjects and by-items). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -1.627, p > .108; U2 > -1.316, p > .188).*

The most complex model did not converge, thus correlations were removed and random effects were reduced. The results from the reduced model are reported here. Overall, there was a significant effect of semantics on the intercept term *(Estimate = 0.05, SE = 0.00, p < 0.00)*. There was no significant effect of group *(Estimate = -0.01, SE = 0.02, p = 0.59)*. There were no interactions between group and any of the time polynomials, which indicates that the temporal trajectory of the semantic effect did not differ for deaf and hearing readers (See Table 8-11).

**Table 8-11 - Parameter estimates for each time term, group and interactions between each time term with group for semantic effects in the orthographic condition**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.05 | 0.01 | 5.19 | <0.00 |
| Time term 1 | -0.94 | 0.30 | -3.14 | 0.00 |
| Time term 2 | -0.00 | 0.17 | -0.2 | 0.98 |
| Time term 3 | 0.15 | 0.17 | 0.92 | 0.36 |
| Time term 4 | 0.04 | 0.17 | 0.24 | 0.80 |
| Group | -0.01 | 0.02 | -0.55 | 0.59 |
| Time term 1 x Group | -0.16 | 0.60 | -0.27 | 0.79 |
| Time term 2 x Group | 0.36 | 0.34 | 1.08 | 0.28 |
| Time term 3 x Group | 0.34 | 0.33 | 1.02 | 0.31 |
| Time term 4 x Group | -0.53 | 0.33 | -1.60 | 0.11 |

**Looks to orthographically similar distracters.** Neither group looked significantly more to orthographic similar items in comparison to unrelated items in this condition (by-subjects and by-items). No significant difference was found in the comparison between the two groups across all time windows in the formal comparison using the U-statistics *(U1 > -1.537, p > .142; U2 > -1.379, p > .168).*

Again, the most complex model did not converge, thus results from the reduced models are reported here. Overall, there was a significant effect of orthography on the intercept term *(Estimate = 0.02, SE = 0.01, p = 0.01),* which indicates that looks towards orthographically similar items were greater than 0. There was no significant effect of group *(Estimate = -0.00, SE = 0.01, p = 0.91).* There were no interactions between group and any of the time polynomials, which indicates that the temporal trajectory of the orthographic distracter effect did not seem to differ for deaf and hearing readers (See Table 8-12).

**Table 8-12 - Parameter estimates for each time term, group and interactions between each time term with group for orthographic effects in the orthographic condition**

| Fixed Effects | Estimate | SE | T value | P value |
|---|---|---|---|---|
| Intercept | 0.02 | 0.01 | 2.68 | 0.01 |
| Time term 1 | -0.02 | 0.23 | -0.07 | 0.95 |
| Time term 2 | 0.23 | 0.23 | 1.00 | 0.32 |
| Time term 3 | 0.01 | 0.28 | 0.03 | 0.97 |
| Time term 4 | 0.15 | 0.27 | 0.57 | 0.57 |
| Group | -0.00 | 0.01 | -0.11 | 0.91 |
| Time term 1 x Group | -0.14 | 0.47 | -0.31 | 0.76 |
| Time term 2 x Group | 0.59 | 0.46 | 1.27 | 0.21 |
| Time term 3 x Group | 0.54 | 0.55 | 0.98 | 0.34 |
| Time term 4 x Group | -0.06 | 0.54 | -0.12 | 0.91 |

As there was no effect of orthography, follow up analyses were carried out to determine the reason for the lack of effect. Differences in orthographic neighbourhood size between the target and orthographically similar distracters were checked and analyses revealed that there were significant differences between target and distracter items *(t (20) = -2.48, p = .001 (2-tailed))*.

### Correlations

For the results from the correlation analyses on language measures, see end of section 7.2.2. There were no correlations between reading scores or performance on the visual world task (for both accuracy rates and RTs, in either condition, see Table 8-13).

**Table 8-13 - Results from the correlation analyses for all participants.**

|  | N | *r* | p |
|---|---|---|---|
| Reading score/homophone accuracy | 40 | .012 | .943 |
| Reading score/orthographic accuracy | 40 | -.138 | .394 |
| Reading score/homophone RT | 40 | -.235 | .144 |
| Reading score/orthographic RT | 40 | -.291 | .069 |

Further correlation analyses were undertaken, separating out the deaf and hearing groups. For the deaf readers there were no significant correlations between reading scores and performance in both conditions (Table 8-14).

**Table 8-14 - Results from the correlation analyses for the deaf readers.**

|  | N | *r* | p |
|---|---|---|---|
| Reading score/homophone accuracy | 20 | -.108 | .649 |
| Reading score/orthographic accuracy | 20 | -.218 | .356 |
| Reading score/homophone RT | 20 | .143 | .549 |
| Reading score/orthographic RT | 20 | -.161 | .497 |

For the hearing readers, there was a significant correlation between reading scores and RTs in the homophone condition. None of the other correlations were significant (See Table 8-15). For hearing readers, those with higher reading proficiency had quicker RTs in the homophone condition (see Figure 8-7).

**Table 8-15 - Results from the correlation analyses for the hearing readers.**

| | N | r | p |
|---|---|---|---|
| Reading score/homophone accuracy | 20 | .051 | .832 |
| Reading score/orthographic accuracy | 20 | -.056 | .816 |
| Reading score/homophone RT | 20 | -.507 | .023 |
| Reading score/orthographic RT | 20 | -.403 | .078 |

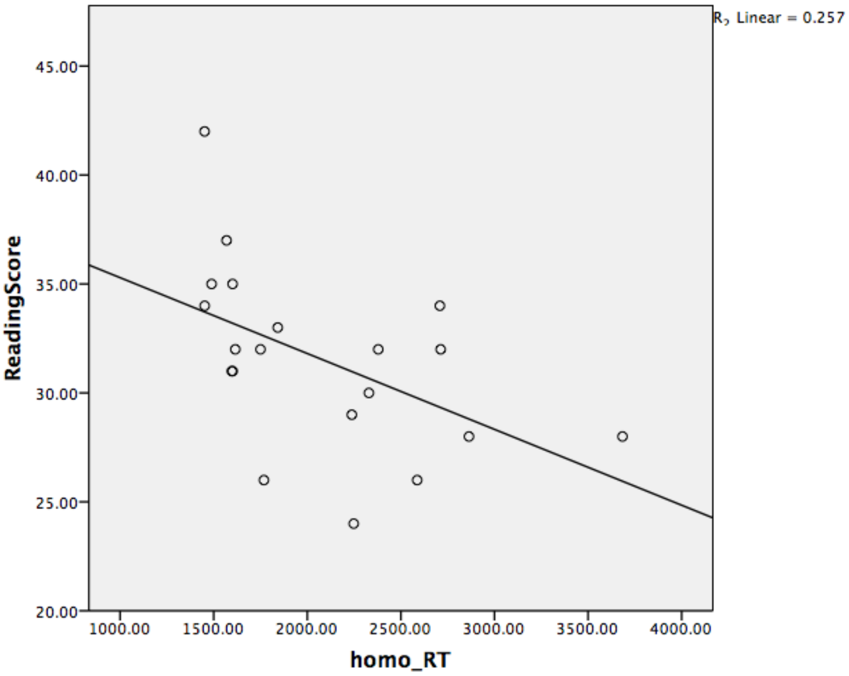


**Figure 8-7 - The above scattergraph depicts the relationship between reading scores (Y axis) and RTs (X axis) in the homophone condition for hearing readers.**

## 8.3 General Discussion

We recorded the eye movements of deaf and hearing readers, who were carefully matched on a number of important factors using the visual world paradigm. There were three main aims; 1) to further assess results from our previous study where we used a successful novel adaptation of the visual world paradigm to investigate phonological and semantic processing in deaf and hearing readers; 2) to explore orthographic processing in both groups using the same adaptation of the visual world paradigm; 3) we wanted to further explore whether or not deaf skilled readers can automatically activate phonological information in a task that focuses on meaning using homophones.

In both conditions, there was very little difference in looks towards target items between deaf and hearing participants. This replicates results from Experiment 4.1 described in Chapter 7. Additionally, in the orthographic condition, both groups were drawn to semantic distracters between 0-700ms and again, there was very little difference between the two groups. This finding also replicates results from Experiment 4 described in the previous chapter. This further supports the conclusion deaf and hearing readers process written words similarly and activate semantics to those words following a similar time course.

Neither group looked at distracters that were orthographically similar to target words in the orthographic condition more frequently than unrelated items. In the past, orthographic effects were found in experiments where target and distracter items were presented as printed words rather than pictures (e.g. Salverda & Tanenhaus, 2010), which may have led to orthographic effects. Moreover, as mentioned in the methods section, there were significant differences in orthographic neighbourhood size between target and distracter words. This could also be a reason for the lack of orthographic effect.

In the homophone condition, hearing participants were more drawn to homophonic distracters. A significant difference was detected during the 200ms time window and looks towards homophones were also marginally significant between 0 and 100ms, whereas deaf participants did not show any significant effects. This finding provides some further support to the idea that although deaf readers CAN process phonology, they do not always do so. Crucially, however, group comparisons do not show any group differences (Mann-Whitney and Growth Curve analyses), thus interpreting differences between groups must be treated with great caution.

There was little evidence of semantic processing in the homophone condition for either group, which was surprising as semantic effects were strong in orthographic condition and also in Experiment 4.1 described in Chapter 7. As hearing readers were distracted by homophones (evident by the increase in looks to homophonic distracters and the effect on accuracy), this could explain why there were less looks to semantic distracters. However, deaf readers were unaffected by homophonic distracters, which suggests that there must be another explanation for this. As mentioned earlier, it was not possible to match the word frequencies in homophonic pairs and many of the words were relatively low in frequency in comparison to the orthographic condition, this may explain the reduced effect of semantics in this condition.

When analysing reaction times, there were no significant differences between deaf and hearing readers in either condition, thus providing additional evidence that both groups process words in a similar way. However, accuracy rates in the two groups were quite different in the homophone condition. Hearing readers were less accurate in the homophone condition (90% accuracy) in comparison to the orthographic condition (97% accuracy) and there was an interaction effect. For deaf readers, accuracy rates were unaffected in the homophone condition (accuracy rates for the deaf readers was 97% for both conditions). This demonstrates that hearing readers were distracted by homophones, as they were phonologically identical to the target item and this did not occur for the deaf readers. Again, this indicates that deaf readers do not activate phonology in the same way as hearing readers.

Correlations between reading scores and performance on the visual world task were significant for hearing readers only. Hearing readers with higher reading proficiency had quicker RTs in the homophone condition compared to those with lower reading proficiency. This shows that reading proficiency is important for word recognition skills, which is in line with findings from previous studies looking into hearing readers (Nation & Snowling, 1998). As the correlation was only significant for hearing readers, this suggests that reading proficiency impacts word recognition skills in hearing readers more profoundly in comparison to deaf readers. Deaf readers seem to be more efficient in recognising words despite reading proficiency, which has been reported in other studies. For example, Belanger et al (2013), reported that deaf, less skilled readers performed similarly to hearing skilled readers in a sentence processing task whereas deaf skilled readers were more efficient (i.e. less refixations on target words).

To summarise, Experiment 5 lends further support that deaf and hearing readers extract and activate semantic information in remarkably similar ways, following a similar time course. Again, there were differences in the connections between phonological and semantic information in deaf and hearing readers, which replicates and supports the findings from Experiments 4.1 and 4.2.

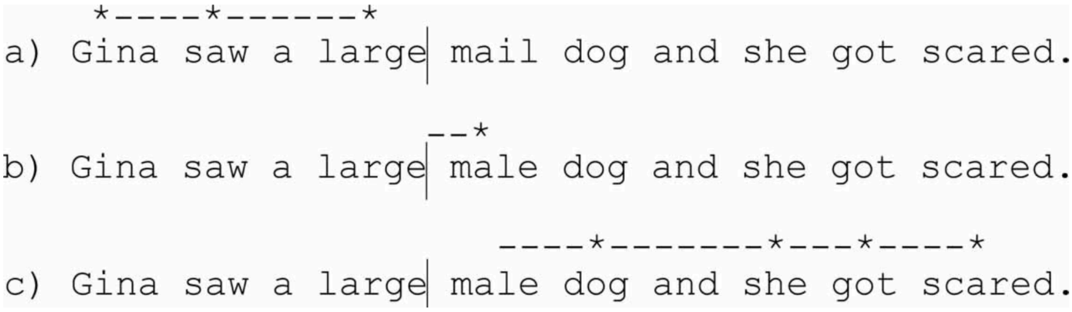
However, there was a null effect of orthography for deaf and hearing readers despite orthographic manipulations (inclusion of orthographically similar distracters), which may be due to lack of preview of the target and distracter picture items. This is in contradiction to several studies that have demonstrated the early activation of orthographic information in both spoken word recognition (Perre & Ziegler, 2008; Salverda & Tanenhaus, 2010) and visual word recognition (Rayner et al., 2013) in hearing readers. Additionally, studies looking into orthographic processing in deaf and hearing readers have shown that these two groups differ in this aspect (Bélanger, Baum, et al., 2012; Bélanger et al., 2013; Cripps et al., 2005)..Taking into account the previous findings in relation to orthographic processing in deaf and hearing readers, the time course activations of orthographic information should be explored further.

So far in this thesis, I have explored single word recognition in deaf and hearing readers and provided further insights into how deaf readers process orthographic, semantic and phonological information using various methodologies. However, as mentioned in Chapter 3, we rarely read words in isolation, thus it is important to explore word recognition in the context of sentences, which will be the focus of the next chapter.

# 9 Experiment 6: Orthographic and Phonological Preview Benefits During Sentence Reading

The experiments described in this thesis so far have explored the interplay between orthography, semantics and phonology during single word reading. In this chapter I aim to expand on the insights obtained by those studies by exploring further the role of orthography, semantics and phonology during <u>sentence</u> reading. Specifically, I examine orthographic and phonological preview benefits during sentence processing using the invisible boundary paradigm (Bélanger et al., 2013).

As described in Chapter 2, previous research with hearing readers has demonstrated that information about the phonology and orthography of words can be extracted whilst still in the parafoveal region. This means that readers initiate the processing of words during sentence reading before they have been fixated upon. This phenomenon is known as the 'parafoveal preview benefit' (Rayner & Pollatsek, 1987; Belanger et al, 2013) and is explored using the invisible boundary paradigm (Rayner, 2009; Schotter, Angele, & Rayner, 2012; Schotter, Reichle, & Rayner, 2014). When using this paradigm, a series of sentences are presented to participants and within these sentences the phonological or orthographic relationship between target and preview words is manipulated. The preview will be placed in the same location as the target word and is processed while still in the parafoveal region. Once the boundary is crossed, the preview is replaced by the target word. For example, in the sentence, 'she took her blue bear everywhere as it was her favourite toy', the target word is 'bear'. However, with a phonological manipulation, 'bear' would be replaced with 'bare', which is a homophone of 'bear'. After the word 'blue', there is an invisible boundary, which would trigger a change from the preview word (bare) to the target word (bear). With an orthographic manipulation, the preview item might be ‘bean’ and this would be changed to ‘bear’ as soon as the eyes move from ‘blue’ to the next word in the sentence. Participants are generally unaware of the change from preview to target words, as the change would occur during the saccade (Bélanger et al., 2013), see Figure 9-1.


a) Gina saw a large mail dog and she got scared.

b) Gina saw a large male dog and she got scared.

c) Gina saw a large male dog and she got scared.

**Figure 9-1. An example of the trajectory of the eyes and the related events in the invisible boundary paradigm. The stars represent the location of the eye fixations, and the dashed lines represent the saccades. The vertical lines indicate the location of the invisible boundary and are not seen by the participants. In line a, the word large (word 4) is fixated, and the word mail (word 5) begins to be processed in the parafoveal vision. During the saccade from word 4 (large) to word 5 (mail), the eyes cross the boundary and trigger the display change so that the preview word mail (line a) is replaced by the target word male (line b). When the eyes land on word 5 (male), the preview word (mail) is already changed for the target word (male). After the target word has been fixated, reading continues normally (line c). Taken from Belanger et al (2013: 2239).**

As explained in Chapter 2, orthographic and phonological preview benefits are usually measured by looking at the duration of first fixation on target words, the total gaze duration on target words and also the number of regressions back to the target words (Rayner, 2009; Rayner et al., 2013). If there is any kind of preview benefit, whether orthographical or phonological, participants are more likely to make shorter fixations and less regressions on the target word compared to unrelated previews.

Based on the findings from previous experiments, we hypothesize that deaf readers will benefit less from phonological previews in comparison to hearing readers. Additionally, based on previous study findings (Bélanger, Baum, et al., 2012; Bélanger et al., 2013), we expect to see orthographic preview benefits amongst the deaf and hearing readers.

## 9.1 Method

### 9.1.1 Participants

See section 4.1.1 for participant criteria and description of how background information was obtained. Twenty deaf adults (with severe to profound hearing loss) and 20 hearing English native speakers took part in this study. Data collected from 3 deaf participants and 1 hearing participant was unusable thus they (and their matches) were removed from subsequent data analyses. Thus, 16 participants from each group (32 in total) were included in this study. Table 9-1 provides demographic information about the participants. Table 9-2 provides information about deaf participants' degree of deafness, use of amplification aids and sign language background.

**Table 9-1. Participants' age, gender, education and reading level**

| | Deaf | Hearing |
|---|---|---|
| Average age | 34.13 | 34.05 |
| Male | 5 | 5 |
| Female | 11 | 11 |
| College | 4 | 2 |
| Bachelors | 7 | 3 |
| Masters | 3 | 10 |
| Postgraduate Diploma | 2 | 1 |
| Reading level (mean; max = 42) | 32.5 | 32.13 |

**Table 9-2. Deaf participants' degree of deafness, use of amplification aids and sign language background**

| | |
|---|---|
| **Degree of Deafness** | Severe to profound – 16 |
| **Amplification aids** | Hearing aids – 6 |
| | Cochlear Implants – 4 |
| | None used - 6 |
| **Sign language background** | Native – 9 |
| | *Near native – 4 |
| | **Late learner– 3 |

*Near native signers in this study were exposed to sign language from aged 2 (i.e. attended signing schools for deaf children)

** Late learners used BSL as their main language for more than 10 years

#### 8.3.1.1 Reading measures

See section 4.1.1 for participant criteria and a description of how background information was elicited. A pairwise comparison of the reading level of hearing readers *(n = 16, m = 32.13, SD = 3.77, range = 26 – 42)* and deaf readers *(n = 16, m = 32.5, SD = 4.43, range = 24 – 42)* showed no significant differences *(t (32) = .478, p = .64).*

#### 8.3.1.2 BSL Measures

See section 4.1.1 for description of the BSL assessment used. On average, deaf participants scored *27.57 out of 42 (n = 14, SD = 6.30, range = 11 – 38).* BSL SRT scores were not available for two participants due to corrupted video files.

#### 8.3.1.3 Speechreading Measures

See end of section 7.2.1.1 for description of speechreading measures. Deaf participants scored an average of *33.13 out of 45 (n = 16, SD = 3.01, range = 27 – 38).* Average scores were around the 55nd percentile and percentiles ranged from the 25th to the 90th percentile.

### 9.1.2 Stimuli

Stimuli were taken from Belanger et al (2013) see Appendix 22. First, 36 pairs of homophonic words were selected, consisting of preview and target words (e.g. bored/board). All target and preview pairs were matched exactly for length, number of phonemes and number of syllables. Additionally, they were matched as closely as possible for orthographic and phonological neighbourhood size. To account for frequency, target and preview pairs were switched, thus creating a further 36 target/preview pairs. In 36 of the trials, previews were low frequency, targets were high frequency (e.g. bored/board) and in 36 trials, this was reversed (e.g. board/bored). In total there were 72 experimental sentences and four conditions. In the first condition, target words (e.g. board) were identical to the preview words thus no change was made when participants' eyes crossed the invisible boundary. In the homophone condition, the preview was a homophone (e.g. bored) of the target word. In the orthographic condition, the preview word was orthographically similar to the target word (e.g. beard) and finally in the unrelated condition, the preview word was not phonologically or orthographically related to the target word (e.g. tight). Participants were presented with 18 experimental sentences from each of the four conditions. As explained in Belanger et al (2013), these 4 conditions were created to allow for disassociations between orthographic and phonological information, as there were different percentages of orthographic and phonological overlaps across conditions. For orthographic preview benefits, the identical condition is compared to the homophone condition, as the only difference between the two conditions is the percentage of shared letters between the preview and target, otherwise they are phonologically identical (e.g. bored, board). To assess phonological preview benefits, the orthographic condition is compared to the homophone condition, as the only difference between these two conditions is the percentage of phoneme overlap between the preview and target (i.e. target and previews have the same percentage of shared letters but differ in shared percentage of phonemes e.g. beard, board). Finally, to examine overall preview benefits, the identical condition is compared to the unrelated condition, as target and previews are orthographically and phonologically dissimilar (i.e. there are no shared letters or phonemes e.g. tight, board, see Table 9-3).

**Table 9-3 - The four preview conditions and the orthographic and phonological overlap between preview and target words for each condition.**

| Preview condition | Shared letters (%) | Shared Phonemes (%) |
|---|---|---|
| Identical (board/board) | 100 | 100 |
| Homophone (bored/board) | 75 | 100 |
| Orthographically similar (beard/board) | 75 | 57 |
| Unrelated (tight/board) | 0 | 0 |

There were also 72 filler sentences, all of which were taken from Belanger et al (2013). There were 128 filler sentences in Belanger el al (2013), some of which were not included in this study. Some of the experimental sentences had comprehension questions that were included in this study and again, these were taken from Belanger et al's (2013) study (see Appendix 23).

All sentences were syntactically simple, consisted of relatively high frequency words and presented in neutral contexts to ensure that participants would be able to comprehend the sentences without difficulty (Bélanger et al., 2013).

Some changes were made to the stimuli largely because of differences between American and British English. The homophone pairs BEAT/BEET was changed to BARE/BEAR as BEET is rarely used in British English. As a result of those changes, the sentences and some of the comprehension questions that followed also had to be changed accordingly. There were some other changes due to different uses of English words in the American and British vernacular as well as corrections to mistakes spotted in the original stimuli. For further information on the changes made, see Appendix 24.

### 9.1.3 Procedure

Participants were tested individually in a dark and acoustically adapted room to reduce distractions. Participants' eye movements were recorded using an SR Research Eyelink 2 © system and Experiment Builder Software (SR Research ©). Participants' eyes were around 20 to 25 inches away from the display. A chinrest was provided to minimize movements throughout the experiment. Prior to practice trials, camera setup, calibration and validation of the eye tracker took place. If needed, re-calibration was carried out between trials. Participants were presented with 10 practice trials and some of those practice trials were followed with a comprehension question to ensure participants became familiar with the Y and N buttons on the keyboard. Participants were instructed to press Y for 'yes' and N for 'no'. After the practice trials, participants were presented with 128 experimental trials with a single break in the middle (after 72 experimental trials). Participants were advised to continue after the break whenever they felt ready to do so.

### 9.1.4 Data Analysis

Data was analysed in the same way as Belanger et al, 2013. To compare similarities and differences in the eye movements of deaf and hearing readers, we analysed the duration of first fixations on target words, the total gaze duration of target words and the number of refixations on target words. These eye movement measures are well-established in the literature and have been used by a number of studies (Rayner, 2009). Prior to analysis, we carried out data preprocessing (following Belanger et al, 2013) to exclude trials; (a) if the display change occurred during a fixation, (b) if the boundary change was triggered by a saccade that landed to the left of the boundary (0% of trials) and (c) if a blink occurred just before or after the target word or on the target word (0% of trials). However, due to technical problems, in 72% of trials, the display change occurred during a fixation rather than a saccade, thus making the change potentially visible to the subjects. Given the large number of trials affected, we decided not to eliminate these trials from a general analysis. Thus, the primary analyses include trials in which there was a boundary change during a fixation. However, we also carried out analyses on the small subset of trials (28%) in which the change occurred during a saccade.

To analyse the first fixation and gaze duration data, linear mixed-effects models (LMMs) were used. To analyse the refixations data, general linear mixed models (GLMMs) were used. All analyses were carried out in the R environment (R Core Team, 2017) using the lme4 package (Bates et al., 2015).

For each of the dependent variables (first fixation duration, gaze duration and refixations) where participants and items were specified as crossed random effects (Baayen, 2008), a model was specified. Group, relative frequency and preview were fixed factors and frequency and group were within-subject variables. In each model, there were three successive contrasts (Venables & Ripley, 2002) to analyse the independent effects of orthography, phonology and overall preview. To explore effects of orthography a contrast between the homophone and identical conditions was set up, to explore the effects of phonology a contrast between the homophone and orthographically similar conditions was set up and finally, to explore overall preview benefits a contrast between the identical and unrelated conditions was set up. A difference contrast was carried out between the two groups, deaf and hearing readers, to investigate the similarities and differences in the eye movements of the two groups. Group, frequency and their interactions were included in each of the models as random slopes. At first a complex model was used and gradually the models were reduced and were followed by likelihood ratio tests to compare the reduced models with more complex models. All interactions that were not significant were dropped from the complex models and any significant interactions were subsequently analysed separately to explore effects further. There were no main or interaction effects involving frequency, thus frequency was dropped from the model. Here we report the regression coefficient (*b*), standard errors (SE) and p-values.

Responses to the comprehension questions were also compared for the deaf and hearing readers using a paired sample t-test.

Correlations (Pearson's *r)* between reading scores, speechreading scores and BSL SRT scores were tested for deaf participants. Correlation analyses between reading scores and performance on the sentence-processing task were also carried out.

## 9.2 Results

There were no differences in the accuracy of responses to the comprehension questions *(t (16) = .393, p = .700 (two tailed)).* Both deaf and hearing readers achieved 91% accuracy.

**First fixation duration.** The difference between the identical and unrelated conditions approached significance *(b = 20.19, SE = 10.75, p = .06)* suggesting that there was a trend towards an overall preview benefit for all participants. Interactions between group and condition were not significant *(b = 10.51, SE = 15.00, p = .48).*

The difference between the identical and homophone conditions was almost significant *(b = 20.15, SE = 10.71, p = .06)*. There was also an interaction between group and condition *(b = 47.82, SE = 15.21, p < .01) (See Figure 9-2)*. There was a significant difference between the identical and homophone conditions for the hearing readers *(b = 67.75, SE = 11.61, p < .01)* and for deaf readers *(b = 20.10, SE = 9.85, p = .04).* The results indicate that both deaf and hearing readers benefitted from orthographic previews, however preview benefits were greater for the hearing readers, which explains why there was an interaction effect between group and condition (See Figure 9-2).

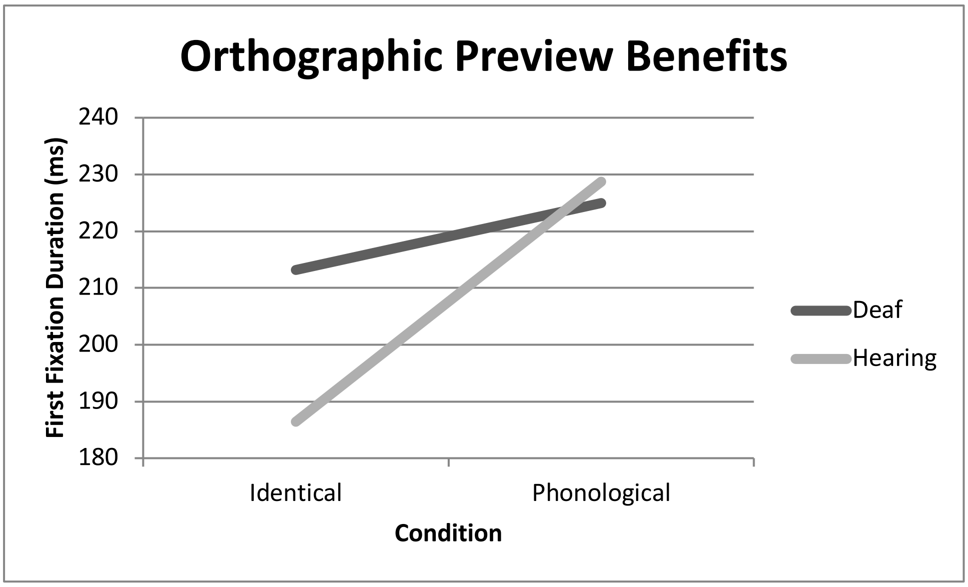


**Figure 9-2 - The above figure depicts the average first fixation duration on the target word for the deaf and hearing readers. Any difference between the two conditions shows that there was an orthographic preview benefit.**

Overall, there were no significant differences between the homophone and orthographic conditions *(b = -1.40, SE = 10.86, p = .90)* but there was an interaction between group and condition *(b = 35.90, SE = 15.58, p = .02) (See Figure 9-3)*. There was a significant difference between the homophone and orthographic conditions for the hearing readers *(b = 34.02, SE = 11.98, p < .01)* but not for the deaf readers *(b = -1.50, SE = 10.02, p = .88).* Hearing readers benefitted from phonological previews whereas deaf readers did not.

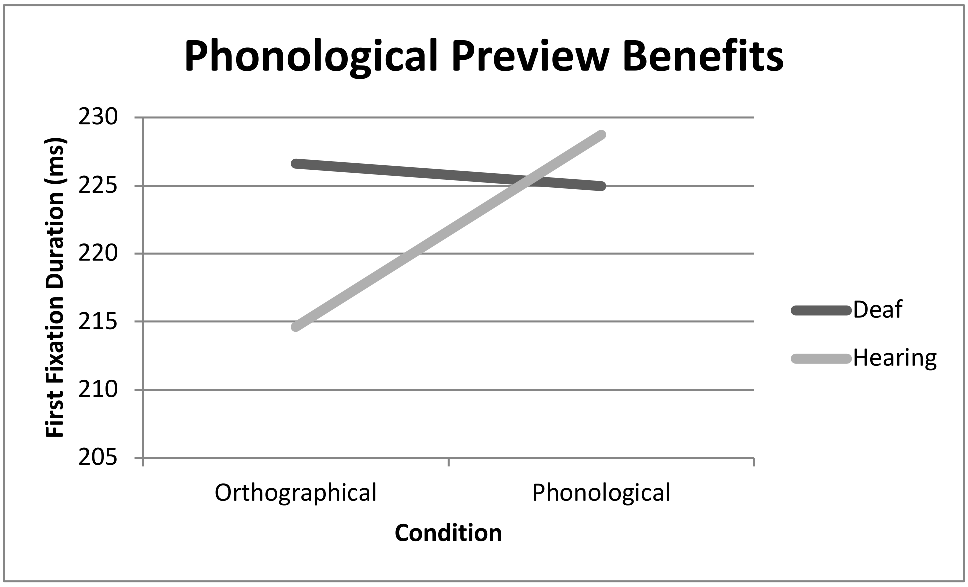


**Figure 9-3 - The above figure depicts the average first fixation duration on the target word for the deaf and hearing readers. Any difference between the two conditions shows that there was a phonological preview benefit.**

**Gaze duration.** The difference between identical and unrelated conditions was significant *(b = 23.03, SE = 15.53, p = .03)*, showing an overall preview benefit. Interactions between group and condition were not significant *(b = 23.03, SE = 21.67, p = .28)*.

There was a significant difference between the identical and homophone conditions *(b = 34.37, SE = 15.42, p = .03)* showing an orthographic preview benefit. There was an interaction effect between group and condition *(b = 62.30, SE = 21.89, p < .01) (See Figure 9-4)*. Separate analyses for group showed significant differences between conditions for the hearing readers *(b = 96.69, SE = 14.46, p < .01*) and for the deaf readers *(b = 34.33, SE = 16.41, p = .03)*. Orthographic preview benefits were greater for the hearing readers, which explains why there was an interaction effect between group and condition (See Figure 9-4).

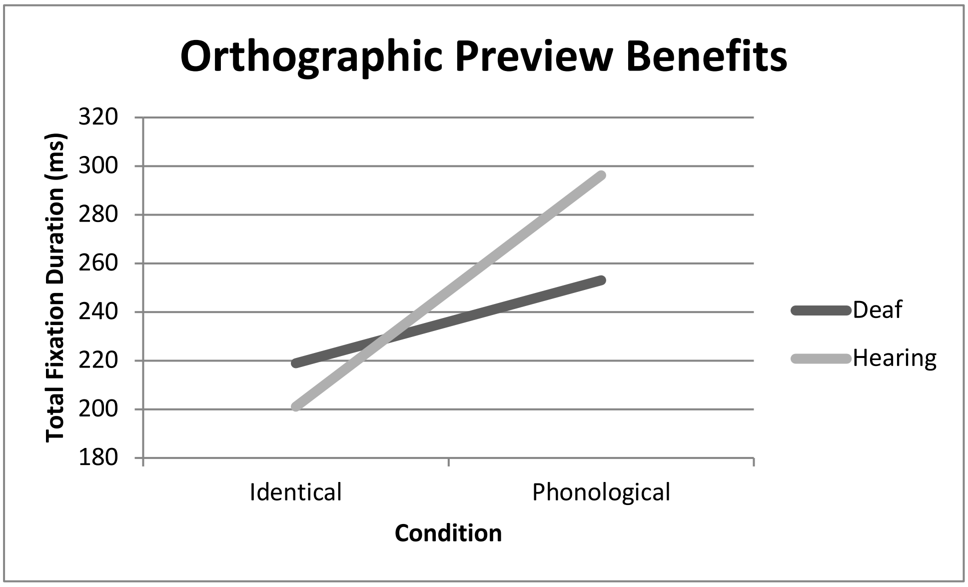


**Figure 9-4 - The above figure depicts the average total fixation duration on the target word for the deaf and hearing readers. Any difference between the two conditions shows that there was an orthographic preview benefit.**

Overall, there were no main effects or interactions when comparing the homophone and orthographic conditions, suggesting that there were no phonological preview benefits. For the hearing readers, the means table seems to show that phonological previews may have an inhibitory rather than a facilitatory effect, as the mean fixation duration on the target word was significantly greater in the phonological condition compared to the unrelated condition (See Table 9-4).

**Refixations.** There were no significant main or interaction effects in the refixation data for any of the conditions. This is likely to be due to technical difficulties encountered. Subjects were aware of the change happening and it is possible that this reduced the likelihood of regressing back on what they have read. Thus, the results are not reported here.

**Table 9-4 - Means (and standard deviations) for first fixation and gaze duration for each group.**

| Measure | Identical | Orthographic | Homophone | Unrelated |
|---|---|---|---|---|
| First fixation | | | | |
| Deaf | 213.17 (40.16) | 226.61 (36.04) | 224.96 (38.80) | 245.96 (80.56) |
| Hearing | 186.42 (30.84) | 214.62 (36.83) | 228.73 (39.51) | 211.18 (37.05) |
| Gaze duration | | | | |
| Deaf | 218.94 (81.71) | 254.55 (105.93) | 253.06 (84.87) | 252.56 (118.71) |
| Hearing | 201.09 (54.06) | 261.03 (60.91) | 296.22 (71.26) | 259.33 (48.78) |

Analyses carried out on a subset of data (28% of trials) showed no significant main or interaction effects.

**Correlations.** For deaf readers, correlations between the language measures were not significant; reading scores/BSL SRT *(r = .048, n = 14, p = .871 (2 tailed)),* reading and speechreading scores *(r = .025, n = 16, p = .927 (2 tailed),* BSL SRT/speechreading measures *(r = -.109, n = 14, p = .711 (2 tailed)).* There was a significant overall correlation between reading scores and overall preview benefits for first fixation duration *(r = .430, n = 32, p = .014 (2 tailed)).* Separate analyses for the deaf and hearing groups revealed that there was only a correlation between reading scores and overall preview benefits for the deaf group *(r = .723, n = 16, p = .002 (2 tailed))*. There were no further correlations between reading proficiency and preview benefits (overall, phonological or orthographic) for first fixation duration or for total fixation duration (See Appendix 25 for all results).

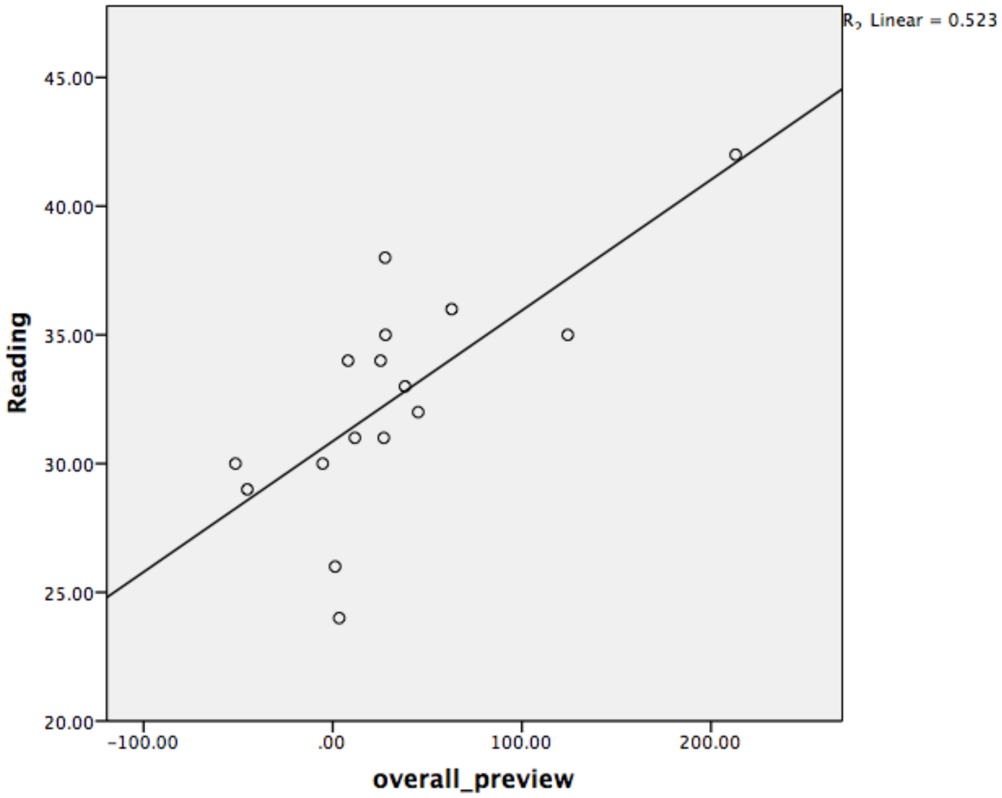


**Figure 9-5 - This figure depicts the relationship between reading scores and overall preview benefits for deaf readers.**

Figure 9-5 shows that those with higher reading proficiency showed greater overall preview benefits for first fixation duration.

## 9.3 General Discussion

The present study explored orthographic and phonological preview benefits in deaf and hearing readers who were carefully matched on a number of important dimensions (age, gender and reading level. Much of the literature has shown that hearing readers benefit from orthographically and phonologically similar previews of target words during sentence reading. However, deaf readers seem to benefit less from phonological information during reading (Bélanger et al., 2013; Mayberry et al., 2011) and results from this study provides further support to the above finding.

Overall, the fact that most observations in this study come from trials where the subject was aware of the preview as well as of the target words because the change occurred during fixation rather than during saccade movements, renders the current task more similar to a standard priming experiment. Thus, we believe that the results concerning first fixation on target word may be most revealing of the underlying processes, whereas total fixation duration on target may be more susceptible to strategies and therefore be less informative. First fixation duration analyses show that there was an overall preview benefit for deaf and hearing readers as both groups spent less time fixating on the target word in the identical condition compared to the unrelated condition. For both groups, there was an orthographic preview benefit however; there was a greater preview benefit for hearing readers compared to deaf readers. Hearing readers also demonstrated a phonological preview benefit but the deaf readers did not.

In the gaze duration analyses, there was an overall preview benefit for deaf and hearing readers. However, for the hearing readers, phonological previews seem to have an inhibitory rather than a facilitatory effect (based on the average total fixation time on the target word). It is unclear why phonological preview led to longer gaze durations rather than the other way around. This may be linked to the fact that because of technical difficulties, the subjects were aware of the change happening (and possibly of the relation between the preview and target word). The lack of any effect in the re-fixation analyses may also be linked to this fact. However, for hearing readers, most of the results are in line with previous literature where there were overall, orthographic and phonological preview benefits.

For the deaf readers, results replicate findings from Belanger et al's (2013) study where deaf readers did not display any phonological preview benefits, which has also been reported in several other studies (e.g. Bélanger, Baum, & Mayberry, 2012; Cripps, McBride, & Forster, 2005; Mayberry, del Giudice, & Lieberman, 2011). These findings also lend further support to results reported in earlier chapters where deaf readers do not seem to engage phonological codes when the task requires access to meaning. This has also been reported in other studies (e.g. Gutierrez-Sigut, Vergara-Martínez, & Perea, 2017), which will be further discussed in Chapter 10. Importantly, despite differences in the activation of phonological codes during sentence reading, reading proficiency is not affected as both deaf and hearing readers were matched for reading level. Additionally, performance on the comprehension questions did not differ for the two groups of readers. This shows that phonological processing is less crucial for successful literacy for deaf readers compared to hearing readers.

Correlations between the reading, speechreading and BSL measures were not significant and this is likely to be because deaf readers included in this study had similar levels of language proficiency. As explained in earlier chapters, correlations between different language measures such as reading proficiency and sign language proficiency have been found (e.g. Chamberlain & Mayberry, 2008). If there were more variability in the language proficiency of the deaf readers included in this study, the probability of identifying correlations between those language measures would increase. However, there was a positive correlation between reading scores and overall preview benefits for first fixation duration for the deaf readers. Those with higher reading proficiency had greater overall preview benefits, which show that highly skilled deaf readers were more sensitive to orthographic manipulations. This could mean that they are more efficient readers and similar findings have been reported for hearing readers where hearing skilled readers process single words more efficiently than less skilled readers (Nation, 2017).

In the next chapter, the general discussion chapter, I discuss the results from the experiments reported in this thesis and the implications of these findings on general theories of word recognition. I highlight important differences between deaf and hearing readers and how this can impact the teaching of literacy in the deaf population. I also propose a new model of word recognition for deaf readers.

# 10 General Discussion

In this thesis, the word recognition processes of deaf skilled readers whose main language is BSL were compared to hearing participants. The two overarching goals of the work reported here were: (1) To explore the interplay between orthography, semantic and phonological information used by deaf skilled readers during single word recognition and during sentence reading. Deaf individuals have different language experiences from hearing readers. In particular, for the group of deaf readers investigated here, English is an additional language. It is therefore important to establish whether these differences in language experience influence how orthographic information links to semantic and phonological information and the time course of their activation. (2) To investigate further the role of phonology during word recognition and reading in deaf skilled readers. As deaf readers access phonology primarily via speechreading, which provides only coarse information, it is crucial to assess the extent to which such phonological information is necessary for semantic activation and ultimately for skilled reading. For hearing readers, the ability to process phonological information is an important predictor for successful literacy attainment (Coltheart et al., 2001; Harm & Seidenberg, 1999; Rayner et al., 2001), thus it is important to explore the role of phonology in deaf readers. Bringing together the two main goals of the thesis, the research reported here provides new insights into word recognition and reading across populations and illustrates constraints for theories of word recognition and reading.

To answer both questions, deaf skilled readers were compared to hearing readers carefully matched on a number of demographic dimensions such as age, gender, education and most importantly reading level. Chapter 4 assessed the influences of different lexical and semantic variables on single word reading using a lexical decision task and a sufficient number of words to allow us to paint a picture of similarities and differences between deaf and hearing readers. Chapters 5 and 6 described two experiments in which the activation of phonological representations during visual word recognition was investigated using a lexical decision task. Chapters 5 and 6 also investigated the use of phonological information in a lexical decision task in which pseudohomophones are used as nonwords (Chapter 5) or primes (Chapter 6). Chapters 7 and 8 provided insights into the time course of orthographic, semantic and phonological activation using the Visual World paradigm. Finally, Chapter 9 moved from single word processing to sentences assessing orthographic and phonological processes during reading using the "invisible boundary" paradigm. Below, there is a summary of the main findings from each study.

## 10.1 Do lexical and semantic variables influence word recognition in similar ways for deaf and hearing readers?

In Chapter 4, I reported on a lexical decision experiment where I compared how different lexical and semantic variables influenced lexical decision in deaf skilled readers and hearing readers. The variables I considered were: orthographic neighbourhood, length, frequency, familiarity, imageability, concreteness, arousal, valence, hedonic valence, age of acquisition (AOA) and bigram frequency-by-position. Effects of these variables on word recognition by hearing individuals are well established in the literature. In order to sample as large as possible number of words, a parametric design was used in which each lexical variable varied along a continuum. Overall we found that frequency, orthographic neighbourhood and number of morphemes influenced the decision latencies of both groups in similar ways. There were also effects of familiarity and age of acquisition on decision latencies for both groups, however both effects were modulated by frequency. This is an important result, which is far from trivial as the two groups differ in terms of language experience. Therefore, variables such as frequency and age of acquisition might have been predicted to differ between groups. For frequency, while the effect for hearing readers may reflect joint experience with written and spoken language, for the deaf readers, plausibly, the written experience would have more weight. This study's finding is in line with Belanger & Rayner's (2013) study where word frequency effects were found in severely to profoundly deaf readers who use ASL. Both skilled and less-skilled deaf readers had longer fixations and were less likely to skip target words that were low in frequency in a sentence processing task (Bélanger & Rayner, 2013, 2015). For age-of-acquisition, despite the fact that our deaf participants were all skilled readers, there could be influential differences in terms of when the English words were acquired (given that all of our participants use BSL as their primary language). However, we found similar effects of age of acquisition in both groups. This finding replicates effects found in previous studies investigating lexical and semantic variables in hearing readers (Balota et al., 2004; Cortese & Balota, 2012; Keuleers et al., 2012; Rastle, 2007). Thus, overall, despite the potentially important differences in language experiences across the groups the differences in processes primarily relating to orthographic codes as nonetheless strikingly similar.

There were also some interesting differences across the groups. First, although both groups were affected by word length, there were differences in how word length impacted the decision latencies of each group. The deaf readers showed stronger effects of word length. For every letter increase, decision latencies were 11ms longer for deaf readers and 5ms longer for hearing readers. In the literature, word length is considered to be one of the strongest predictors of decision latencies in the lexical decision task (Ferrand et al., 2011; New et al., 2006). Therefore, it is unsurprising we see it amongst deaf and hearing readers, however it is interesting that it is stronger for deaf than hearing readers. There may be a number of plausible potential accounts for this difference. For example, it might be that because deaf readers do not have the support of spoken word recognition, they need to process the entirety of the word via orthographic codes whereas hearing readers may not need such an exhaustive processing of the orthography. It will be for future research to provide an account for the effect.

Second, semantic effects were stronger for deaf readers. There was an effect of valence for the deaf readers but not for the hearing readers. Follow up analyses also showed that arousal and concreteness also had a larger impact on decision latencies in deaf readers compared to hearing readers. Effects of semantic variables such as concreteness and valence are well established among hearing readers (Kousta et al., 2011; Vinson et al., 2014), thus it is surprising that we fail to see such effects here. Importantly, however, the number of hearing participants in this study is far smaller (n=16) than most lexical decision studies (e.g. in Kousta et al's (2011) study, there were a total of 58 participants) and analyses revealed very small effect sizes, which is a likely explanation for the lack of effect. However, there were also a small number of deaf participants (n=16) and there was still an effect, which suggests that semantic effects may be stronger in deaf skilled readers compared to hearing readers, although the present results do not allow us to draw any firm conclusion. As outlined in earlier chapters, deaf readers have limited access to spoken language and use print as a primary route to access information e.g. subtitles, speech-to-text-relay (STTR), emails, texts etc. As a result of this increased exposure to orthography, the connections between orthography and semantics may become more robust than they are for hearing readers. As mentioned in Chapter 4, reading experience is one of the most important predictors of both reading skill and word recognition processes in hearing children and adults (Nation, 2017), which may explain why semantic effects are more robust in this group of deaf readers.

Additionally, deaf readers in this study are likely to rely more on orthography compared to their reading-age matched hearing readers. This is because, as skilled readers, they are likely to be exposed to printed words in more varied contents than their hearing peers. This may contribute to increased processing efficiency at the word level (Nation, 2017; Perfetti, 2007). This may not be true for all deaf readers, especially for deaf, less skilled readers, as this population may not have as much reading experience compared to deaf skilled readers.

Deaf readers were more accurate overall compared to hearing readers. This lends further support to the argument that the connections between orthography and semantics are more robust for deaf readers. Several other studies have also reported that deaf readers are more efficient readers compared to hearing readers (e.g. Bélanger, Baum, & Mayberry, 2012; Bélanger, Slattery, Mayberry, & Rayner, 2012; Dye, Hauser, & Bavelier, 2009). Interestingly, for the deaf readers there was only a simple main effect of frequency on accuracy rates, whereas for the hearing readers there were simple main effects of familiarity, orthographic neighbourhood size, age of acquisition and frequency. However, age of acquisition effects disappeared with high frequency words and orthographic neighbourhood size effects were larger with low frequency words, which indicates that word frequency is also important for hearing readers. It is likely that there were no further effects for the deaf readers as their accuracy levels were at ceiling levels. In summary, the results from Experiment 1 suggest that similar lexical and semantic variables influence lexical decision in deaf and hearing readers. However, there are some important differences such as deaf skilled readers displayed stronger semantic and word length effects, as well as increased processing efficiency at the word level. That is, deaf readers seem to be able to extract more information about the semantic properties of words compared to hearing readers despite having similar processing times (RTs) and higher accuracy rates (there was no trade off between RTs and accuracy rates).

## 10.2 Are phonological codes activated in deaf readers during single word recognition?

To explore the role of phonology during single word recognition, two lexical decision experiments were carried out. In Experiment 2, reported in Chapter 5, I presented words, non-homophonic nonwords and pseudohomophones to participants in a simple lexical decision task to see if there was a pseudohomophone effect in deaf readers. In Experiment 3, reported in Chapter 6, I used the masked phonological priming paradigm to further explore phonological processing, comparing the deaf and hearing groups' performance. The results from Experiment 2 indicate that there are no differences in how deaf skilled and hearing readers are affected by phonology. Both groups had longer decision latencies and higher error rates when presented with pseudohomophones in comparison to non-homophonic nonwords, replicating results from previous studies on hearing readers (Frost, 1998; Seidenberg et al., 1996; Ziegler et al., 2001). However, the pseudohomophones used in this experiment were also visually similar to the words from which they were derived e.g. sirf/SURF. Thus the significant pseudohomophone effect could be explained as an effect of orthography rather than phonology (Martin, 1982; Rastle & Brysbaert, 2006; Ziegler et al., 2001). Interestingly, analyses revealed a significant correlation between reading scores and accuracy on the lexical decision task for the hearing readers. Hearing readers with lower reading proficiency had lower accuracy rates in the non-homophonic nonword and pseudohomophone conditions. There was no such effect for deaf readers, which may suggest that deaf readers better process the orthographic details of the words, in line with the speculation presented in 10.1 concerning differences in the length effect.

The results from Experiment 3 (Chapter 6) also support the use of phonological information by deaf skilled readers in a masked priming lexical decision task. Here, both groups were more accurate when words were preceded by a phonological prime (e.g. ‘groe’ for the target ‘grow’) compared to control primes (e.g., ‘groy’ for ‘grow’). As masked priming is generally believed to tap into automatic processes (Leinenger, 2014; Rastle & Brysbaert, 2006), the results suggest that like hearing readers, deaf readers also can process phonology in an automatic manner when reading. It is important to note that differences in accuracy rates did not reach significance in the by-items analyses for either group of readers, which we attributed to the small sample size (effect size calculations revealed a small effect size ($r < .1$)). To ascertain if this was the case, the study was replicated with a larger group of hearing readers. In this study with hearing participants only, we replicated the results by Rastle and Brysbaert (2006) for accuracy. However, while we found an effect of phonology in the accuracy data, we did not find such effect in the RTs, in contrast to the original study. Analyses show that the two lists used in the study (for counterbalancing purposes) generated different results i.e. in one list, reaction times were slower when targets were preceded by graphemic controls and in the other list reaction times were slower when targets were preceded by phonological primes. It is unclear why results differed in the two lists and this should be investigated further. Nonetheless, overall the two lexical decision tasks seem to indicate that deaf skilled readers do make use of phonological information in a similar way to hearing readers, which is in support of some studies that found an effect of phonology amongst deaf readers ((Gutierrez-Sigut et al., 2017; Hanson & Fowler, 1987; Mayer & Trezek, 2014) and in contrast to others (Bélanger, Baum, et al., 2012; Bélanger et al., 2013; Cripps et al., 2005; Mayberry et al., 2011). Differences in the findings of these studies could be attributed to varying methodologies and lack of control for reading level, which will be discussed further later in the chapter.

Deaf skilled readers were found to be significantly more accurate than hearing readers, which suggest that deaf readers are highly efficient readers (i.e. deaf and hearing readers process words following a similar time course, but deaf readers do so with increased accuracy). This finding lends further support to the results from Experiment 1, where deaf readers were more accurate overall in a lexical decision task. Additionally, this finding is in line with the 'word processing efficiency' hypothesis introduced by Belanger and Rayner (2015). Like hearing readers, deaf readers' reading processes are modulated by reading level, word frequency and predictability, however skilled deaf readers (although matched to hearing readers) were found to be more efficient when reading. In several studies measuring the eye movements of deaf readers (Bélanger et al., 2013; Bélanger & Rayner, 2013, 2015; Bélanger, Slattery, et al., 2012), deaf skilled readers were found to have less regressions and less refixations when reading text compared to hearing readers matched for reading level. Deaf skilled readers were also more likely to skip words, yet reading comprehension was unaffected. Belanger and Rayner (2015) suggest that deaf skilled readers are more efficient at processing words in a single fixation and this indicates that there are tighter connections between orthography and semantics for this population.

## 10.3 Do deaf and hearing readers activate orthographic, semantic and phonological information following a similar time course?

Although many studies in the past have looked at the role of phonology in deaf readers, none have considered how deaf skilled readers activate orthographic, semantic and phonological information online. It is still unknown whether the different types of information are activated following the same time-course for deaf and hearing readers. I carried out three different experiments (Experiments 4.1, 4.2 and 5, reported in Chapters 7 and 8, respectively) using the visual world paradigm to address the above question. In Experiment 4.1, I introduce a novel adaptation of the visual world paradigm in which target words are presented visually rather than acoustically. Here I used words, non-homophonic nonwords and pseudohomophones along with four pictures that included the target item, semantic and phonological distracters as well as an unrelated item. When letter strings were words, participants were instructed to click on the target picture and when they were nonwords, participants were instructed to do nothing.

In the word condition, deaf and hearing readers' performance was very similar. Results show that deaf and hearing readers both activated orthographic and semantic information over a similar time course. However, when letter strings were pseudohomophones, there were differences between the two groups. Hearing readers looked to pseudotarget items (the picture that corresponded to the word from which the pseudohomophone was derived, e.g., coat/KOTE) more frequently compared to unrelated items. They also looked at pseudosemantic items (e.g. shirt) more frequently than unrelated items in some time windows. There were no effects for deaf readers i.e. they did not look to pseudotarget or pseudosemantic distracters significantly more than unrelated items in any time window. Group analyses also showed that there were some differences in the duration of the fixations on pseudotarget and pseudosemantic items, at least in some time windows, for deaf and hearing readers. This suggests that although deaf readers can process phonological information, as is evident from the lexical decision tasks, they do not activate this information when the task focuses on meaning, rather than on orthographic form.

However, there was a task difference within the experiment, which could be an explanation for the differences between deaf and hearing readers in this study. Namely, participants were instructed to do two tasks: choose the picture corresponding to the letter string, when this was a word; or do nothing when the letter string was a nonword. Although this task difference was equated across the two groups, one can still argue that it might affect deaf readers more than hearing readers. To ensure task requirements are not responsible for the difference between deaf and hearing readers, I carried out a follow-up study again using the visual world paradigm but this time only with pseudohomophones as targets. The same pseudohomophones that were used in Experiment 4.1 were also used in Experiment 4.2 and this experiment is described in the second part of Chapter 7. Here, participants were asked to click on the picture that they felt was the best match to the letter string presented to them (i.e. pseudohomophones). Results indicate that deaf skilled readers were able to select the correct picture (i.e. the pseudotarget) and did so following a similar time course to hearing readers. Analyses also show that hearing readers looked to pseudosemantic distracters more frequently compared to unrelated items across several time windows from 300 to 1200ms, whereas deaf readers only seemed to do so during the 1000 and 1100ms time windows. Looks at semantically related distracters in this late time window plausibly indexes post-decision processes to check the correctness of the decision. However, it is important to note that there were no significant differences between the two groups in the group analyses.

Experiment 4.2 shows that the lack of pseudohomophone activation in Experiment 4.1 is not due to confounds related to the task given to subjects: deaf readers can activate words corresponding to pseudohomophones when explicitly asked to do so, however they do not do so automatically. In Experiment 4.1, they did not look to pseudohomophonic distracters more frequently than unrelated distracters and in Experiment 4.2 they did not look to pseudosemantic distracters more frequently than unrelated distracters. In both conditions, the hearing readers did show this pattern. This suggests that there are differences in the way deaf and hearing readers activate lexical information from pseudohomophones. For hearing readers, phonological processing seems to be automatic, whether it is a requirement of the task or not. Indeed, it may be that deaf readers carry out a more detailed analysis of the orthographic form of the letter string and therefore are not distracted by the phonological form in early stages of processing. This finding is in line by Emmorey et al (2013a) who used fMRI to compare semantic and phonological processing at the word level in deaf and hearing readers and found differences in brain activity. For deaf readers, there was a clear segregation between semantic and phonological processing in the left inferior prefrontal cortex (Emmorey, Weisberg, McCullough, & Petrich, 2013b). Emmorey et al (2013a) thus concluded that deaf readers did not automatically employ phonological codes during word reading, whereas hearing readers automatically processed phonological information even if it was not a task requirement. Segregation between semantic and phonological processing was less clear for hearing readers, which suggests they are activating both semantic and phonological codes simultaneously during single word reading (Emmorey et al., 2013b).

A general account for these differences is spelled out in Chapter 7. Given a simple triangle model of reading, the difference can be accounted for in terms of lack (or weaker) of activation from phonological forms to semantics. This is likely to be because deaf readers' phonological representations of spoken language are less well specified than for hearing individuals. The deaf readers in this study consisted mainly of native and near-native signers who used BSL on a daily basis, which means they are not activating semantic information from phonological information (via speechreading) as often as hearing readers who use spoken language on a daily basis. Additionally, many of the deaf readers are likely to have acquired English as a second language, which could be another factor in why the connections between phonology and semantics are weaker for deaf readers. Similar results have been found for hearing bilinguals whose performance on tasks in their L2, indicates a less active semantic network in their L2 when performing phonological tasks (Midgley, Holcomb, & Grainger, 2009).

These studies however did not use real words to assess phonological activation. The processes involved in lexical retrieval might differ. Experiment 5, reported in Chapter 8, uses again the visual world paradigm. Here, I used only real words as targets. The aim was to compare the activations of not only phonological but also orthographic information in deaf and hearing readers. In the previous experiments, although I have demonstrated that deaf and hearing readers extract semantic and phonological information from orthographic information (printed words), there were no orthographic manipulations. Some previous studies have shown that deaf readers make more use of orthographic information in comparison to hearing readers. For example, in a masked priming lexical decision task with identical and pseudohomophonic primes, deaf readers presented an inhibitory orthographic effect, whereas there was a facilitatory phonological effect for hearing readers (Cripps et al., 2005). However, as outlined in Chapter 3, it seems that there was a possible confound between orthographic and phonological information in the stimuli used in Cripps et al's (2005) study thus I wanted to investigate orthographic processing in deaf readers further using the visual world paradigm.

As in Experiments 4.1 and 4.2, I presented words along with 4 pictures and participants were instructed to click on the picture that matched the target word. I included homophonic distracters e.g. night/KNIGHT and orthographically similar distracters e.g. boat/BOOT. For target items, results from the previous visual world experiments (Experiments 4.1 and 4.2) were replicated, both deaf and hearing readers looked to target items more frequently compared to unrelated items across almost all time windows during the experimental trials and there were no temporal differences between the two groups. Both groups also looked to semantically related distracters more frequently than unrelated items across several time windows in the orthographic condition, again, replicating results from Experiments 4.1 and 4.2. However, hearing readers looked towards homophonic distracters more frequently than unrelated items in early time windows (between 0 to 300ms), whilst deaf readers did not, in line with the results reported in Experiment 4.1 with pseudohomophones. Again, it is important to note that group comparisons did not reveal any significant differences between deaf and hearing readers.

Surprisingly, in the homophone condition, neither group of readers looked to semantically related distracters. As hearing readers looked towards homophonic distracters more frequently than unrelated distracters, this could be an explanation as to why looks towards semantic distracters were reduced. However, deaf readers did not look to homophonic distracters, and they did not look to semantic distracters as much as they did in the orthographic condition so being distracted by homophones does not seem to be a plausible explanation. An alternative account could be that the semantic similarity between targets and distracters in the homophonic condition was lower than in the orthographic condition, however, analyses to check semantic similarity (paired sample t-tests, two-tailed) using both the British National Corpus and WikiB indicates that this is not the case. There were no differences in the semantic similarity between targets and distracters used in each condition. Finally, it is possible that this effect came about due to there being fewer items in the homophone condition (16 trials) compared to the orthographic condition (20 trials) and the items in the homophone conditions were also of lower frequency.

Also surprisingly, both deaf and hearing readers did not look towards orthographically similar distracters more frequently than unrelated items. A possible explanation of this null result is that there were significant differences in the orthographic neighbourhood size of target and orthographic distracter items. Several studies have reported effects of orthographic neighbourhood size on decision latencies in lexical decision tasks, however the direction of these effects (whether facilitatory or inhibitory) are still largely under debate (Rastle, 2007). Differences in orthographic neighbourhood size may also influence looks towards targets/distracters in the visual world paradigm.

The experiment further measures RTs to click on the picture. Here we also did not find any differences between the two groups, which lends further support that the processing time for words is similar for the deaf and hearing readers. However, accuracy rates for deaf and hearing readers differed. Hearing readers' accuracy rates was 97% in the orthographic condition; however, in the homophone condition their accuracy rates were 90% (i.e. they selected the wrong target item more frequently). Deaf readers' accuracy rates were 97% in both conditions. Taken together, these results show that hearing readers were more affected by homophonic distracters compared to deaf readers. Again, this shows that compared to hearing readers, deaf readers are less likely to activate phonological information when reading words, which lends further support to the hypothesis that adult deaf skilled readers do not automatically activate phonological codes when it is not a necessary task requirement (Emmorey et al., 2013b). Additionally, analyses revealed that there were significant correlations between reading scores and decision latencies in the homophone condition for the hearing readers. There were no such effects for deaf readers. As mentioned earlier, this indicates that compared to deaf readers, phonological processing plays a larger role in reading proficiency for hearing readers.

Taken together Experiments 4.1, 4.2 and 5 first demonstrate that the Visual World paradigm can be adapted successfully to explore the time course of activation of orthographic, semantic and phonological information in visual word recognition of deaf and hearing readers providing novel insight in the time course of activation of semantic and phonological information in the two groups. Crucially, although the visual world experiments showed differences in how deaf and hearing readers process and activate phonological information, this does not seem to have an impact on reading level as the two groups were matched on this aspect. Furthermore, despite differences in the language experiences of the two groups, the activation of semantic information from orthography did not differ for the two groups (i.e. deaf and hearing readers' activation of semantic information from orthography followed a similar time course).

However, caution should be taken when interpreting these results, as although there seems to be clear differences in how deaf skilled and hearing readers utilise and activate phonological information when each group was analysed separately, there were very little differences in the group comparisons (Mann-Whitney and Growth Curve Analyses). However, the pattern is consistent across the three visual world experiments, which suggests that this is likely to be due to the small sample size, which needs to be addressed in future studies.

## 10.4 Comparing orthographic and phonological preview benefits in deaf and hearing readers

Experiment 6 in Chapter 9, reports a sentence-processing task where orthographic and phonological preview benefits in deaf skilled and hearing readers are compared. Both deaf and hearing readers were found to have orthographic preview benefits but, crucially, only the hearing readers demonstrated a phonological preview benefit. For example, when the target item was ‘board’, for both deaf and hearing readers there was a significant difference in the fixation durations of identical (board) and homophonic (bored) conditions. This shows an orthographic preview benefit as the target and previews are phonologically identical but orthographically dissimilar. However, when comparing the target (e.g. board) to the orthographic conditions (e.g. beard), there were no differences in the fixation duration in these conditions for deaf readers. Any differences between these two conditions can be interpreted as a phonological preview benefit, as the only difference between these two conditions is the percentage of phoneme overlap between the preview and target. These findings replicate Belanger et al’s (2013) findings where both skilled and less skilled deaf readers did not benefit from phonological previews whilst the hearing readers did. Additionally, these findings lend further support to the hypothesis that whilst deaf readers can activate phonological codes from orthographic information, this information may not be used when the task requires access to meaning. Despite differences in processing, reading proficiency was unaffected as both groups were matched on this aspect. Additionally, there were no differences in the performance of the two groups when answering comprehension questions after sentence reading. Accuracy rates were 91% on average for each group.

Correlation analyses revealed that deaf readers with higher levels of reading proficiency benefitted more from overall previews (in the first fixation duration analyses). For deaf readers, this shows that increased reading skill leads to the ability to process words more efficiently. Skilled hearing readers process words more efficiently than less skilled hearing readers (Nation, 2017). This supports the above finding.

As discussed in Chapter 9, the preview primes were most likely visible to participants rather than being presented subliminally because in 72% of the trials, the boundary change occurred during a fixation rather than during a saccade. As a consequence of this, we analysed only data from first fixation duration and total duration time on target words. Thus, while the findings replicate previous studies (Belanger et al., 2013) we cannot conclude that phonological processing (or lack thereof) is carried out subconsciously.

## 10.5 General Theoretical Implications

Findings from the studies reported in this thesis have important implications both for theories of word recognition and our understanding of reading processes in deaf adult skilled readers. Below, I discuss phonological processing in deaf readers based on the findings from the studies described in this thesis and its implications for both theories of word recognition as well as teaching literacy to deaf children. I also propose a new triangle model of word recognition for deaf readers and provide an overall conclusion to this thesis.

### 10.5.1 Do deaf readers process phonology?

Findings from the studies reported here help with reconciling mixed findings from previous studies. As discussed in Chapter 3, several previous studies have reported that deaf readers did show evidence of phonological processing and/or awareness in their tasks (e.g. Emmorey, Weisberg, McCullough, & Petrich, 2013; Hanson & Fowler, 1987; Hanson, Goodell, & Perfetti, 1991; Leybaert, 1993; MacSweeney, Brammer, Waters, & Goswami, 2009; Mayer & Trezek, 2014). However there were also several studies that found deaf readers did not show any evidence of phonological processing (e.g. Bélanger, Baum, & Mayberry, 2012; Bélanger et al., 2013; Chamberlain, 2002; Cripps et al., 2005; Mayberry, del Giudice, & Lieberman, 2011; McQuarrie & Parrila, 2009). Crucially, a methodological weakness in many of those studies was that reading levels of the two populations were not carefully controlled for (See Table 3-1 in Chapter 3), whereas in the experiments reported in this thesis participants were matched pairwise for reading level. Any differences in the two groups in the studies presented in this thesis cannot be attributed to reading level. More interestingly, previous studies did not take into account the degree to which the task engaged semantic processing, as it can be seen in Table 10-1 below.

**Table 10-1. Previous studies that explored the role of phonology in deaf readers: whether or not reading level was controlled for, the task, whether or not evidence of phonological processing was found and whether or not the task required access to meaning**

| Study | Reading level matched? | Task | Evidence of phonological processing | Semantic processing needed? |
|---|---|---|---|---|
| **Hanson & Fowler, 1987** | No | Rhyme judgment task | Yes | No |
| **Hanson, Goodell & Perfetti, 1991** | No | Semantic acceptability judgment task | Yes | Yes |
| **Chamberlain, 2002 (Experiment 1)** | No | Spelling-to-sound correspondences | No | No |
| **Chamberlain, 2002 (Experiment 2)** | No | Masked phonological priming lexical decision task | No | No |
| **Cripps, McBride & Forster, 2005** | No | Masked phonological priming lexical decision task | No | No |
| **MacSweeney, Brammers, Waters & Goswami, 2009** | Yes | Phonemic awareness task | Yes | No |
| **Belanger, Baum & Mayberry, 2012 (Experiment 1)** | No | Masked phonological priming lexical decision task | No | No |
| **Belanger, Baum & Mayberry, 2012 (Experiment 2)** | No | Serial recall task | No | No |
| **Belanger, Mayberry & Rayner, 2013** | Yes | Invisible boundary Paradigm | No | Yes |
| **MacSweeney, Goswami & Neville, 2013** | No | Rhyme judgment task | Yes | No |
| **Emmorey, Weisberg, McCullough & Petrich, 2013** | Yes | Phonemic awareness task | Yes | No |
| **Experiment 2** | Yes | Lexical decision with pseudohomophones | Yes | No |

| | | | | |
|---|---|---|---|---|
| **Experiment 3** | Yes | Masked phonological priming lexical decision | Yes | No |
| **Experiment 4.1** | Yes | Visual world paradigm with words and pseudohomophones | No | Yes |
| **Experiment 4.2** | Yes | Visual world paradigm with pseudohomophones only | Yes (only for pseudotargets) | Yes |
| **Experiment 5** | Yes | Visual world paradigm with homophones | No | Yes |
| **Experiment 6** | Yes | Invisible boundary paradigm | No | Yes |

Looking through the table, it is clear that, with the exception of the study by Hanson et al., (1991) and Experiment 4.2 reported in this thesis, no other study that has found a phonological effect in deaf readers in tasks that required access to semantics. Whereas for studies using tasks that did not require access to meaning (e.g., lexical decision, rhyme judgment) effects of phonology were found. Hanson et al. (1991) used a semantic acceptability judgment task, measuring performance on control and tongue twister sentences. Additionally, they included a memory interference task where participants needed to recall a series of numbers that were phonetically similar to the words used in the sentences presented (Hanson et al., 1991). Both hearing and deaf participants made more errors with the tongue twister sentences and also when the series of numbers to recall were phonetically similar to the words used in the sentences, showing evidence of phonological processing. However, it is important to note that Hanson and colleagues (1991) did not control for reading level so differences between skilled and less skilled deaf readers are unclear. Additionally, Chamberlain (2002) pointed out that the numbers to recall in the memory interference task were confusable in ASL thus for deaf readers, it is possible that what Hanson and colleagues (1991) interpreted as phonological interference may be interference from ASL.

Bélanger and colleagues (2013) found that deaf readers did not make use of phonological information in a sentence-processing task (which requires access to meaning), which lend further support to the hypothesis that deaf readers utilise phonological information less in tasks that require access to meaning. The table also demonstrates that Experiment 4.2 reported in this thesis showed that deaf readers utilise phonological codes in a task that requires access to meaning (i.e. select the correct target picture that matched the pseudohomophone presented to them). However, it is important to note that this was a necessary requirement of the task assigned to the participants (task) and thus not necessarily indicative of automatic phonological processing. Deaf readers did not look towards pseudosemantic items significantly more than other distracter items, whereas hearing readers did, which suggests that phonological processing is automatic for hearing readers. Findings from the various experiments in this thesis explain why such mixed results were obtained in previous studies terms of both (a) the extent to which semantic processing is required and (b) reading skills.

### 10.5.2 The interplay between orthography, semantic and phonological information in deaf skilled readers – a proposed model for deaf readers

As discussed in Chapter 2, theoretical proposals of reading in adult skilled hearing readers assume interplay between activation of orthographic, semantic and phonological codes. A general assumption is that phonological activation arises from phonological decoding processes, namely, the operation by which beginning hearing readers recover the pronunciation of any pronounceable string of letters by using knowledge about the associations between phonemes and graphemes (Grainger, Dufau, & Ziegler, 2016). Because beginning hearing readers already have phonological representations for spoken words, this process can support the activation of semantic codes. For adult hearing readers, activation of phonological codes can support visual word recognition in two ways. First, because phonological codes are connected to orthographic codes, activation of phonological codes can enhance orthographic (visual) recognition. Second, because phonological codes are linked to semantics, it can enhance activation of semantic information about the word, thus enhancing the processing of its meaning.

Phonological codes for deaf readers must develop in a different manner. One primary source of information from which deaf people can derive phonological information is from speechreading (Elliott et al., 2012; Kyle et al., 2009). That is by extracting lexical and sublexical level information (e.g. phonological information) from visual information (also referred to as visemes) associated to words. The question then is to what extent the phonological codes based on non-auditory information, can also support reading in adult deaf skilled readers. Just as discussed for hearing individuals, these phonological codes, in principle, could support word recognition in two ways: by enhancing activation of corresponding orthographic representation, and by enhancing semantic activation. These studies allowed me to address orthographic – semantic – phonological activation for the two groups of readers and therefore allowed for the assessment of similarities and differences.

We have found that the interplay between those three elements differ for deaf and hearing readers. The lexical decision tasks show us that deaf and hearing readers seem to activate phonological information from orthographic information in similar ways. Evidence from the visual world studies demonstrate that deaf and hearing readers can both activate semantic information from orthographic information in a similar fashion, following a similar time course. However, results from the lexical decision tasks also show that deaf readers seem to be more influenced by semantic variables (Experiment 1), had faster and more accurate decision latencies (Experiments 1 and 3) compared to hearing readers, all of which suggest that the connections between orthography and semantics are more robust for deaf readers compared to hearing readers. Although there are indicators from the studies reported in this thesis that these connections between orthographic and semantics are stronger in deaf than hearing readers, there is insufficient evidence to reach a firm conclusion. With regards to phonological processing, we failed to observe phonological activation in deaf readers when the task requires access to meaning (i.e. the visual world paradigm and sentence-processing tasks). In a recent ERP study, deaf readers had a lower negativity for N400 (related to whole-word forms and their meanings) compared to hearing readers when performing a phonological task, which indicates a less active semantic network during such tasks (Gutierrez-Sigut et al., 2017). However, in the same study, N250 (related to sub-lexical components i.e. phonological codes) activation was comparable in deaf and hearing readers, showing that deaf readers do activate phonological codes but they do not always link up to semantic codes (Gutierrez-Sigut et al., 2017). This means when deaf and hearing readers are performing phonological tasks, both groups show evidence of activating phonological codes. However, only the hearing readers seem to be activating semantic codes, which indicates they are simultaneously and automatically processing semantic and phonological information (Gutierrez-Sigut et al., 2017). These differences between deaf and hearing readers are in line with the findings reported in this study.

Overall, deaf readers do not seem to extract semantic information from pseudohomophones and homophones in an automatic fashion, whereas the hearing readers do. It is important to note that deaf readers can extract semantic information from phonological information if it is necessary to do so, as is evident in Experiment 4.2. Based on the results from the various tasks, we propose a new model of word recognition for deaf readers (see Figure 10-1).

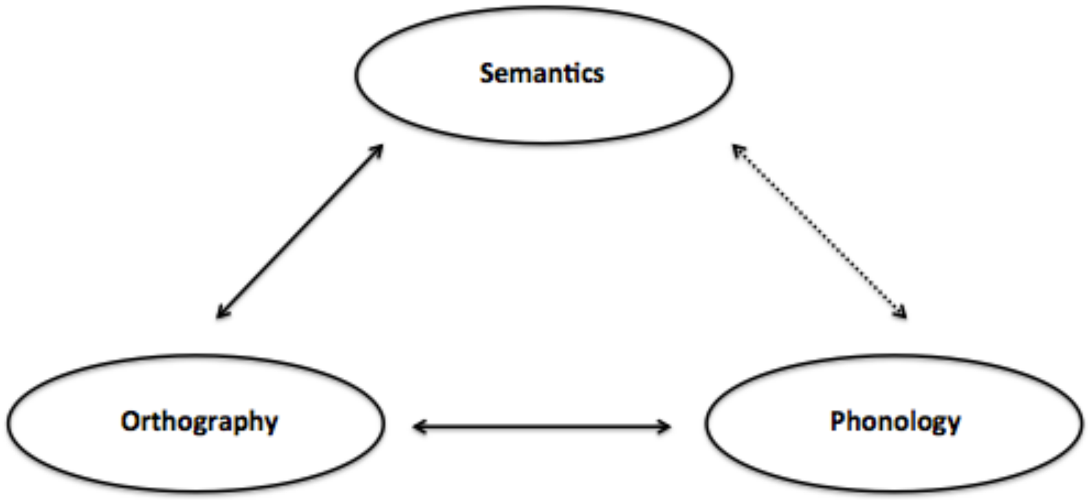


**Figure 10-1 - Proposed Model of Word Recognition for Deaf Skilled Readers**

In the proposed model of word recognition for deaf readers, the connections between orthography and phonology are shown to be robust (indicated by a bold line). The connections between orthography and semantics are also shown to be robust (indicated by a bold line). However, the connections between semantics and phonology are weak at best for deaf skilled readers (indicated by the jagged line).

The findings from the studies described in this thesis indicate that deaf adults do not engage strong connections between phonology and semantics during successful visual word recognition. Furthermore, and importantly, the deaf and hearing participants in the current study were matched pairwise for reading level. Deaf readers did not perform any worse than hearing readers across all of the studies; in fact, in some cases they outperformed hearing readers. They had faster and more accurate decision latencies in Experiments 1 (lexical decision) and 3 (masked priming) and higher accuracy in the homophone condition of Experiment 5. Several studies have pointed out that although some deaf readers may make use of phonological codes, this does not always predict successful reading, for example, Emmorey and colleagues (2016) found that reading ability did not correlate positively with neural activity during a phonological task or with phonological awareness scores (Emmorey, McCullough, & Weisberg, 2016; note however that many other studies DO show a relationship).

If successful reading can be achieved without having such connections, why do they exist for hearing readers? For hearing readers, these connections exist as they were present prior to learning to read (mapping between spoken word form and spoken word meaning) and orthographic to semantic mappings were formed via those existing phonological codes. It is possible that the connections we see between phonology and semantics during word recognition in hearing readers may be ‘left-over’ effects from their learning history (i.e. learning to map between orthography and semantic codes via phonological codes). Alternatively, these phonological codes may increase semantic activation and this information may make the retrieval of semantic information more secure.

Compared to hearing readers, deaf readers in this study are likely to have had less developed spoken language phonological/semantic networks prior to learning to read, these connections are weaker for deaf readers but not non-existent (as evident in Experiment 4.2, where they were able to choose pseudotargets correctly). Deaf and hearing readers both began developing connections between orthography and semantic codes at around the same time, however deaf readers become more dependent on written information, which could explain why the strength of these connections seem stronger for deaf readers. Prior to learning to read, it is possible that most deaf readers in this study developed connections between sign language phonology (sign forms) and semantics, which they may then have mapped onto print (Hoffmeister & Caldwell-Harris, 2014). Early access to language has enabled them to develop robust connections between orthographic and semantic codes. Many deaf people struggle to achieve the same levels of proficiency as hearing people and this is likely to be because of delayed language, thus a less developed semantic network prior to learning to read.

Despite lack of activation of phonological information when the task includes meaning, deaf readers' reading performance does not seem to be hindered. This could be because the increased robustness of the connections between orthography/semantics and the robustness of the connections between orthography/phonology may help to stabilize the input code, even if the connections between phonology and semantics are weak. For deaf skilled readers in this study, phonology is activated upon reading a word as it helps with orthographic encoding. However, phonology is not always a necessary component in skilled reading as semantic information can be extracted directly from orthographic information. Findings from deaf skilled readers in this study lends support to the hypothesis that there are multiple pathways to word recognition and that readers will make use of what information is readily available to them (Brysbaert & Praet, 1992; Harm & Seidenberg, 2004; Rastle & Brysbaert, 2006).

As mentioned earlier, some results from this study and from previous studies seem to indicate that the connections between orthography and semantics are stronger for deaf readers in comparison to hearing readers. However, this has not been explored in enough depth in this thesis to determine this and to incorporate this phenomenon into the proposed model of word recognition for deaf readers. Future studies should address this and the proposed model can be adjusted to reflect the strength of the connections between orthography and semantics for deaf readers.

### 10.5.3 Implications on weak versus strong phonological theories

It is clear from the literature that hearing readers process phonological information during word recognition, however, as outlined in Chapter 2, the extent to which phonological activation is required for skilled word recognition is still under debate. Supporters of ‘strong’ phonological theories posit that phonology is a vital component of word recognition and without this component, word recognition would not be possible (Frost, 1998). This means that readers must first obtain phonological information from orthographic information, which will then allow them to activate the meaning of words (Coltheart et al., 2001; Frost, 1998). ‘Weak’ phonological theorists claim that phonology is not always a necessary component for word recognition as ‘dual access’ is possible, i.e. it is possible to extract meaning directly from the orthography (Brysbaert & Praet, 1992; Coltheart et al., 2001; Rastle & Brysbaert, 2006). Our results support a weak phonological theory. While hearing readers show evidence of phonological activation in all tasks, results from our deaf readers, who are equally skilled in reading as their hearing counterparts, provide evidence for the non-necessity of phonological activation in visual word recognition. These findings have implications for theories of word recognition and reading. As outlined in Chapter 2, models of word recognition such as the dual-route ((Coltheart et al., 2001) and connectionist (Seidenberg, 2005) models both posit that the activation of phonological codes are a necessary prerequisite for successful word recognition. However, as explained in Chapter 3, the dual-route model can be adapted to explain visual word recognition in deaf readers by incorporating phonological codes obtained via lipreading (visemes rather than phonemes) and via sign language (for access to semantic representations) (Elliott et al., 2012).

Connectionist models could also be adapted to provide an account of how deaf readers recognize words, which is also outlined in Chapter 3. In between the connections between orthographic, semantic and phonological information, there are hidden units that contain information about each element (Harm & Seidenberg, 1999). These elements are activated upon reading a word. The amount of information carried in each hidden unit is dependent on reading experience, thus for deaf readers there will be more information in the hidden units connecting between orthography and semantics, orthography and phonology compared to the connections between phonology and semantics. This information stored in the hidden units helps deaf readers to recognize words.

As outlined in Chapter 2, the simple view of reading posits that there are two crucial elements that are required for successful literacy, which are oral language comprehension (i.e. spoken language skills) and decoding skills (i.e. the ability to extract phonological information from orthography to obtain the word’s pronunciation) (Gough & Tunmer, 1986). For deaf readers who sign, the simple view of reading can be adapted to include oral language comprehension, namely sign language fluency. Several studies have reported significant correlations between sign language and reading skills, those who are more fluent in sign language have better reading skills (Chamberlain, 2002; Mayberry et al., 2011). The second component focuses on decoding skills. For some deaf readers who sign, this may not be important, but may be replaced with the ability to efficiently extract a word's meaning from its orthography. In turn this efficiency may depend on reading experience (Nation, 2017). This efficiency allows deaf skilled readers to quickly discriminate between words and nonwords, as is evident from the studies reported in this thesis.

However, it is important to note that deaf readers in this study show some evidence of phonological processing (Experiment 2, 3 and 4.2) and this phonological knowledge, although limited, may be of assistance when deaf readers encounter novel words. These possibilities should be the focus of future research, which will enable us to better develop models of word recognition and reading for deaf readers. Developing such models will enable us to understand more about how deaf people learn to read and what processes are involved in skilled reading. This in turn will allow us to become better informed in how to teach deaf children literacy.

### 10.5.4 Implications for teaching literacy to deaf children

The findings from the studies described in this thesis has implications for teaching literacy to deaf children, as many are taught literacy using methods that have been developed for hearing children (e.g. teaching spelling-to-sound correspondences). As outlined in Chapter 2, the role of phonology plays a large role in reading acquisition for hearing children as they already have access to those codes prior to learning to read, whereas most deaf children (especially those who sign) do not. However, it is important to note that although phonological coding seems less important for successful reading for deaf readers included in this study, the experiments carried out in this study does not tell us anything about how they became skilled readers. Nevertheless, if the role of phonology is less important for deaf adults, it is possible that it could also be less important for deaf children learning to read and educational practices should reflect this. It may be more useful to focus on form to meaning connections when teaching deaf children how to read.

For hearing children, mapping between phonological and orthographic codes is a vital part of learning to read. The same could be true for deaf children, but as they become skilled readers, they become less reliant on phonology due to differences in language and reading experiences. However, this is unlikely as previous studies report that deaf children were found to develop phonological skills as they learnt to read and that early reading ability was directly correlated to later phonological awareness (Harris et al., 2017a; Kyle & Harris, 2010, 2011). A crucial finding from these studies was that in hearing children, phonological awareness was a longitudinal predictor of reading. However, for deaf children phonological awareness was a concurrent correlate at different times of testing. It was also the case that across the various measures used in Harris et al's (2017) study; there were many more significant correlations between these measures and reading for the deaf children than the hearing children. The authors conclude that the skills underpinning skilled reading, including phonological awareness and vocabulary, are more salient for deaf children (Harris et al., 2017a). This pattern of finding suggests that for some deaf children phonological skills may indeed play a role in reading development, but that the nature of this contribution is likely to differ between deaf and hearing children. In particular this pattern is likely to be affected by whether deaf children use a signed language or not (Harris & Moreno, 2004; Harris et al., 2017a; Kyle & Harris, 2011).

## 10.6 General Conclusion

The present study has led to two important conclusions. Firstly, although there are some differences in word processing by deaf and hearing people, overall, the two groups show important similarities in the activation of orthographic and semantic codes. Secondly, we have shown that unlike hearing readers, deaf readers do not activate phonological information automatically whilst reading. Despite this, deaf individuals can become skilled readers. The thesis opens a number of other questions relating to the strategies that deaf skilled readers may use to overcome the lack of phonological activation. A potentially informative approach to answer these questions could be to develop population level studies that capitalize on the methods we have used in the thesis (lexical decision, visual world and invisible boundary paradigms) to explore word processing across deaf and hearing readers with different levels of reading skills, age and experience with other languages. Understanding crucial differences in the reading processes of these groups across all ages will help inform teaching practices and this, in turn, will improve literacy attainment in the deaf population.

# Appendix 1. Language History Questionnaire

**Participant Number _____________(Researcher to fill in)**

Name: ________________________________________________

Email: ________________________________________________

Participant identities and contact details will be kept confidential, accessed only by Professor Gabriella Vigliocco and Kate Rowley.

1. a. Age: ____________ b. Sex: Male / Female

2. Education _____________________________________________
   (highest degree obtained or school level attended)

3. Your country of origin: ______________________________

4. Do you know more than one language: Yes / No

If you answered "No", you need not continue this form.

If you answered "Yes", list the languages in order of fluency (most fluent first) (*If you know any sign languages, list these as well*):

| **Languages** |
|---|
| |
| |
| |
| |
| |

5. In the table below, indicate at which age you started to learn each language you know in the following settings, providing information for only those settings relevant to each language.

| **Language** | **At home** | **At school** | **After moving to country where spoken** | **In informal settings (e.g. from friends)** | **Through software** | **Other (please specify)** |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

6. In the table below, indicate at which age you first learned each language you know in terms of production (speaking/signing), reading, and writing, and the number of years you have spent learning each language. **(Note: for deaf participants do not fill in 'Production' for English, 'Reading', 'Writing' for sign language)**

| **Language** | **Age first learned the language** | | | **# years spent learning** |
|---|---|---|---|---|
| | **Production** | **Reading** | **Writing** | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

7. Please rate your ability in terms of reading, writing, production (speaking/signing), and comprehension for each language you know according to the following scale. Do this by

circling the appropriate number in the table below. **(Note: for deaf participants, do not fill in Reading/Writing for BSL or for Production/Comprehension of English)**

*Very poor Poor Fair Functional Good Very good Native-like*

1______________2__________3__________4_______________5__________6__________
____7_________

| Language | Reading | Writing | Production | Comprehension |
|---|---|---|---|---|
| | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 |
| | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 |
| | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 |
| | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 |
| | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 | 1 2 3 4 5 6 7 |

8. Write down the name of the language(s) used by your teachers for general instruction (e.g. history, math, science) at each schooling level. If you switched language during a school level (perhaps due to a change of schools), please write down what language you switched to e.g. primary school – Spoken English then BSL.

Primary/Elementary School: _________________________________

Secondary/Middle: _____________________________________________

High School: _____________________________________________________

College/University: ____________________________________________

9. Estimate, in terms of percentages, how often you use each language you know with the following people. (For example, if you use English with half your friends, and French with the other half of your friends, indicate 50% for English and 50% for French in the Friends column. Columns should add up to 100%.)

| **Language** | **Family** | **Friends** | **Classmates** | **Co-workers** |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

10. If there is anything else that you feel is interesting or important about your language background or language use, please comment below:

# Appendix 2. Deafness, Language and Education Questionnaire

Please provide your contact information below

Name:

Email:

What is your degree of deafness?

Mild Moderate Severe Profound

Were you born deaf?

Yes No

If you were not born deaf, at what age did you become deaf?

---

How useful is your hearing to you (with aids)? Rate the usefulness of your hearing according to the scale below.

1 - Cannot hear at all

2 - Hear some sounds but cannot make them out

3 - Hear lots of sounds and can recognise some of them (environmental sounds)

4 - Hear lots of sounds and can recognise many of them (environmental sounds)

5 - Can recognise some speech (without lip-reading) i.e. own name and occasional words

6 - Can recognise many speech sounds (able to speak on the phone with familiar people)

7 - Can speak on the phone with both familiar and unfamiliar people

Do you currently wear hearing aids or cochlear implants?

Yes No

Are your parents;

Deaf Hearing One parent deaf

Are your siblings;

Deaf Hearing Both

State how many of each______________________________________________

If you come from a deaf family, please state how many generations of deaf people there are in your family (up to you)?

______________________________________________________________

Do you have children?

Yes No

If yes, are they;

Deaf Hearing Both

State how many of each____________________________________________

What were your parents’ occupations when you were growing up (0-18)?

Mother_____________________________

Father______________________________

Tell us about your educational experience at home with your parents below. Did your parents;

Read with you: Yes (often) Yes (sometimes) Yes (rarely) No

Do homework with you:

Yes (often) Yes (sometimes) Yes (rarely) No

Have educational conversations with you:

Yes (often) Yes (sometimes) Yes (rarely) No

Tell you stories: Yes (often) Yes (sometimes) Yes (rarely) No

What language did you use with your parents when growing up?

________________________________________________________________

What language did you use with your siblings when growing up?

________________________________________________________________

Where did you go to school and what was the teaching language of the school? Did you have any communication support?

Nursery__________________________________________________________

Primary__________________________________________________________

Secondary________________________________________________________

What language did you use with your peers?

Nursery__________________________________________________

Primary__________________________________________________

Secondary________________________________________________

Is there anything more about your experiences that you would to add here and that may be relevant to this study?

Thank you for taking the time to complete this questionnaire.

# Appendix 3. Words used in Experiment 1.

**Table A3-4-1. List of words included in Experiment 1.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| accident | business | creature | failure | horn | measure | peace | salad |
| accordance | butter | crime | farewell | hunger | meat | peep | salary |
| acre | cabinet | crowd | fate | hush | medicine | permit | saloon |
| act | cake | culture | fatigue | ideal | meeting | personality | salt |
| actuality | calf | damage | feat | illusion | messenger | personnel | sardine |
| addition | call | dawn | film | impersonation | method | pet | sauce |
| adolescence | camp | debt | filth | incident | midnight | phase | scale |
| adultery | cancer | decomposition | finance | industry | minute | photograph | scent |
| aerial | candidate | defence | flag | infantry | misery | piano | scholar |
| affection | candy | defiance | flame | infringement | missile | pig | secretary |
| aggressor | cartilage | definition | fleet | inhabitant | mist | pillow | segment |
| agony | cash | delight | fool | innocence | mistress | plain | self |
| aisle | cause | demon | football | intelligence | month | platform | sentiment |
| anecdote | cellar | dent | footstep | interruption | monument | poison | servant |
| ankle | century | depression | forfeit | intoxication | moral | pond | sex |
| apartment | chain | deputy | fork | invader | motor | Pope | shield |
| apology | champion | desk | fortification | irritation | mountain | porch | shirt |
| appeal | character | detective | fox | isle | movie | potato | shoe |
| archery | charity | diamond | freedom | jail | mud | pouch | shore |
| army | charm | dimension | frenzy | jar | multitude | presence | shrub |
| arrow | chatterbox | diner | frog | jerk | murder | president | sigh |
| ash | cheese | direction | fuel | jockey | music | pressure | sin |
| athlete | circuit | dirt | fullness | joke | mustard | prison | siren |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| atom | circus | discharge | gallery | journal | mutilation | psychologist | situation |
| attempt | clay | discord | game | joy | mystery | punch | skull |
| aunt | cleaver | disease | gender | jump | nature | punishment | slave |
| author | clock | dispute | generation | justice | nip | queen | slime |
| babe | clue | dock | gentleman | justification | note | quickness | slipper |
| bag | coat | dog | gesture | lamb | nurse | rain | smell |
| bagpipe | cold | dot | girl | lamp | nutrient | realm | smoke |
| banner | cologne | dozen | gloom | leader | oath | receptacle | snub |
| base | commander | dream | glory | lens | object | reduction | soap |
| beam | committee | drink | goal | lettuce | oblivion | refuse | soldier |
| beast | communication | duke | goddess | liberty | opposition | relation | sorrow |
| beginning | competition | dust | gospel | line | orange | repair | spasm |
| benefactor | complication | dwelling | grade | linen | order | representative | spear |
| berry | comrade | earl | graduate | liquor | origin | republic | sphere |
| bird | condition | echo | grandfather | lock | otter | rescue | square |
| bite | confusion | edge | grave | lust | ounce | respect | stake |
| blame | consequence | education | greed | luxury | outset | result | starch |
| blessing | conservation | effect | groan | magazine | overcoat | revenge | station |
| block | consideration | egg | guess | magic | overlap | revenue | statue |
| book | conspirator | elaboration | gun | mail | pact | review | steam |
| boot | contamination | elimination | habit | majority | pain | reward | step |
| booth | continent | emergency | hall | maker | pair | ride | storm |
| bother | coolness | enemy | hammer | manicure | palace | ridge | stove |
| bristle | core | equipment | handkerchief | marble | paradise | riot | substance |
| brother | corpse | error | havoc | margin | parliament | risk | substitute |
| brute | correspondent | essay | hay | market | part | roar | success |
| budget | corridor | establishment | hell | material | participant | room | sum |
| buffer | couch | excitement | hero | matter | passion | rosebud | supply |
| burden | count | experience | hint | meadow | paste | saddle | surprise |
| burner | cousin | face | history | measles | payment | saga | Suspect |
| sweat | sweep | swell | sword | tail | tank | tap | tax |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| teacher | technicality | teeth | temptation | terror | thermometer | thistle | threat |
| thrill | throw | timber | tip | tobacco | toilet | token | toll |
| tongue | tooth | torture | tower | toy | track | traitor | treaty |
| trend | trouble | truck | trunk | umbrella | uneasiness | union | veal |
| vegetable | verse | victim | victory | wage | waist | waltz | warmth |
| wash | weapon | wedding | wheel | win | winter | yacht | year |

# Appendix 4. Nonwords used in Experiment 1.

**Table A4-4-1. List of nonwords used in Experiment 1.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| danal | injot | chritting | nona | accreviation | affist | detty | oreans |
| elic | seeny | lefer | seniolaty | rab | addolade | watsif | reists |
| atle | atal | stocessed | Darlete | rorn | storst | calks | fimbly |
| elso | prail | yate | lonojin | bratues | postung | thwerted | mepped |
| mons | dacit | halet | plusted | gocker | fourting | innigrate | traniel |
| lote | sild | misose | zale | oning | cou'd | blarkles | tersia |
| toopy | armeniot | wreatka | vot | tavishly | strashed | marnal | rampagins |
| gelon | plaircases | delsh | phild | reinstatamont | shere | gynecolufist | illovation |
| peir | als | brinsuit | ganic | clooping | mengy | plansports | slarves |
| vand | asslauded | dradowing | donveyed | plimming | roveless | dijol | dom |
| putu | crunkles | mookend | anitseruk | bludying | plorn | sheribb's | loutly |
| blaps | greelworker | futed | phurch | fompolations | ile | hing | platcher |
| brap | giminder | transmimed | osp | glanslator | glerapist | realp | gentips |
| dimos | ellist | tryles | blavitation | probidden | thider | thrattered | smort |
| drair | oggiciate | ribrard | replicatium | resonstatute | chrik | horrowing | voils |
| fleek | trallywag | mefuge | hombsight | constipameon | ceasons | sawker | logey |
| waber | gaussiop | wald | annluence | concomipunce | draggering | crouting | ting |
| breat | artar | blunger | glueamishness | templed | diskong | incirs | tam |
| thap | allembled | raded | washindtan | dinnertume | jin | intercontunted | wip |
| artor | plirrup | cols | meteorates | oupt | nans | travelan | crefers |
| trest | munith | tradder | phirits | gope | accition | trokes | prubbornness |
| vores | cridded | reenterod | thations | gon | fedoba | ollered | addointing |
| posp | spuly | proteched | tate | adrica | clowcase | peflin | prelts |
| grive | aiv | congresswobin | atteals | gips | attointees | graline | aggreviated |
| cet | chesume | conciliatiak | kear | ottosed | puties | dipules | unopian |
| foom | omle | crelled | bliffer | voe | ovner | parung | rungle |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| nopied | pliffen | ponterers | gorgo | mazs | clieer | ninged | mayats |
| spod | plab | comminble | hoos | nastior | drirl | allempt | maf's |
| modil | chipod | attelerated | bursitun | expeditionivy | grefab | tefine | basint |
| beru | gat | connotatake | plorched | clab | annarent | sagi | jad |
| rast | thrunch | blaining | phripes | garted | purbish | tharl | alfonba |
| trize | prones | deaged | jark | snisons | tereof | addied | lepeat |
| fobe | gritching | branking | framatization | pheties | allented | thibes | kest |
| driss | schetching | corax | hez | slan | coolidsk's | bratter | pro'll |
| poog | drail | barflime | onnicer | frade | plansaction | moily | drereby |
| foon | staw | teady | issing | clurdy | blosper | nelay | wores |
| adday | heaks | tedside | drod | lide | citer | abbives | dum |
| doat | frunning | glirts | smop | athuct | spaises | appracted | farrack |
| hesk | jine | zera | perocity | prallpox | praft | trourge | opders |
| feaps | neave | gleculatively | trather | affaying | tade | heso | utler |
| tooch | ciston | irserts | jats | ciminded | albern | chreaming | flanish |
| jope | farrows | folonial | kander | gesser | ippensities | scrones | appacker |
| rold | orlern | interpuyer | diberation | trated | ubuversal | fut | monticallu |
| furch | cleory | thraped | plarifies | domber | cay | chuare | uglimatum |
| villo | creath | tarce | drodged | masteref | opate | faths | clirst |
| peow | bresis | consuger's | pilt | rander | jewishnest | erded | alimeth |
| wull | gented | thrinx | whoma | allent | thaid | pab | trithy |
| smag | halamine | stre | erptied | vamerio | seb | fonah | chithe |
| bous | rinder | sollowing | spavel | tremish | vallop | agglicted | dattles |
| tomp | achirin | haurded | peatle's | bram | oddonent | tawdy | cax |
| teck | plar | chitching | pettijestes | snailers | shoney | chove | sarder |
| thram | sest | foner | vit | rearoom | deng | citches | |
| blont | gearer | appisting | receit | bratement | helt | dramens | |

# Appendix 5. Models fitted and model comparisons for the reaction time data in Experiment 1.

```
full.lmer = lmer(StimulusDisplayed.RT ~ valence*logfreq*SubjectGroup +
 imageability*logfreq*SubjectGroup + hedvalence*logfreq*SubjectGroup +
 arousal*logfreq*SubjectGroup + cnc*logfreq*SubjectGroup + aoa*logfreq*SubjectGroup +
 fam*logfreq*SubjectGroup + Nlett*logfreq*SubjectGroup + logfreq +
 orthon*logfreq*SubjectGroup + nmorph2*logfreq*SubjectGroup +
 bgfreq*logfreq*SubjectGroup + SubjectGroup + (logfreq+1|Subject) + (1|LetterString), rt,
 x=T)
```

```
nofreqinteraction.lmer = lmer(StimulusDisplayed.RT ~ valence*SubjectGroup +
 imageability*SubjectGroup + hedvalence*SubjectGroup + arousal*SubjectGroup +
 cnc*SubjectGroup + aoa*SubjectGroup + fam*SubjectGroup + Nlett*SubjectGroup +
 logfreq + orthon*SubjectGroup + nmorph2*SubjectGroup + bgfreq*SubjectGroup +
 SubjectGroup + (logfreq+1|Subject) + (1|LetterString), rt, x=T)
```

```
summary(full.lmer)

summary(nofreqinteraction.lmer)

anova(full.lmer,nofreqinteraction.lmer)
```

Chi square = 78.523, $p < 0.00$

The non-significant interactions involving frequency were dropped and the reduced model was tested.

```
goodfreq.lmer = lmer(StimulusDisplayed.RT ~ valence*SubjectGroup +
imageability*SubjectGroup + hedvalence*SubjectGroup + arousal*logfreq*SubjectGroup +
cnc*logfreq*SubjectGroup + aoa*logfreq*SubjectGroup + fam*logfreq*SubjectGroup +
Nlett*logfreq*SubjectGroup + logfreq + orthon*SubjectGroup + nmorph2*SubjectGroup +
bgfreq*SubjectGroup + SubjectGroup + (logfreq+1|Subject) + (1|LetterString), rt, x=T)
```

```
summary(goodfreq.lmer)

anova(goodfreq.lmer,full.lmer)
```

Chi square = 16.536, p = 0.167

The non-significant 3-way interactions involving frequency were then dropped from the model.

```
goodfreq2.lmer = lmer(StimulusDisplayed.RT ~ valence*SubjectGroup +
imageability*SubjectGroup + hedvalence*SubjectGroup + arousal*logfreq*SubjectGroup +
cnc*logfreq*SubjectGroup + aoa*logfreq + aoa*SubjectGroup + fam*logfreq
+fam*SubjectGroup + Nlett*SubjectGroup + logfreq + orthon*SubjectGroup +
nmorph2*SubjectGroup + bgfreq*SubjectGroup + SubjectGroup + (logfreq+1|Subject) +
(1|LetterString), rt, x=T)
```

```
summary(goodfreq2.lmer)

anova(goodfreq.lmer,goodfreq2.lmer)
```

Chi square = 2.94, p = 0.567

The non-significant interactions involving group were then dropped from the model.

```
goodfreq2goodgroup.lmer = lmer(StimulusDisplayed.RT ~ valence*SubjectGroup +
 imageability*SubjectGroup + hedvalence*SubjectGroup + arousal*logfreq*SubjectGroup +
 cnc*logfreq*SubjectGroup + aoa*logfreq + fam*logfreq + Nlett*SubjectGroup + logfreq +
 orthon + nmorph2 + bgfreq + SubjectGroup + (logfreq+1|Subject) + (1|LetterString), rt,
 x=T)
```

```
summary(goodfreq2goodgroup.lmer)

anova(goodfreq2goodgroup.lmer,goodfreq2.lmer)
```

Chi square = 5.5475, p = 0.3528

Non-significant main effects and additional interactions involving group were then eliminated from the model.

```
goodfreq2goodgroup2.lmer = lmer(StimulusDisplayed.RT ~ hedvalence*SubjectGroup +
 arousal*logfreq*SubjectGroup + cnc*logfreq*SubjectGroup + aoa*logfreq + fam*logfreq +
 Nlett*SubjectGroup + logfreq + orthon + nmorph2 + SubjectGroup + (logfreq+1|Subject) +
 (1|LetterString), rt, x=T)
```

```
summary(goodfreq2goodgroup2.lmer)

anova(goodfreq2goodgroup.lmer,goodfreq2goodgroup2.lmer)
```

Chi square = 4.3489, p = 0.5004

Next, any 3-way interactions involving group, frequency and arousal/concreteness were removed from the model.

```
goodfreq2goodgroup3.lmer = lmer(StimulusDisplayed.RT ~ hedvalence*SubjectGroup +
arousal*SubjectGroup + cnc*SubjectGroup + aoa*logfreq + fam*logfreq +
Nlett*SubjectGroup + logfreq + orthon + nmorph2 + SubjectGroup + (logfreq+1|Subject) +
(1|LetterString), rt, x=T)
```

```
summary(goodfreq2goodgroup3.lmer)

anova(goodfreq2goodgroup2.lmer,goodfreq2goodgroup3.lmer)
```

Chi square = 11.906, p = 0.0361

The last model (goodfreq2goodgroup2.lmer) is better than the last model (goodfreq2goodgroup3.lmer) so use this as the final model.

# Appendix 6. Models fitted and model comparisons for the accuracy data in Experiment 1.

```
full.lmer = lmer(Accuracy ~ valence*logfreq*SubjectGroup +
 imageability*logfreq*SubjectGroup + hedvalence*logfreq*SubjectGroup +
 arousal*logfreq*SubjectGroup + cnc*logfreq*SubjectGroup + aoa*logfreq*SubjectGroup +
 fam*logfreq*SubjectGroup + Nlett*logfreq*SubjectGroup + logfreq +
 orthon*logfreq*SubjectGroup + nmorph2*logfreq*SubjectGroup +
 bgfreq*logfreq*SubjectGroup + SubjectGroup + (logfreq+1|Subject) + (1|LetterString), rt,
 x=T)
```

The above model did not converge thus the random subject slope for frequency was removed.

```
fullnorandomfreq.lmer = lmer(Accuracy ~ valence*logfreq*SubjectGroup +
 imageability*logfreq*SubjectGroup + hedvalence*logfreq*SubjectGroup +
 arousal*logfreq*SubjectGroup + cnc*logfreq*SubjectGroup + aoa*logfreq*SubjectGroup +
 fam*logfreq*SubjectGroup + Nlett*logfreq*SubjectGroup + logfreq +
 orthon*logfreq*SubjectGroup + nmorph2*logfreq*SubjectGroup +
 bgfreq*logfreq*SubjectGroup + SubjectGroup + (1|Subject) + (1|LetterString), rt, x=T)
```

```
summary(fullnorandomfreq.lmer)
```

The above model converged and next all of the non significant frequency interactions was dropped.

```
dropnonsigfreqint.lmer = lmer(Accuracy ~ valence*SubjectGroup +
 imageability*SubjectGroup + hedvalence*SubjectGroup + arousal*SubjectGroup +
 cnc*SubjectGroup + aoa*SubjectGroup + fam*SubjectGroup + Nlett*SubjectGroup +
 logfreq + orthon*logfreq*SubjectGroup + nmorph2*SubjectGroup + bgfreq*SubjectGroup
 + SubjectGroup + (1|Subject) + (1|LetterString), rt, x=T)
```

```
summary(dropnonsigfreqint.lmer)

anova(fullnorandomfreq.lmer,dropnonsigfreqint.lmer)
```

```
#model significantly better
```

Non significant interactions involving group were dropped from the next model.

```
dropnonsiggroupint.lmer = lmer(Accuracy ~ valence + imageability + hedvalence + arousal +
 cnc + aoa + fam*SubjectGroup + Nlett + logfreq + orthon*logfreq*SubjectGroup +
 nmorph2 + bgfreq + SubjectGroup + (1|Subject) + (1|LetterString), rt, x=T)
```

```
summary(dropnonsiggroupint.lmer)
```

```
anova(dropnonsigfreqint.lmer,dropnonsiggroupint.lmer)
```

There was no difference in the last 2 models so keep the less complex model and the non significant main effects were dropped.

```
dropnonsigmaineffects.lmer = lmer(Accuracy ~ aoa + fam*SubjectGroup + logfreq +
 orthon*logfreq*SubjectGroup + SubjectGroup + (1|Subject) + (1|LetterString), rt, x=T)
```

```
summary(dropnonsigmaineffects.lmer)
```

```
anova(dropnonsiggroupint.lmer,dropnonsigmaineffects.lmer)
```

There was no difference between last 2 models, keep last model as final model as it is the simplest model.

Deaf and hearing data was split for comparison.

```
# create separate data structures for groups
rtH=rt[which(rt$SubjectGroup=="Hearing"),]
rtD=rt[which(rt$SubjectGroup=="Deaf"),]
```

```
dropnonsigmaineffectsH.lmer = lmer(Accuracy ~ aoa + fam + logfreq + orthon*logfreq +
 (1|Subject) + (1|LetterString), rtH, x=T)
```

```
summary(dropnonsigmaineffectsH.lmer)
```

```
dropnonsigmaineffectsD.lmer = lmer(Accuracy ~ aoa + fam + logfreq + orthon*logfreq +
 (1|Subject) + (1|LetterString), rtD, x=T)
```

```
summary(dropnonsigmaineffectsD.lmer)
```

Data was split between high and low frequency for the hearing group only, as there were interaction effects between frequency and orthographic neighbourhood size.

```
rtHlow=rtH[which(rtH$logfreq<9.05),]

rtHhigh=rtH[which(rtH$logfreq>9.06),]
```

Testing low frequency.

```
dropnonsigmaineffectsHlow.lmer = lmer(Accuracy ~ aoa + fam + orthon + (1|Subject) +
 (1|LetterString), rtHlow, x=T)
```

Testing high frequency.

```
dropnonsigmaineffectsHhigh.lmer = lmer(Accuracy ~ aoa + fam + orthon + (1|Subject) +
 (1|LetterString), rtHhigh, x=T)
```

```
summary(dropnonsigmaineffectsHlow.lmer)
```

```
summary(dropnonsigmaineffectsHhigh.lmer)
```

# Appendix 7. Full results from the final model in Experiment 1 (Reaction times).

**Table A7-4-1. Results from the final model for the Deaf Group.**

| Fixed Effects | Estimate | Std. Error | df | t value | p value |
|---|---|---|---|---|---|
| Intercept | 1181.54 | 252.75 | 473.60 | 4.67 | <0.01 |
| hedvalence | -11.87 | 3.09 | 450.20 | -3.85 | <0.01 |
| arousal | -39.05 | 16.67 | 457.20 | -2.34 | 0.02 |
| logfreq | -68.90 | 28.14 | 461.60 | -2.45 | 0.01 |
| cnc | -0.20 | 0.15 | 467.40 | -1.34 | 0.18 |
| aoa | 0.52 | 0.19 | 459.80 | 2.77 | <0.01 |
| fam | -0.92 | 0.27 | 459.70 | -3.37 | <0.01 |
| Nlett | 11.24 | 1.75 | 458.90 | 6.42 | <0.01 |
| orthon | 1.64 | 0.68 | 455.80 | 2.40 | 0.02 |
| Nmorph2poly | -17.94 | 7.52 | 452.80 | -2.39 | 0.02 |
| arousal:logfreq | 3.97 | 1.80 | 456.10 | 2.20 | 0.03 |
| logfreq:cnc | 0.02 | 0.02 | 464.10 | 1.15 | 0.25 |
| Logfreq:aoa | -0.04 | 0.02 | 457.50 | -1.87 | 0.06 |
| Logfreq:fam | 0.09 | 0.03 | 457.00 | 2.80 | <0.01 |

**Table A7-4-2. Results from the final model for the Hearing Group**

| Fixed Effects | Estimate | Std. Error | df | t value | p value |
|---|---|---|---|---|---|
| Intercept | 803.58 | 247.00 | 474.30 | 3.25 | <0.01 |
| hedvalence | -3.15 | 3.01 | 444.60 | -1.05 | 0.30 |
| arousal | 5.13 | 16.27 | 454.60 | 0.32 | 0.75 |
| logfreq | -14.56 | 27.52 | 462.40 | -0.53 | 0.60 |
| cnc | 0.23 | 0.15 | 465.90 | 1.60 | 0.11 |
| aoa | 0.65 | 0.18 | 462.90 | 3.53 | <0.01 |
| fam | -0.90 | 0.27 | 462.50 | -3.37 | <0.01 |
| Nlett | 4.51 | 1.70 | 451.30 | 2.65 | <0.01 |
| orthon | 3.06 | 0.66 | 449.70 | 4.61 | <0.01 |
| Nmorph2poly | -16.17 | 7.32 | 445.90 | -2.21 | 0.03 |
| arousal:logfreq | -0.87 | 1.76 | 451.10 | -0.50 | 0.62 |
| logfreq:cnc | -0.03 | 0.02 | 460.10 | -1.81 | 0.07 |
| Logfreq:aoa | -0.06 | 0.02 | 459.00 | -2.80 | <0.01 |
| Logfreq:fam | 0.07 | 0.03 | 459.10 | 2.51 | 0.01 |

# Appendix 8. Results of high and low frequency effects in Experiment 1 (Reaction times).

**Table A8-4-1. Low frequency effects for the deaf group.**

| Fixed | Estimate | Std. Error | Df | t value | p value |
|---|---|---|---|---|---|
| Intercept | 732.12 | 78.17 | 236.54 | 9.37 | <0.01 |
| hedvalence | -10.08 | 5.44 | 225.35 | -1.85 | 0.07 |
| arousal | -7.03 | 5.51 | 224.41 | -1.28 | 0.02 |
| cnc | -0.04 | 0.05 | 228.31 | -0.77 | 0.44 |
| aoa | 0.18 | 0.06 | 226.60 | 3.04 | <0.01 |
| fam | -0.43 | 0.09 | 227.74 | -4.98 | <0.01 |
| Nlett | 10.94 | 2.91 | 229.81 | 3.76 | <0.01 |
| orthon | 2.00 | 1.49 | 229.46 | 1.34 | 0.18 |
| nmorph2poly | -3.58 | 13.27 | 227.08 | -0.27 | 0.79 |

**Table A8-4-2. High frequency effects for the deaf group.**

| Fixed | Estimate | Std. Error | Df | t value | p value |
|---|---|---|---|---|---|
| Intercept | 455.52 | 62.34 | 226.60 | 7.31 | <0.01 |
| hedvalence | -12.36 | 3.49 | 221.26 | -3.55 | <0.01 |
| arousal | 2.70 | 3.64 | 221.95 | 0.74 | 0.46 |
| cnc | 0.02 | 0.03 | 221.50 | 0.59 | 0.55 |
| aoa | 0.13 | 0.04 | 221.61 | 3.07 | <0.01 |
| fam | -0.07 | 0.07 | 221.46 | -0.99 | 0.32 |
| Nlett | 14.52 | 2.14 | 223.57 | 6.78 | <0.01 |
| orthon | 2.28 | 0.67 | 224.80 | 3.41 | <0.01 |
| nmorph2poly | -24.04 | 8.40 | 222.16 | -2.86 | <0.01 |

**Table A8-4-3. Low frequency effects for the hearing group.**

| Fixed | Estimate | Std. Error | Df | t value | p value |
|---|---|---|---|---|---|
| Intercept | 774.10 | 74.51 | 227.23 | 10.39 | <0.01 |
| hedvalence | -5.97 | 5.15 | 221.72 | -1.16 | 0.25 |
| arousal | -1.16 | 5.22 | 222.33 | -0.22 | 0.82 |
| cnc | 0.06 | 0.05 | 226.70 | 1.29 | 0.20 |
| aoa | 0.17 | 0.06 | 224.65 | 3.07 | <0.01 |
| fam | -0.56 | 0.08 | 223.97 | -6.93 | <0.01 |
| Nlett | 8.09 | 2.75 | 225.39 | 2.95 | <0.01 |
| orthon | 4.07 | 1.42 | 232.29 | 2.87 | <0.01 |
| nmorph2poly | -10.38 | 12.53 | 222.57 | -0.83 | 0.41 |

**Table A8-4-4. High frequency effects for the hearing group.**

| Fixed | Estimate | Std. Error | Df | t value | p value |
|---|---|---|---|---|---|
| Intercept | 725.90 | 69.53 | 229.34 | 10.44 | <0.01 |
| hedvalence | 2.03 | 3.86 | 223.55 | 0.53 | 0.60 |
| arousal | -5.31 | 4.02 | 224.53 | -1.32 | 0.19 |
| cnc | -0.05 | 0.03 | 223.28 | -1.48 | 0.14 |
| aoa | 0.07 | 0.05 | 226.98 | 1.48 | 0.14 |
| fam | -0.24 | 0.08 | 227.59 | -3.07 | <0.01 |
| Nlett | 2.84 | 2.36 | 222.99 | 1.20 | 0.23 |
| orthon | 2.40 | 0.74 | 223.98 | 3.25 | <0.01 |
| nmorph2poly | -9.13 | 9.28 | 223.47 | -0.98 | 0.33 |

# Appendix 9. Accuracy Results for Experiment 1.

**Table A9-4-1. Comparison of results from all 3 final models.**

| | Estimate | Std. Error | t value | p |
|---|---|---|---|---|
| Full model | | | | |
| AOA | -5.42 | 1.82 | -2.99 | <0.01 |
| Bigram frequency* | N/A | N/A | N/A | N/A |
| Concreteness | N/A | N/A | N/A | N/A |
| Group | -1.33 | 2.19 | -6.06 | <0.01 |
| Frequency | 3.53 | 1.77 | 2.00 | 0.05 |
| Length | N/A | N/A | N/A | N/A |
| ONS** | -3.88 | 2.80 | -1.39 | 0.17 |
| No imageability model | | | | |
| AOA | 6.23 | 1.64 | 3.80 | <0.01 |
| Bigram frequency* | N/A | N/A | N/A | N/A |
| Concreteness | -1.51 | 1.42 | -1.06 | 0.29 |
| Frequency | -6.03 | 2.45 | -2.47 | 0.01 |
| Length | 5.99 | 7.31 | 0.82 | 0.41 |
| ONS** | 1.44 | 4.43 | 0.33 | 0.75 |
| No valence model | | | | |
| AOA | 6.10 | 2.03 | 3.00 | <0.01 |
| Bigram frequency* | N/A | N/A | N/A | N/A |
| Concreteness | -1.16 | 1.49 | -0.78 | 0.44 |
| Group | -1.26 | 4.04 | -3.11 | <0.01 |
| Frequency | -1.05 | 4.08 | -2.57 | 0.01 |

| | | | | |
|---|---|---|---|---|
| Length | -4.18 | 3.81 | -1.10 | 0.27 |
| ONS** | 3.15 | 4.77 | 0.66 | 0.50 |

*Bigram frequency = bigram frequency-by-position

**ONS = orthographic neighbourhood size

Note, in instances where N/A is inserted, this indicates that these variables were removed from earlier models, as there were no significant main or interaction effects involving these variables.

# Appendix 10. Stimuli used in Experiment 2.

**Table A10-5-1. Matched words, nonwords and psuedohomophones used in Experiment 2.**

| Words | Nonwords | Pseudohomophones |
|---|---|---|
| **crowd** | danal | shoor |
| **riot** | elic | kyte |
| **girl** | atle | naim |
| **army** | elso | wyne |
| **Mist** | mons | carm |
| **base** | lote | nale |
| **token** | toopy | grume |
| **filth** | gelon | stirn |
| **camp** | vand | berd |
| **film** | putu | taim |
| **block** | blaps | bloan |
| **beam** | brap | deen |
| **magic** | dimos | murth |
| **tooth** | drair | stoan |
| **slime** | fleek | dreik |
| **oath** | thap | stup |
| **slime** | artor | shurt |
| **track** | trest | crain |
| **beast** | vores | drane |
| **oath** | posp | bair |
| **flame** | grive | steem |
| **dot** | cet | hed |
| **wash** | foom | soop |
| **nature** | nopied | brooze |
| **clue** | spod | sirf |
| **trunk** | modil | furst |
| **salt** | Beru | kure |
| **hell** | rast | mear |
| **punch** | trize | snale |
| **bird** | fobe | kirl |
| **roar** | poog | toan |
| **flag** | foon | toor |
| **agony** | adday | skoap |
| **acre** | hesk | shef |
| **spear** | feaps | burch |
| **scale** | tooch | cheet |
| **hush** | jope | leep |
| **face** | rold | lode |
| **queen** | furch | blede |
| **brute** | villo | fraim |

| | | |
|---|---|---|
| **sign** | peow | hurb |
| **tail** | wull | nock |
| **dawn** | smag | nife |
| **risk** | bous | keap |
| **horn** | tomp | dred |
| **lens** | teck | fome |
| **teeth** | thram | payne |
| **truck** | blont | peece |
| **aisle** | injot | cleen |
| **sweat** | seeny | nurve |
| **jerk** | atal | doap |
| **otter** | prail | trane |
| **ounce** | dacit | blaim |
| **babe** | sild | meel |

# Appendix 11. Visual similarity of stimuli in Experiment 2.

**Table A11-5-1. Percentage of similarity between the pseudohomophones used in Experiment 2 and the words from which they were derived.**

| Pseudohomophone | Word | Similarity (%) |
|---|---|---|
| **hed** | head | 0.95 |
| **kyte** | kite | 0.83 |
| **naim** | name | 0.62 |
| **wyne** | wine | 0.83 |
| **carm** | calm | 0.83 |
| **nale** | nail | 0.62 |
| **berd** | bird | 0.83 |
| **taim** | tame | 0.62 |
| **deen** | dean | 0.83 |
| **stup** | stoop | 0.79 |
| **bair** | bear | 0.79 |
| **soop** | soup | 0.83 |
| **sirf** | surf | 0.83 |
| **kure** | cure | 0.67 |
| **mear** | mere | 0.62 |
| **kirl** | curl | 0.5 |
| **toan** | tone | 0.62 |
| **shef** | chef | 0.67 |
| **leep** | leap | 0.83 |
| **lode** | load | 0.62 |
| **hurb** | herb | 0.83 |
| **nock** | knock | 0.83 |
| **nife** | knife | 0.83 |
| **keap** | keep | 0.83 |
| **dred** | dread | 0.95 |
| **fome** | foam | 0.62 |
| **doap** | dope | 0.62 |
| **meel** | meal | 0.83 |
| **skoap** | scope | 0.53 |
| **grume** | groom | 0.53 |
| **murth** | mirth | 0.86 |
| **stoan** | stone | 0.68 |
| **blede** | bleed | 0.78 |
| **fraim** | frame | 0.68 |
| **payne** | pain | 0.57 |
| **cleen** | clean | 0.86 |
| **blaim** | blame | 0.68 |
| **shoor** | sure | 0.33 |
| **furst** | first | 0.86 |
| **bloan** | blown | 0.86 |

| | | |
|---|---|---|
| **nurve** | nerve | 0.86 |
| **trane** | train | 0.68 |
| **dreik** | drake | 0.57 |
| **shurt** | shirt | 0.86 |
| **burch** | birch | 0.86 |
| **peece** | peace | 0.82 |
| **steem** | steam | 0.86 |
| **snale** | snail | 0.68 |
| **crain** | crane | 0.68 |
| **drane** | drain | 0.68 |
| **cheet** | cheat | 0.86 |
| **toor** | tore | 0.62 |
| TOTAL | | 0.74 |

# Appendix 12. Stimuli used in Experiment 3.1 and 3.2.

**Table A12-6-1. Stimuli used in the masked phonological priming lexical decision task described in Chapter 6. The relationship between target/prime (phonological or graphemic) and the conditions are also shown here for both lists used (List A and B).**

| Relationship | Condition | List A: target | List A: prime | List B: target | List B: prime |
|---|---|---|---|---|---|
| Phonological | DDD | neaf | kneeph | roze | wroes |
| Phonological | DDD | cautch | korch | neas | gneeze |
| Phonological | DDD | corgue | kaugg | rize | wrighs |
| Phonological | DDD | knide | nighed | suide | psewed |
| Phonological | DDD | reace | wreese | whares | wairze |
| Phonological | DDD | rauce | rhawse | sord | psawed |
| Phonological | DDD | wheam | weemb | werce | whurse |
| Phonological | DDD | phease | feece | kares | cairze |
| Phonological | DDS | werch | whurch | rhume | roome |
| Phonological | DDS | furve | pherve | fawm | phorm |
| Phonological | DDS | feen | phean | reak | wreek |
| Phonological | DDS | ribe | rhybe | nome | knoam |
| Phonological | DDS | feek | pheak | phine | fighn |
| Phonological | DDS | gope | ghoap | wurd | wherd |
| Phonological | DDS | reat | rhete | wrove | roave |
| Phonological | DDS | nurch | knirch | nune | gnoon |
| Phonological | DSD | feb | phebb | rhum | rumm |
| Phonological | DSD | phof | foff | fligh | phly |
| Phonological | DSD | fid | phidd | fel | phell |
| Phonological | DSD | rin | rhinn | phib | fibb |
| Phonological | DSD | phick | fique | ruph | wruff |
| Phonological | DSD | weff | wheph | caim | kaimm |
| Phonological | DSD | cice | sise | rimm | rhimn |
| Phonological | DSD | fuch | phutch | coak | koack |
| Phonological | SDD | shoof | shuiff | vears | vierze |
| Phonological | SDD | soys | soize | gize | gighs |
| Phonological | SDD | loys | loize | shayed | shaid |
| Phonological | SDD | zays | zaize | tize | tighs |
| Phonological | SDD | deak | deeck | beas | beeze |
| Phonological | SDD | hase | haiss | purke | perck |
| Phonological | SDD | berge | burdge | baws | borze |
| Phonological | SDD | zake | zaick | heers | hierze |
| Phonological | DSS | nurk | gnurk | ceap | seap |
| Phonological | DSS | cig | sig | nooze | knooze |
| Phonological | DSS | fown | phown | fite | phite |
| Phonological | DSS | fet | phet | weap | wheap |
| Phonological | DSS | gert | jert | repe | rhepe |
| Phonological | DSS | wone | whone | roal | rhoal |

| | | | | | |
|---|---|---|---|---|---|
| Phonological | DSS | roid | wroid | whym | wym |
| Phonological | DSS | cesh | sesh | feal | pheal |
| Phonological | SDS | zeat | zeet | koat | kote |
| Phonological | SDS | veam | veme | tawn | taughn |
| Phonological | SDS | rause | rourse | shaze | shaize |
| Phonological | SDS | pode | poad | vise | vighse |
| Phonological | SDS | gome | goam | mase | maise |
| Phonological | SDS | wabe | waib | dert | durt |
| Phonological | SDS | thale | thail | kope | koap |
| Phonological | SDS | zane | zain | kead | keed |
| Phonological | SSD | juff | juph | teek | teeck |
| Phonological | SSD | slee | slea | skore | skoar |
| Phonological | SSD | pum | pumb | lak | lac |
| Phonological | SSD | bick | bique | hed | hedd |
| Phonological | SSD | sech | setch | stear | stier |
| Phonological | SSD | lum | lumb | pek | pec |
| Phonological | SSD | lod | lodd | beaf | beaph |
| Phonological | SSD | shick | shique | kuff | kuph |
| Graphemic | DDD | pess | daich | stey | blie |
| Graphemic | DDD | frew | bleigh | pach | shirl |
| Graphemic | DDD | yarm | poarb | snoe | frur |
| Graphemic | DDD | jark | soub | gurl | wheff |
| Graphemic | DDD | derd | coib | boes | nirl |
| Graphemic | DDD | yight | fairn | leed | shait |
| Graphemic | DDD | rarp | veed | beed | marf |
| Graphemic | DDD | jurse | taid | cill | vach |
| Graphemic | DDS | bup | meep | kave | soiv |
| Graphemic | DDS | chupe | vaip | whif | yarf |
| Graphemic | DDS | mome | hoarm | whove | firv |
| Graphemic | DDS | yine | woin | whide | broid |
| Graphemic | DDS | vart | seight | ratt | chett |
| Graphemic | DDS | leck | dack | rane | gien |
| Graphemic | DDS | hile | jairl | saive | pheev |
| Graphemic | DDS | shan | knin | mutch | zatch |
| Graphemic | DSD | tein | peith | wede | chele |
| Graphemic | DSD | yome | chope | kub | zum |
| Graphemic | DSD | nim | thipp | whish | vitt |
| Graphemic | DSD | lerge | serne | dimb | pidge |
| Graphemic | DSD | cose | wroke | phole | sofe |
| Graphemic | DSD | lub | humb | rale | vafe |
| Graphemic | DSD | thock | jong | pauze | thaule |
| Graphemic | DSD | louch | thoudd | voat | toadge |
| Graphemic | SDD | jass | jeeth | laim | leeth |
| Graphemic | SDD | hade | hoinn | dene | daip |
| Graphemic | SDD | meem | mairt | whill | whoir |
| Graphemic | SDD | nush | naid | chude | chait |
| Graphemic | SDD | sares | searth | kool | kib |
| Graphemic | SDD | youch | yain | wheek | whain |
| Graphemic | SDD | tol | teave | trey | taich |
| Graphemic | SDD | curn | caidd | lide | leedge |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| Graphemic | DSS | jone | chone | wod | dod |
| Graphemic | DSS | jave | yave | peech | zeech |
| Graphemic | DSS | yeared | meared | hirt | lirt |
| Graphemic | DSS | beve | cheve | mard | thard |
| Graphemic | DSS | mib | hib | wrood | shood |
| Graphemic | DSS | gowd | sowd | rhice | sice |
| Graphemic | DSS | petch | hetch | wrace | hace |
| Graphemic | DSS | meck | veck | lews | gews |
| Graphemic | SDS | beash | baish | kap | kep |
| Graphemic | SDS | zile | zel | buss | biss |
| Graphemic | SDS | sheed | shad | boch | buch |
| Graphemic | SDS | shog | sheeg | yooth | yieth |
| Graphemic | SDS | darred | deighed | whoze | whoiz |
| Graphemic | SDS | degg | dagg | mame | meim |
| Graphemic | SDS | kive | korve | tole | tuil |
| Graphemic | SDS | zorgue | zaigue | nise | nais |
| Graphemic | SSD | dobe | dode | yel | yed |
| Graphemic | SSD | coob | coom | dait | daich |
| Graphemic | SSD | vig | vib | rhed | rhell |
| Graphemic | SSD | paim | paith | boath | boam |
| Graphemic | SSD | vove | vope | froe | frie |
| Graphemic | SSD | nuck | nutch | harve | harge |
| Graphemic | SSD | shace | shafe | bumb | buth |
| Graphemic | SSD | thutch | thunn | sead | seaph |

# Appendix 13. Correlation analyses for Experiment 3.1.

**Table A13-6-1. Correlations between reading scores and performance in the masked priming lexical decision task**

| | *N* | *r* | p |
|---|---|---|---|
| Reading score/overall RT | 36 | -.137 | .426 |
| Reading score/overall accuracy | 36 | -.044 | .801 |
| Reading score/phonological RT | 36 | -.038 | 826 |
| Reading score/phonological accuracy | 36 | -.116 | .499 |
| Reading score/graphemic RT | 36 | -.038 | .828 |
| Reading score/graphemic accuracy | 36 | -.149 | .385 |

# Appendix 14. Stimuli used in Experiment 4.1.

**Table A14-7-1. Words, nonwords and pseudohomophones used in the visual world experiment. Semantic, phonological and unrelated items/distracters are also shown here (labels of pictures displayed to participants).**

| Pseudo-homophone | English Word | **Phonological Distracter** | **Semantic Distracter** | **Unrelated** | Matched Word | Control Nonwords | **Phonological Distracter** | **Semantic Distracter** | **Unrelated** |
|---|---|---|---|---|---|---|---|---|---|
| **phly** | **fly** | sky | ant | crisps | **edge** | **adge** | wedge | target | stamp |
| **rhum** | **rum** | gum | wine | pen | **itch** | **atch** | stitch | cut (finger) | wall |
| **tize** | **ties** | pies | shoes | box | **guys** | **kuys** | dyes | ladies | cat |
| **nune** | **noon** | moon | watch | book | **wipe** | **jipe** | pipe | spray | clip |
| **kote** | **coat** | boat | shirt | swing | **claw** | **glaw** | saw | nails | curtains |
| **knoam** | **gnome** | foam | doll | pear | **queue** | **bueue** | shoe | crowd | flock |
| **skoar** | **score** | door | grade (exam/paper) | glove | **zebra** | **lebra** | bra | giraffe | jar |
| **wroes** | **rows** | bows | surf | glass | **alarm** | **olarm** | arm | police | peg |
| **beeze** | **bees** | peas | worm | hat | **whisk** | **chisk** | disc | bowl | bone (dog) |
| **koac** | **coke** | cloak | juice | ball | **crumb** | **grumb** | drum | drop | desk |
| **phell** | **fell** | well | run | brick | **eagle** | **aagle** | angle | crow | paint |
| **beaph** | **beef** | leaf | fish | car | **devil** | **tevil** | level | angel | apple |
| **phite** | **fight** | light | hug | spoon | **world** | **jorld** | gold | mars | bin |
| **wheap** | **weep** | sheep | smile | hop | **brush** | **prush** | flush | comb | cake |
| **wreek** | **reek** | beak | smoke | hands | **elves** | **alves** | shelves | fairy | pins |
| **hierze** | **hears** | beers | smells | drill | **robots** | **jobots** | dots | spock | jug |
| **knooce** | **noose** | goose | knot | phone | **pyjama** | **byjama** | llama | suit | poppies |
| **gneeze** | **knees** | cheese | feet | pool | **sydney** | **bydney** | knee | paris | rocket |
| **taughn** | **torn** | corn | cut (paper) | keys | **lizard** | **nizard** | wizard | frog | bells |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **blede** | **bleed** | lead | cast | mug | **yacht** | **wacht** | cot | boat | chain |
| **trane** | **train** | rain | ship | plug | **queen** | **fueen** | bean | king | grass |
| **nale** | **nail** | tail | screw | belt | **lips** | **mips** | dips | nose | lemon |
| **stoan** | **stone** | cone | coal | knife | **razor** | **cazor** | laser | scissors | beach |
| **bair** | **bear** | chair | horse | heart | **glue** | **plue** | blue | pin | tin |
| **brooze** | **bruise** | fuse | grazed | snake | **toffee** | **doffee** | coffee | sweets | bat |
| **snale** | **snail** | whale | slug | fruit | **nappy** | **mappy** | happy | pants | lamp |
| **kirl** | **curl** | pearl | hair | lawn | **smog** | **swog** | dog | snow | folder |
| **fraim** | **frame** | flame | plaque (award) | purse | **cycle** | **gycle** | icicle | drive | lock |

*Note.* Columns in bold show target letter strings displayed to participants.

# Appendix 15. Full results from the non-parametric tests for the word condition in Experiment 4.1.

**Table A15-7-1. Wilcoxon Signed Rank Test Results for Word Condition (by-subjects)**

| | Target vs Unrelated | | Semantic vs Unrelated | | Phonological vs Unrelated | |
|---|---|---|---|---|---|---|
| Time Window | Deaf | Hearing | Deaf | Hearing | Deaf | Hearing |
| 400 | z = .000, p = 1.000 | z = .000, p = 1.000 | Z = -1.000, p = .317 | Z = -1.000, p = .317 | Z = -.477, p = .655 | Z = .000, p = 1.000 |
| 500 | z =-1.510, p = .131 | z = -1.604, p = .109 | Z = -.962, p = .336 | Z = -1.000, p = .317 | **Z = -2.070, p = .038** | Z = -1.604, p = .109 |
| 600 | z = -2.232, p = .026 | z = -1.813, p = .070 | Z = -.882, p = .378 | Z = -1.487, p = .137 | Z = -.039, p = .969 | Z = -1.115, p = .265 |
| 700 | **z = -3.888, p = .000** | **z = -3.832, p = .000** | **Z = -3.185, p = .001** | **Z = -3.364, p = .001** | Z = -.433, p = .665 | Z = -.797 p = .425 |
| 800 | **z = -3.921, p = .000** | **z = -3.922, p = .000** | **Z = -3.323, p = .001** | **Z = -3.411, p = .001** | Z = -.632, p = .527 | Z = -1.062, p = .288 |
| 900 | **z = -3.921, p = .000** | **z = -3.921, p = .000** | **Z = -3.140, p = .002** | **Z = -3.084, p = .002** | Z = -1.231, p = .218 | Z = -.060, p = .952 |
| 1000 | **z = -3.922, p = .000** | **z = -3.922, p = .000** | **Z = -3.826, p = .000** | **Z = -3.456, p = .001** | Z = -1.491, p = .136 | **Z = -1.930, p = .054** |
| 1100 | **z = -3.922, p = .000** | **z = -3.824, p = .000** | **Z = -3.466, p = .001** | **Z = -3.628, p = .000** | Z = -.134, p = .893 | Z = -1.906, p = .057 |
| 1200 | **z = -3.921, p = .000** | **z = -3.923, p = .000** | **Z = -2.898, p = .004** | **Z = -3.231, p = .001** | Z = -.433, p = .665 | **Z= -2.100, p = .036** |
| 1300 | **z = -3.922, p = .000** | **z = -3.824, p = .000** | **Z = -3.019, p = .003** | **Z = -3.296, p = .001** | Z= -1.649, p = .099 | Z = -1.041, p = .298 |
| 1400 | **z = -3.921, p = .000** | **z = -3.922, p = .000** | **Z = -2.923, p = .003** | **Z = -3.263, p = .001** | Z = -1.129, p = .259 | Z = -.931, p = .352 |
| 1500 | **z = -3.921, p = .000** | **z = -3.921, p = .000** | **Z = -2.280, p = .023** | Z = -.312, p = .755 | Z = -.765, p = .444 | Z = -.491, p = .623 |
| 1600 | **z = -3.921, p = .000** | **z = -3.921, p = .000** | Z = -.597, p = .550 | Z = -.934, p = .350 | Z = -.668, p = .504 | Z = -.491, p = .624 |
| 1700 | **z = -3.920, p = .000** | **z = -3.920, p = .000** | Z = -.311, p = .756 | **Z = -2.829, p = .005** | Z = -1.193, p = .233 | **Z = -2.201, p = .028** |
| 1800 | **z = -3.920, p = .000** | **z = -3.921, p = .000** | Z = -.401, p = .689 | Z = -2.668, p = .008 | Z = -.771, p = .440 | Z = -.845, p = .398 |
| 1900 | **z = -3.921, p = .000** | **z = -3.921, p = .000** | **Z = -1.958, p = .050** | **Z = -3.065, p = .002** | Z = -.205, p = .837 | Z = -1.886, p = .059 |
| 2000 | **z = -3.922, p = .000** | **z = -3.922, p = .000** | **Z = -3.061, p = .002** | Z = -1.129, p = .259 | Z = -.205, p = .248 | Z = -1.689, p = .091 |

*Note.* Figures in bold indicate a significant result.

**Table A15-7-2. Mann-Whitney Test Results for the Word Condition (comparing group differences, by subjects).**

| Time Window | Target - Unrelated | Semantic - Unrelated | Phonological - Unrelated |
|---|---|---|---|
| **400** | Z = .000, p = 1.000 | Z = -1.396, p = .163 | Z = -1.717, p = .086 |
| **500** | Z = -.204, p = .839 | Z = -.849, p = .396 | Z = -.130, p = .896 |
| **600** | Z = -.651, p = .515 | Z = -.532, p = .595 | Z = -368 p = .713 |
| **700** | Z = -2.238, p = .025 | Z = -.545, p = .586 | Z = -.081, p = .935 |
| **800** | Z = -1.097, p = .273 | Z = -.137, p = .891 | Z = -.068, p = .946 |
| **900** | Z = -1.015, p = .310 | Z = -.271, p = .786 | Z = -.095, p = .924 |
| **1000** | Z = -1.218, p = .223 | Z = -.556, p = .578 | Z = -.652, p = .515 |
| **1100** | Z = -.650, p = .516 | Z = -.163, p = .871 | Z = -.801, p = .423 |
| **1200** | Z = -.515, p = .607 | Z = 1.136, p = .892 | Z = -.286, p = .775 |
| **1300** | Z = -1.422, p = .155 | Z = -.965, p = .334 | Z = -.833, p = .405 |
| **1400** | Z = -2.003, p = .045 | Z = -.505, p = .613 | Z = -.816, p = .414 |
| **1500** | Z = -1.218, p = .223 | Z = -1.280, p = .200 | Z = -1.129, p = .259 |
| **1600** | Z = -1.083, p = .279 | Z = -.014, p = .989 | Z = -.826, p = .409 |
| **1700** | Z = -.460, p = .646 | Z = -.2.502, p = .012 | Z = -2.097, p = .036 |
| **1800** | Z = -.649, p = .516 | Z = -1.901, p = .057 | Z = -1.605, p = .108 |
| **1900** | Z = -.866, p = .387 | Z = -.901, p = .398 | Z = -.490, p = .624 |
| **2000** | Z = -1.801, p = .072 | Z = -2.062, p = .039 | Z = -2.704, p = .007 |

**Table A15-7-3. Wilcoxon Signed Rank Test Results for Word Condition (by-items).**

| | **Target vs Unrelated** | | **Semantic vs Unrelated** | | **Phonological vs Unrelated** | |
|---|---|---|---|---|---|---|
| Time Window | Deaf | Hearing | Deaf | Hearing | Deaf | Hearing |
| 400 | z = -2.251, p = .024 | z = -1.552, p = .121 | z = -1.014, p = .311 | z = -.577, p = .564 | z = -1.218, p = 223 | z = -1.633, p = .102 |
| 500 | z = -2.497, p = .013 | z = -1.949, p = .051 | z = -1.426, p = .154 | z = -.992, p = .321 | z = -.728, p = .467 | z = -.996, p = .319 |
| 600 | **z = -4.652, p = .000** | **z = -4.097, p = .000** | **z = -2.974, p = .003** | **z = -3.374, p = .001** | z = -.659, p = .510 | z = -.465, p = .642 |
| 700 | **z = -5.852, p = .000** | **z = -4.773, p = .000** | **z = -3.936, p = .000** | **z = -3.661, p = .000** | z = -.953, p = .340 | z = -1.419, p = .156 |
| 800 | **z = -6.086, p = .000** | **z = -5.644, p = .000** | **z = -4.182, p = .000** | **z = -3.333, p = .001** | z = -1.536, p = .124 | z = .000, p = 1.000 |
| 900 | **z = -6.230, p = .000** | **z = -6.093, p = .000** | **z = -4.006, p = .000** | **z = -4.667, p = .000** | z = -1.543, p = .123 | z = -1.741, p = .082 |
| 1000 | **z = -6.440, p = .000** | **z = -6.220, p = .000** | **z = -3.781, p = .000** | **z = -4.384, p = .000** | z = -.070, p = .944 | z = -1.912, p = .056 |
| 1100 | **z = -6.470, p = .000** | **z = -6.340, p = .000** | **z = -3.266, p = .001** | **z = -4.455, p = .000** | z = -.825, p = .410 | z = -1.832, p = .067 |
| 1200 | **z = -6.403, p = .000** | **z = -6.164, p = .000** | **z = -3.256, p = .001** | **z = -3.047, p = .002** | z = -1.553, p = .120 | z = -.695, p = .487 |
| 1300 | **z = -6.457, p = .000** | **z = -6.215, p = .000** | **z = -2.981, p = .003** | **z = -3.285, p = .001** | z = -.919, p = .358 | z = -.396, p = .692 |
| 1400 | **z = -6.508, p = .000** | **z = -6.395, p = .000** | z = -2.202, p = .028 | z = -.397, p = .691 | z = -1.174, p = .240 | z = -1.320, p = .187 |
| 1500 | **z = -6.421, p = .000** | **z = -6.395, p = .000** | z = 1.433, p = .152 | z = -.946, p = .344 | z = -.830, p = .407 | z = -.714, p = .475 |
| 1600 | **z = -6.454, p = .000** | **z = -6.395, p = .000** | z = -.472, p = .637 | **z = -3.007, p = .003** | z = -1.399, p = .162 | z = -.875, p = .382 |
| 1700 | **z = -6.458, p = .000** | **z = -6.338, p = .000** | z = -.031, p = .975 | z = -1.760, p = .078 | z = -.820, p = .412 | z = -.040, p = .968 |
| 1800 | **z = -6.505, p = .000** | **z = -6.279, p = .000** | z = -2.401, p = .016 | **z = -2.814, p = .005** | z = -1.367, p = .172 | z = -1.068, p = .286 |
| 1900 | **z = -6.456, p = .000** | **z = -6.382, p = .000** | z = -2.315, p = .021 | z = -1.091, p = .275 | z = -1.378, p = .168 | z = -1.062, p = .288 |
| 2000 | **z = -6.466, p = .000** | **z = -6.158, p = .000** | z = -2.527, p = .011 | z = -.908, p = .364 | z = -.667, p = .505 | z = -1.298, p = .194 |

*Note.* Figures in bold indicate a significant result.

**Table A15-7-4. Mann-Whitney Test Results for the Word Condition (comparing group differences, by-items).**

| Time Window | Target - Unrelated | Semantic - Unrelated | Phonological - Unrelated |
|---|---|---|---|
| 400 | z = -.690, p = .490 | z = -.656, p = .512 | z = -.464, p = .643 |
| 500 | z = .-.140, p = .889 | z = -.345, p = .730 | z = -.231, p = .817 |
| 600 | z = -1.389, p = .165 | z = -.323, p = .746 | z = -.872, p = .383 |
| 700 | z = -2.106, p = .035 | z = -.098, p = .922 | z = -.727, p = .467 |
| 800 | z = -1.449, p = .147 | z = -1.244, p = .214 | z = -1.322, p = .186 |
| 900 | z = -1.597, p = .110 | z = -.024, p = .981 | z = -.300, p = .764 |
| 1000 | z = -1.058, p = .290 | z = -.386, p = .699 | z = -1.803, p = .071 |
| 1100 | z = -1.023, p = .306 | z = -.856, p = .392 | z = -.497, p = .619 |
| 1200 | z = -1.988, p = .047 | z = -.677, p = .498 | z = -.145, p = .884 |
| 1300 | z = -1.992, p = .046 | z = -.850, p = .395 | z = -.783, p = .434 |
| 1400 | z = -2.110, p = .035 | z = -1.054, p = .292 | z = -1.193, p = .233 |
| 1500 | z = - 1.666, p = .096 | z = -.391, p = .696 | z = -1.000, p = .317 |
| 1600 | z = -1.258, p = .208 | z = -2.640, p = .008 | z = -1.663, p = .096 |
| 1700 | z = -1.680, p = .093 | z = -1.625, p = .104 | z = -.311, p = .756 |
| 1800 | z = -.837, p = .403 | z = -.821, p = .412 | z = -.426, p = .670 |
| 1900 | z = -2.013, p = .044 | z = -1.396, p = .163 | z = -.130, p = .897 |
| 2000 | z = -.242, p = .808 | z = -1.632, p = .103 | z = -.100, p = .921 |

# Appendix 16. Full results from the non-parametric tests for the pseudohomophone condition in Experiment 4.1.

**Table A16-7-1. Wilcoxon Signed Rank Test Results for Pseudohomophone Condition (by-subjects).**

| | **Target Items vs Unrelated** | | **Semantic vs Unrelated** | | **Phonological vs Unrelated** | |
|---|---|---|---|---|---|---|
| Time Window | Deaf | Hearing | Deaf | Hearing | Deaf | Hearing |
| 400 | Z = .000, p = 1.000 | Z = .000, p = 1.000 | Z = .000, p = 1.000 | Z = .000, p = 1.000 | Z = .000, p = 1.000 | Z = .000, p = 1.000 |
| 500 | Z = .000, p = 1.000 | Z = 1.138, p = .890 | Z = -1.000, p = .317 | Z = -1.633, p = .102 | Z = .000, p = 1.000 | Z = -1.069, p = .285 |
| 600 | Z = -1.134, p = .257 | Z = -.604, p = .546 | Z = .000, p = 1.000 | Z = -.889, p = .374 | Z = -.707, p = .480 | Z = -1.529, p = .126 |
| 700 | Z = -.333, p = .739 | Z = -.960, p = .337 | Z = -1.119, p = .263 | Z = -.430, p = .667 | Z = -1.414, p = .157 | Z = -.172, p = .863 |
| 800 | Z = -.992, p = .321 | Z = -1.213, p = .225 | Z = -.090, p = .928 | Z = -.360, p = .719 | Z = -.973, p = .330 | Z = -1.080, p = .280 |
| 900 | Z = -1.792, p = .073 | Z = -.875, p = .382 | Z = -.940, p = .347 | Z = -.198, p = .843 | Z = -1.194, p = .232 | Z = -.926, p = .354 |
| 1000 | **Z = -2.787, p = .005** | Z = -1.575, p = .115 | Z = -1.493, p = .136 | Z = 1.162, p = .245 | Z = -1.917, p = .055 | Z = -478, p = .633 |
| 1100 | Z = -.861, p = .389 | Z = -2.630, p = .009 | Z = -.721, p = .471 | Z = -1.835, p = .067 | Z = -.178, p = .859 | Z = -.248, p = .804 |
| 1200 | Z = -2.086, p = .037 | **Z = -3.314, p = .001** | Z = -.673, p = .501 | **Z = -3.334, p = .001** | Z = -.951, p = .342 | Z = -2.567, p = .010 |
| 1300 | Z = -.926, p = .354 | Z = 2.312, p = .021 | Z = -1.359, p = .174 | Z = -1.419, p = .156 | Z = -.352, p = .725 | Z = -.631, p = .528 |
| 1400 | Z = -1.752, p = .080 | **Z = -3.406, p = .001** | Z = -.712, p = .477 | **Z = -2.852, p - .004** | Z = -1.319, p = .187 | Z = -1.621, p = .105 |
| 1500 | Z = -1.482, p = .138 | Z = -2.392, p = .017 | Z = -.127, p = .899 | Z = -2.357, p = .018 | Z = -.281, p = .779 | Z = -1.382, p = .167 |
| 1600 | Z = -.154, p = .877 | Z = -1.605, p = .109 | Z = -.230, p = .818 | Z = -.874, p = .382 | Z = -.834, p = .404 | Z = -.745, p = .456 |
| 1700 | Z = -.721, p = .471 | Z = -1.742, p = .082 | Z = .000, p = 1.000 | Z = -1.118, p = .264 | Z = -.744, p = .457 | Z = -1.154, p = .249 |
| 1800 | Z = -1.206, p = .228 | Z = -1.415, p = .157 | Z = -1.804, p = .071 | Z = -1.069, p = .285 | Z = -1.144, p = .251 | Z = -.435, p = .664 |
| 1900 | Z = -.1223, p = .221 | Z = -.494, p = .622 | Z = -.361, p = .718 | Z = -.622, p = .534 | Z = -1.545, p = .122 | Z = -.135, p = .892 |
| 2000 | Z = -2.033, p = .042 | Z = -.926, p = .354 | Z = -.879, p = .379 | Z = -1.134, p = .257 | Z = -.106, p = .915 | Z = -9.58, p = .338 |

*Note.* Figures in bold indicate a significant result.

**Table A16-7-2. Mann-Whitney Test Results for the Pseudohomophone Condition (by subjects).**

| **Time Window** | **Target – Unrelated** | **Semantic – Unrelated** | **Phonological - Unrelated** |
|---|---|---|---|
| 400 | Z = .000, p = 1.000 | Z = .000, p = 1.000 | Z = .000, p = 1.000 |
| 500 | Z = -.471, p = .638 | Z = -2.000, p = .045 | Z = -.592, p = .554 |
| 600 | Z = -.948, p - .343 | Z = -.391, p = .696 | Z = -.574, p = .566 |
| 700 | Z = -1.233, p = .218 | Z = -.255, p = .799 | Z = -1.658, p = .097 |
| 800 | Z = -.748, p = .455 | Z = -.462, p = .644 | Z = -.060, p = .952 |
| 900 | Z = -.567, p = .571 | Z = -.042, p = .967 | Z = -1.472, p = .141 |
| 1000 | Z = -.332, p = .740 | Z = -.213, p = 832 | Z = -1.352, p = .176 |
| 1100 | **Z = -2.878, p = .004** | Z = -1.314, p = .189 | Z = -.042, p = .967 |
| 1200 | Z = -1.164, p = .244 | Z = -2.193, p = .028 | Z = -.928, p = .353 |
| 1300 | Z = -1.643, p = .244 | Z = -2.542, p = .011 | Z = -.014, p = .989 |
| 1400 | Z = -2.169, p = .030 | Z = -1.711, p = .087 | Z = -.686, p = -.442 |
| 1500 | Z = -.332, p = .740 | Z = -1.775, p = .076 | Z = -.442, p = .658 |
| 1600 | Z = -1.010, p = .313 | Z = -1.179, p = .238 | Z = -.243, p = .808 |
| 1700 | Z = -1.255, p = .209 | Z = -1.075, p = .282 | Z = -1.223, p = .221 |
| 1800 | Z = -.042, p = .966 | Z = -.293, p = .770 | Z = -.584, p = .559 |
| 1900 | Z = -.140, p = .889 | Z = -.607, p = .544 | Z = -.950, p = .342 |
| 2000 | Z = 1.615, p = .539 | Z = -.180, p = .857 | Z = -.406, p = .685 |

*Note.* Figures in bold indicate significant results.

**Table A16-7-3. Wilcoxon Signed Rank Test Results for Pseudohomophone Condition (by-items).**

| | **Target us unrelated** | | **Semantic vs Unrelated** | | **Phonological vs Unrelated** | |
|---|---|---|---|---|---|---|
| **Time Window** | Deaf | Hearing | Deaf | Hearing | Deaf | Hearing |
| **400** | z = .000, p = 1.000 | z = -.125, p = .901 | z = -1.414, p = .157 | z = -1.952, p = .051 | z = .000, p = 1.000 | **z = -3.194, p = .001** |
| **500** | z = -1.000, p = .317 | z = -.057, p = .955 | z = -.577, p = .564 | **z = -4.170, p = .000** | z = .000, p = 1.000 | z = -1.188, p = .235 |
| **600** | z = -.785, p = .433 | z = -.947, p = .344 | z = -1.071, p =.284 | z = -2.256, p = .024 | z = -.341, p = .733 | z = -2.560, p = .010 |
| **700** | z = -.371, p = .711 | z = -.973, p = .331 | z = -.573, p = .566 | z = -.158, p = .874 | z = -1.246, p = .213 | z = -.975, p = .330 |
| **800** | z = -1.306, p = .192 | z = -1.369, p = .171 | z = -.636, p = .525 | z = -.846, p = .398 | z = -.918, p = .359 | z = -.969, p = .332 |
| **900** | z = -2.483, p = .013 | z = -1.503, p = .133 | z = -1.492, p = .136 | z = -.664, p = .507 | z = -1.143, p = .253 | z = -2.384, p = .017 |
| **1000** | z = -.319, p = .750 | z = -2.034, p = .042 | z = -.101, p = .920 | z = -.747, p = .455 | z = -.095, p = .924 | z = -1.518, p = .129 |
| **1100** | z = -2.451, p = .014 | z = -2.404, p = .016 | z = -1.073, p = .283 | z = -2.247, p = .025 | z = -1.017, p = .309 | z = -1.660, p = .097 |
| **1200** | z = -.594, p = .553 | **z = -6.746, p = .000** | z = -.946, p = 344 | **z = -6.912, p = .000** | z = -.308, p = .758 | **z = -7.142, p = .000** |
| **1300** | **z = -3.853, p = .000** | **z = -4.049, p = .000** | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 |
| **1400** | **z = -3.935, p = .000** | **z = -3.573, p = .000** | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 |
| **1500** | **z = -3.746, p = .000** | **z = -3.684, p = .000** | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 |
| **1600** | **z = -3.843, p = .000** | **z = -3.853, p = .000** | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 | z = .000, p = 1.000 |
| **1700** | z = -1.154, p = .249 | z = -977, p = .329 | z = -.887, p = .375 | z = -.686, p = .493 | z = -.735, p = .462 | z = -.492, p = .623 |
| **1800** | z = -1.271, p = .204 | z = -.066, p = .947 | z = -.720, p = .472 | z = -.668, p = .504 | z = -1.211, p = .226 | z = -.221, p = .825 |
| **1900** | z = -1.639, p = .101 | z = -1.020, p = .308 | z = -.743, p = .457 | z = -1.642, p = .101 | z = -.316, p = .752 | z = -1.033, p = .302 |
| **2000** | z = -.405, p = .686 | z = -.193, p = .847 | z = -.581, p = .561 | z = -.467, p = .640 | z = -.831, p = .406 | z = -.263, p = .792 |

*Note.* Figures in boldface indicate significant results.

**Table A16-7-4. Mann-Whitney Test Results for the Pseudohomophone Condition (comparing group differences, by-items).**

| Time Window | Target | Semantic | Phonological |
|---|---|---|---|
| 400 | z = .000, p = 1.000 | z = -2.442, p = .015 | z = -1.392, p = .164 |
| 500 | z = -.624, p = .532 | z = -1.046, p = .296 | z = -.841, p = .400 |
| 600 | z = -.906, p = .365 | z = -1.452, p = .146 | z = -.185, z = .853 |
| 700 | z = -.036, p = .971 | z = -.558, p = .577 | z = -.129, p = 898 |
| 800 | z = -.133, p = .894 | z = -.369, p = .712 | z = -1.113, p = .266 |
| 900 | z = -.200, p = .841 | z = -.195, p = .846 | z = -1.238, p = .216 |
| 1000 | z = -2.611, p = .009 | z = -1.470, p = .142 | z = -.137, p = .891 |
| 1100 | z = -.449, p = .654 | z = -.949, p = .343 | z = -.654, p = .513 |
| 1200 | z = -1.079, p = .281 | z = -1.866, p = .062 | z = -.248, p = .804 |
| 1300 | z = -1.802, p = .072 | z = -1.343, p = .179 | z = -.925, p = .355 |
| 1400 | z = -.261, p = .794 | z = -1.849, p = .065 | z = -.869, p = .385 |
| 1500 | z = -.971, p = .332 | z = -.944, p = .345 | z = -.677, p = .498 |
| 1600 | z = -.682, p = .495 | z = -.728, p = .467 | z = -1.155, p = .248 |
| 1700 | z = -.153, p = .878 | z = -.334, p = .739 | z = -.215, p = .829 |
| 1800 | z = -.979, p = .327 | z = -.124, p = .901 | z = -1.122, p = .262 |
| 1900 | z = -.425, p = .671 | z = -.042, p = .966 | z = -.607, p = .544 |
| 2000 | z = -.042, p = .967 | z = -.341, p = .733 | z = -.415, p = .678 |

# Appendix 17. Stimuli used in Experiment 4.2.

**Table A17-7-1. Pseudohomophones used in the Experiment 4.2. Semantic, phonological and unrelated items/distracters are also shown here (labels of the pictures displayed to participants).**

| Pseudohomophone | Phonological Distracter | Semantic Distracter | Unrelated |
|---|---|---|---|
| **phly** | sky | ant | crisps |
| **rhum** | gum | wine | pen |
| **tize** | pies | shoes | box |
| **nune** | moon | watch | book |
| **kote** | boat | shirt | swing |
| **knoam** | foam | doll | pear |
| **skoar** | door | grade (exam/paper) | glove |
| **wroes** | bows | surf | glass |
| **beeze** | peas | worm | hat |
| **koac** | cloak | juice | ball |
| **phell** | well | run | brick |
| **beaph** | leaf | fish | car |
| **phite** | light | hug | spoon |
| **wheap** | sheep | smile | hop |
| **wreek** | beak | smoke | hands |
| **hierze** | beers | smells | drill |
| **knooce** | goose | knot | phone |
| **gneeze** | cheese | feet | pool |
| **taughn** | corn | cut (paper) | keys |
| **blede** | lead | cast | mug |
| **trane** | rain | ship | plug |
| **nale** | tail | screw | belt |
| **stoan** | cone | coal | knife |
| **bair** | chair | horse | heart |
| **brooze** | fuse | grazed | snake |
| **snale** | whale | slug | fruit |
| **kirl** | pearl | hair | lawn |
| **fraim** | flame | plaque (award) | purse |

# Appendix 18 Full results from the non-parametric tests for Experiment 4.2.

**Table A18-4-1. Wilcoxon Signed Rank Test Results for pseudotarget v.s. pseudounrelated items in Experiment 4.2.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| 0 | Z = -1.848, p = .065 | Z = -1.558, p = .119 | Z = -2.748, p = .006 | Z = -2.288, p = .022 |
| 100 | **Z = -3.363, p = .001** | **Z = -3.646, p = .000** | **Z = -3.401, p = 001** | **Z = -2.822, p = .002** |
| 200 | **Z = -3.828, p = .000** | **Z = -3.849, p = .000** | **Z = -3.846, p = 000** | **Z = -3.557, p = .000** |
| 300 | **Z = -3.921, p = .000** | **Z = -4.373, p = .000** | **Z = -3.920, p = .000** | **Z = -4.122, p = .000** |
| 400 | **Z = -3.920, p = .000** | **Z = -4.556, p = .000** | **Z = -3.824, p = .000** | **Z = -4.453, p = .000** |
| 500 | **Z = -3.921, p = .000** | **Z = -4.542, p = .000** | **Z = -3.883, p = .000** | **Z = -4.458, p = .000** |
| 600 | **Z = -3.925, p = .000** | **Z = -4.520, p = .000** | **Z = -3.884, p = .000** | **Z = -4.507, p = .000** |
| 700 | **Z = -3.920, p = .000** | **Z = -4.541, p = .000** | **Z = -3.883, p = .000** | **Z = -4.470, p = .000** |
| 800 | **Z = -3.924, p = .000** | **Z = -4.623, p = .000** | **Z = -3.920, p = .000** | **Z = -4.544, p = .000** |
| 900 | **Z = -3.921, p = .000** | **Z = -4.626, p = .000** | **Z = -3.921, p = .000** | **Z = -4.600, p = .000** |
| 1000 | **Z = -3.922, p = .000** | **Z = -4.623, p = .000** | **Z = -3.921, p = .000** | **Z = -4.623, p = .000** |
| 1100 | **Z = -3.922, p = .000** | **Z = -4.623, p = .000** | **Z = -3.921, p = .000** | **Z = -4.623, p = .000** |
| 1200 | **Z = -3.921, p = .000** | **Z = -4.624, p = .000** | **Z = -3.920, p = .000** | **Z = -4.625, p = .000** |
| 1300 | **Z = -3.922, p = .000** | **Z = -4.542, p = .000** | **Z = -3.921, p = .000** | **Z = -4.557, p = .000** |
| 1400 | **Z = -3.921, p = .000** | **Z = -4.624, p = .000** | **Z = -3.920, p = .000** | **Z = -4.558, p = .000** |
| 1500 | **Z = -3.921, p = .000** | **Z = -4.541, p = .000** | **Z = -3.922, p = .000** | **Z = -4.601, p = .000** |
| 1600 | **Z = -3.921, p = .000** | **Z = -4.623, p = .000** | **Z = -3.771, p = .000** | **Z = -4.518, p = .000** |
| 1700 | **Z = -3.823, p = .000** | **Z = -4.624, p = .000** | **Z = -3.846, p = 000** | **Z = -4.542, p = .000** |
| 1800 | **Z = -3.824, p = .000** | **Z = -4.627, p = .000** | **Z = -3.810, p = 000** | **Z = -4.625, p = .000** |
| 1900 | **Z = -3.726, p = .000** | **Z = -4.396, p = .000** | **Z = -3.724, p = 000** | **Z = -4.624, p = .000** |
| 2000 | **Z = -3.664, p = .000** | **Z = -4.286, p = .000** | **Z = -3.885, p = 000** | **Z = -4.628, p = .000** |
| 2100 | **Z = -3.219, p = .001** | **Z = -4.222, p = .000** | **Z = -3.923, p = .000** | **Z = -4.527, p = .000** |
| 2200 | **Z = -3.174, p = .002** | **Z = -4.027, p = .000** | **Z = -3.883, p = .000** | **Z = -4.024, p = .000** |
| 2300 | **Z = -3.152, p = .002** | **Z = -3.774, p = .000** | **Z = -3.684, p = .000** | **Z = -3.739, p = .000** |

| | | | | |
|---|---|---|---|---|
| 2400 | Z = -3.404, p = .001 | Z = -3.567, p = .000 | Z = -3.362, p = .001 | Z = -3.370, p = .001 |
| 2500 | **Z = -3.419, p = .001** | **Z = -3.238, p = .001** | **Z = -3.410, p = .001** | **Z = -3.978, p = .000** |

*Note.* Figures in boldface indicate a significant result.

**Table A18-7-2. Wilcoxon Signed Rank Test Results for pseudosemantic v.s. pseudounrelated items in Experiment 4.2.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| 0 | Z = -.259, p = .796 | Z = -.731, p = .465 | Z = -1.422, p = .155 | Z = -1.482, p = .138 |
| 100 | Z = -.201, p = .840 | Z = -.394, p = .693 | Z = -2.239, p = .025 | Z = -1.924, p = .054 |
| 200 | Z = -1.220, p = .222 | Z = -1.080, p = .280 | Z = -2.375, p = .018 | Z = -2.212, p = .027 |
| 300 | **Z = -2.820, p = .005** | **Z = -2.997, p = .003** | Z = -2.430, p = .015 | Z = -1.715, p = .086 |
| 400 | **Z = -3.716, p = .000** | **Z = -4.078, p = .000** | Z = -2.232, p = .020 | Z = -2.430, p = .015 |
| 500 | **Z = -3.754, p = .000** | **Z = -4.304, p = .000** | Z = -1.831, p = .067 | Z = -1.658, p = .097 |
| 600 | **Z = -3.173, p = .002** | **Z = -3.886, p = .000** | Z = -1.233, p = .218 | Z = -.80, p = .419 |
| 700 | Z = -2.638, p = .008 | Z = -2.618, p = .009 | Z = -1.657, p = .097 | Z = -1.058, p = .290 |
| 800 | Z = -2.297, p = .022 | Z = -1.801, p = .072 | Z = -2.198, p = .028 | Z = -1.811, p = .070 |
| 900 | Z = -2.595, p = .009 | Z = -2,331, p = .020 | Z = -2.236, p = .025 | Z = -1.715, p = .046 |
| 1000 | Z = -2.738, p = .006 | **Z = -3.114, p = .002** | **Z = -2.834, p = .005** | Z = -1.982, p = .048 |
| 1100 | **Z = -2.942, p = .003** | **Z = -3.127, p = .002** | Z = -2.768, p = .006 | Z = -2.355, p = .019 |
| 1200 | Z = -2.711, p = .007 | Z = -2.725, p = .006 | Z = -2.108, p = .035 | Z = -1.745, p = .081 |
| 1300 | Z = -2.074, p = .038 | Z = -1.618, p = .106 | Z = -1.613, p = .107 | Z = -1.244, p = .213 |
| 1400 | Z = -1.508, p = .132 | Z = -.878, p = .380 | Z = -2.125, p = .034 | Z = -1.501, p = .133 |
| 1500 | Z = -2.040, p = .041 | Z = -1.841, p = .066 | Z = -.458, p = .647 | Z = -.283, p = .777 |
| 1600 | Z = -.881, p = .378 | Z = -1.308, p = .191 | Z = -.474, p = .635 | Z = -.504, p = .614 |
| 1700 | Z = -1.610, p = .107 | Z = -2.300, p = .021 | Z = -.026, p = .979 | Z = 1.174, p = .862 |
| 1800 | Z = -1.446, p = .148 | **Z = -2.801, p = .005** | Z = -1.279, p = .201 | Z = -1.130, p = .258 |
| 1900 | Z = -.350, p = .727 | Z = -.181, p = .856 | Z = -1.475, p = .140 | Z = -1.756, p = .079 |
| 2000 | Z = -.119, p = .905 | Z = -.252, p = .801 | Z = -1.383, p = .167 | Z = -.992, p = .331 |
| 2100 | Z = -.236, p = .814 | Z = -440, p = .660 | Z = -.569, p = .570 | Z = -.207, p = .836 |
| 2200 | Z = -408, p = .683 | Z = -.666, p = .506 | Z = -.379, p = .705 | Z = -.362, p = .717 |
| 2300 | Z = -.153, p = 878 | Z = -.648, p = .517 | Z = -.560, p = .576 | Z = -.595, p = .552 |
| 2400 | Z = -.051, p = .959 | Z = -.951, p = .342 | Z = -356, p = .722 | Z = -1.023, p = .306 |
| 2500 | Z = -1.122, p = .262 | Z = -1.199, p = .231 | Z = -1.114, p = .265 | Z = -044, p = .965 |

Note. Figures in bold indicate a significant result after Bonferroni correction.

**Table A18-7-3. Wilcoxon Signed Rank Test Results for pseudophonological v.s. pseudounrelated items in Experiment 4.2.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| 0 | Z = -1.494, p = .135 | Z = -1.073, p = .283 | Z = -.545, p = .586 | Z = -.570, p = .569 |
| 100 | Z = -1.010, p = .313 | Z = -1.149, p = .251 | Z = -.094, p = .925 | Z = -.628, p = .530 |
| 200 | Z = -.087, p = .930 | Z = -.057, p = .954 | Z = -.131, p = .896 | Z = -.619, p = .536 |
| 300 | Z = -1.397, p = .162 | Z = -.121, p = .904 | Z = -.484, p = .629 | Z = -.597, p = .550 |
| 400 | Z = -1.397, p = .162 | Z = -1.462, p = .144 | Z = -1.169, p = .242 | Z = -1.311, p = .190 |
| 500 | Z = -2.494, p = .013 | Z = -2.318, p = .020 | Z = -.498, p = .619 | Z = -.737, p = .461 |
| 600 | Z = -1.942, p = .052 | Z = -1.511, p = .131 | Z = -.744, p = .457 | Z = -.305, p = .760 |
| 700 | Z = -.525, p = .600 | Z = -.730, p = .465 | Z = -.570, p = .569 | Z = -.390, p = .696 |
| 800 | Z = -.142, p = .887 | Z = -.152, p = .879 | Z = -1.352, p = .176 | Z = -.441, p = .659 |
| 900 | Z = -.754, p = .451 | Z = -.639, p = .523 | Z = -1.445, p = .148 | Z = -1.112, p = .266 |
| 1000 | Z = -.937, p = .349 | Z = -.498, p = .618 | Z = -1.656, p = .098 | Z = -1.436, p = .151 |
| 1100 | Z = -2.075, p = .038 | Z = -2.050, p = .040 | Z = -1.542, p = .123 | Z = -1.787, p = .074 |
| 1200 | Z = -1.571, p = .116 | Z = -1.252, p = .211 | Z = -.975, p = .330 | Z = -1.079, p = .280 |
| 1300 | Z = -1.530, p = .126 | Z = -1.394, p = .163 | Z = -.020, p = .984 | Z = -.946, p = .344 |
| 1400 | Z = -.725, p = .469 | Z = -.548, p = .584 | Z = -.805, p = .421 | Z = -.840, p = .401 |
| 1500 | Z = -.880, p = .379 | Z = -.372, p = .710 | Z = -1.397, p = .162 | Z = -1.004, p = .315 |
| 1600 | Z = -.543, p = .587 | Z = -.382, p = .702 | Z = -.052, p = .959 | Z = -.470, p = .639 |
| 1700 | Z = -1.382, p = .167 | Z = -.968, p = .333 | Z = -.259, p = .796 | Z = -.052, p = .958 |
| 1800 | Z = -1.762, p = .078 | Z = -1.915, p = .055 | Z = -.251, p = .801 | Z = -.170, p = .865 |
| 1900 | Z = -.157, p = .875 | Z = -.262, p = .793 | Z = -.659, p = .510 | Z = -.222, p = .825 |
| 2000 | Z = -.712, p = .477 | Z = -.114, p = .909 | Z = -.315, p = .753 | Z = -.086, p = .932 |
| 2100 | Z = -.275, p = .783 | Z = -.985, p = .324 | Z = -.709, p = .478 | Z = -.245, p = .807 |
| 2200 | Z = -.534, p = .594 | Z = -.650, p = .515 | Z = -1.068, p = .286 | Z = -.628, p = .530 |
| 2300 | Z = -1.180, p = .238 | Z = -.911, p = .362 | Z = -.826, p = .409 | Z = -.934, p = .350 |
| 2400 | Z = -1.424, p = .154 | Z = -.825, p = .410 | Z = -.525, p = .600 | Z = -.525, p = .600 |
| 2500 | Z = -1.378, p = .168 | Z = -.358, p = .721 | Z = -.347, p = .729 | Z = -.105, p = .916 |

*Note.* Figures in bold indicate a significant result after Bonferroni correction.

**Table A18-7-4. Mann-Whitney Test Results for Experiment 4.2 (by-subjects).**

| Time | Pseudotarget - Unrelated | Pseudosemantic - Unrelated | Pseudophonological - Unrelated |
|---|---|---|---|
| **0** | Z = -.800, p = .424 | Z = -.869, p = .385 | Z = -1.504, p = .132 |
| **100** | Z = -.826, p = .409 | Z = -1.669, p = .095 | Z = -.477, p = .633 |
| **200** | Z = -.772, p = .440 | Z = -.934, p = .350 | Z = -.054, p = .957 |
| **300** | Z = -.487, p = .626 | Z = -.1.557, p = .119 | Z = -597, p = .551 |
| **400** | Z = -.568, p = .570 | Z = -1.651, p = .099 | Z = -.095, p = .924 |
| **500** | Z = -1.137, p = .256 | Z = -2.262, p = .024 | Z = -1.565, p = .118 |
| **600** | Z = -1.597, p = .110 | Z = -1.844, p = .065 | Z = -.678, p = .498 |
| **700** | Z = -.893, p = .372 | Z = -.569, p = .569 | Z = -.122, p = .903 |
| **800** | Z = -.690, p = .490 | Z = -.393, p = .694 | Z = -.610, p = .542 |
| **900** | Z = -.961, p = .337 | Z = -.163, p = .871 | Z = -.491, p = .623 |
| **1000** | Z = -1.367, p = .172 | Z = -.569, p = .560 | Z = -.041, p = .968 |
| **1100** | Z = -1.421, p = .155 | Z = -.407, p = .684 | Z = -1.151, p = .250 |
| **1200** | Z = -1.760, p = .078 | Z = -.190, p = .850 | Z = -1.127, p = .260 |
| **1300** | Z = -1.137, p = .255 | Z = -.339, p = .735 | Z = -1.087, p = .277 |
| **1400** | Z = -.663, p = .507 | Z = -.519, p = .604 | Z = -.122, p = .903 |
| **1500** | Z = -.839, p = .401 | Z = -1.131, p = .258 | Z = -.421, p = .674 |
| **1600** | Z = -1.069, p = .285 | Z = -.693, p = .488 | Z = -.054, p = .957 |
| **1700** | Z = -1.178, p = .239 | Z = -.782, p = .434 | Z = -.259, p = .795 |
| **1800** | Z = -.866, p = .386 | Z = -.356, p = .722 | Z = -.919, p = .358 |
| **1900** | Z = -.515, p = .607 | Z = -.889, p = .374 | Z = -.650, p = .516 |
| **2000** | Z = -.448, p = .654 | Z = -1.154, p = .248 | Z = -1.007, p = .314 |
| **2100** | Z = -.313, p = .755 | Z = -.124, p = .901 | Z = -1.077, p = .281 |
| **2200** | Z = -.518, p = .605 | Z = -.182, p = 856 | Z = -1.178, p = .239 |
| **2300** | Z = -.367, p = .713 | Z = -.364, p = .716 | Z = -1.259, p = .208 |
| **2400** | Z = -.353, p = .724 | Z = -.656, p = .512 | Z = -1.034, p = .301 |
| **2500** | Z = -.351, p = .725 | Z = -1.062, p = .288 | Z = -.886, p = .376 |

**Table A18-7-5. Mann-Whitney Test Results for Experiment 4.2 (by-items).**

| **Time** | **Pseudotarget - Unrelated** | **Pseudosemantic - Unrelated** | **Pseudophonological - Unrelated** |
|---|---|---|---|
| **0** | Z = -.588, p = .577 | Z = -.337, p = .736 | Z = -.742, p = .458 |
| **100** | Z = -.960, p = .337 | Z = -.919, p = .358 | Z = -1.306, p = .191 |
| **200** | Z = -.713, p = .476 | Z = -.680, p = .496 | Z = -.681, p = .496 |
| **300** | Z = -.434, p = .664 | Z = -1.009, p = .313 | Z = -.090, p = .928 |
| **400** | Z = -.746, p = .456 | Z = -1.804, p = .071 | Z = -.395, p = .693 |
| **500** | Z = -1.779, p = .075 | Z = -2.863, p = .004 | Z = -1.103, p = .270 |
| **600** | Z = -2.001, p = .045 | Z = -2.174, p = .030 | Z = -.624, p = .533 |
| **700** | Z = -1.139, p = .255 | Z = -.180, p = .857 | Z = -.165, p = .869 |
| **800** | Z = -.976, p = .329 | Z = -.336, p = .737 | Z = -.526, p = .599 |
| **900** | Z = -1.476, p = .140 | Z = -.041, p = .967 | Z = -.460, p = .645 |
| **1000** | Z = -1.738, p = .082 | Z = -.460, p = .645 | Z = -.697, p = .486 |
| **1100** | Z = -1.770, p = .077 | Z = -.369, p = .712 | Z = -.033, p = .974 |
| **1200** | Z = -1.550, p = .121 | Z = -.098, p = .922 | Z = -.173, p = .862 |
| **1300** | Z = -1.107, p = .268 | Z = -.214, p = .831 | Z = -.597, p = .550 |
| **1400** | Z = -1.385, p = .166 | Z = -.914, p = .361 | Z = -.017, p = .987 |
| **1500** | Z = -.664, p = .507 | Z = -.534, p = .593 | Z = -.541, p = .588 |
| **1600** | Z = -.549, p = .583 | Z = -1.157, p = .247 | Z = -.008, p = .993 |
| **1700** | Z = -.812, p = .417 | Z = -2.017, p = .044 | Z = -.622, p = .534 |
| **1800** | Z = -.831, p = .406 | Z = -1.136, p = .256 | Z = -1.258, p = .208 |
| **1900** | Z = -.328, p = .743 | Z = -1.578, p = .115 | Z = -.292, p = .770 |
| **2000** | Z = -.577, p = .564 | Z = -1.066, p = .287 | Z = -.276, p = .782 |
| **2100** | Z = -.762, p = .446 | Z = -.601, p = .548 | Z = -.134, p = .894 |
| **2200** | Z = -1.036, p = .300 | Z = -.819, p = .413 | Z = -.894, p = .372 |
| **2300** | Z = -1.222, p = .222 | Z = -.959, p = .338 | Z = -.969, p = .332 |
| **2400** | Z = -.387, p = .699 | Z = -1.665, p = .537 | Z = -.617, p = .537 |
| **2500** | Z = -1.289, p = .197 | Z = -1.195, p = .232 | Z = -.030, p = .976 |

# Appendix 19. Stimuli used in Experiment 5.

**Table A19-8-1. List A of the target and distracter items used in Experiment 5.**

| Condition | Target | Distracter | Semantic | Unrelated |
|---|---|---|---|---|
| **homophone** | **board** | bored | pins | gold |
| **homophone** | **break** | brake | rip | table |
| **homophone** | **flower** | flour | tree | file |
| **homophone** | **jeans** | genes | shirt | crisps |
| **homophone** | **hare** | hair | cow | lock |
| **homophone** | **leek** | leak | onion | printer |
| **homophone** | **moose** | mousse | bear | hat |
| **homophone** | **night** | knight | day | chocolate |
| **homophone** | **mussels** | muscles | lobster | desert |
| **homophone** | **poor** | pour | money | key |
| **homophone** | **rain** | rein | sun | worm |
| **homophone** | **rose** | rows | leaves | desk |
| **homophone** | **stake** | steak | bowarrow | envelope |
| **homophone** | **tail** | tale | monkey | comb |
| **homophone** | **tea** | tee | sugar | boy |
| **homophone** | **toe** | tow | fingers | bat |
| **ortho_sim** | **bell** | bull | alarm | jumper |
| **ortho_sim** | **beak** | bean | wing | path |
| **ortho_sim** | **beef** | beer | chicken | river |
| **ortho_sim** | **boat** | boot | anchor | mug |
| **ortho_sim** | **claw** | clap | fingernails | curtains |
| **ortho_sim** | **coat** | coal | skirt | swing |
| **ortho_sim** | **coke** | cone | juice | ball |
| **ortho_sim** | **cut** | cat | chop | lemon |
| **ortho_sim** | **food** | foot | milk | paper |
| **ortho_sim** | **frame** | flame | plaque | purse |
| **ortho_sim** | **glass** | grass | plate | house |
| **ortho_sim** | **gum** | gun | sweets | bee |
| **ortho_sim** | **ham** | hay | cheese | hook |
| **ortho_sim** | **hear** | head | smell | drill |
| **ortho_sim** | **pen** | peg | pencil | glasses |
| **ortho_sim** | **poke** | pole | hug | mouse |
| **ortho_sim** | **run** | rug | swim | baby |
| **ortho_sim** | **stone** | scone | sand | knife |
| **ortho_sim** | **tie** | tin | shoes | box |
| **ortho_sim** | **wire** | wine | wool | clip |

*Note.* Distracter refers to either homophone or orthographically similar items (see column labelled, 'condition').

**Table A19-8-2. List B of the target and distracter items used in Experiment 5.**

| Condition | Target | Distracter | Semantic | Unrelated |
|---|---|---|---|---|
| **homophone** | **brake** | break | bike | frog |
| **homophone** | **bored** | board | happy | table |
| **homophone** | **flour** | flower | butter | file |
| **homophone** | **genes** | jeans | brain | crisps |
| **homophone** | **hair** | hare | bald | lock |
| **homophone** | **knight** | night | castle | chocolate |
| **homophone** | **leak** | leek | tap | printer |
| **homophone** | **mousse** | moose | gel | bed |
| **homophone** | **muscles** | mussels | bone | desert |
| **homophone** | **pour** | poor | jug | key |
| **homophone** | **rein** | rain | saddle | worm |
| **homophone** | **rows** | rose | stack | desk |
| **homophone** | **steak** | stake | fish | envelope |
| **homophone** | **tale** | tail | newspaper | comb |
| **homophone** | **tee** | tea | golfball | boy |
| **homophone** | **tow** | toe.png | car | bat |
| **ortho_sim** | **bean** | beak | rice | heart |
| **ortho_sim** | **beer** | beef | whiskey | river |
| **ortho_sim** | **boot** | boat | slipper | mug |
| **ortho_sim** | **bull** | bell | pig | jumper |
| **ortho_sim** | **clap** | claw | dance | curtains |
| **ortho_sim** | **coal** | coat | firewood | swing |
| **ortho_sim** | **cone** | coke | trafficlights | ball |
| **ortho_sim** | **cat** | cut | dog | lemon |
| **ortho_sim** | **foot** | food | hand | paper |
| **ortho_sim** | **flame** | frame | matches | purse |
| **ortho_sim** | **grass** | glass | soil | pipe |
| **ortho_sim** | **gun** | gum | sword | bee |
| **ortho_sim** | **hay** | ham | wheat | hook |
| **ortho_sim** | **head** | hear | legs | drill |
| **ortho_sim** | **peg** | pen | clothes | glasses |
| **ortho_sim** | **pole** | poke | lampost | mouse |
| **ortho_sim** | **rug** | run | cushion | ring |
| **ortho_sim** | **scone** | stone | cake | knife |
| **ortho_sim** | **tin** | tie | jar | clip |
| **ortho_sim** | **wine** | wire | cocktail | box |

*Note.* Distracter refers to either homophone or orthographically similar items (see column labelled, ‘condition’).

## Appendix 20. Full results from the non-parametric tests for the homophone condition in Experiment 5.

**Table A20-8-1. Wilcoxon Signed Rank Test Results for target v.s. unrelated items for the homophone condition in Experiment 5.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| **0** | Z = -3.885, p = .065 | Z = -4.056, p = .000 | Z = -3.824, p = .000 | Z = -3.590, p = .000 |
| **100** | *Z = -3.824, p = .001* | *Z = -4.422, p = .000* | *Z = -3.809, p = 000* | *Z = -3.940, p = .000* |
| **200** | *Z = -3.921, p = .000* | *Z = -4.861, p = .000* | *Z = -3.920, p = .000* | *Z = -4.255, p = .000* |
| **300** | *Z = -3.923, p = .000* | *Z = -4.861, p = .000* | *Z = -3.922, p = .000* | *Z = -4.783, p = .000* |
| **400** | *Z = -3.920, p = .000* | *Z = -4.842, p = .000* | *Z = -3.920, p = .000* | *Z = -4.707, p = .000* |
| **500** | *Z = -3.923, p = .000* | *Z = -4.861, p = .000* | *Z = -3.922, p = .000* | *Z = -4.824, p = .000* |
| **600** | *Z = -3.920, p = .000* | *Z = -4.939, p = .000* | *Z = -3.922, p = .000* | *Z = -4.863, p = .000* |
| **700** | *Z = -3.921, p = .000* | *Z = -4.938, p = .000* | *Z = -3.824, p = .000* | *Z = -4.862, p = .000* |
| **800** | *Z = -3.921, p = .000* | *Z = -4.921, p = .000* | *Z = -3.887, p = .000* | *Z = -4.493, p = .000* |
| **900** | *Z = -3.883, p = .000* | *Z = -4.846, p = .000* | *Z = -3.923, p = .000* | *Z = -4.023, p = .000* |
| **1000** | *Z = -3.848, p = .000* | *Z = -4.786, p = .000* | *Z = -3.825, p = .000* | *Z = -4.027, p = .000* |
| **1100** | *Z = -3.683, p = .000* | *Z = -4.550, p = .000* | *Z = -3.480, p = .001* | *Z = -3.710, p = .000* |
| **1200** | *Z = -3.789, p = .000* | *Z = -4.468, p = .000* | *Z = -3.576, p = .000* | *Z = -3.847, p = .000* |
| **1300** | *Z = -2.390, p = .017* | *Z = -4.036, p = .000* | *Z = -3.482, p = .000* | *Z = -3.926, p = .000* |
| **1400** | *Z = -2.911, p = .004* | *Z = -4.155, p = .000* | *Z = -2.939, p = .003* | *Z = -3.177, p = .001* |
| **1500** | *Z = -2.956, p = .003* | *Z = -3.564, p = .000* | *Z = -2.450, p = .014* | *Z = -2.758, p = .006* |
| **1600** | *Z = -3.778, p = .000* | *Z = -3.650, p = .000* | *Z = -2.526, p = .012* | *Z = -3.201, p = .001* |
| **1700** | *Z = -3.589, p = .000* | *Z = -3.489, p = .000* | *Z = -3.204, p = 001* | *Z = -2.492, p = .013* |
| **1800** | *Z = -3.047, p = .002* | *Z = -3.104, p = .002* | *Z = -2.952, p = 003* | *Z = -1.925, p = .054* |
| **1900** | *Z = -3.023, p = .003* | *Z = -2.954, p = .003* | *Z = -3.020, p = 003* | *Z = -2.649, p = .008* |
| **2000** | *Z = -2.965, p = .003* | *Z = -3.550, p = .000* | *Z = -3.019, p = 003* | *Z = -3.082, p = .002* |

| | | | | |
|---|---|---|---|---|
| **2100** | *Z = -2.842, p = .004* | *Z = -3.056, p = .002* | *Z = -3.066, p = .002* | *Z = -3.064, p = .002* |
| **2200** | *Z = -2.699, p = .007* | *Z = -2.855, p = .004* | *Z = -2.187, p = .029* | *Z = -2.751, p = .006* |
| **2300** | *Z = -2.536, p = .011* | *Z = -3.021, p = .003* | *Z = -2.810, p = .005* | *Z = -3.006, p = .002* |
| **2400** | *Z = -2.214, p = .027* | *Z = -2.217, p = .027* | *Z = -2.828, p = .005* | *Z = -2.887, p = .004* |
| **2500** | *Z = -2.533, p = .011* | *Z = -1.785, p = .074* | *Z = -2.646, p = .008* | *Z = -2.828, p = .005* |

*Note.* Figures in bold indicate a significant result after Bonferroni correction.

**Table A20-8-2. Wilcoxon Signed Rank Test Results for semantic v.s. unrelated items for the homophone condition in Experiment 5.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| **0** | Z = -1.232, p = .218 | Z = -1.182, p = .237 | Z = -2.014, p = .044 | Z = -1.655, p = .098 |
| **100** | Z = -1.772, p = .076 | Z = -1.491, p = .136 | Z = -2335, p = .020 | Z = -1.397, p = .162 |
| **200** | Z = -2.549, p = .011 | Z = -2.659, p = .008 | Z = -2.138, p = .032 | Z = -.758, p = .448 |
| **300** | Z = -1.872, p = .061 | Z = -1.846, p = .065 | Z = -2.749, p = .006 | Z = -2.309, p = .021 |
| **400** | Z = -2.811, p = .005 | Z = -2.403, p = .016 | Z = -1.670, p = .095 | Z = -1.800, p = .072 |
| **500** | Z = -2.416, p = .016 | Z = -2.084, p = .037 | Z = -1.517, p = .129 | Z = -.888, p = .375 |
| **600** | Z = -2.344, p = .019 | Z = -2.309, p = .021 | Z = -.436, p = .663 | Z = -.411, p = .681 |
| **700** | Z = -2.315, p = .021 | Z = -2.477, p = .013 | Z = -1.392, p = .164 | Z = -1.186, p = .235 |
| **800** | Z = -1.790, p = .074 | Z = -2.505, p = .012 | Z = -2.224, p = .026 | Z = -1.141, p = .254 |
| **900** | Z = -.654, p = .513 | Z = -1.221, p = .222 | Z = -1.562, p = .118 | Z = -1.424, p = .154 |
| **1000** | Z = -.210, p = .834 | Z = -1.044, p = .296 | Z = -2.010, p = .044 | Z = -2.178, p = .029 |
| **1100** | Z = -.949, p = .343 | Z = -.305, p = .761 | Z = -1.854, p = .064 | Z = -1.167, p = .243 |
| **1200** | Z = -.178, p = .859 | Z = -1.170, p = 242 | Z = -2.040, p = .041 | Z = -1.065, p = .287 |
| **1300** | Z = -.078, p = .937 | Z = -.926, p = .354 | Z = -2.086, p = .037 | Z = -.717, p = .473 |
| **1400** | Z = -1.072, p = .284 | Z = -2.245, p = .025 | Z = -2.271, p = .023 | Z = -1.348, p = .178 |
| **1500** | Z = -.408, p = .683 | Z = -1.254, p = .210 | Z = -1.557, p = .119 | Z = -1.263, p = .207 |
| **1600** | Z = -1.689, p = .091 | Z = -1.548, p = .122 | Z = -1.637, p = .102 | Z = -2.308, p = .021 |
| **1700** | Z = -.552, p = .581 | Z = -.179, p = .858 | Z = -1.129, p = .259 | Z = .971, p = .331 |
| **1800** | Z = -.535, p = .593 | Z = -1.442, p = .149 | Z = -.338, p = .735 | Z = -.258, p = .796 |
| **1900** | Z = -.730, p = .465 | Z = -.630, p = .529 | Z = -.742, p = .458 | Z = -.756, p = .450 |
| **2000** | Z = -1.682, p = .093 | Z = -.595, p = .552 | Z = -2.003, p = .045 | Z = -1.841, p = .066 |
| **2100** | Z = -1.069, p = .285 | Z = -170, p = .865 | Z = -2.032, p = .042 | Z = -2.032, p = .042 |
| **2200** | Z = -1.761, p = .078 | Z = -.983, p = .326 | Z = -.557, p = .577 | Z = -1.163, p = .245 |
| **2300** | Z = -1.782, p = 075 | Z = -.983, p = .326 | Z = -1.342, p = .180 | Z = -1.473, p = .141 |
| **2400** | Z = -1.633, p = .102 | Z = -.343, p = .732 | Z = -1.414, p = .157 | Z = -1.342, p = .180 |
| **2500** | Z = -1.095, p = .273 | Z = -.071, p = .943 | Z = -1.000, p = .317 | Z = -1.000, p = .317 |

*Note.* Figures in bold indicate a significant result after Bonferroni correction.

**Table A20-8-3. Wilcoxon Signed Rank Test Results for homophone v.s. unrelated items in the homophone condition in Experiment 5.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| **0** | Z = -2.476, p = .013 | Z = -1.959, p = .050 | Z = -.521, p = .602 | Z = -.848, p = .396 |
| **100** | Z = -2.436, p = .015 | Z = -1.166, p = .244 | Z = -.256, p = .798 | Z = -.685, p = .494 |
| **200** | Z = -2.961, p = .003 | Z = -1.981, p = .048 | Z = -.819, p = .413 | Z = -1.112, p = .266 |
| **300** | Z = -1.244, p = .214 | Z = -1.234, p = .217 | Z = -1.375, p = .169 | Z = -.195, p = .845 |
| **400** | Z = -.687, p = .492 | Z = -.700, p = .484 | Z = -2.141, p = .032 | Z = -.818, p = .413 |
| **500** | Z = -.057, p = .955 | Z = -.196, p = .845 | Z = -1.366, p = .172 | Z = -.853, p = .394 |
| **600** | Z = -1.061, p = .289 | Z = -.928, p = .353 | Z = -.736, p = .461 | Z = -.852, p = .394 |
| **700** | Z = -2.062, p = .039 | Z = -1.987, p = .047 | Z = -.569, p = .570 | Z = -.901, p = .368 |
| **800** | Z = -2.511, p = .012 | Z = -1.809, p = .070 | Z = -.220, p = .826 | Z = -.780, p = .436 |
| **900** | Z = -.944, p = .345 | Z = -1.347, p = .178 | Z = -.245, p = .806 | Z = -.161, p = .872 |
| **1000** | Z = -.134, p = .894 | Z = -.518, p = .605 | Z = -.874, p = .382 | Z = -.838, p = .402 |
| **1100** | Z = -.031, p = .975 | Z = -.880, p = .379 | Z = -1.023, p = .306 | Z = -.356, p = .722 |
| **1200** | Z = -.353, p = .724 | Z = -1.080, p = .280 | Z = -2.055, p = .040 | Z = -.818, p = .413 |
| **1300** | Z = -.562, p = .574 | Z = -.631, p = .528 | Z = -1.477, p = .140 | Z = -.310, p = .757 |
| **1400** | Z = -.919, p = .358 | Z = -.878, p = .380 | Z = -.170, p = .865 | Z = .000, p = 1.000 |
| **1500** | Z = -.847, p = .397 | Z = -1.077, p = .282 | Z = -.106, p = .916 | Z = -.159, p = .874 |
| **1600** | Z = -.677, p = .498 | Z = -.254, p = .799 | Z = -1.126, p = .260 | Z = -1.586, p = .113 |
| **1700** | Z = -.944, p = .345 | Z = -.875, p = .382 | Z = -1.854, p = .064 | Z = -1.092, p = .275 |
| **1800** | Z = -1.342, p = .180 | Z = -.714, p = .475 | Z = -.681, p = .496 | Z = -.103, p = .918 |
| **1900** | Z = -1.859, p = .063 | Z = -1.010, p = .313 | Z = -1.219, p = .223 | Z = -.680, p = .496 |
| **2000** | Z = -1.761, p = .078 | Z = -.423, p = .672 | Z = -1.342, p = .180 | Z = -1.095, p = .273 |
| **2100** | Z = -1.069, p = .285 | Z = -.210, p = .833 | Z = -1.000, p = .317 | Z = -.1.000, p = .317 |
| **2200** | Z = -.447, p = .655 | Z = -.542, p = .588 | Z = -1.342, p = .180 | Z = -1.342, p = .180 |
| **2300** | Z = -1.342, p = .180 | Z = -.271, p = .786 | Z = -1.000, p = .317 | Z = -.1.000, p = .317 |
| **2400** | Z = -1.342, p = .180 | Z = -.137, p = .891 | Z = .000, p = 1.000 | Z = .000, p = 1.000 |
| **2500** | Z = -1.089, p = .276 | Z = -.108, p = .914 | Z = .000, p = 1.000 | Z = .000, p = 1,000 |

*Note.* Figures in bold indicate a significant result after Bonferroni correction.

**Table A20-8-4. Mann-Whitney Test Results for the homophone condition in Experiment 5 (by-subjects).**

| Time | Pseudotarget -Unrelated | Pseudosemantic - Unrelated | Pseudophonological - Unrelated |
|---|---|---|---|
| 0 | Z = -.244, p = .807 | Z = -1.991, p = .047 | Z = -1.665, p = .096 |
| 100 | Z = -.041, p = .968 | Z = -2.626, p = .009 | Z = -2.613, p = .009 |
| 200 | Z = -.541, p = .588 | Z = -2.074, p = .038 | Z = -.272, p = .786 |
| 300 | Z = -.393, p = .694 | Z = -1.327, p = .185 | Z = -.693, p = .489 |
| 400 | Z = -.798, p = .425 | Z = -.081, p = .935 | Z = -1.889, p = .059 |
| 500 | Z = -1.070, p = .285 | Z = -.624, p = .533 | Z = -1.029, p = .304 |
| 600 | Z = -.365, p = .715 | Z = -.162, p = .871 | Z = -.258, p = .797 |
| 700 | Z = -1.285, p = .199 | Z = -.633, p = .527 | Z = -1.289, p = .197 |
| 800 | Z = -.934, p = .350 | Z = -.667, p = .505 | Z = -1.126, p = .260 |
| 900 | Z = -.825, p = .409 | Z = -.299, p = .765 | Z = -.802, p = .423 |
| 1000 | Z = -1.017, p = .309 | Z = -.222, p = .824 | Z = -.479, p = .632 |
| 1100 | Z = -.521, p = .602 | Z = -.120, p = .905 | Z = -.131, p = .896 |
| 1200 | Z = -.734, p = .463 | Z = -.723, p = .469 | Z = -.408, p = .683 |
| 1300 | Z = -.764, p = .445 | Z = -1.629, p = .103 | Z = -.796, p = .426 |
| 1400 | Z = -.434, p = .664 | Z = -1.564, p = .118 | Z = -.101, p = .920 |
| 1500 | Z = -1.751, p = .080 | Z = -1.010, p = .312 | Z = -.307, p = .759 |

**Table A20-8-5. Mann-Whitney Test Results for the homophone condition in Experiment 5 (by-items).**

| Time | Pseudotarget -Unrelated | Pseudosemantic - Unrelated | Pseudophonological - Unrelated |
|---|---|---|---|
| 0 | Z = -.107, p = .914 | Z = -.222, p = .824 | Z = -1.044, p = .296 |
| 100 | Z = -.719, p = .472 | Z = -.068, p = .946 | Z = -1.134, p = .257 |
| 200 | Z = -.591, p = .554 | Z = -1.041, p = .298 | Z = -1.798, p = .072 |
| 300 | Z = -1.303, p = .192 | Z = -.190, p = .849 | Z = -.779, p = .436 |
| 400 | Z = -2.365, p = .018 | Z = -2.094, p = .036 | Z = .000, p = 1.000 |
| 500 | Z = -2.600, p = .009 | Z = -1.085, p = .278 | Z = -.591, p = .554 |
| 600 | Z = -.961, p = .336 | Z = -1.607, p = .108 | Z = -1.575, p = .115 |
| 700 | Z = -.181, p = .856 | Z = -.959, p = .338 | Z = -2.227, p = .026 |
| 800 | Z = -.740, p = .459 | Z = -1.034, p = .301 | Z = -1.962, p = .050 |
| 900 | Z = -.128, p = .898 | Z = -1.253, p = .210 | Z = -.525, p = .599 |
| 1000 | Z = -.229, p = .819 | Z = -.931, p = .352 | Z = -1.121, p = .262 |
| 1100 | Z = -1.584, p = .113 | Z = -.682, p = .495 | Z = -.571, p = .568 |
| 1200 | Z = -1.830, p = .067 | Z = -.266, p = .790 | Z = -1.275, p = .202 |
| 1300 | Z = -1.460, p = .144 | Z = -.015, p = .988 | Z = -.389, p = .697 |
| 1400 | Z = -1.649, p = .099 | Z = -.047, p = .963 | Z = -.290, p = .772 |
| 1500 | Z = -.782, p = .434 | Z = -.420, p = .675 | Z = -1.009, p = .313 |

# Appendix 21 Full results from the non-parametric tests for the orthographic condition in Experiment 5.

**Table A21-8-1. Wilcoxon Signed Rank Test Results for target v.s. unrelated items for the orthographic condition in Experiment 5.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| 0 | Z = -3.530, p = .000 | Z = -3.403, p = .001 | Z = -3.324, p = .001 | Z = -3.375, p = .001 |
| 100 | *Z = -3.922, p = .000* | *Z = -4.983, p = .000* | *Z = -3.922, p = .000* | *Z = -5.381, p = .000* |
| 200 | *Z = -3.921, p = .000* | *Z = -5.115, p = .000* | *Z = -3.923, p = .000* | *Z = -5.429, p = .000* |
| 300 | *Z = -3.921, p = .000* | *Z = -5.311, p = .000* | *Z = -3.922, p = .000* | *Z = -5.446, p = .000* |
| 400 | *Z = -3.921, p = .000* | *Z = -5.499, p = .000* | *Z = -3.921, p = .000* | *Z = -5.403, p = .000* |
| 500 | *Z = -3.921, p = .000* | *Z = -5.512, p = .000* | *Z = -3.922, p = .000* | *Z = -5.513, p = .000* |
| 600 | *Z = -3.922, p = .000* | *Z = -5.513, p = .000* | *Z = -3.921, p = .000* | *Z = -5.514, p = .000* |
| 700 | *Z = -3.920, p = .000* | *Z = -5.445, p = .000* | *Z = -3.922, p = .000* | *Z = -5.445, p = .000* |
| 800 | *Z = -3.921, p = .000* | *Z = -5.514, p = .000* | *Z = -3.920, p = .000* | *Z = -5.465, p = .000* |
| 900 | *Z = -3.921, p = .000* | *Z = -5.266, p = .000* | *Z = -3.826, p = .000* | *Z = -5.381, p = .000* |
| 1000 | *Z = -3.827, p = .000* | *Z = -5.310, p = .000* | *Z = -3.824, p = .000* | *Z = -4.662, p = .000* |
| 1100 | *Z = -3.727, p = .000* | *Z = -5.155, p = .000* | *Z = -3.927, p = .000* | *Z = -4.413, p = .000* |
| 1200 | *Z = -3.624, p = .000* | *Z = -4.538, p = .000* | *Z = -3.733, p = .000* | *Z = -4.331, p = .000* |
| 1300 | *Z = -3.645, p = .000* | *Z = -3.564, p = .000* | *Z = -3.740, p = .000* | *Z = -4.061, p = .000* |
| 1400 | *Z = -3.585, p = .000* | *Z = -3.248, p = .001* | *Z = -3.132, p = .002* | *Z = -3.054, p = .002* |
| 1500 | *Z = -3.587, p = .000* | *Z = -3.537, p = .000* | *Z = -3.148, p = .002* | *Z = -2.996, p = .003* |
| 1600 | *Z = -3.236, p = .001* | *Z = -3.772, p = .000* | *Z = -3.019, p = .003* | *Z = -3.382, p = .001* |

| | | | | |
|---|---|---|---|---|
| 1700 | $Z = -3.302$, $p = .001$ | $Z = -3.881$, $p = .000$ | $Z = -3.023$, $p = .003$ | $Z = -3.730$, $p = .000$ |
| 1800 | $Z = -3.279$, $p = .001$ | $Z = -3.346$, $p = .001$ | $Z = -2.803$, $p = .005$ | $Z = -3.152$, $p = .002$ |
| 1900 | $Z = -2.925$, $p = .003$ | $Z = -2.911$, $p = .004$ | $Z = -2.240$, $p = .025$ | $Z = -3.008$, $p = .003$ |
| 2000 | $Z = -2.155$, $p = .031$ | $Z = -2.685$, $p = .007$ | $Z = -1.671$, $p = .095$ | $Z = -2.346$, $p = .019$ |
| 2100 | $Z = -2.015$, $p = .044$ | $Z = -1.941$, $p = .052$ | $Z = -1.429$, $p = .158$ | $Z = -1.720$, $p = .086$ |
| 2200 | $Z = -1.958$, $p = .050$ | $Z = -2.496$, $p = .013$ | $Z = -1.723$, $p = .085$ | $Z = -1.475$, $p = .140$ |
| 2300 | $Z = -1.833$, $p = .067$ | $Z = -2.846$, $p = .004$ | $Z = -2.032$, $p = .042$ | $Z = -1.831$, $p = .067$ |
| 2400 | $Z = -1.466$, $p = .143$ | $Z = -3.271$, $p = .001$ | $Z = -2.121$, $p = .034$ | $Z = -2.530$, $p = .011$ |
| 2500 | $Z = -1.831$, $p = .067$ | $Z = -2.923$, $p = .003$ | $Z = -1.890$, $p = .059$ | $Z = -2.449$, $p = .014$ |

*Note.* Figures in bold indicate a significant result after Bonferroni correction.

**Table A21-8-2. Wilcoxon Signed Rank Test Results for semantic v.s. unrelated items for the orthographic condition in Experiment 5.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| 0 | Z = -2.701, p = .007 | Z = -2.704, p = .007 | Z = -2.970, p = .003 | Z = -2.539, p = .011 |
| 100 | Z = -3.202, p = .001 | Z = -3.015, p = .003 | Z = -3.736, p = .000 | Z = -3.713, p = .000 |
| 200 | Z = -2.985, p = .003 | Z = -2.899, p = .004 | Z = -3.830, p = .000 | Z = -3.814, p = .000 |
| 300 | Z = -3.381, p = .001 | Z = -3.281, p = .001 | Z = -3.046, p = .002 | Z = -2.704, p = .007 |
| 400 | Z = -3.053, p = .002 | Z = -3.124, p = .002 | Z = -3.248, p = .001 | Z = -2.189, p = .029 |
| 500 | Z = -3.086, p = .002 | Z = -2.928, p = .003 | Z = -2.717, p = .007 | Z = -2.588, p = .010 |
| 600 | Z = -3.242, p = .001 | Z = -2.816, p = .005 | Z = -3.149, p = .002 | Z = -3.632, p = .000 |
| 700 | Z = -2.955, p = .003 | Z = -2.843, p = .004 | Z = -2.698, p = .007 | Z = -3.138, p = .002 |
| 800 | Z = -2.459, p = .014 | Z = -2.007, p = .045 | Z = -2.571, p = .010 | Z = -2.250, p = .024 |
| 900 | Z = -.971, p = .331 | Z = -1.804, p = .071 | Z = -1.791, p = .073 | Z = -1.108, p = .268 |
| 1000 | Z = -.824, p = .410 | Z = -1.333, p = .183 | Z = -1.250, p = .211 | Z = -.520, p = .603 |
| 1100 | Z = -1.022, p = .307 | Z = -1.540, p = .124 | Z = -.909, p = .363 | Z = -.548, p = .583 |
| 1200 | Z = -.549, p = .583 | Z = -.552, p = .581 | Z = -.702, p = .483 | Z = -.403, p = .687 |
| 1300 | Z = -.237, p = .812 | Z = -.586, p = .558 | Z = -.847, p = .397 | Z = -.176, p = .861 |
| 1400 | Z = -.296, p = .767 | Z = -.405, p = .686 | Z = -.089, p = .929 | Z = -.853, p = .394 |
| 1500 | Z = -1.183, p = .237 | Z = -.761, p = .447 | Z = -.623, p = .533 | Z = -.045, p = .964 |
| 1600 | Z = -1.483, p = .138 | Z = -.957, p = .339 | Z = -.845, p = .398 | Z = -1.543, p = .123 |
| 1700 | Z = -.365, p = .715 | Z = -.720, p = .471 | Z = -.085, p = .933 | Z = .000, p = 1.000 |
| 1800 | Z = -.420, p = .674 | Z = -1.535, p = .125 | Z = -.085, p = .933 | Z = -.085, p = .933 |
| 1900 | Z = -.931, p = .352 | Z = -.916, p = .360 | Z = -.552, p = .581 | Z = -.552, p = .581 |
| 2000 | Z = -.676, p = .499 | Z = -.682, p = .495 | Z = -.756, p = .450 | Z = -.577, p = .564 |
| 2100 | Z = -.136, p = .892 | Z = -.447, p = .655 | Z = -1.089, p = .276 | Z = -.756, p = .450 |
| 2200 | Z = -.184, p = .854 | Z = -.000, p = 1.000 | Z = -1.069, p = .285 | Z = -.687, p = .492 |
| 2300 | Z = -.552, p = .581 | Z = -.577, p = .564 | Z = -1.105, p = .269 | Z = -1.000, p = .317 |
| 2400 | Z = -.426, p = .670 | Z = -.447, p = .655 | Z = -1.633, p = .102 | Z = -1.732, p = .083 |
| 2500 | Z = -.272, p = .785 | Z = -.447, p = .655 | Z = -1.732, p = .083 | Z = -1.633, p = .102 |

*Note.* Figures in bold indicate a significant result after Bonferroni correction.

**Table A21-8-3. Wilcoxon Signed Rank Test Results for orthographic v.s. unrelated items in the orthographic condition in Experiment 5.**

| Time Window | Hearing (by-subjects) | Hearing (by-items) | Deaf (by-subjects) | Deaf (by-items) |
|---|---|---|---|---|
| 0 | Z = -1.578, p = .114 | Z = -.127, p = .899 | Z = -.666, p = .506 | Z = -1.249, p = .212 |
| 100 | Z = -2.075, p = .038 | Z = -1.301, p = .193 | Z = -1.893, p = .058 | Z = -1.313, p = .189 |
| 200 | Z = -.333, p = .739 | Z = -.323, p = .746 | Z = -.383, p = .702 | Z = -.505, p = .613 |
| 300 | Z = -.862, p = .389 | Z = -.280, p = .780 | Z = -.704, p = .481 | Z = -.381, p = .704 |
| 400 | Z = -0.63, p = .950 | Z = -.093, p = .926 | Z = -.095, p = .924 | Z = -.152, p = .879 |
| 500 | Z = -.914, p = .361 | Z = -1.009, p = .313 | Z = -.462, p = .644 | Z = -.052, p = .958 |
| 600 | Z = -.455, p = .649 | Z = -.346, p = .730 | Z = -.312, p = .755 | Z = -.523, p = .601 |
| 700 | Z = -1.085, p = .278 | Z = -.196, p = .844 | Z = -.420, p = .675 | Z = -.471, p = .637 |
| 800 | Z = -.350, p = .726 | Z = -.426, p = .670 | Z = -.724, p = .469 | Z = -.535, p = .593 |
| 900 | Z = -.420, p = .674 | Z = -.022, p = .983 | Z = -.569, p = .570 | Z = -.350, p = .726 |
| 1000 | Z = -2.121, p = .034 | Z = -.403, p = .687 | Z = -.385, p = .700 | Z = -1.317, p = .188 |
| 1100 | Z = -1.274, p = .203 | Z = -.561, p = .575 | Z = -.157, p = .875 | Z = -.426, p = .670 |
| 1200 | Z = -1.580, p = .114 | Z = -.191, p = .848 | Z = -.445, p = .656 | Z = -.944, p = .345 |
| 1300 | Z = -1.125, p = .260 | Z = -.829, p = .407 | Z = -.356, p = .722 | Z = -.505, p = .613 |
| 1400 | Z = -.524, p = .600 | Z = -1.373, p = .170 | Z = -.415, p = .678 | Z = -.314, p = .754 |
| 1500 | Z = -.085, p = .933 | Z = -.234, p = .815 | Z = -1.482, p = .138 | Z = -.444, p = .657 |
| 1600 | Z = -.153, p = .878 | Z = -.447, p = .655 | Z = -1.363, p = .173 | Z = -.347, p = .728 |
| 1700 | Z = -.850, p = .395 | Z = -.732, p = .464 | Z = -.674, p = .500 | Z = -1.703, p = .089 |
| 1800 | Z = -.638, p = .524 | Z = -.282, p = .778 | Z = -.135, p = .892 | Z = -1.328, p = .184 |
| 1900 | Z = -1.011, p = .312 | Z = -.751, p = .452 | Z = -.845, p = .398 | Z = -1.078, p = .281 |
| 2000 | Z = -.516, p = .606 | Z = -.568, p = .570 | Z = -.674, p = .500 | Z = -.904, p = .366 |
| 2100 | Z = -.516, p = .606 | Z = -.000, p = 1.000 | Z = -.000, p = 1.000 | Z = -.723, p = .470 |
| 2200 | Z = -.137, p = .891 | Z = -.577, p = .564 | Z = -1.342, p = .180 | Z = -.756, p = .450 |
| 2300 | Z = -.535, p = .593 | Z = -.272, p = .785 | Z = -1.342, p = .180 | Z = -.000, p = 1.000 |
| 2400 | Z = -1.000, p = .317 | Z = -.000, p = 1.000 | Z = -1.761, p = .078 | Z = -1.000, p = .317 |
| 2500 | Z = -1.000, p = .317 | Z = -.000, p = 1.000 | Z = -.1.069, p = .285 | Z = -1.000, p = .317 |

*Note.* Figures in boldface indicate a significant result after Bonferroni correction.

**Table A21-8-4. Mann-Whitney Test Results for the orthographic condition in Experiment 5 (by-subjects)**

| Time | Pseudotarget -Unrelated | Pseudosemantic - Unrelated | Pseudophonological - Unrelated |
|---|---|---|---|
| 0 | Z = -.027, p = .978 | Z = -.149, p = .882 | Z = -.623, p = .533 |
| 100 | Z = -1.692, p = .091 | Z = -.176, p = .860 | Z = -.868, p = .386 |
| 200 | Z = -1.530, p = .126 | Z = -1.627, p = .104 | Z = -.244, p = .807 |
| 300 | Z = -.338, p = .735 | Z = -1.047, p = .295 | Z = -.747, p = .455 |
| 400 | Z = -.839, p = .401 | Z = -1.111, p = .266 | Z = -.055, p = .956 |
| 500 | Z = -.650, p = .516 | Z = -.530, p = .596 | Z = -.195, p = .845 |
| 600 | Z = -.934, p = .350 | Z = -.366, p = .714 | Z = -.233, p = .816 |
| 700 | Z = -.582, p = .561 | Z = -.366, p = .714 | Z = -.250, p = .802 |
| 800 | Z = -.325, p = .745 | Z = -.651, p = .515 | Z = -.000, p = 1.000 |
| 900 | Z = -.149, p = .882 | Z = -.639, p = .523 | Z = -.653, p = .514 |
| 1000 | Z = -.434, p = .665 | Z = -.498, p = .619 | Z = -1.084, p = .278 |
| 1100 | Z = -1.375, p = .169 | Z = -.238, p = .812 | Z = -1.164, p = .245 |
| 1200 | Z = -.995, p = .320 | Z = -.618, p = .536 | Z = -1.537, p = .124 |
| 1300 | Z = -.046, p = .963 | Z = -.558, p = .577 | Z = -1.589, p = .112 |
| 1400 | Z = -.161, p = .872 | Z = -.309, p = .757 | Z = -.137, p = .891 |
| 1500 | Z = -1.196, p = .232 | Z = -.226, p = .821 | Z = -.407, p = .731 |

**Table A21-8-5. Mann-Whitney Test Results for the orthographic condition in Experiment 5 (by-items)**

| Time | Pseudotarget -Unrelated | Pseudosemantic - Unrelated | Pseudophonological - Unrelated |
|---|---|---|---|
| 0 | Z = -.231, p = .817 | Z = -.125, p = .900 | Z = -.724, p = .469 |
| 100 | Z = -1.429, p = .153 | Z = -.227, p = .821 | Z = -.232, p = .816 |
| 200 | Z = -.770, p = .441 | Z = -1.062, p = .288 | Z = -.408, p = .683 |
| 300 | Z = -.482, p = .630 | Z = -1.068, p = .286 | Z = -.407, p = .684 |
| 400 | Z = -.992, p = .321 | Z = -.845, p = .398 | Z = -.167, p = .867 |
| 500 | Z = -.718, p = .473 | Z = -.189, p = .850 | Z = -.346, p = .729 |
| 600 | Z = -.728, p = .467 | Z = -.566, p = .571 | Z = -.898, p = .369 |
| 700 | Z = -.260, p = .795 | Z = -.238, p = .812 | Z = -.035, p = .972 |
| 800 | Z = -.338, p = .736 | Z = -.010, p = .992 | Z = -.142, p = .887 |
| 900 | Z = -.696, p = .487 | Z = -.238, p = .812 | Z = -.650, p = .516 |
| 1000 | Z = -.650, p = .516 | Z = -.703, p = .482 | Z = -.791, p = .429 |
| 1100 | Z = -.080, p = .936 | Z = -1.316, p = .188 | Z = -.068, p = .490 |
| 1200 | Z = -.691, p = .490 | Z = -.519, p = .604 | Z = -1.379, p = .168 |
| 1300 | Z = -.137, p = .891 | Z = -.694, p = .488 | Z = -1.261, p = .207 |
| 1400 | Z = -.412, p = .680 | Z = -.490, p = .624 | Z = -.424, p = .671 |
| 1500 | Z = -.335, p = .737 | Z = -.800, p = .424 | Z = -.091, p = .927 |

# Appendix 22. Stimuli used in Experiment 6.

**Table A22-9-1. Sentences used in the sentence processing task described in Chapter 9 (taken from Belanger et al. 2013). The frequencies of prime and target pairs are shown in the frequency column. The identical, homophone, orthographically similar and unrelated columns show what primes were used in each of the conditions during the experimental trials.**

| Frequency | Sentences | Identical | Homophone | Orthographically Similar | Unrelated |
|---|---|---|---|---|---|
| **HF-LF** | She took her blue **bear** everywhere, as it was her favourite toy. | bear | bare | bean | golf |
| **HF-LF** | Joe is always saving **blue** paper for the letters he writes to his wife. | blue | blew | blur | mass |
| **HF-LF** | The students carried the heavy **board** to the room in order to hide it from the teacher. | board | bored | beard | tight |
| **HF-LF** | The children took a long **break** from school during the summer. | break | brake | bread | fifty |
| **HF-LF** | The little girl wanted to see her **dear** friend before going to her new school. | dear | deer | deaf | pity |
| **HF-LF** | The ants slowly **die** when I spray them with insect spray. | die | dye | dip | tan |
| **HF-LF** | My friend and I missed our **hair** appointment this morning. | hair | hare | hail | plug |
| **HF-LF** | The woman tried to quickly **flee** from the large brown dog. | flee | flea | flex | yawn |
| **HF-LF** | My mother looked at her black **heel** because she thought it was broken. | heel | heal | heed | wisp |
| **HF-LF** | Dan was always **here** for me if I needed to talk to him. | here | hear | hire | copy |

| | | | | | |
|---|---|---|---|---|---|
| **HF-LF** | The children carefully **made** pancakes for their mother and father this morning. | made | maid | mode | long |
| **HF-LF** | Inside the house there was **fur** everywhere as the owners had two cats. | fur | fir | far | top |
| **HF-LF** | Greg and Tina will probably **meet** Jacob at the party next weekend. | meet | meat | melt | paid |
| **HF-LF** | The old man wanted to make **minor** changes to his diet. | minor | miner | manor | guest |
| **HF-LF** | Sarah and Sam were a great **pair** when they first met. | pair | pear | paid | note |
| **HF-LF** | My parents became **pale** because I was hurt during the football game. | pale | pail | palm | sink |
| **HF-LF** | Everybody wanted the largest **piece** of pizza in the box. | piece | peace | niece | mouth |
| **HF-LF** | Bob's hair colour looked **plain** after he changed it last week. | plain | plane | plaid | tempt |
| **HF-LF** | Her bottom **right** leg was really painful after she fell. | right | write | eight | moral |
| **HF-LF** | The boy saw several **road** signs fall over during the storm. | road | rode | read | view |
| **HF-LF** | My little girl loved to say **bye** to everyone she passed in the street. | bye | buy | bee | job |
| **HF-LF** | Fred gave the pretty **rose** to his girlfriend before the dance. | rose | rows | rise | walk |
| **HF-LF** | My father went to his favourite **sale** with his friend on Friday. | sale | sail | salt | pink |
| **HF-LF** | My parents never **see** the red bird in the garden because they wake up too late. | see | sea | set | big |
| **HF-LF** | Amy wants her lonely **son** to find a wife and start a family. | son | sun | soy | tab |
| **HF-LF** | Nadia met a man with bad soul and she did not want to talk to him. | soul | sole | soup | kick |

| | | | | | |
|---|---|---|---|---|---|
| **HF-LF** | The man found a yellow **stake** next to his flowers this morning. | stake | steak | stage | brown |
| **HF-LF** | The man greeted me with a strange **stare** when I walked into the room. | stare | stair | state | union |
| **HF-LF** | Jen reads next to the large **steel** wall in the restaurant down the street. | steel | steal | steep | odour |
| **HF-LF** | My best friend buys **sweet** apples for his girlfriend every week. | sweet | suite | sweat | rally |
| **HF-LF** | Ray was attaching a long **tail** to his new Halloween costume. | tail | tale | tail | nose |
| **HF-LF** | My mother always asks for green **tea** in the morning before going to work. | tea | tee | ten | boy |
| **HF-LF** | My sister quickly **tied** her shoes before leaving for school. | tied | tide | tier | harp |
| **HF-LF** | Taylor showed his small **toe** to his sisters in the hospital. | toe | tow | top | six |
| **HF-LF** | Tim found hidden **waste** in the cupboard of his first home. | waste | waist | caste | drink |
| **HF-LF** | Jason had an amazing **week** because he bought his first dog. | week | weak | weep | yarn |
| **LF-HF** | His house was **bare** as he moved in last week. | bare | bear | bore | chin |
| **LF-HF** | Kim and George **blew** on the hot soup before drinking it at dinner. | blew | blue | bled | fish |
| **LF-HF** | My brother and sister were **bored** because they were alone at home. | bored | board | boxed | night |
| **LF-HF** | The man did not slowly **brake** before the car crash yesterday. | brake | break | brave | solid |
| **LF-HF** | Danny saw a large **deer** on the road in front of his house. | deer | dear | deep | bill |
| **LF-HF** | Dan forgot to buy the yellow **dye** for his mother. | dye | die | due | tax |
| **LF-HF** | My sister loved the beautiful **hare** in the movie she saw last night. | hare | hair | hate | rain |

| | | | | | |
|---|---|---|---|---|---|
| **LF-HF** | My mom found a large **flea** on our dog after they went for a walk. | flea | flee | flew | soon |
| **LF-HF** | My grandpa thought he would never **heal** after his bad car accident. | heal | heel | hell | firm |
| **LF-HF** | Mike could barely **hear** the music because of the loud yelling upstairs. | hear | here | head | nose |
| **LF-HF** | Bob needed a better **maid** to clean up the mess he had made in the kitchen. | maid | made | main | born |
| **LF-HF** | My friend saw a large **fir** tree at the bottom of the garden. | fir | fur | fit | eat |
| **LF-HF** | My father and brother like eating **meat** for dinner almost everyday. | meat | meet | melt | wood |
| **LF-HF** | Jesse asked the brave **miner** if he was ever afraid of the dark. | miner | minor | mixer | watch |
| **LF-HF** | Willy stole a cheap **pear** and got in trouble after he got caught. | pear | pair | peas | miss |
| **LF-HF** | David could not carry the heavy **pail** across the huge garden. | pail | pale | pair | next |
| **LF-HF** | My mother wanted **peace** in the house after a hard day at work. | peace | piece | place | found |
| **LF-HF** | They were worried when they saw a **plane** flying over the city park. | plane | plain | plant | truth |
| **LF-HF** | Britney really wanted to **write** an email to her friend before going to bed. | write | right | white | young |
| **LF-HF** | My sister and I **rode** to the park on Friday. | rode | road | rude | film |
| **LF-HF** | My neighbour went to **buy** the cat a new collar. | buy | bye | bay | tip |
| **LF-HF** | My mum looked at many **rows** of seats in the theatre but she didn't find us. | rows | rose | rods | blue |
| **LF-HF** | The man lost the **sail** for his boat and could not leave for his trip. | sail | sale | said | poor |
| **LF-HF** | Tommy stayed away from the dark **sea** when he wanted to swim. | sea | see | set | low |

| | | | | | |
|---|---|---|---|---|---|
| **LF-HF** | My brother did not see the morning **sun** because he woke up late. | sun | son | sin | try |
| **LF-HF** | My brother found a stinky **sole** in the back of his wardrobe. | sole | soul | some | farm |
| **LF-HF** | My dad burned the large **steak** because he was distracted. | steak | stake | speak | wrong |
| **LF-HF** | Jane missed the first **stair** and fell on the person in front of her. | stair | stare | stin | month |
| **LF-HF** | My sister saw our grandfather **steal** a cookie from the plate before dinner. | steal | steel | steam | round |
| **LF-HF** | Everyone liked the large **suite** better than the little room without a view. | suite | sweet | spite | known |
| **LF-HF** | When she was young, her mother told her a short **tale** every night after dinner. | tale | tail | tape | kind |
| **LF-HF** | Jerry kept the plastic **tee** from his first lesson with the golf teacher. | tee | tea | ten | job |
| **LF-HF** | Esther saw the high **tide** when she went to the ocean yesterday. | tide | tied | tire | park |
| **LF-HF** | The man wanted to **tow** away the very expensive car parked on his street. | tow | toe | toy | aid |
| **LF-HF** | The little girl measured her **waist** before she bought a new shirt. | waist | waste | wrist | hello |
| **LF-HF** | Bobby was feeling **weak** after he ate a big lunch. | weak | week | wear | turn |

*Note.* Words in boldface show where the stimuli manipulations were made.

# Appendix 23. Sentences and comprehension questions used in Experiment 6.

**Table A23-9-2. Sentences and comprehension questions for the sentence processing task.**

| Trial | Frequency | Sentences | Questions |
|---|---|---|---|
| **1** | HF-LF | She took her blue bear everywhere as it was her favourite toy. | Did she take her blue bear everywhere? |
| **2** | HF-LF | Joe is always saving blue paper for the letters he writes to his wife. | |
| **3** | HF-LF | The students carried the heavy board to the room in order to hide it from the teacher. | Did the students hide the board? |
| **4** | HF-LF | The children took a long break from school during the summer. | Did the children take a break in the autumn? |
| **5** | HF-LF | The little girl wanted to see her dear friend before going to her new school. | |
| **6** | HF-LF | The ants slowly die when I spray them with insect spray. | Did the bees die? |
| **7** | HF-LF | My friend and I missed our hair appointment this morning. | Did we go to the appointment? |
| **8** | HF-LF | The woman tried to quickly flee from the large brown dog. | |
| **9** | HF-LF | My mother looked at her black heel because she thought it was broken. | Was my mother looking at her shoes? |
| **10** | HF-LF | Dan was always here for me if I needed to talk to him. | |
| **11** | HF-LF | The children carefully made pancakes for their mother and father this morning. | Did the children make pancakes? |
| **12** | HF-LF | Inside the house there was fur everywhere as the owners had two cats. | |
| **13** | HF-LF | Greg and Tina will probably meet Jacob at the party next weekend. | |
| **14** | HF-LF | The old man wanted to make minor changes to his diet. | Did the man exercise more? |
| **15** | HF-LF | Sarah and Sam were a great pair when they first met. | |
| **16** | HF-LF | My parents became pale because I was hurt during the football game. | |
| **17** | HF-LF | Everybody wanted the largest piece of pizza in the box. | Did they want a piece of chocolate? |
| **18** | HF-LF | Bob's hair colour looked plain after he changed it last week. | Did Bob change his hair colour? |
| **19** | HF-LF | Her bottom right leg was really painful after she fell. | |
| **20** | HF-LF | The boy saw several road signs fall over during the storm. | |
| **21** | HF-LF | My little girl loved to say bye to everyone she passed in the street. | |

| | | | |
|---|---|---|---|
| **22** | HF-LF | Fred gave the pretty rose to his girlfriend before the dance. | Did Fred give a tulip to his girlfriend? |
| **23** | HF-LF | My father went to his favourite sale with his friend on Friday. | |
| **24** | HF-LF | My parents never see the red bird in the garden because they wake up too late. | |
| **25** | HF-LF | Amy wants her lonely son to find a wife and start a family. | Does Amy want her son to get married? |
| **26** | HF-LF | Nadia met a man with bad soul and she did not want to talk to him. | |
| **27** | HF-LF | The man found a yellow stake next to his flowers this morning. | |
| **28** | HF-LF | The man greeted me with a strange stare when I walked into the room. | Did the man look at me when I came in the room? |
| **29** | HF-LF | Jen reads next to the large steel wall in the restaurant down the street. | |
| **30** | HF-LF | My best friend buys sweet apples for his girlfriend every week. | |
| **31** | HF-LF | Ray was attaching a long tail to his new Halloween costume. | |
| **32** | HF-LF | My mother always asks for green tea in the morning before going to work. | Does my mother ask for coffee? |
| **33** | HF-LF | My sister quickly tied her shoes before leaving for school. | |
| **34** | HF-LF | Taylor showed his small toe to his sisters in the hospital. | Was Taylor in the hospital? |
| **35** | HF-LF | Tim found hidden waste in the cupboard of his first home. | |
| **36** | HF-LF | Jason had an amazing week because he bought his first dog. | |
| **37** | LF-HF | His house was bare as he moved in last week. | |
| **38** | LF-HF | Kim and George blew on the hot soup before drinking it at dinner. | |
| **39** | LF-HF | My brother and sister were bored because they were alone at home. | |
| **40** | LF-HF | The man did not slowly brake before the car crash yesterday. | Was there a car crash? |
| **41** | LF-HF | Danny saw a large deer on the road in front of his house. | |
| **42** | LF-HF | Dan forgot to buy the yellow dye for his mother. | |
| **43** | LF-HF | My sister loved the beautiful hare in the movie she saw last night. | Did my sister see a play last night? |
| **44** | LF-HF | My mom found a large flea on our dog after they went for a walk. | |
| **45** | LF-HF | My grandpa thought he would never heal after his bad car accident. | |
| **46** | LF-HF | Mike could barely hear the music because of the loud yelling upstairs. | Could Mike hear the music? |
| **47** | LF-HF | Bob needed a better maid to clean up the mess he had made in the kitchen. | |
| **48** | LF-HF | My friend saw a large fir tree at the bottom of the garden. | |
| **49** | LF-HF | My father and brother like eating meat for dinner almost everyday. | |
| **50** | LF-HF | Jesse asked the brave miner if he was ever afraid of the dark. | Was the miner afraid of Jesse? |
| **51** | LF-HF | Willy stole a cheap pear and got in trouble after he got caught. | Did Willy get in trouble? |

| | | | |
|---|---|---|---|
| **52** | LF-HF | David could not carry the heavy pail across the huge garden. | |
| **53** | LF-HF | My mother wanted peace in the house after a hard day at work. | Is my mother working hard? |
| **54** | LF-HF | They were worried when they saw a plane flying over the city park. | |
| **55** | LF-HF | Britney really wanted to write an email to her friend before going to bed. | Did Britney want to write a book? |
| **56** | LF-HF | My sister and I rode to the park on Friday. | |
| **57** | LF-HF | My neighbour went to buy the cat a new collar. | |
| **58** | LF-HF | My mum looked at many rows of seats in the theatre but she didn't find us. | Did my mum find us? |
| **59** | LF-HF | The man lost the sail for his boat and could not leave for his trip. | |
| **60** | LF-HF | Tommy stayed away from the dark sea when he wanted to swim. | |
| **61** | LF-HF | My brother did not see the morning sun because he woke up late. | Did my brother wake up early? |
| **62** | LF-HF | My brother found a stinky sole in the back of his wardrobe. | |
| **63** | LF-HF | My dad burned the large steak because he was distracted. | |
| **64** | LF-HF | Jane missed the first stair and fell on the person in front of her. | Did Jane fall? |
| **65** | LF-HF | My sister saw our grandfather steal a cookie from the plate before dinner. | |
| **66** | LF-HF | Everyone liked the large suite better than the little room without a view. | |
| **67** | LF-HF | When she was young, her mother told her a short tale every night after dinner. | |
| **68** | LF-HF | Jerry kept the plastic tee from his first lesson with the golf teacher. | |
| **69** | LF-HF | Esther saw the high tide when she went to the ocean yesterday. | Did Esther go to the ocean yesterday? |
| **70** | LF-HF | The man wanted to tow away the very expensive car parked on his street. | Did the man tow an expensive car? |
| **71** | LF-HF | The little girl measured her waist before she bought a new shirt. | |
| **72** | LF-HF | Bobby was feeling weak after he ate a big lunch. | |

# Appendix 24. Changes to stimuli for Experiment 6.

The following changes to sentences were made due to differences between British and American English (changes are indicated in **bold**).

1. I am going to **beat** you in the race this Thursday. (beat, beet, belt, golf) and this has been changed to ‘His house was **bare** as he moved in last week’ (bare, bear, bore, chin). ‘*Beet’ is rarely used in British English.*
2. Gina saw a large **male** dog and she got scared. (male, mail, mule, spin), changed to ‘inside the house there was **fur** everywhere as the owners had two cats’ (fur, fir, far, top). *‘Mail’ is rarely used in British English.*
3. The children threw a large **beet** at the mean dog (beet, beat, best, door), changed to ‘She took her blue **bear** everywhere as it was her favourite toy’ (bear, bare, bean, golf). ‘*Beet’ is rarely used in British English.*
4. My family and I never **rode** the bus (rode, road, rude, film), changed to ‘my sister and I **rode** to the park on Friday’ (same as previous). *In British English, people don’t say ‘rode’ the bus, ‘rode’ only refers to cycling or horse riding.*
5. My friend never reads his regular **mail** he always checks his emails (mail, male, mall, type), changed to ‘my friend saw a large **fir** tree at the bottom of the garden’ (fir, fur, fit, eat). *‘Mail’ is rarely used in British English.*
6. My sister loved the beautiful **fairy** she saw in the movie last night (fairy, ferry, fairs, melon), changed to ‘my friend and I missed our **hair** appointment this morning (hair, hare, hail, plug). *‘Fairy’ and ’ferry’ are not homophones in British English.*
7. My family and I missed the early **ferry** ride this morning (ferry, fairy, furry, music) changed to ‘my sister loved the beautiful **hare** she saw in the movie last night’ (hare, hair, hate, rain) *‘Fairy’ and ’ferry’are not homophones in British English.*

The following changes to sentences were made due to mistakes in the original stimuli.

8. My neighbour threw away the dried **roll** after dinner the other day (roll, role, reel, fine) changed to ‘my neighbour went to **buy** the cat a new collar (buy, bye, bay, tip) *Reel was used as an orthographically similar item in the original stimuli but there was a difference of two letters, and no orthographically similar item for ‘roll’, thus this was changed.*
9. My son had an important **role** in the play next month (role, roll, rule, gain) to ‘my little girl loved to say **bye** to everyone she passed in the street (bye, buy, bee, job). *See previous explanation. This sentence was changed to preserve high/low frequency word pairs.*

**Single word changes**

I also spotted a few mistakes with the original stimuli. There were a couple of orthographically similar (OS) items that actually differed in more than 1 letter. The rest of the sentence was preserved.

1. Target = **sail**, Orthographically Similar Item = **salt**, which differed by two letters and thus changed to **‘said’**.
2. Target = **rows**, Orthographically Similar Item = **cows**, which was changed to **‘robs’** to avoid word initial change.
3. Target = **tea**, Orthographically Similar Item = **tie**, which differed by two letters and thus changed to **‘ten’**.

### Other Items

These are a few other orthographically similar items that differed in word initial positions, which have been left unchanged to prevent too many changes to the stimuli.

1. Piece/niece
2. Right/eight
3. Waste/caste

### Comprehension questions

Some comprehension questions were amended as the original sentences were amended.

1. *Sentence 37* (the children threw a large beet, changed to ‘She took her blue bear everywhere as it was her favourite toy’. Comprehension question changed from, ‘was the dog nice?’ to ‘did she take her blue bear everywhere?’
2. *Sentence 43* – sentence changed thus question changed from ‘did we miss the bus?’ to ‘did my sister see a play last night?’

### Changes within sentences

Some changes were made within the sentences to accommodate for differences between British and American English, however in these cases target and preview pairs were preserved.

- Mom to mum
- Closet to cupboard
- Bug to insect
- Yelling to shouting
- Baseball to football
- Favorite to favourite
- Backyard to garden

# Appendix 25. Correlation analyses for Experiment 6.

**Table A25-9-1. Results from the correlation analyses carried out between reading levels and performance on the sentence processing task.**

| Group | Correlations | N | r | p (2-tailed) |
|---|---|---|---|---|
| Both | Reading/Orthographic preview | 32 | .140 | .446 |
| Both | Reading/Phonological previews | 32 | .092 | .616 |
| Deaf | Reading/Orthographic previews | 16 | -.022 | .937 |
| Hearing | Reading/Orthographic previews | 16 | .451 | .080 |
| Deaf | Reading/Phonological previews | 16 | .012 | .964 |
| Hearing | Reading/Phonological previews | 16 | .258 | -.334 |
| Hearing | Reading/Overall previews | 16 | -.210 | .434 |

# Appendix 26. Glossary of abbreviations

| **Abbreviations** | |
|---|---|
| **Acc** | Accuracy |
| **ANOVA** | Analysis of Variance |
| **AOA** | Age of Acquisition |
| **ASL** | American Sign Language |
| **BSL** | British Sign Language |
| **dBHL** | Reaction Times |
| **DGS** | Deutsche Gebärdensprache (German Sign Language) |
| **DRC Model** | Dual Route Cascaded Model |
| **ELP** | English Lexicon Project |
| **GLMM** | General Linear Mixed Models |
| **GPC Rules** | Grapheme-to-phoneme correspondence rules |
| **HND** | Higher National Diploma |
| **IQ** | Intelligent Quotient |
| **L1** | First Language |
| **L2** | Second Language |
| **LMM** | Linear Mixed Effects Models |
| **LSQ** | Langue des Signes Québécoise (Quebec Sign Language) |
| **M** | Mean |
| **ms** | Milliseconds |
| **N** | Sample number |
| **NW** | Nonword |
| **ONS** | Orthographic Neighbourhood Size |

| | |
|---|---|
| **PH** | Pseudohomophone |
| **RT** | Decibels Hearing Level |
| **SD** | Standard Deviation |
| **SE** | Standard Error |
| **SOA** | Stimulus Onset Asynchrony |
| **SRT** | Sentence Repetition Task |
| **TAS** | Test of Adult Speechreading |

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