VISUAL WORD RECOGNITION IN BILINGUALS AND MONOLINGUALS:

BEHAVIOURAL AND ERP INVESTIGATIONS OF THE ROLE OF WORD FREQUENCY, LEXICALITY AND REPETITION

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Thesis Abstract

This thesis investigated visual word recognition in bilinguals and monolinguals through the effects of word frequency, lexicality and repetition. The first series of experiments focused on whether bilinguals can suppress lexical access in a non-target language and the role of task demands in L1 and L2 lexical access. The next series of experiments further investigated the role of task demands, list composition and repetition in monolinguals. The ERP data show, for the first time, that in bilinguals, lexical access occurs in the non-target language, supporting the notion of a nonselective lexical access. Delayed lexicality effects in ERPs for L2 compared to L1 suggested a delay in lexical access for L2 in late bilinguals, although behavioural data showed a similar word frequency effect to L1. These conflicting responses have not been anticipated by current models of bilingual visual word recognition. However, monolingual data make clear that lexical effects can be modulated by task demands and list composition in behavioural responses. In monolinguals, the slower processing of less familiar items was enhanced by item repetition only when the task required a lexical decision and words and word-like letter strings were presented. Lastly, this thesis has demonstrated that current models of visual word recognition have not fully implemented these elements and have not predicted response times distribution or ERPs. Future models of visual word recognition should incorporate these elements to be able to characterise lexical access in bilinguals and monolinguals.

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Chapter 1. Introduction to Visual Word Recognition

Literacy has been one of the main achievements of a civilised society. The ability to read and write has enabled human communication to transcend time and distance. Visual word recognition is a key component of reading. This process involves identifying words in the mental lexicon from printed symbols and retrieving information about these from long-term memory (Dixon and Rothkopf, 1979). This process, which is also referred to as lexical access, consists of a set of operations that start when readers are presented with a sequence of letters and spaces. Readers compute a form representation based on the physical signal and match it to representations stored in long-term memory (Grainger & Jacobs, 1996). Some of the most important factors that affect lexical access in monolinguals and bilinguals will be discussed in this chapter, as well as their implications for models of visual word recognition.

This chapter provides an overview of visual word recognition in monolinguals and in bilinguals. I will focus on the factors that have been found to influence the visual word recognition process: lexicality (differences in responses between words and nonwords), word frequency (differences in responses between high and low frequency words), repetition and experimental task demands. Behavioural and event-related potentials (ERP) findings in the literature will be discussed. I will also consider "mega studies" and highlight gaps in the literature that require further investigation. Other factors that also influence the visual word recognition process will be discussed briefly in relation to lexicality, word frequency, repetition and task demands. Finally, the most prominent theoretical and computational models of visual word recognition in monolinguals and bilinguals will be presented and evaluated in terms of their ability to account for effects of lexicality, word frequency, repetition and task demands.

1.1. MONOLINGUAL VISUAL WORD RECOGNITION

Word recognition research has played an important role in cognitive psychology and psycholinguistics since the information defined and carried by words allow different levels of analysis and the processes related to this analysis (Balota, Yap & Cortese, 2006).

To investigate visual word recognition, research has detected differences in the speed of responses and the number of errors associated with letter strings of specific characteristics in different experimental tasks. Later, more research has been conducted investigating changes in brain responses, such as electrical brain potentials associated with specific stimuli (event-related potentials or ERPs). This section focuses on monolinguals visual word recognition, namely, behavioural and electrophysiological findings.

1.1.1. BEHAVIOURAL FINDINGS

The storage of representations in memory has been investigated using different tasks that directly request the identification of "real" words (Meyer & Schvaneveldt, 1971) or indirectly investigate the effect of the manipulation of lexical variables through letter identification (Reicher, Wheeler) or by the identification of similar stimuli (Barron & Pittenger, 1974). One of the first studies that used the lexical decision task was that of Rubenstein, Garfield and Milikan (1970). In the lexical decision task, participants decide whether a letter string is a "real" word or not. Rubenstein, Garfield and Milinkan's study showed that responses were faster when they were made to words compared to nonwords, as well as they observed that the frequency of usage of the words influenced the speed of responses.

The above findings supported the idea that the mental lexicon is accessed when participants make lexical decisions. Letter strings that are represented in the lexicon ("real" words) are recognised without delays. Furthermore, the influence of the frequency of exposure to words supported the proposal that representations that are used more often are more available than less used representations. This was, according to Meyer and Schvaneveldt (1971), evidence of the importance that specific letter strings recognised as "real" words compared to nonwords (lexicality effect), as well as the frequency of usage of the words (word frequency effect). The next sections discuss in more depth the role of lexicality and frequency in visual word recognition tasks. Findings from behavioural responses (reaction times and error rate) are described in the following sections.

1.1.1.1. LEXICALITY EFFECTS

Lexicality refers to the difference between responding or processing real words compared to responding or processing 'wordlike' letter strings (i.e., pronounceable letter strings or pseudowords). It was first demonstrated in the Reicher-Wheeler paradigm (Reicher, 1969; Wheeler, 1970). In this experimental paradigm participants decide whether a previously shown letter is present in a letter string.

Reicher's (1969) research focussed on whether information processing in humans worked in a serial or a parallel manner. Participants saw letters (one or two), four-letter words and four-letter nonwords. In a pre-cued condition, the two alternative letters were verbally given to the subjects, in contrast to a noncue condition in which no information was provided. The task instruction was to identify one of the previously shown letters within the letters or letters strings (Figure 1.1). Participants' responses were more accurate when letters were previously presented within words than when these were presented as letters or within nonwords. This higher accuracy in responses to words compared to responses to letters was interpreted as opposing the hypothesis of a serial and hierarchical processing of the letter strings. Reicher argued that instead, these results indicated that lexical access occurred in a parallel manner during the first stages of visual processing.

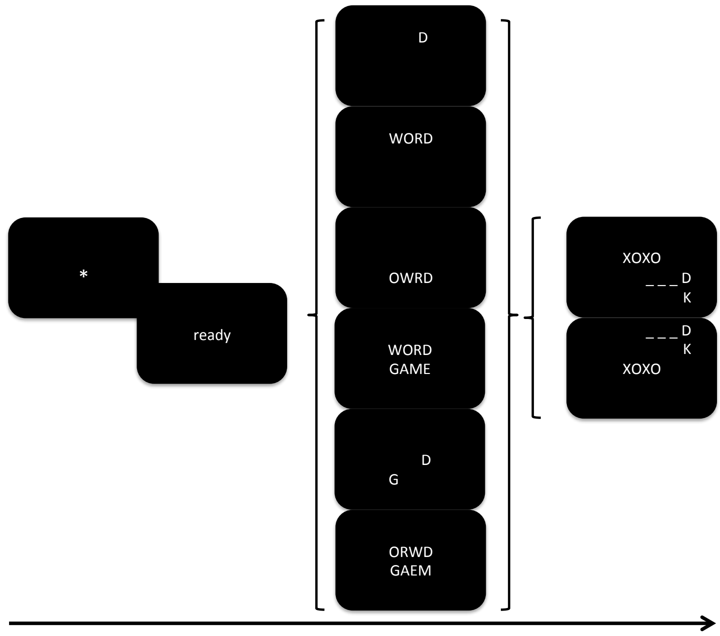

Figure 1.1 Task used in Reicher (1969)'s study. The figure presents the sequence in time from the presentation of a fixation until the screen where response was expected. The task presented here is the version with one stimulus row and no pre-cue condition

Wheeler (1970) further investigated these more accurate responses to letters presented in words ('word superiority effect') using the same paradigm as Reicher (1969). His research focused on whether the word superiority effect could be accounted for by either a serial or a parallel model. With this purpose, he proposed that separate processes consistent with serial and parallel models could account for the word superiority effect. Five mechanisms were tested: interference from the choice letters aiding recognition of word stimuli, pre-processing occurring before the recognition process and letter position uncertainty, focusing on differences in letter position within words, response bias towards more frequent word alternatives in recognition, and "easier" access to more frequent words. Consistent with Reicher's results, Wheeler's (1970) results revealed more accurate responses to words over single letter items. Wheeler rejected the five mechanisms to explain the word superiority effect and concluded that word recognition cannot be analysed into a set of independent letter recognition processes. However, he emphasised that the letters conforming the letter string provided a context in a letter sequence that could improve recognition. Therefore, the letter arrangements of various letter strings can improve performance in word recognition.

Faster responses for words compared to nonwords have also been found in tasks in which the decision does not involve word or letter recognition decision directly (Barron & Pittenger, 1974; Chambers & Forster, 1975). Based on previous evidence that lexical meaning (Eichelman, 1970) and orthographic structure (Baron & Thurston, 1973) influence word perception, Barron and Pittenger (1974) suggested that the type of task decision influences the identification within words and nonwords. They used the simultaneous matching task, also known as the "same-different" task (Figure 1.2). In this task, participants are presented with two letter strings, which could be real words, pseudowords (e.g., sloce) or nonwords (e.g., oevrc). Participants in this task should decide whether or not the letter strings are the same. Barron and Pittenger's results from "same" decisions revealed faster responses to words compared to pseudowords, as well as faster responses to pseudowords compared to nonwords. However, results from "different" responses did not exhibit any difference between the stimulus conditions. Therefore, it was suggested that different processes take place for "different" and "same" decisions. Chambers and Forster (1975) later confirmed these results.

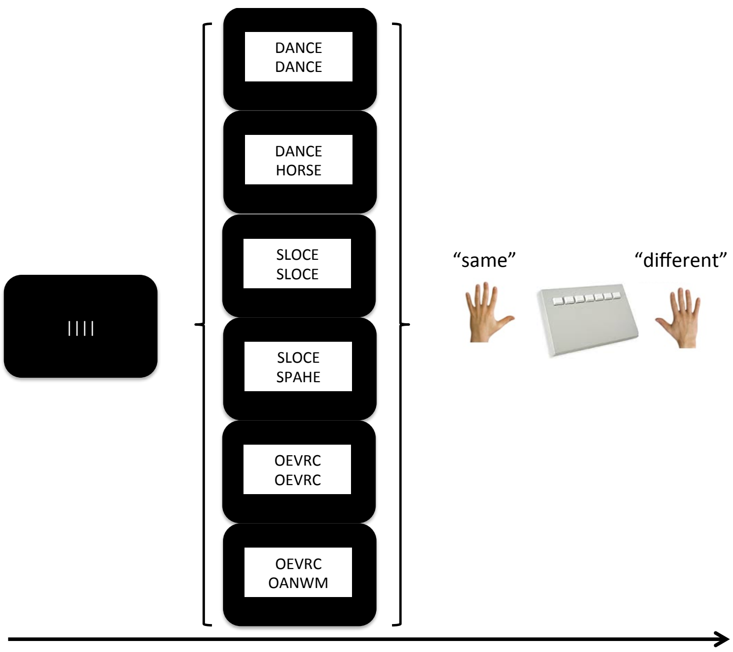

Figure 1.2 The "Same-different" task employed by Barron and Pittenger (1974)

Three levels of identification (word, letter cluster and letter) have been proposed to operate simultaneously when the stimuli are processed in the simultaneous matching task (Chambers & Forster, 1975). Adams (1979) has also proposed different levels of identification in visual word recognition. She found a "word superiority effect" regardless of letter type in a series of experiments using a backward masking paradigm (Figure 1.3). The stimulus onset asynchrony was variable, as well as the letter case. In this task participants were required to write down the stimulus list seen during the task at the end of the stimuli block or at the end of the trial. Additionally, they included a forced-choice categorisation task where individuals reported whether or not the presented letter string was a word. In both tasks, words, pronounceable nonwords and nonpronounceable words were presented. Responses were more accurate for words than for nonwords; however, these were also more accurate for pronounceable nonwords that for nonpronounceable nonwords.

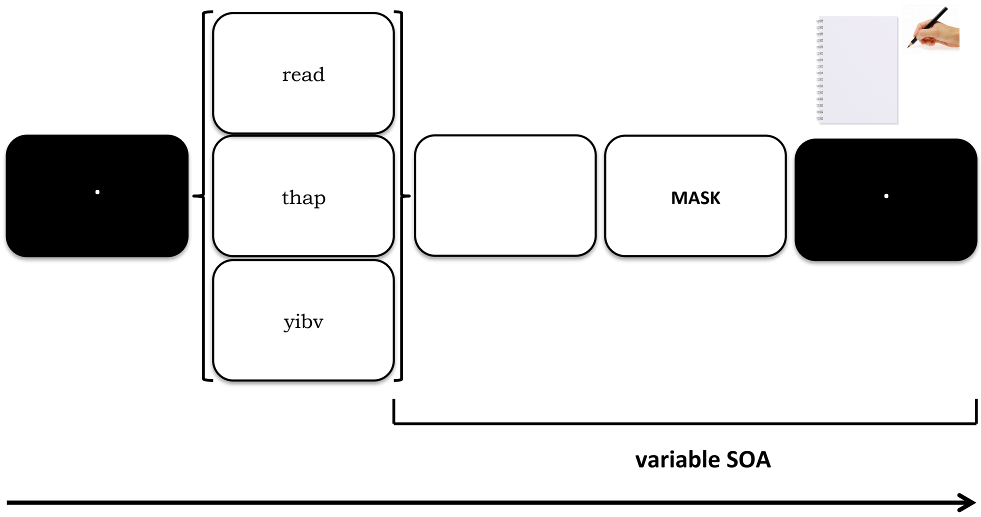

Figure 1.3 Backward masking paradigm used by Adams (1979). SOA = Stimulus onset asynchrony

In addition to the important evidence of the role of lexicality in visual recognition tasks (Henderson, 1980), findings of lexical decision tasks have supported this. The 'yes' and 'no' decisions in the lexical decision task have been considered as confound for the effect of lexicality (Pachella, 1974). Even though the type of response is confounded with the lexicality effect in the lexical decision task, findings from this task also provide evidence that the lexicality of the stimuli determines participants' performance. However, an opposite pattern of results has been observed in the lexical decision task compared to the recognition tasks previously mentioned. This pattern consists of faster and more accurate responses to pure consonant letter strings (e.g. CCCs) relative to responses to words and pronounceable letter strings (e.g. consonant-vowel-consonant strings) (e.g. Rubenstein et al., 1971a; Stanners, Forbach & Headley, 1971; Stanners, Forbach, Lewis & Rubenstein, 1973). Stanners, Forbach and Headley (1971) found a word frequency effect in words and pseudowords but not in nonpronounceable nonwords. The frequency for pseudowords was based on Venezky's (1962) norms. These norms were calculated with a computer program and consisted of a large-scale analysis of the sound-to-spelling correspondences in the English language with 20,000 of the most frequent words from the Thorndike Century Senior Dictionary (1941). Grapheme clusters (1-5 letters) were obtained from each word and associated with a phoneme cluster, which were one or more phonemes in length. The frequency was then obtained by including the entire word sample and a frequency distribution was partitioned based on the position of the correspondence on the letter string: initial, medial or final cluster. A more detailed description of these methods can be found in Stanners (1970). Stanners, Forbach & Headley (1971) proposed a two-stage process consistent of evaluation of the phonological structure of the item (evaluation-encoding) followed by a decision to reject that item or not (search-scan).

In a different study, Stanners & Forbach (1973) also presented words, consonant strings (CCCCCs) and consonant-vowel letter strings (CCVCCs) in a lexical decision task. The frequency of the first and the last consonant pair for all the three types of stimuli was manipulated in their experiment. The results were similar to Stanners, Forbach & Headley's (1971) where participants responded faster to consonant strings compared to words and consonant-vowel letter strings, the latter being the ones that showed the slowest responses. Stanners & Forbach (1973) concluded that the information from the consonant pairs was crucial to address a subset of memory representations especially for consonant-vowel letter strings.

In summary, these findings provide evidence of the important role of lexicality in the process of visual word recognition to facilitate (faster and more accurate) responses to items in words in recognition tasks that emphasise letter identification or on item similarity (e.g. Reicher-Wheeler, simultaneous matching, backward mask paradigm). In contrast, in the lexical decision task where the task decision is closely related to the lexicality of the letter strings, responses are usually faster and more accurate to nonwords (consonant strings) compared to words and pseudowords.

Although an explanation of the lexicality effect can vary according to the task, its contribution to the study of the mental lexicon is important since, although some letter strings are not real words (i.e. pseudowords or nonwords), they can show responses similar to those of words by incorporating letter clusters used in real words. This provides evidence of the needed letter organization required for lexical access. Moreover, as we will see later in this chapter the effect of lexicality can also be modulated by other factors (e.g. repetition and task demands). An important question is whether current models of lexical access can account for the lexicality effects reported in the literature. The models and their predictions in terms of the lexicality effect will be discussed later in this chapter. In the next section I will focus on the word frequency effect in visual word recognition tasks.

1.1.1.2. WORD FREQUENCY EFFECTS

The effect of word frequency is characterized by faster and more accurate responses to high frequency words compared to low frequency words. Usually, the responses to two or three levels of word frequency (e.g. high, medium, low) are considered in experiments. Among the first experiments to focus on word frequency and describe its effects on the number of errors was that of Howes and Solomon (1951). These authors investigated the relationship between word-probability (defined by relative frequency of occurrence) and the time it would take to perceive the word stimuli in what it was known as the visual threshold task. In this task, a word is presented for a very short duration initially that is gradually increased on successive exposures until the participant is able to report the word correctly. In Howes and Solomon's experiment, word frequency was estimated according to the written language in books and magazines (Thorndike-Lorge *Teacher's Word Book of 30,000 Words*). Although, only 75 words were included in their experiment, a strong inverse relationship between word frequency and the duration needed to report the word correctly was found. High frequency words were reported with shorter exposure durations.

Word frequency effects have been observed in a wide variety of experimental tasks, e.g. pronunciation tasks (e.g., Balota & Chumbley, 1984; Balota & Spieler, 1999), delayed naming tasks (e.g., Balota & Chumbley, 1985), semantic categorisation task (e.g., Monsell, Doyle, & Haggard, 1989), simultaneous matching task (e.g., Chambers and Forster, 1975) and lexical decision tasks (e.g., Scarborough, Cortese, & Scarborough, 1977; Balota & Spieler, 1999, Allen, Smith, Lien, Grabbe, & Martin, 2005). Word frequency has been consistently found to predict reaction times in the lexical decision task (e.g., Landauer & Freedman, 1968; Rubenstein, Garfield & Millikan, 1970).

Importantly, the effect of word frequency varies in size depending on the experimental task and it also interacts and modulates with other factors that influence visual word recognition. For example, the word frequency effect observed in a simultaneous matching task is smaller (38 ms) compared to the effect observed in other tasks (Chambers & Forster, 1975).

Balota and Chumbley (1984) showed that the size of the frequency effect was different in three different tasks: category verification, a lexical decision and a pronunciation task. The category verification task required the participants to decide whether word stimuli belonged to a category presented before the stimuli. In the pronunciation task the participants were required to read aloud the presented letter string. Results from the category verification task showed no effect of word frequency, whereas in the lexical decision and in the pronunciation tasks, the effect was significant, although larger for the lexical decision task (about 100 ms) compared to the pronunciation task (about 50 ms).

Monsell, Doyle & Haggard (1989) compared the effect of frequency between a syntactic categorisation task and a lexical decision task. They found that the effect varied significantly by task: the effect was 100 ms smaller in a syntactic categorisation task compared to the effect in a lexical decision task.

Grainger (1990) also reported a larger word frequency effect in the lexical decision task compared to a naming task. Interestingly, his results additionally indicated that words with at least one higher frequency, orthographically similar word (orthographic neighbour) were responded to more slowly compared to words without higher frequency orthographically similar words in the lexical decision task. However, in the naming task, the stimuli that had at least one high frequency neighbour had faster responses than words without a high frequency neighbour.

Whether words are concrete or abstract (e.g. factory vs anecdote) has been found to interact with word frequency (Winnick & Kressel, 1965). However, open category words such as verbs and nouns compared to words in the closed classes such as prepositions, conjunctions and pronouns, correlates with the effect of word frequency regardless of syntactic category (Segui, Mehler, Frauenfelder & Morton, 1982). Other variables that interact with word frequency include variations in the visual characteristics of presentation (Norris, 1984), phonology (McCann, Besner & Davelaar, 1988), and semantic category (Monsell, Doyle & Haggard, 1989). The word frequency effect is one of the most influential variables in visual word recognition research.

Given that several factors can influence visual word recognition, researchers have conducted so-called mega studies to consider these factors. A mega study provides analysis of large databases of participants' responses in a specific task (Balota et al., 1997). Some of the first mega studies were conducted to obtain naming latencies for a set of more than 2,000 set of English words (e.g. Spieler & Balota, 1997).

Another important mega study involving visual word recognition is the English Lexicon Project (ELP, Balota et al., 2007). In this study, data was collected from 816 participants across six universities. Participants either performed a lexical decision task or a speeded naming task. This project leads to a large behavioural database containing descriptive and behavioural data for 40,481 monosyllabic and multisyllabic words and nonwords. Frequency norms were created based on the frequency accounts from Kucera and Francis (1967) and CELEX (Baayen, Piepenbrock & Bulikers, 1993). Although, the ELP considered word frequency to be one of the most important variables to account for lexical decisions, no further analysis was presented in this paper. However, given that the dataset is freely available, it is possible to calculate the effect of different variables in this large dataset.

Brysbaert and New (2009) analysed the effects of a range of variables in the ELP dataset. They found that word frequency estimates explained more than 40% of the variance in lexical decision times, which further emphasised the importance of the quality of the frequency norms by improving the size of the corpus, the representativeness of the materials and the definition of the norms themselves (Brysbaert & New, 2009).

Mega studies have also been conducted in other languages and a high correlation between word frequency and lexical decision times has been observed in French (Ferrand, New, Brysbaert et al., 2010), Dutch (Brysbaert, Stevens, Mandera & Keuleers, 2016; Keuleers, Diependaele & Brysbaert, 2010b), and in non-European languages such as Malay (Yap, Liow, Jalil et al., 2010).

The regional language variation used in different countries is a potential variable that influences the word frequencies. For example, the British Lexicon Project (Keuleers, Lacey, Rastle & Brysbaert, 2012) collected lexical decision latencies of 78 participants to 8,010 monosyllabic (taken from Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and 20,720 disyllabic words taken from the written part of the British National Corpus (BNC, Leech, Rayson & Wilson, 2001). As expected, high correlations were found between the ELP and the BLP (Keuleers et al., 2012). Importantly, the word frequency effect is similar between the BLP and ELP. The effect in both lexicon projects showed a nonlinear relationship between the logarithmic word frequency and the mean reaction times, although it was observed that response times in the BLP were shorter than in the ELP. Virtual experiments were conducted by Keuleers et al. to compare the BLP data to previous findings on visual word recognition. The results from these virtual experiments regarding the effect of word frequency were similar to those reported by Chateau & Jared (2000) and Yap et al (2008). Participants with a large vocabulary and/or high reading exposure (as measured by vocabulary size, reading comprehension and author recognition tests) tend to be faster and showed a smaller frequency effect. In the BLP participants, shorter reaction times evidenced a larger vocabulary size compared to the ELP participants.

Moreover, Keuleers et al. (2012) suggested that the frequency effect is probably larger in small-scale factorial lexical decision experiments because only words of low and high frequency are compared, in contrast to mega studies that include a wider range of word frequencies. They also showed that the frequency count that has mostly been used in the literature is that of Kučera and Francis measures, which is based on a corpus that consists of only 1 million words, is poor compared to more recent estimates of word frequency (Brysbaert & New, 2009).

Brysbaert and New (2009) introduced improved estimates of American English word frequencies. Their word frequencies were based on a corpus of subtitles from films and television programs (SUBTLEX-US). The frequency norms were analysed in terms of their ability to predict lexical decision and naming latencies of mega studies (Balota et al., 2004; Balota et al., 2007). Larger corpora are better at predicting the word frequency effect, in particular for responses to low frequency words. In larger corpora, however, the language register or the language use in different sources such as books, magazines, TV and the Internet became more important. Language registers based on Internet discussion groups and subtitles had the highest correlations with the variables that influence word recognition.

Despite the common use of the Kučera and Francis (1967) norms of word frequency in visual word recognition research, this database has a limited number of entries, a nonrepresentative language register (books, newspapers, magazines), and poorly predicted the performance in lexical decision and naming tasks. In contrast, word frequencies based on subtitles were better predictors of reaction times. SUBTLEX-US correctly predicted performance in lexical decision and naming tasks and is also more representative of the language register encountered in daily life (films and television). Subtitles based frequency norms have also been shown to predict lexical decision and naming latencies in other languages better than norms based on books and newspapers. These languages include French (New, Brysbaert, Veronis & Pallier, 2007), Dutch (Keuleers, Brysbaert & New, 2010), German (Brysbaert, Buchmeier, Conrad, Jacobs, Bölte & Böhl, 2011), Spanish (Cuetos, Glez-Nosti, Barbón & Brysbaert, 2011) and Chinese (Cai & Brysbaert, 2010).

Furthermore, frequency norms can also be adapted to regional language variations. British subtitles (SUBTLEX-UK) predicted reaction times in the BLP (Keuleers et al., 2012) better than norms based on American subtitles (van Heuven, Mandera, Keuleers and Brysbaert, 2012). Van Heuven et al. also introduced the Zipf scale as a measure of word frequency because it is a logarithmic scale that, using relatively few points without negative values, separated the low frequency words from the high frequency words in the middle of the scale. The use of this scale not only facilitated the measure of word frequency but also allowed the inclusion of words that were not observed in the previous corpora (frequency count of 0). The Zipf scale is a logarithmic scale with values from 1 (very low frequent) to 7 (very high frequent).

To summarise this section, word frequency is one of the key predictors of the speed of visual word recognition. The effect of word frequency has been found in a variety of tasks and languages. Although the size of this effect varies across tasks, the effect has been strongly associated with the response times in the lexical decision task where the effect is larger in comparison to other tasks. Mega studies have confirmed these observations and have further proposed the use of frequency counts based on film and TV subtitles, as well as the use of an improved frequency measure (Zipf scale) in visual word recognition research.

The effect of word frequency has been studied extensively in the visual word recognition literature. Importantly, factorial and mega studies have agreed on the importance of this factor in determining the speed and accuracy of responses in recognition tasks and in the lexical decision task. Word frequency effects have been observed in different languages, suggesting that this effect is universal. Since it is modulated by frequency of exposure to lexical representations, experience with a language contributes to this effect. Interestingly, the effect of the frequency of exposure can also be manipulated within an experimental design. Previous research has suggested that repeated presentations of stimuli can lead to faster responses to these stimuli in successive trials (Scarborough, Cortese, Scarborough, 1977). An important question is whether the word frequency effect can influence the effect of item repetition and whether the effect is the same for low and high frequency words.

The next section will focus on the impact of item repetition in experimental tasks and will further describe the findings regarding the interaction of item repetition with lexicality and word frequency.

1.1.1.3. REPETITION EFFECTS

In general, prior experience with a stimulus affects further performance to it. For example, in a task where a series of events (e.g. light signal) are presented and the participants should respond to a specific event, it was observed that response times were shorter if the event was repeated (Bertelson, 1961, Keele, 1969). In visual word recognition, this "repetition effect" has been explored to study the operation of the word recognition system and to understand the nature of this system, as well as to understand general mechanisms that determine how prior experience affects performance or how repetition relates to memory for prior episodes (episodic memory) (Humphreys, Besner, & Quinlan, 1988).

The effect of repetition has been studied by repeating the same stimulus immediately after its previous presentation within the same experiment trial (Meyer, Schvaneveldt & Ruddy, 1972). In these types of experiments, pairs of letter strings, words or nonwords (pronounceable or unpronounceable) are presented. The first item (prime) is usually briefly displayed in either an unmasked presentation or followed by a "mask", which is a letter string conformed by symbols or "x" letters (e.g. Evett & Humphreys, 1981; Humphreys, Besner & Quinlan, 1988) followed by the second stimulus presentation (target). In one of the experiments reported by Meyer, Schvaneveldt & Ruddy (1972), participants were required to decide whether each of the presented letter strings were real words or not (prime and target). The results revealed faster reaction times to repeated items and responses were also faster to different words that were related in meaning (semantic priming). Although this paradigm has also been used to further investigate semantic priming, the present section mainly focuses on the faster responses to previously seen stimuli ("repetition effect").

The effect of repetition can also be studied by repeating stimuli in a different posterior trial. For example, Morton (1964) observed that there was an influence of a previously presented stimulus on responses of further presentations. However, Howes and Solomon (1951) reported practice effects in the form of reduced recognition times the second time participants performed the same experimental task. To investigate the impact of repetition on the activation of memory representations and practice effects, Forbach, Stanners and Hochhaus (1974) conducted a study in which words (high and low frequency) and pseudowords were repeated across four blocks. Each of the items was presented to the participants in a lexical decision task. The first block presented items that were not previously seen by the participant, while the consecutive blocks incorporated the items seen in the previous block and "new" (unseen) items. Faster reaction times were found when words were shown the second time, whereas slower reaction times were observed for repeated pseudowords. Practice effects were investigated by analysing non-repeated items of each block. The results revealed faster mean latencies for pseudowords but not for words. Forbach et al. argued that the activation of a memory representation of a word leads to a faster activation (priming) of the same memory representation on subsequent presentations. Because such priming effects did not occur for pseudowords, participants did not store pseudowords in memory when they performed the task. The priming (repetition) effect occurred for both high and low frequency words but at different latency ranges, suggesting an organisation of the mental lexicon relative to the frequency of usage. The study found practice effects that differed between words and pseudowords, which suggested, according to the authors, that the effect of lexicality was due to some process different from encoding or initial search, that would probably require that the subject "re-check" the memory representations as they do not possess experience with pseudowords.

It has been observed that letter strings that are less similar to real words are quickly discarded, whereas letter strings that are more similar to real words take more time to be discarded in the lexical decision task (Stanners & Forbach, 1973). The pronounceability of letter strings also affects response times because pronounceable nonwords are responded to more slowly than nonpronounceable nonwords (Schuberth & Eimas, 1977; Scarborough, Cortese & Scarborough, 1977; Stone & Van Orden, 1993). If the repetition of words results in faster responses to a subsequent presentation but the effect is opposite (slower responses to repeated items) in pronounceable nonwords (pseudowords), it would be interesting to identify the mechanisms behind the effect of repetition in words and pseudowords.

An important question that Scarborough, Cortese and Scarborough (1977) explored was at which stage in the visual word recognition process the repetition effect for words and pseudowords/nonwords occurs. They investigated this by looking at the impact of repetition on frequency and lexicality effects in lexical decision, naming and memory (old vs. new) tasks. In their first lexical decision task, target words and nonwords as well as filler words and nonwords were presented. The target words were repeated once using five different lags (number of intervening trials) within each stimulus block. Across lags, repeated (second presentation) words and nonwords were responded to faster than non-repeated items (first presentation). This repetition effect was larger for nonwords at short lags and decreased at longer lags, whereas for words the effect remained stable across lags. Post-hoc analyses revealed that the effect of repetition was larger for low-frequency words than for high frequency words. The authors explained this by assuming a common processing stage at which frequency and repetition occur. To test this hypothesis, a similar second lexical decision task was conducted in which the frequency of words and pronounceability of the nonwords was manipulated. The results of this experiment revealed the effects of frequency and repetition and a significant interaction between these factors were found. Furthermore, an interaction between repetition and pronounceability was also found. Because of these observed interactions, the authors suggested that the effect of frequency and repetition occur at the same point in time in the visual word recognition process. Furthermore, because pronounceability also interacted with repetition, the effect of lexicality could also be occurring at the same stage as repetition. It was concluded that the effects of frequency, lexicality and repetition occur at initial encoding stages in visual word recognition.

The key finding of Scarborough et al., (1977) is that the repetition effect was different for high and low frequency words and for pseudowords and that the effect of repetition interacts with the effect of lexicality and frequency.

To further explore these interactions, Balota and Spieler (1999) investigated item repetition across tasks. In their first experiment, participants performed first a rhyme judgment task in which they had to respond “yes” if a repeated letter string rhymed with the previously presented one, or “no” when the repeated letter string did not rhyme. Next, participants performed a lexical decision task in which half of the stimuli (high and low frequency words, and nonwords) were repeated from the previous task and half were new items (nonrepeated). Faster reaction times were observed for repeated compared to nonrepeated words and the repetition effect was larger for low frequency words than for high frequency words.

Balota and Spieler (1999) were also interested in how repetition impacts the shape of the reaction time distribution. To investigate this, they fitted the empirical data to a mathematical function to obtain parameter estimates of the underlying theoretical distribution. The distribution that has been proven to be the best fit for reaction time data is the exponential distribution (i.e. ex-Gaussian distribution) that consists of three parameters: Mu (mean of the Gaussian component of the distribution), sigma (standard deviation associated with the Gaussian component) and tau (mean and standard deviation associated with the exponential component of the distribution) (Ratcliff, 1978, 1979).

The analysis of the reaction times distributions revealed an effect of word frequency on the Gaussian component of the distribution (Mu and Sigma) and on the tail of the distribution (Tau). As explained by the authors, a stretching of the tail of the distribution was observed for low frequency words compared to high frequency words. In agreement with the proposal that different characteristics of the reaction times distribution may reflect different types of cognitive processes, the authors suggested that this word frequency effect was probably reflecting a search process that required additional attention demands because the significant effect was on the tail of the distribution (the exponential component), contrary to automatic processes that would affect the mean of the distribution, as previously suggested by other studies (Balota, Black & Cheney, 1992; Neely, 1977; Posner & Snyder, 1975). In addition, word frequency interacted with repetition in the mean of the distribution, indicating that the effect of repetition was driven by low-frequency words. The authors interpreted these findings as consistent with the argument that repeated presentations of the stimuli would decrease the likelihood of an extra attention-demanding process. In contrast, an inhibitory repetition effect was found for nonwords, because responses to repeated nonwords were slower than to nonrepeated nonwords. The nonword repetition impacted the estimates of mu and tau of the reaction times distribution; this is the mean and the tail of the distribution. Post hoc comparisons observed that the inhibitory effect for nonwords was found in the tail of the distribution. A downside of this study, as pointed out by Perea, Marcet, Vergara-Martínez & Gomez (2016), was the usage of a rhyming task, which might have created associations between nonwords and words, increasing the familiarity/wordness of the nonwords, and therefore, the repetition effects.

The inhibitory repetition effect for nonwords was further investigated by Wagenmakers, Zeelenberg, Steyvers, Shiffrin and Raaijmakers (2004). Their study used the lexical decision task to investigate if the repetition effects for nonwords would either be facilitatory (faster responses to repeated nonwords) or inhibitory (slower responses to repeated nonwords). They consider the existence of two opposing processes determining responses to nonwords: an inhibitory familiarity process that relies on global lexical memory and a facilitatory process that could be explained by the retrieval of episodic information (according to Bowers (2000), this could be mediated by newly constructed perceptual codes). Because previous research in the field of memory had observed that high speed-stress would lead to more reliance on familiarity and therefore reducing the contribution of episodic traces (see Yonelinas, 2002 for a review), they manipulated the allowed time to make a lexical decision across three experiments: 1500 ms (experiment 1), 400 ms (experiment 2) and 350-600 (experiment 3). They used a block design to avoid the time-on-task (practice-fatigue) effects and the confounding between the time since the last stimulus presentation and the total number of prior presentations. The design consisted of a sequence of blocks where each stimulus is presented up to five times. Each block contained each of the five repetition conditions and included almost all the stimuli from the previous block, only replacing the stimuli presented for the fifth time in the previous block with new stimuli. In their first experiment, facilitatory repetition effects for nonwords (27 ms) and words (63 ms) were found. The effect was especially pronounced for LF words (75 ms) from the first to the second presentation. However, this facilitatory repetition effect for nonwords was not found in their second experiment. Results from the third experiment were similar to those of the second experiment; facilitatory repetition effects for words but not for nonwords. The authors argued that under the condition of what they referred to as extreme speed-stress, the contribution of a facilitatory episodic process is reduced but an inhibitory repetition priming effect is enhanced by increasing the participant's reliance on familiarity. Considering that the second and third experiments failed to find an effect of repetition for nonwords, it seems that the speed-stress might not be the ideal variable to investigate the inhibitory/facilitatory nonword repetition effect. Investigating other variables related to repetition could provide additional information to these phenomena.

More recently, Perea et al. (2016) examined the dissociative effects of repetition for words and nonwords to test the predictions of a "familiarity/wordness" model of the lexical decision task (i.e. diffusion model, see section 1.1.3.3). They conducted a study in which participants performed a two-block lexical decision task. The first block incorporated high frequency words and nonwords. The second block contained half of the items presented in the first block (repeated items) and matched new items (non-repeated). Similar to Balota and Spieler (1999), the results revealed that responses to repeated words were faster but responses to repeated nonwords were slower than responses to non-repeated items. The reaction time distributions were also explored and an increase across quantiles with repetition of words and nonwords was observed. Based on the diffusion model parameters, they suggested that the encoding time and the parameter of familiarity/wordness in the model (drift rate) would interact for nonwords. This would be reflected by a small facilitation in faster responses (higher quantiles) and an inhibition in slower responses (higher quantiles) for repeated nonwords. The authors concluded that the dissociative repetition effect for words and nonwords depended on the degree of familiarity/wordness of the strings, and further proposed dissociation between encoding and discriminability in the decision process. However, because this study did not include low frequency words, the impact of repetition on the frequency effect could not be explored.

Perea et al. (2016) interpreted the repetition effects in the context of the diffusion model (Ratcliff, McKoon & Gomez, 2004).

The inhibitory nonword repetition effect is probably due to an increase in familiarity that results in slower response times for repeated nonwords (Balota et al., 2004). Faster responses for repeated nonwords have been previously reported in identification tasks (Bentin & Moscovitch, 1988; Feustel, Shiffrin & Salasoo, 1983) and lexical decision tasks (Logan, 1988, 1990). Although the latter effect of repetition has been explained as relying on episodic processes (Feustel, Shiffrin & Salasoo, 1983), it has also been suggested that the direction of the effect (facilitation rather than inhibition) could be due to the design used in the experiment task. For example, Gordon, Soldan, Thomas & Stern (2013) suggested that the investigation of episodic processes over time could be achieved by using a block design due to the possibility of avoiding the interference from intervening stimuli in visual word processing. Excluding the interference from the intervening stimuli in a blocked design would help to investigate the effect of list context in the nonword repetition effect. The inclusion of new items might affect the encoding of the different items in the stimuli by modifying the resting activation level of the items presented in the lexical decision task (see interactive activation account, McClelland & Rumelhart, 1981, discussed in section 1.1.3.1).

Moreover, some studies have investigated whether the effect of repetition can be transferred from one task to another. Some studies reported that this is the case only if the tasks are within the same modality (Scarborough, Gerard & Cortese, 1979); however, other studies have failed to find such transfers (Balota & Spieler, 1999).

To summarise, research has revealed that repetition of words (high and low frequency) and nonwords led to different response patterns. While the effect is usually facilitatory for words (higher impact on low frequency words), this is not the case for nonwords that can exhibit inhibitory and facilitatory effects. The experimental design and the task used could be important factors in determining the direction of the repetition effect for nonwords. Therefore, there is a need to further clarify the mechanisms behind the effect of repetition for words and nonwords. Repetition in visual word recognition is therefore one of the key variables of this thesis. Given that the studies discussed above involved a varied range of tasks, an important question is how task demands influence the effect of repetition and its interaction with lexicality and frequency.

In previous sections (lexicality, frequency and repetition), different tasks have been used to investigate visual word recognition; the following section will therefore focus on the effect of task demands on this process.

1.1.1.4. THE ROLE OF TASK DEMANDS

Lexical access has been investigated using many tasks. While some of the tasks directly involved a decision of whether a word is a real word (lexical decision), other tasks focused on letter identification or the detection of differences between letter strings.

Research on visual word recognition also includes the development of models to predict reaction times in specific paradigms (e.g. Sternberg, 1966) or tasks like the Reicher-Wheeler (Reicher, 1969, Wheeler, 1970). However, it has been pointed out that to be able to integrate previous findings and to better understand the microstructure and dynamics of processing that generalise across paradigms, explicit assumptions are needed in the models (Grainger & Jacobs, 1996). According to Grainger and Jacobs, the fact that different tasks capture different aspects of visual word recognition does not undermine the need to investigate lexical access using many paradigms. However, it emphasizes the importance of integrating of the findings into models that can account for the differences and similarities across tasks.

As has been explored in the previous sections, the effect of lexicality, frequency and repetition can show different patterns of results or different effect sizes according to the task at hand. The important question would be if these effects were indeed modulated by task or not. For example, the effects of some lexical variables have been found to be task-dependent when lexical decision and naming tasks are compared (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004).

The effect of lexicality gained importance in visual word recognition from the observations in the Reicher-Wheeler task (Reicher, 1969, Wheeler, 1970). In this paradigm, the “word superiority effect” or more accurate letter identification for letters embedded in words than letters embedded in nonwords was observed (Reicher, 1969; Wheeler, 1970; Grainger & Jacobs, 1994; Jacobs and Grainger, 2005). The organisation of the letters in the letter string is a key factor that influences response times in identification tasks. For example, pseudowords that are more similar to words show more accurate identification compared to unpronounceable nonwords in visual recognition tasks that do not require a lexical decision (e.g. Barron & Pittenger, 1974; Chambers & Forster, 1975). Interestingly, when the task required the participant to identify the presented letter string as a real or nonsense word in the lexical decision task, the pattern of the results showed that faster and more accurate responses were made for words and unpronounceable nonwords compared to pseudowords (e. g. Balota et al., 2007; Rubenstein et al., 1971a; Stanners, Forbach & Headley, 1971; Stanners & Forbach, 1973). As discussed in section 1.1.1, different response patterns have been observed for words, pseudowords and nonpronounceable letter strings between tasks.

The word frequency effect has been observed in experimental tasks with single word presentations (Balota & Chumbley, 1984; Balota et al., 2004; Broadbent, 1967) and in sentence reading (Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Schilling, Rayner & Chumbley, 1988). The size of the effect has been found to vary according to the task.

Balota and Chumbley (1984) compared the word frequency effects across category verification, lexical decision and naming tasks. The results revealed that the word frequency effect in the lexical decision task (100 ms) was larger than in naming (50 ms). Furthermore, no word frequency effect was found in a semantic categorisation task (24 ms). They proposed that the word frequency effect was closely related to the lexical decision task and suggested that this effect was in part related to the decision stage of the experimental task, therefore emphasising the importance to consider the decision stage in visual word recognition.

Monsell, Doyle, and Haggard (1989) also compared the size of the word frequency effect across different tasks. While keeping the materials and procedure constant, their experiments only varied the decision criteria in the different tasks. Similar word frequency effects (size and direction of the effect) were found in the semantic categorisation and lexical decision tasks. However, the word frequency effect in the syntactic categorisation task (decide whether a word is a noun or adjective) was significantly weaker to that observed in the lexical decision task. Furthermore, the word frequency effect in the Naming tasks were significantly smaller effect than in their lexical decision task. No frequency effect was found in the delayed naming conditions. The authors discussed these findings in terms of the locus of the word frequency effect and concluded that lexical access (or lexical identification as they refer in their paper) is strongly sensitive to the effect of word frequency. Nevertheless, other processes in the different tasks could also be contributing in either masking of diluting the final observed word frequency effect.

As discussed in section 1.1.1, the stimulus repetition also impacts word frequency and lexicality effects (Balota & Spieler, 1999; Scarborough, Cortese & Scarborough, 1977). However, this effect of repetition is not always found. For example, Balota and Spieler (1999) did not observe an effect of repetition when they used a rhyming task followed by a lexical decision task. However, when they used a lexical decision task followed by a naming task, they observed repetition effects that interacted with lexicality and frequency.

Moreover, it has been suggested that some effects of repetition (i.e. priming) depend on the nature of the experimental task (Kinoshita & Norris, 2012). They exemplify this proposal by reviewing the findings regarding the masked priming effect. It is worth noticing that in the masked priming paradigms the first presentation (prime) of an item is presented very briefly and followed by a "mask", before the repetition of the same item (target) within the same trial. This paradigm is different from the paradigms described in this thesis; however, they contribute to the knowledge of the effect of repetition being found or not in different paradigms. In their paper, Kinoshita and Norris discussed that previous findings had suggested that masked priming was an index of lexical access or had a lexical nature (Forster and Davis, 1984; Forster, 1998), therefore, a priming effect had mainly been reported for words and not for nonwords. However, when the influence of the task modulation was accounted for, a priming effect for nonwords was found in Norris (2009), which illustrates that the effect of masked priming is task-dependent. They concluded that the different tasks used in visual word recognition research tap into different aspects of the word recognition process in a systematic way that can be accounted for by some mathematical calculations (i.e. Bayesian decision in masked priming).

Similar proposals have been made by Chen, Davis, Pulvermüller and Hauk, (2015) and Strijkers, Bertrand & Grainger, (2015) that suggested that the processes involved in word recognition can be modulated in speed and quality according to the top-down intention of the individual to engage in a linguistic task. These studies will be further discussed in the section 1.1.2 when I describe the electrophysiological findings of the role of task demands.

Lexical access occurs in tasks that require letter and stimulus identification after reading the complete letter string. A key question is whether lexical access also occurs in tasks that only require the earlier stages of visual word recognition, for example first letter identification. Umansky and Chambers (1980) suggested that a letter in a word can be analysed independently of a word. They further proposed that when the task involves matching the first letter in a word, the decision is controlled by a lower level of analysis (letter or letter cluster) that is faster than the word level of analysis, although they incorporated the idea of possible different mechanisms involved in the rejection of words. In their study, a judgment task was used. In this task participants were simultaneously presented a pair of letter strings and they had to decide whether the first letters or the complete letter strings were the same or if they were different in separate tasks. The results revealed that when the task criterion was only discriminating the first letters of the letters strings, no effects of word frequency were observed. However, when the criterion involved the discrimination of the complete letter strings, the word frequency effect was found. The authors interpreted the presence of the word frequency effect as reflecting of lexical access. Therefore, they concluded that no lexical access was found in the task because it only required the participants to make a decision on the first letter or the string.

Although the idea of different levels of processing in visual word recognition has been made by proposed in models (see section 1.1.3). The tasks needed to provide evidence for earlier levels of processing such as the letter level are limited in behavioural research. I will further discuss alternative methods that allow this investigation in section 1.1.2. However, it is also important to mention that in visual word recognition, other factors of a visual and lexical nature can influence responses in the lexical decision and other paradigms. I have focused on the effects of lexicality, frequency and repetition because these factors have been demonstrated to be the most influential. Nevertheless, research in the last 50 years has revealed many other factors that influence visual word recognition. In the next section I will briefly mention some of the other key factors that have been identified in the literature.

1.1.1.5. OTHER INFLUENCES ON LEXICAL ACCESS

As mentioned above, visual word recognition research has identified a number of factors that contribute to the responses observed in behavioural experiments (e.g. response times and accuracy). The nature of these factors is varied and includes many characteristics that letter strings have, for example, effects have been observed at different levels: feature (i.e. visual patterns, letters), sublexical (onsets, rhymes, syllables, morphemes), lexical (length, word frequency, familiarity, age of acquisition, orthographic and phonological neighbourhood) and semantic (concreteness/imageability, meaningfulness) (see Balota, Yap & Cortese, 2006 for more details on the factors mentioned above).

In the following sections I will focus on some of the lexical factors that are relevant for this thesis: word length, orthographic similarity and orthographic neighbourhood.

I. WORD LENGTH

The word length effect refers to the correlation of longer reaction times to words with more letters (Barton, Manif, Björnström & Hills, 2014).

Although this effect has been broadly investigated in naming tasks (e.g. Cosky, 1976; Frederiksen & Kroll, 1976; Jared & Seidenberg, 1990), some studies have also explored the effect in the lexical decision task (e.g. Balota et al., 2004; Forster & Chambers, 1973). Forster and Chambers (1973) found word length effects based on the number of letters but not on the number of syllables. Futhermore, Balota et al. (2004) reported stronger word-length effects for low frequency words compared to high frequency words. Regression analyses of the ELP data have confirmed a greater effect of the number of letters on lexical decision latencies to low frequency words compared to high frequency words (Yap & Balota, 2009).

Interestingly, the study from New et al. (2006) explored lexical decisions from 816 subjects to 3,000 words of 3 to 13 letters long. Inhibitory effects were found for words that have 8-11 letters, however, this was not the case for words containing 5-8 letters. In contrast, the effect of word length was facilitatory for very short words of 3-5 letters. New et al. proposed a U-shaped function with optimum decision times for words of 5-8 letters. Yap and Balota (2009) confirmed the existence of a U-shaped function for word length in naming and lexical decision times and further suggested that words of 5-8 letters are the best approximation to the typical perceptual span of 6-9 letters in readers.

In their review of the word-length effect, Barton et al. (2014) have suggested that a dual-mode concept of reading explains the effect of word-length as it follows: the absence of the effect would indicate a "whole-word" processing and a parallel processing given that the number of letters did not have an impact on responses, whereas the presence of the effect would indicate a sublexical processing in a serial part-based manner that operates in a letter-by-letter fashion. Moreover, they suggested that the high frequency words are not sensitive to the effect of word-length because familiarity or frequent exposure promotes whole-word processing. Furthermore, he proposed that the modulation of the word-length effect by other factors such as word frequency demonstrates that top-down linguistic effects can modify low-level visual effects.

II. THE ROLE OF LETTER PROCESSING

A suggestion that different combinations of letters influences visual word recognition was initially observed in the Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970). Research proposed the possible role of specific letter codes for each letter position (McClelland & Rumelhart, 1981), syllables, letter triples (Wickelgren, 1969), as well as letter pairs or open bigram coding (Grainger & van Heuven, 2003; Grainger & Whitney, 2004).

Furthermore, not only letter combination but also the role of the vowel and consonant structure of words has been suggested by previous research. Chetail et al. (2015) conducted global and three-step regression analyses on the lexical decision data from the ELP (Balota et al., 2007) and the BLP (Keuleers et al., 2012) to examine the effect of the consonant-vowel patterns on visual word recognition in English. They compared hiatus words with control words. Hiatus words represent a low proportion of the words in the language and reflect a mismatch between orthographic and phonological units. In most words in English, groups of adjacent vowel letters map onto single phonemes, e.g. people = /piːpəl/; however, in words with a hiatus pattern, adjacent vowel letters map onto two different phones, e.g. oasis = /əʊeɪsɪs/. According to the authors, these characteristics make it possible to test whether the pattern of consonants and vowels determines the orthographic structure of words and influences visual word recognition. Their lexical decision task results suggested that words of high frequency rely more on an orthographically oriented processing, whereas phonology plays a more important role in the processing of low frequency words. The authors interpreted this finding as supporting the proposal that the consonant and vowel arrangements in orthographic units mediate visual word recognition.

Another perspective on the vowel and consonant structure influencing visual word recognition is that of a consonant over vowel preference. Soares, Perea & Comesaña (2014) investigated the presence of a preference in the processing of consonants compared to vowels at the early stages of visual word recognition in developing children and skilled adult readers using a masked priming lexical decision task. Target words had either a consonant or a vowel initial letter and could be preceded by the same target (identity), a word with the same consonants as the target but with different vowels (consonant preserving), a word with the same vowels but different consonants (vowel preserving) or an unrelated prime. The structure of the words was also manipulated such that half of the target words were vowel-consonant words (e.g. VCVC or VCVCVC) whereas the other half were consonant-vowel words (e.g. CVCV or CVCVCV) Faster responses were observed to target words that were preceded by vowel-consonant preserving words compared to the other prime conditions in 10 years-olds and adult readers but not in 7-8 years-olds revealing that a consonant bias emerges at intermediate stages of reading acquisition. The advantage on consonant-preserving words was found in both structures CV and VC in adults but only in CV in 10 years-olds, also suggesting that the consonant bias emerges in a gradual manner in reading modulated by the consonant-vowel structure. The authors suggested that the consonant-vowel skeleton needs to be included in future models of visual word recognition and reading.

Although it has been suggested that consonants may play a greater role during letter identity processing at early stages of processing (New & Nazzi, 2014; Vergara-Martínez et al., 2011), studies that explore the consonant bias usually explored this by using letter transposition/changes within the letter strings (from the 2nd letter position) without considering the role of letters in the outer positions (initial and final). Taft, Xu & Li (2017) very recently conducted one of the few studies that focus on the amount of interference over the final letter of the string arising from the presence of an embedded word (e.g. shadow – shadowl vs. coffee – coffeep). They found that an initially embedded word interferes more when it ends in a consonant than when it does with a vowel.

Although the outer positions of the letter strings were more explored when serial models (see section 1.1.3) were tested, since the incorporation of models that disregard letter position, the first letter or the onset of the letter string has been less explored. Additional issues such as the level of processing to what the processing of the first letter belongs, e.g. pre-lexical or lexical, and the role of vowel and consonants within these levels or its capacity to trigger lexical access has not been clarified. Therefore, although the letter combination might play an important role in visual word recognition, I will only control for the onset of the letter strings in the stimuli in the present thesis. The role of orthographic onset (vowel or consonant) will be considered within the levels of processing in terms of the task decision.

Another factor that has been considered important in visual word recognition is orthographic similarity. This factor also depends on the letter combination but in terms of the possible word combinations that could emerge from the target stimulus. This factor is further explored in the next section.

III. ORTHOGRAPHIC SIMILARITY

Words can have a degree of similarity between themselves due to the use of the same letters or similar letter combinations. In visual word recognition, the role of the number of similar words that a target word has can influence the speed of its recognition (Grainger, 1990). The number of similarly spelled letter strings obtained by changing only one letter while preserving the other letter positions (orthographic neighbourhood as defined by Coltheart et al., 1977) has been used to study lexical access (Andrews, 1997).

Coltheart et al. (1977) investigated the code and the procedure needed to access the mental lexicon. In their study, participants performed a lexical decision task where words and nonwords with a high number of neighbours (high-N) and low number of neighbours (low-N) were presented. Orthographic neighbours were defined as words of the same length of a target word that can be generated by changing only one letter into another one while keeping the same letter position (e.g. WEEK and WEAK). Neighbourhood size (density) refers to the number of neighbours that a word has. Coltheart et al. found that the neighbourhood size influenced the speed of lexical decisions to pronounceable nonwords but it had no effect on lexical decisions to words. Responses were slower for pseudowords with many neighbours than to pseudowords with a small number of neighbours.

Later studies have also observed inhibitory effects (slower responses) for nonwords with many neighbours than for nonwords with few neighbours (e.g., Forster & Shen, 1996; Grainger & Jacobs, 1996; Sears, Hino & Lupker, 1995; Andrews, 1989, 1992). However, the effects of neighbourhood size on words has been less clear: whereas facilitatory effects (faster reaction times) have been reported in the recognition of low frequency words (e.g., Carreiras, Perea & Grainger, 1997; Forster & Shen, 1996; Andrews, 1989, 1992), other studies have reported no effect of neighbourhood size in the lexical decision latencies (Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989) or inhibitory effects (Andrews, 1997).

The word frequency of the neighbours, and specifically high frequency neighbours, has also been observed to slow the speed of responses in lexical decision tasks (Perea & Rosa, 2000). In their review, Perea and Rosa (2000) concluded that the effect of neighbourhood frequency has been found to be cumulative in reading as evidenced by analysis of reading data (Pollatsek, Perea & Binder, 1999; Perea & Pollatsek, 1998) but not in lexical decision tasks (Grainger, O´Regan, Jacobs & Segui, 1989; Perea & Pollatsek, 1998).

However, in her review Andrews (1997) highlighted that the inhibitory effects of higher frequency neighbours had been observed in results from lexical decisions using French and Spanish words but that these effects had not been observed in English, a language with a high level of phonological inconsistency compared to French and Spanish. She suggested that the facilitatory N effects in English may be primarily due to the influence of words that share a body with the target word. This view was similar to that of Grainger (1990) arguing that bigram frequency was the critical factor to influence lexical decision times.

Moreover, shorter words have more neighbours in English and Dutch, whereas longer words tend to have none or very few neighbours and this suggests a strong relationship between length and neighbourhood size (Fraunfelder, Baayen, Hellwig, and Schreuder, 1993). Also, words with a higher number of neighbours are more likely to have either high or low frequency neighbours; as well as, words with higher neighbourhood size are also more likely to have neighbours at several positions, although the relationship between word frequency and neighbour distribution is not linear according to Andrews (1997).

Yarkoni, Balota and Yap (2008) pointed out the restrictiveness of the orthographic neighbourhood size (also known as Coltheart *N*) that does not account for neighbours obtained by letter transposition or letter omission (e.g. TRIAL and TRAIL, WIDOW and WINDOW). They proposed a measure based on the "distance" or the minimum number of substitutions, insertions and deletions needed to generate one string of elements from another (Levenshtein, 1966). This measure is known as OLD20 and is calculated as the mean Levenshtein Distance (LD) from a word to its 20 closest orthographic neighbours (Yakoni, Balota & Yap, 2008). Vergara-Martínez and Swaab (2012) propose several advantages of this measure such as overcoming potential limitations of the orthographic size consisting of being a binary measure and length-determined, which is not the case with OLD20, which enables substitution in different letter positions and the possibility of the calculation among letter strings of different lengths. In their ERP study Vergara-Martínez and Swaab observed evidence to support the lateral inhibitory at a lexical level hypothesis and emphasised the effect of word frequency as a modulator of the effect of orthographic neighbourhood. This important role of word frequency as one of the strongest factors to influence visual word recognition has been discussed in section 1.1.1b.

As mentioned at the beginning of this section, the aim of studying neighbourhood effects is to understand the mechanisms by which the process of visual word recognition operates. Different models of visual word recognition have proposed to account for neighbourhood effects (see section

1.1.3). The importance of the neighbourhood effect relies on the potential evidence of competition and/or inhibition of lexical representations in the mental lexicon triggered by words with many neighbours.

So far, I have described the most important effects in visual word recognition in in terms of behavioural responses. Another way to study lexical access is using techniques that allow the observation of the different factors on brain processing before a response is made.

Electroencephalography (EEG) consists of the recording of brain electrical activity. In visual word recognition, the use of EEG has involved the study of brain potentials that are related to the stimulus presentation and are known as event-related potentials (ERPs, Coles & Rugg, 1995; Kutas & Dale, 1997). The following section will further explain the advantages of using ERPs to study visual word recognition and will also describe the main findings regarding the effects of lexicality, frequency, repetition and task demands on brain responses.

1.1.2. ELECTROPHYSIOLOGICAL FINDINGS

Understanding how cognitive functions arise from brain activity has been one of the main interests of Cognitive Neuroscience (Rugg, 1997). The importance of the investigation of ERPs in visual word recognition as mentioned above is the fact that one can observe the effects of different factors on the brain responses from the moment a stimulus is presented to the time the participant makes a response (e.g. a key press). Because the recording of the electrical brain activity has a temporal resolution of miliseconds at multiple scalp locations (Otten & Rugg, 2005), a fine-grained observation of word processing is possible with the study of ERPs. This also allows the articulation of research questions at the functional level (Otten & Rugg, 2005).

Research on language processing and ERPs was initially focused on hemispheric specialisation (for a review of earlier studies see Hillyard & Woods, 1979 and Bentin, 1989), semantic manipulations (e.g. Chapman, Bragdon, Chapman, and McCrary, 1977; Kutas & Donchin, 1978) or phonological processing of printed words (e.g. Lawson & Gaillard, 1981).

In visual word recognition, one of the key questions is how some ERP components are sensitive to the processes involved in word recognition and the locus of those information processes (Osterhout & Holcomb, 1995). An ERP component was initially defined based on its polarity, latency and general scalp distribution, it has been later defined as "scalp-recorded neural activity that is generated in a given neuro-anatomical module when a specific computational operation is performed" (Luck, 2005, p. 22).

Different ERP components have been identified as language-related (e.g. P1, N1, N2, N3, N400). I have focused on the N400 component since it is the best-studied language-related ERP component (Swaab, Ledoux, Camblin & Boudewyn, 2012). Initially associated with semantic processing, the N400 component was first reported by Kutas and Hillyard (1980b). They investigated the ERPs when a semantically inappropriate word occurs unexpectedly at the end of a sentence, for example, in the sentence "I take coffee with cream and _________", the expected word to fill the blank space would be "sugar" and an unexpected would be "dog". In their study, participants silently read a series of sentences that were presented word by word. Kutas and Hillyard observed a negative component beginning at about 250 ms and peaking at about 400 ms after stimulus onset of the semantically inappropriate words. They interpreted this N400 component as reflecting the interruption of the sentence by a semantically inappropriate word that would result in the "reprocessing" to seek the meaning from senseless sentences. They further suggested that the investigation of the N400 would provide key information regarding the timing, classification and interaction of cognitive processes involved in natural language comprehension.

Since this study from Kutas and Hillyard (1980b), the N400 has been studied in a variety of settings and paradigms (for a review see Kutas and Federmeier, 2011). This component has become crucially important because "the N400 arises from a period in which stimulus-driven activity enters into temporal synchrony with a broad, multimodal neural network, whose current states have been shaped by recent and long-term experience of a wide range of types (e.g. based on world experience, long-standing and recent linguistic and nonlinguistic inputs, attentional states, and affect/mood)" (Kutas & Federmeier, 2011, p. 641).

The N400 component is one of the key components in language processing and later I will describe how this component is relevant in the processing of words of different frequency, repetition and task demands. However, in visual word recognition, one of the key factors is the different processing to letter strings that constitute words compared to pseudowords and nonwords (nonpronounceable or consonant letter strings). In the following section these differences will be referred to as the effect of lexicality.

1.1.2.1. LEXICALITY EFFECTS

Buchsbaum and Fedio (1969) were interested in examining average evoked responses (AER) from the left and right hemispheres during verbal and nonverbal (random dot patterns or nonverbal designs) visual stimuli presentation. Participants only had to observe each stimulus in two experimental conditions that were separated for at least 6 weeks. The first condition presented words and random dot patterns, whereas the second condition included words and nonverbal designs. The results showed that the evoked responses were more different in the left hemisphere compared to the right hemisphere, and that the verbal stimuli exhibited shorter AER latencies. Buschsbaum and Fedio concluded that there was an asymmetrical role of the cerebral hemispheres in cognitive behaviour where the left hemisphere was more related to linguistic processing.

The subsequent studies, as in the case of behavioural studies, not only required the participant to read the stimulus but also used different tasks to investigate visual word processing. Some of these tasks required the participant to detect visual features in different letter strings (words, pseudowords, nonwords), whereas others used the lexical decision task. For example, Compton, Grossenbacher, Posner and Tucker (1991) investigated feature identification, visual word forms and semantic associations with a Positron Emission Topography (PET) and ERPs. In this study, three tasks were included: a thickness search task, a case search task and a lexical decision task. In the thickness search task, participants had to identify if the letter string contained a letter with a thickened segment. The case search task required the participant to decide if the letter string contained a lower-case letter among upper case letters. Only consonant strings and words were presented as stimuli. Results from the lexical decision task revealed an early lexicality effect where words were more negative than consonant strings, reversing the findings in the other tasks. This effect started by 150-200 ms and was observed in frontal areas followed by posterior discrimination. According to the authors, the task instructions lead to changes in the time course of the effect. Because they observed different lexicality effects in feature identification and lexical tasks, they further proposed that attention systems would allow the brain to rearrange its processing of the stimuli according to the task instructions.

Ziegler, Besson, Jacobs, Nazir & Carr (1997) were interested in investigating the time course and the activation of linguistic information while words, pseudowords and nonwords were processed in three different tasks. In this study participants performed a letter search task, a delayed letter search task and a semantic categorisation task where words, pseudowords and nonwords (orthographically and phonologically illegal letter strings) were presented. In the letter search task, participants had to decide whether a target letter presented on each trial was present in the stimulus. The delayed letter search task was similar to the letter search task; the only difference was that the target letter was presented after the stimulus instead of before. In the semantic categorisation task the participant had to decide whether the stimulus belonged to a previously presented category within the same trial. The results at left posterior sites showed a lexicality effect between nonwords and pseudowords from 25 to 50 ms in the semantic categorization task, at 225 ms in the delayed search task and at 250 ms in the letter search task. The authors interpreted these results as a spelling check only occurring in the semantic categorisation task to exclude nonwords for analysis, which was not the case in the letter search tasks. Additionally, a lexicality effect between words and pseudowords was observed in left anterior locations between 75-100ms in the semantic categorisation task and at 275ms in the letter search task, whereas no effect was observed in the delayed letter search task. This was interpreted as the lexico-semantic information playing a role in the semantic categorisation task but not in the letter search task. The authors suggested that the effect of lexicality was dependent on the type of processing required to perform the task. They further proposed that the language system is highly flexible and adaptive, only requiring the necessary sources of linguistic information if the task performance requires it; however, they also acknowledged the limits of cognitive control.

Sereno, Rayner and Posner (1998) investigated the time course or reading processing using eye-movement and ERPs measurements in a reading and a lexical decision task. Participants were presented words of high and low frequency, consonant strings (e.g. *fhvr*) and pseudowords (pronounceable nonwords, e.g. *welf*). Results from the lexical decision task regarding the effect of lexicality revealed that words differed from pseudowords and consonant strings in the first positive ERP component at 100 ms. (P1). However, pseudowords and consonant strings did not differ among themselves. According to the authors, these results can be explained by the fact that lexical processing beginning 100 ms after the word is fixated, demonstrating that early components of the ERP waveform can reflect lexical processing.

Interestingly, Coch and Mitra (2010) have also reported early lexicality effects. To investigate the word (more accurate responses to words compared to pseudowords) and pseudoword (more accurate responses to pseudowords compared to nonwords) superiority effects, Coch and Mitra used a variant of the Reicher-Wheeler paradigm with ERPs. Words, pseudowords (e.g. *DARL*, *PARL*), nonwords (e.g. *RDKA*, *RPKA*) and letter-in-x's (e.g. *DXXX*, *PXXX*) were presented as stimuli. Participants had to decide which of the presented letters occurred at a given position in the letter string. Behaviourally, they observed more accurate responses to words compared to pseudowords, as well as to pseudowords compared to nonwords and letter-in-x stimuli. Importantly, an effect of lexicality was found in the time window from 160-200ms, and peak amplitude in the N300 and N400 time window that differ for words and pseudowords compared to the other stimuli. Orthographically irregular and unfamiliar letter strings (nonwords and letter-in-x's) elicited greater P150 than words and pseudowords. Moreover, only words (not pseudowords) elicited larger N200 than nonwords at medial occipital sites. By contrast, larger N300 for words compared to nonwords, and pseudowords compared to nonowords were observed at widespread locations (N300). Furthermore, larger N400 were observed for words and pseudowords compared to nonwords at posterior sites. Results from the P150 were interpreted as reflecting an index of the activation of feature-level, location-specific letter detectors during an "initial phase of sublexical orthographic processing" or perceptual fluency for more common letter forms". However, they suggested that task and stimulus characteristics should be systematically manipulated in future studies to further delineate the sensitivity of the P150. Interestingly, the authors explained the N200 as an effect of lexicality (word superiority effect), orthographic familiarity and lexical access. In the case of N300 and N400, similar patterns were found between words and pronounceable pseudowords compared to nonwords and letter-in-xs. The N400 was larger for words and pseudowords at posterior sites which was consistent with the interpretation of the N400 as an index of higher-level interpretation for these type of stimuli, a "form-meaning interface" that would complement a "sublexical-lexical" interaction effect as reflected by the P150 and N200 components. This study not only reported effects of lexicality in the peak amplitude of early (P150) components but also emphasised that late (N400) components might reflect lexical-level effects on orthographic processing.

Interested in the time course of visual word recognition, Hauk, Davis, Ford, Pulvermüller and Marslen-Wilson (2006) explored the effect of different psycholinguistic features (e.g. word-length, letter n-gram frequency, word frequency, etc) on the responses given in a lexical decision task. They presented words and pronounceable pseudowords. A regression analysis on the ERPs revealed effects of lexicality at about 160 ms, 202 ms and 240 ms. The general pattern consisted in positive-going (less negative) potentials for words than pseudowords at occipital electrode sites that had been previously referred to as the "recognition potential" (Rudell, 1991; Martin-Loeches et al., 1999; Rudell et al., 2000; Hinojosa et al., 2001). However, larger effects of lexicality were observed around 425 and 500 ms where pseudowords produced more negative potentials at centro or centro-parietal electrode sites. The authors interpreted the early effects as the initial phase of visual word recognition that included access and selection of lexical and semantic information. However, the later effects were interpreted as related to post-lexical processing.

A speeded lexical decision task was used by Hauk, Patterson, Woollams, et al. (2006) to investigate the early spatiotemporal aspects of cortical activation of word and pseudoword processing. Homophone matching pairs of a word and a pseudoword were presented individually; each pair differed in orthographic "goodness" or typicality measured by bigram and trigram frequency, for example, *drew* and *driew* (orthographical typical) or *yacht* and *yot* (orthographical atypical) (Rogers, Lanbon Ralph, Hodges et al., 2004). Behavioural data detected a reliable main effect of lexicality in latency and a marginal effect on accuracy. Interestingly, the analysis of the root mean squared (RMS) peaks showed a significant effect of lexicality at 240 ms that approached significance at 210 ms, showing more negative potentials for pseudowords compared to words, while, more activity for pseudowords relative to words in a mid-posterior region of the left inferior temporal lobe was suggested by the source localisation analyses. This activation was followed by an interaction between lexicality and typicality in anterior temporal and perisylvian areas, which Hauk et al. explained as representing a feedback activation from lexicosemantic representations to stabilise letter string representations in the posterior cortex, consistent with the interactive activation and competition model of word recognition (McClelland, 1979).

The advantage of investigating the process of visual word recognition with the lexical decision task and ERP measures is that the process behind word recognition can be described before the behavioural responses are made. However, it has been suggested that expectancy mechanisms that affect the speed of lexical access for the target can play a role in the process of recognising a word (Neely, Keefe & Ross, 1989) and the decision-making processes are different for words ("yes" response) and nonwords ("no" response) probably reflecting different neural processes (Carr & Pollatsek, 1985) related to phonologic and semantic information dependent on the orthographic discrimination of the word and nonword (Waters & Siedenberg, 1985; James, 1975).

To provide additional evidence for theoretical models of word recognition, Hauk, Coutout, Holden and Chen (2012) measured behavioural responses, ERPs, EEG/MEG source estimation and eye-blink latencies in a Go/NoGo paradigm with lexical and semantic decisions. This paradigm was chosen because it allows the collection of behavioural data and divergence points between response/no-response conditions in electrophysiological data (Thorpe et al., 1996). In this study, the authors focused on the lexicality effect in brain activation at around 200 ms in left anterior middle temporal cortex because according to the comparisons across the tasks and the Go/NoGo conditions, early effects were more stable than late effects. The lexicality effect was then interpreted as evidence of an accumulation of lexico-semantic information from the presented stimulus before 200 ms. The authors suggested that word recognition should be conceived as a continuous accumulation of evidence rather than a sequence of stages and proposed to incorporate this notion into computational models of word recognition.

Whereas early and late lexicality effects in the ERPs have consistently been observed across different tasks, the interpretation of these findings depend not only on the variety of methods used but also in the integration of the evidence from different paradigms, and how these can be explained theoretically incorporating the main factors that influence visual word recognition. Early and late effects have also been observed for word frequency. The findings and their interpretations in the process of visual word recognition are presented in the next section.

1.1.2.2. WORD FREQUENCY EFFECTS

Word frequency can influence the amplitude of the electroencephalographic signal (ERPs) when participants read single words. Among the first ERP studies that observed an effect of word frequency was that of Polich and Donchin (1988). They were interested in the P300 component latency as a measure of processing speed and how this component could be influenced by word frequency. Participants performed a lexical decision task in which words of high and low frequency, as well as pseudowords were presented. Polich and Donchin reported shorter P300 latencies for high frequency compared to low frequency words (20 ms), which was interpreted as a different evaluation time for those stimuli respectively. Results from Principal Components Analysis (PCA) showed smaller P300 amplitudes for low frequency compared to high frequency words. The authors concluded that word frequency influences early stimulus processing during the lexical decision task rather than response production stages.

Word frequency effects have been reported by Sereno et al. (1998). As mentioned in the lexicality section (1.1.2) of this chapter, in this study a reading and a lexical decision tasks were employed. Results from the reading task showed longer gaze durations for low frequency compared to high frequency words. Lexical decisions confirmed this pattern of results with faster responses to high frequency words relative to low frequency words. Interestingly, the ERPs revealed more negative waveforms for low frequency words in the N1 component at 132 ms after stimulus onset. Although, the authors concluded that effects associated with the P300 and the N400 can reflect post-lexical processes, such effects were not reported in this paper. Rather, they demonstrated an early word frequency effect that was interpreted as a reflection of lexical processing at early latencies.

In order to clarify the ERP effects specifically related to word frequency and word length, and to determine the time range of lexical access, Hauk and Pulvermüller (2004) employed a lexical decision task. Words were classified in low, medium and high frequency categories and as short or long (length).

While no main effect of length or an interaction between length and frequency was observed, an early effect of word frequency was found between 150-190 ms in the N1 latency range. Interestingly, word frequency effects were also observed between 320-360ms. According to the authors, these results were evidence of an early lexical access from written word stimuli before 200 ms, and the amplitude modulation of the ERP by word frequency pointed towards neuronal plasticity within the brain network underlying visual word recognition: more efficient synaptic connections and less activation would be needed for words that are encountered more frequently. Furthermore, the authors suggested that later effects after 300 ms can reflect a re-processing of word-related information or post-lexical processes in later effects.

In fact, Hauk et al. (2006) also found early and late effects of word frequency in a linear regression analysis of the ERP data. As described in section 1.1.2 of this chapter, the authors were interested in investigating the influence of a range of psycholinguistic word properties on the EEG responses and their time course using data from lexical decision task. Results showed the earliest effect of word frequency at 110 ms, high frequency words showed lower amplitudes than low frequency words. Later effects of word frequency were observed at around 200 ms in more anterior regions in the left inferior temporal cortex with similar activity in the right hemisphere and a central occipital region, as well as between 300 and 500 ms. Source estimation analyses showed that word frequency modulated activity in left-lateralised regions of the temporal cortex. Specifically, the left inferior temporal cortex was modulated by frequency. Early effects were interpreted as reflecting the retrieval of lexico-semantic information. However, late effects were observed not only for word frequency but also for other lexical and semantic variables. The authors suggested a parallel activation of regions modulated by different variables and an integration of different types of information at later stages (from 200 ms onwards).

Evidence from a reading task has also suggested an early word frequency effect in the ERPs. Dambacher, Kliegl, Hofmann and Jacobs (2006) presented sentences in which target words differed in word frequency, predictability and position in the sentence. The results indicated a strong frequency effect over fronto-central electrodes between 140-200 ms. The effect of word frequency interacted with the effect of predictability in the N400 component, showing stronger effects of predictability for low than for high-frequent words. According to the authors, their results suggested that lexical access occurs before 200 ms and that predictability strongly moderates the late access of low-frequency words especially. However, this contextual facilitation on the N400 might be reflected in lexical and post-lexical stages of word recognition.

As in the case of behavioural mega studies, the influence of many psycholinguistic factors on the ERPs has been investigated in large-scale ERP studies. For example, Dufau, Grainger, Midgley and Holcomb (2015) conducted a study with 960 words presented to 75 participants who performed a go/no-go lexical decision task. Results from partial correlations showed an early effect of word frequency in posterior electrodes from 100-152 ms. This effect was followed by an effect in posterior electrode sties from 180-280 ms and in frontal electrode sites from 280-380 ms. Late effects were found in widespread locations from 380-500 ms. The authors suggested a fast initial feed-forward sweep of neural activity cascading through visual, orthographic, and lexical representations and further proposed the need to consider the nature of the task performed into the analysis of the different variables that could affect visual word recognition.

From these findings, it is possible to suggest that early effects can reflect lexical access, while, later effects could be reflecting feedback processing. However, as in the case of the behavioural findings, further clarification incorporating accounts of word frequency that more accurately reflect language use would be needed to better explain the effect of word frequency and lexical access. Nevertheless, word frequency can consistently modulate ERPs waveforms. As suggested by some of the studies cited above, the effect of word frequency can interact with the effect of other psycholinguistic variables. Based on previous behavioural findings, for this thesis it is important to further describe how the effect of word frequency and lexicality can be further modulated by repetition in the ERPs. The presence of these effect as it has been previously mentioned reflect lexical access. Therefore, in the case of bilinguals, the investigation of these effects would also contribute to the understanding of how language exposure can influence lexical access. The following section, however, first describes the findings in monolingual visual word recognition.

1.1.2.3. REPETITION EFFECTS

The exploration of the effect of word repetition has played a key role in the study of memory and psycholinguistics (Van Petten, Kutas, Kluender, Mitchiner & McIsaac, 1991). The first studies to investigate this effect on ERPs included free recall paradigms followed by recognition tasks (old/new) (e.g. Karis, Fabiani & Donchin, 1984). Even though Karis et al. (1984) were interested in mnemonic processing and not on the process of visual word recognition, their results from the recognition task showed that items that had been previously studied by the participants ("old") elicited larger P300 (with peak latency around 500ms) compared to items that had not been seen before ("new"). The authors suggested that changes in the amplitude of the P300 manifest processes that modulate word representations in memory.

Rugg and Nagy (1989) also studied recognition memory for words through the word repetition effect in a recognition task. Participants were required to identify if a word has been previously seen ("old") or unseen ("new") in two task phases separated by a lexical decision task. In Phase 1, target words were repeated after six or nineteen intervening items (or lag). In Phase 2, participants had to identify items that had been previously presented in phase one. ERP results from Phase 1 showed a more positive-going wave from around 250 ms post stimulus with a negative deflection at approx. 400 ms (N400) and a positive deflection at 600 ms (P600) for the "old" compared to the "new" words. The statistical analysis of the 300-400 ms time-window confirmed a greater positivity associated with "old" compared to "new" words at central and parietal electrodes (Cz and Pz). This pattern was similar in the 400-500 ms time-window but there was no effect of lag in the 500-600 time-window. ERP results from Phase 2 only revealed a sensitivity in the late component to the comparison between "old" and "new" words. The authors interpreted the results of the second phase as a loss of contribution of the episodic retrieval that resulted in the absence of differences between "old" and "new" items. They concluded that the observed ERP effects in Phase 1 reflected a subset of processes that underlie retrieval from episodic memory and do not necessarily play a role in the identification of "old" and "new" items.

Another two-phases study was conducted by Rugg (1990), who used a similar paradigm. In Phase 1 participants were asked to detect nonwords in a series of repeated high and low frequency words, words were repeated after six intervening items. In Phase 2, participants had to identify "new" (non-previously presented) vs. "old" (previously presented) items presented in Phase 1. Results from Phase 1 indicated an attenuation of the frequency effect in the N400 component for repeated words compared to nonrepeated ones. A repetition effect was also observed after 500 ms but only for low-frequency words and not for high frequency words. The results from Phase 2 also only showed a repetition effect for low-frequency words in a 500 ms time window. The author suggested that the interactive nature of repetition with frequency would reflect that these variables act together at multiple loci during word processing. Rugg concluded that, even when information about word frequency in the language is accessible independently of the intra experimental familiarity, the discrepancy between the two variables is quickly computed such that it influences the online processing.

This interaction between the effects of item repetition and word frequency has been revealed in the N400 by a smaller N400 amplitude for the second presentation of open class words (Besson et al., 1992; Karayanadis, Andrews, Ward & McConghy, 1991; Nagy & Rugg, 1989, Rugg, 1985b, 1987, 1990; Rugg, Furda & Lorist, 1988; Rugg & Nagy, 1987, 1989; Smith & Halgren, 1987; Van Petten et al., 1991). However, the N400 repetition effect is sensitive to the lag between occurrences of the word, as it has also been characterised in word lists (Fischler, Boaz, McGovern & Ransdell, 1987).

It has been found that words repeated in lists or in entire sentences exhibit a lack of the frequency effect for the second presentation compared to the first presentation (Besson et al., 1992; Rugg, 1990; Smith & Halgren, 1987). Low frequency words show a disproportionate repetition effect so that N400 amplitude is equalised by repetition (Kutas & Van Petten, 1994).

Van Petten et al. (1991) provided further evidence of this interaction in a reading task. Interested in the effect of repetition in target words immersed in relatively natural context, words were repeated as part of the discourse structure of short passages. ERP results showed a positive component peaking at 200 ms post stimulus, an N400 and a later positivity. The authors suggested that the early effect of repetition was elusive and not subject to experimental control, since only one previous study had reported it before only for immediate repetitions (Nagy and Rugg, 1989). However, the authors discussed the role of the N400 and the late positive component (LPC) in relation to memory processes, which can be addressed by the repetition effect.

The effect of repetition on ERP responses has not only been found in words but it has also been observed for legal and illegal letter strings. Rugg and Nagy (1987) explored if the repetition effect could be explained by lexical search or by a short-lived episodic memory component. Implicit lexical decisions were required of participants in two tasks where they either counted words or items with a nonalphabetic character (@). Results from the word counting task showed a lack of repetition effect for illegal and legal nonwords in the time window of 201-225 ms. However, a small effect of repetition was observed at the Fz electrode for both illegal and legal nonwords between 300-399 ms, while the effect was only found for legal nonwords between 402-600 ms. Results from the second task (counting items with nonalphabetic characters) showed main effects of site and condition between 300-399 and 402-600 ms. Although, information regarding significance of the interactions was not reported and the effect of repetition was smaller than in the previous task, planned comparisons indicated that at both latencies the effect of repetition was significant only for the legal compared to the illegal nonwords. It was concluded that the different activation of legal and illegal items between 300-

399ms showed different processing for these items, where lexical search only occurred for legal items. Moreover, the repetition effect of legal items in the time window between 402-600 ms might have reflected an episodic contribution. It was concluded that the effect of repetition on the ERPs is highly sensitive to the orthographic structure of the items. The access to representations in lexical memory and ERPs modulation by repetition in legal items contrast with the lack of the repetition effect in illegal letter strings on ERPs. Similar results were found by Rugg (1983), and Smith and Halgreen (1987)

More recently, Bermúdez-Margaretto, Beltrán, Domínguez and Cuetos (2015) investigated the repetition effect on pseudowords with a lexical decision task. They were interested in exploring if the effect of lexicality would decrease by pseudoword repetition and its neural correlates expressed in an N400 in frontal locations or a LPC. The task involved six blocks of stimuli and the same set of pseudowords were presented in each block. Half of the experimental words were presented in the first block and the other half in the sixth block, and word fillers were presented from the second to the fifth block. While faster and more accurate responses were observed to pseudoword identification, the effect of lexicality did not disappear with repetition in reaction times. ERP results showed a lexicality effect on the N400 component at fronto-central distribution (referred as FN400) that was not affected by pseudoword repetition. However, a LPC at central and posterior locations showed a larger amplitude for pseudowords after each repetition, reducing the effect of lexicality until it disappeared. The authors concluded that the FN400 and the LPC components reveal different underlying processes where the FN400 is not sensitive to pseudoword repetition, in contrast to the LPC. LPC was interpreted to reflect the formation of memory traces, which impacted the performance over pseudoword recognition and eliminated the lexicality effect on ERP responses. It was concluded that repetition results in a visual memory trace that improves the processing of repeated new stimuli, however, this was not enough to establish a similar functional role between words and pseudowords in the linguistic system that could probably be addressed by the activation of semantic features.

The investigations of item repetition have used different tasks. In the “old-new task”, the effect of word repetition occurred in the N400 time window. However, the effect of item repetition interacted with the effect of word frequency at early (200 ms) and N400 time windows of the ERPs in reading tasks. Results from the lexical decision tasks have also revealed an interaction between lexicality and item repetition effects in ERPs. While early components at approx. 200ms can reflect lexical processing, effects on the N400 have been related to semantic processing and late components such as LPC have been associated to contributions from the episodic memory. The investigation of the effect of repetition through different tasks on the ERPs suggest that task demands play an important role in determining variations in timing and amplitude of the different language-related ERP components. In the next section evidence from tasks comparisons will be presented.

1.1.2.4. THE ROLE OF TASK DEMANDS

The investigations of the impact of word frequency, lexicality and repetition on visual word recognition have used different tasks and these have not only provided evidence of the effect of such factors in different contexts but these have also shown that task demands can modulate the size and timing of those factors on the ERPs. The effect of lexicality was investigated in identification (e.g. letter search), simultaneous matching (‘same-different’), lexical decision and go/no-go tasks. Overlapping components have been observed across tasks regarding this effect, including early effects and late effects of lexicality on the ERPs (further details can be found in section 1.1.2.1). Findings regarding the effect of word frequency were presented in section 1.1.2.2, among the tasks used are the lexical decision and go/no-go tasks, and a consistent effect of word frequency on the ERPs has been found. Finally, repetition effects show different ERP components according to the task, indicating the role of task demands on the repetition effect. Early effects of item repetition have been observed in simultaneous matching tasks; however, effects on the N400 and LPC components have been identified in lexical decision tasks (see section 1.1.2.3).

Chen, Davis, Pulvermüller and Hauk (2013) investigated the role of task demands. Specifically, they explored the flexibility of visual word recognition and compared brain responses in lexical decision, semantic decision and silent reading tasks. Brain activity was studied using EEG/MEG (magnetoencephalography) and fMRI. Results from EEG/MEG showed an effect of task at around 150 ms. This effect was observed when the lexical decision task was compared to the silent reading task, and in the comparison between the semantic and the silent reading tasks. However, no difference was found between the lexical decision task and the semantic decision task. The task effect was found for all comparisons at 250 ms but later effects were only observed in the EEG at 496 ms between the lexical decision and the silent reading task, as well as between the lexical decision and the semantic decision task but not between the silent reading and the semantic decision task. Regarding the localization of the word activation/processing in the different brain regions, the time window between 92-124 ms showed a strong bilateral occipital activation that was followed by a strong widespread activation of the lateral and inferior portions of the temporal lobe between 144 and 175 ms. However, in the 200-300 ms window, the activation extended to left precentral and left inferior frontal cortex showing a left-lateralised activation in the anterior part of the middle temporal region. Later time windows from 300-400 ms. showed a diminished activation in occipital and anterior temporal lobe, but from 400-492 the activation was in the anterior temporal and frontal areas. These results suggested that task demands influence word processing at an early stage beginning from 150 ms in the left inferior temporal, left precentral and right anterior temporal areas. However, the results also showed a differentiation between task starting from 250 ms in the left anterior temporal areas and bilaterally around 480 ms. The lexical decision and semantic decision tasks produced more activation than silent reading except in the precentral cortex; also, the semantic decision task elicited greater activity than lexical decision or silent reading in bilateral anterior temporal lobes at around 480 ms. The authors concluded that visual word recognition is a flexible process that can be adapted according to the task at hand, emphasising the role of decision making in the process of visual word recognition.

In a follow-up study, Chen, Davis, Pulvermüller and Hauk (2015) investigated if task demands modulate how information is retrieved using EEG/MEG. In this study, they used a parametric approach to compare brain responses in silent reading and in lexical decision and semantic decision tasks. The authors were interested in exploring spatiotemporal response patterns of occipito-temporal cortex. The results showed a task modulation for different psycholinguistic variables including word frequency and imageability in ventral occipital temporal regions at approx. 160ms. Also, task-independent effects were observed after 200ms in anterior temporal lobe regions. The task effects overlapping different psycholinguistic variables were interpreted as the role of occipito-temporal areas in perceptual integration in a task-dependent manner. Task independent effects were explained as retrieval of semantic information irrespective of task demands, which suggested an automatic lexical access, although the authors interpreted these results as supporting the conclusion of flexible visual word recognition.

As was mentioned in section 1.1.1.5, there are additional factors that influence the process of visual word recognition. These factors have also been found to influence the ERP signal. The following section will present some of the recent findings regarding the effects of word length, orthographic letter combination (letter identity and letter transposition) and orthographic similarity (e.g., neighbourhood size).

1.1.2.5. OTHER INFLUENCES ON LEXICAL ACCESS

I. WORD LENGTH

Word length effects have also been investigated with EEG and ERPs. For example, Osterhout, Bersick and McKinnon (1997) explored the effects of word length and word frequency on ERPs. In their study, participants read sentences in normal or scrambled prose. The results revealed that quantitative differences in word frequency and word length were highly correlated with latency changes in a negativity that occurred immediately after the N1-P2 complex and before the N400-700 time-window in normal and scrambled prose. This evidence suggested that the effect of word length has an early influence on the ERPs.

Hauk and Pulvermüller (2004) also investigated the effect of word length and word frequency on the amplitude and peak latencies of ERPs to identify the point in time when lexical access occurs in the visual word recognition process. Participants performed a lexical decision task in which the stimuli were orthogonally matched for length and word frequency. Results from this study revealed the strongest brain response for long words at approx. 100 ms after stimulus onset, whereas the strongest response for short words was observed later from 150-360 ms. The word frequency effect (lower ERPs for high frequency compared to low frequency words) was observed between 150-190 ms and 320-360 ms. The authors suggested that these effects had independent and additive effects on the amplitude of the ERP.

Other studies that focused on the time course of visual word recognition, included length as one of the factors in their experiments. Findings from Hauk et al. (2006) and Hauk et al. (2009) using a lexical decision task, revealed effects of word length starting from 100 ms. similar findings were observed in a lexical decision go/no-go task (Dufau et al., 2015). Dufau et al. identified effects of word length from 100-152 ms that had a widespread distribution from 180-280 ms and were followed by the word frequency effect. Additionally, late effects were observed from 380-500ms in posterior electrode sites (for a further description of these studies see section 1.1.1.1).

In summary, the effects of word length can be found at early latencies from 100ms prior to the effects of word frequency. Although, there is an overlap in the onset of these effects on ERPs, it has been suggested that the effects of word frequency and word length could be independent and additive (Hauk & Pulvermüller, 2004). In this thesis and based on behavioural evidence described in section 1.1.1.5, word length was considered as a potential confounding factor and therefore it was controlled in the experimental designs. The next sections present electrophysiological evidence of other orthographic influences on visual word recognition.

II. THE ROLE OF LETTER PROCESSING

The contribution of letter identity (consonant or vowel), letter position, and sublexical orthographic processing, to visual word recognition has been also explored with ERPs.

To investigate the influence of orthographic letter combination on visual word recognition with ERPs, researchers have made use of paradigms such as masked priming and letter transposition. Evidence from masked repetition priming studies suggest that early ERP components such as the posterior N/P150 are sensitive to orthographic (Petit et al., 2006) and sublexical nonword processing (widespread N250) (Grainger, Kiyonaga, and Holcomb, 2006; Holcomb and Grainger, 2006; Carreiras et al., 2009).

The role of letter identity in visual word recognition has been further investigated in priming studies. For example, Carreiras, Duñabeitia and Molinaro (2009) used a semantic categorisation masked priming paradigm. They found similar effects in the N250 and the N400 components for words preceded by its consonants (frl-farol) or by the same word (farol-farol) but they observed that vowels preceding the target word (aeo-acero) were more similar to unrelated primes. They interpreted these results as a predominant role of consonants compared to vowels in visual word recognition.

Moreover, Vergara-Martinez, Perea, Marín and Carreiras (2011) investigated vowel and consonants processing in visual word recognition with a masked priming lexical decision task. Stimuli conditions for words and pseudowords included identity (e.g. chocolate-CHOCOLATE), vowels-delayed (e.g. choc_l_te-CHOCOLATE), consonants-delayed (e.g. cho_o_ate_-CHOCOLATE), vowel-transposed (e.g. chocalote-CHOCOLATE), consonant-transposed (e.g. cholocate-CHOCOLATE), and unrelated (e.g. editorial-CHOCOLATE) conditions. ERP results showed differences between vowel- and consonant-delayed conditions only for words in the 300-525ms time window. Contrastingly, no difference was observed between the vowel- and consonant-transposed conditions. The authors interpreted their results as evidence of a flexible letter position coding in word recognition that differs according to the letter status (vowel or consonant) and suggested that these characteristics should be included in computational models of visual word recognition.

Furthermore, word frequency also seems to play a role in letter position assignment as suggested by Vergara-Martínez, Perea, Gómez and Swaab (2013). This study used semantic categorization and lexical decision tasks. Words of high and low frequency (e.g. BRIDGE), and pseudowords with one letter either transposed (e.g. BRIGDE) or replaced (e.g. BRITGE) were presented. Results revealed similar ERP responses between high frequency words and transposed-letter pseudowords but they were different in the N400 component for high frequency words compared to replaced-letter pseudowords. In contrast, similar differences were found when comparing low frequency words with transposed-letter pseudowords, and low frequency words with replaced-letter pseudowords. The authors concluded that letter position coding is modulated by the word frequency of the base words.

The effect of letter processing has been addressed by ERP research in visual word recognition by exploring the role of vowels and consonants in masked priming paradigms. Nevertheless, it has been pointed out that the word frequency might also play an important role in the modulation of letter coding. Letter transposition and letter replacement are also related to orthographic similarity among words. The following section will present some of the ERP findings regarding the effect of orthographic similarity on visual word recognition.

III. ORTHOGRAPHIC SIMILARITY

Behavioural findings have established the importance of considering orthographic similarity as one of the factors that influences visual word recognition (see section 1.1.1.5). Studies using ERPs have contributed to understanding of the time course of this effect in the visual word recognition.

To study the effects of orthographic neighbourhood size, Holcomb, Grainger and O'Rourke (2002) conducted an electrophysiological study with a speeded lexical decision and a go/no-go semantic categorisation tasks. Neighbourhood sizes (large or small) were defined using the Coltheart *N* (Coltheart et al., 1977). Results from the lexical decision task indicated a similar effect of neighbourhood size on the N400 amplitudes for words and pseudowords. However, stimuli with a large neighbourhood size exhibited more negative deflections compared to stimuli with a small neighbourhood size. Although, ERP results contrasted with the behavioural findings that showed a facilitatory (fast and accurate responses) effect of neighbourhood size for words and an inhibitory (slow and less accurate responses) effect for pseudowords in the lexical decision task. These results were interpreted as evidence of an increase in global lexical activation that would lead to faster responses for words but to slower responses to pseudowords.

The mechanisms and time course of orthographic neighbourhood size on visual word recognition was also investigated by Vergara-Martínez and Swaab (2012). High and low frequent words with large or small orthographic neighbourhood size (as measured by Orthographic Levenshtein Distance, OLD20) were presented in a semantic categorisation go/no-go task. ERP results indicated an effect of orthographic neighbourhood size from 260-380 ms. This effect interacted with word frequency in the distribution of the effect at 380-500ms time-window. While the neighbourhood size effect for high frequency words was widely distributed, this effect was observed at more posterior sites for low frequency words. Interestingly, no effects of orthographic size were observed in the 500-600ms time window. The authors interpreted these results in the framework of interactive activation models (see section 1.1.3.1 and 1.1.3.2). They suggested that the overlap of the effects of orthographic neighbourhood size and word frequency reflected competitive interactions at the lexical level of the representation that matched the input and a subset of the activated lexical network.

Consistent with the evidence of word length and letter identity, the effect of neighbourhood size is also modulated by the effect of word frequency. In the case of neighbourhood size, the effect of lexicality seems to also play an important role in the ERP responses, revealing an intriguing pattern of results when compared to behavioural responses. Effects of word length and letter identity and transposition mainly influenced the ERPs at early latencies from 100ms, whereas the effect of neighbourhood size can be observed at later latencies suggesting that this effect has a semantic component.

Further interpretations of the effects of the presented variables can be made under the framework of the relevant models of visual word recognition. These models have made predictions regarding the effects of word frequency and lexicality, as well as the effect of task demands and item repetition.

In the following section an overview of the visual word recognition models is provided. Furthermore, how these models account for effects of word frequency, lexicality and repetition are also discussed.

1.1.3. MONOLINGUAL MODELS OF VISUAL WORD RECOGNITION

The need to understand the microstructure of language processing in real time rather than its “end products” (Swinney, 1981; Kutas & Van Petten, 1988) has promoted the development of models and theories. In visual word recognition research, it has become critical to understand the mechanisms of a set of time-consuming physical processes that take place when people read words (Barber & Kutas, 2007).

Among the first models of visual word recognition are models of a theoretical nature that attempted to explain the process of word recognition in a qualitative manner. The serial search and parallel processing models are examples of these models. The serial search model (Rubenstein, Lewis & Rubenstein, 1971) proposed that the lexicon is organised by frequency, and therefore every time a word entry is encountered, a comparison to high frequency and then low frequency words is made until a match for the word entry is found. Forster

(1976) further refined this proposal leading to the development of models such as the Activation-Verification model (Paap & Johansen, 1994).

In contrast, parallel processing models are based on the hypothesis of a mental lexicon constituted by lexical entries or word representations. These models include Morton's (1969, 1979) logogen model that considers the existence of word detectors for each word in the lexicon or "logogens". When a letter string is entered, the counters of the logogens that contain the features extracted from the stimulus are increased, and a threshold level for the identification of a word is reached as a function of frequency. The logogen model has two systems: the cognitive and the logogen, in order to separate auditory and visual inputs and for producing oral outputs. Word meanings stored in one of the systems are distinguished from the ones stored in the other system.

Further models have been classified based on their theoretical premises (e.g. logogen and multicomponent, serial search and verification, etc.), their format (verbal, mathematical, algorithmic), the task (e.g. perceptual identification, lexical decision) and the dependent variable they predict (e.g. RT), among other characteristics (for a detailed description see Grainger and Jacobs, 1994b).

However, in the last forty years, computational models of visual word recognition have gained further attention due to the advantages they present. Barber and Kutas (2007) pointed out that computational models are explicit and fully specified, internally consistent, can be simulated allowing comparisons with human performance, and can be "lesioned" or are able to simulate malfunctions resembling human brain damage. Furthermore, Norris (2013) pointed out that the behaviour in these models are determined not only by the theoretical principles but it results from the interaction between those principles and the contents of the lexicon.

Mathematical models have also aimed to explain the effect of psycholinguistic variables in the processing of words in reading through explicit assumptions regarding word processing that have been tested and sometimes falsified

(Gomez, 2012). According to Grainger and Jacobs (1994), mathematical and algorithmic models have the advantages of providing explicitness and precision, and because they are based on mathematical principles are less liable to show inconsistencies.

The models that will be described in more detail in the following sections were included in this chapter for the following reasons: 1) They have been the basis of a number of models, as is the case with the Interactive Activation Model (McClelland & Rumelhart, 1981), and the Diffusion Model (Ratcliff, 1978); 2) They can explain behavioural results in the lexical decision task, which is one of the main tasks used in the research of visual word recognition; 3) They belong to the computational or mathematical family models and can therefore be used to run simulations and their results can be compared to behavioural evidence. More recent models such as the Leaky Competing Accumulator Model (Usher and McClelland, 2001) were included due to its application to the lexical decision task (Dufau, Grainger & Ziegler, 2012).

1.1.3.1. THE INTERACTIVE ACTIVATION MODEL

The interactive activation (IA) model is a localist connectionist model of letter and word perception, it starts with localist rather than distributed representations where different types of information are encoded in different units or group of units (Barber and Kutas, 2007). The model was developed by McClelland and Rumelhart (1981) to account for context effects in letter perception.

The IA model assumes that perceptual processing occurs within a structured system that includes different levels of processing according to the level of abstraction of the input representation. These levels include the visual feature level, the letter level, the word level and higher levels of processing that provide top-down input to the word level (theoretically included in the model but not implemented). This model also assumes that visual perception involves spatial parallel processing. Furthermore, the model theorizes that perception is an interactive process conformed by a top-down (conceptually driven) and a bottom-up (data driven) processes that codetermine the nature and the time course of the perception of the letters in the word.

The existence of *nodes* for each relevant unit in the system (e.g. there is a node for each word and for each letter in each letter position within a four-letter string) in the model allows the classification of two levels of nodes: word level nodes and letter level nodes. Every node has connections with other nodes, and they communicate either in an *excitatory* or an *inhibitory* manner. Connections between the same level or between adjacent levels are possible but nonadjacent levels are not connected. Each node has an associated activation value and positive values make the node *active*. In the absence of inputs from neighbours, the nodes decay to an inactive state (activation value at or below zero). Only active nodes influence other nodes (excitatory or inhibitory). The resting level of the nodes is determined by frequency of activation of the node over the long term. For example, the nodes of high frequency words have resting levels higher than those for low frequency words. The model also incorporates intra-level inhibitory connections that represent a type of lateral inhibition where incompatible units at the same level compete

The model starts operating when visual features of the input are activated. The visual features of the stimulus activate letters that are consistent with the input and inhibit letters that are inconsistent with the input. Within a given letter position channel, the letter nodes attempt to suppress each other with the strongest ones getting the upper hand. The activation of the specific letter-level nodes sends activation to consistent word-level nodes, inhibiting the inconsistent ones. Word-level nodes also compete with one another and they send feedback to the letter-level nodes. With the feedback the node activations quickly converge to the set of letters and word consistent with the input.

The word frequency effect in this model is explained by the different resting activation level of word units based on the frequency of use or word frequency. High frequency words have resting levels that are more available to get quickly activated whereas low frequency have lower resting levels so that it takes longer till they are active. Whereas high frequency words reach a recognition threshold in a speeded manner, low frequency words reach the recognition threshold slower.

The model can explain the effect of lexicality by the relative activation of a unit. Pseudowords or pronounceable letter strings that share more than one letter in common with a word are able to activate nodes for those words. However, the model accounts equally for pronounceable and unpronounceable letter strings, which according to the findings we have described in the lexicality section of this chapter (section 1.1.1.1), behavioural responses are different according to the pronounceability of the letter string.

Regarding the repetition effect, the model describes an activation level that slowly returns towards its resting level after the unit is accessed. In that case, low frequency words would have higher repetition effects compared to high frequency words. However, when a mask is included in the prime (first presentation of the stimulus) the model is not able to explain the effect of masked priming (Taft, 1993).

The first simulations with the model involved simulating the perception of letters in words and nonwords (McClelland & Rumelhart, 1981). The model simulated the word superiority effect although the size of the effect varied according to the parameter values. Performance on pronounceable nonwords was dependant on the relative strength of letter-word excitation compared to inhibition and on the strength of the competition among word units in a specific time set by the task. However, nonwords also showed some advantages with some parameter values.

Further simulations with variations of the IA model have been conducted. For examples, the semistochastic interactive activation model (SIAM: Jacobs and Grainger, 1992), the dual read-out model (Grainger and Jacobs, 1994), as well as the multiple read-out model (Grainger and Jacobs, 1996). More recently, the Spatial Coding Model (Davis, 2010) the Dual-route Cascaded model (Coltheart et al., 2001) are examples of models that include or are based on the interactive activation model.

In the next section, the multiple read-out model (Grainger and Jacobs, 1996) will be further discussed because this model has been specifically developed for the lexical decision task and it has explained the processing of different nonword stimuli, which initially the interactive activation model was not able to account for.

1.1.3.2. THE MULTIPLE READ-OUT MODEL

The multiple read-out model (MROM) was developed by Grainger and Jacobs (1996). This model is an extension of the Interactive Activation Model (McClelland and Rumelhart, 1981; Rumelhart and McClelland, 1982) and attempted to explain the microstructure and dynamics of orthographic processing by predicting various dependent variables (accuracy, RT, and RT distributions) across two paradigms: lexical decision and perceptual identification.

Being based on the IA model, the multiple read-out model keeps the multiple code activations (several codes are activated in parallel when a word is presented) and lateral inhibition hypotheses. When a string of letters is presented to the system, all word representations that are orthographically similar to the input are activated. However, words that share features with one another are in turn inhibited by each other, and the strongest beats the other competitors.

The key addition of this model to the interactive activation framework is the notion of a variable criteria and the multiple read-out hypothesis. The variable criteria hypothesis refers to a trial-to-trial variation around a fixed mean value of the critical level activation value to correctly identify a word by the appropriate whole-word orthographic representation (word unit or M criterion) (Jacobs and Grainger, 1992). In this model, at least one of the codes that is appropriate for responding in a given experimental task needs to reach this critical activation level (multiple read-out hypothesis). Thus, the model assumes that a lexical decision does not necessarily require (complete) identification of the word stimuli.

Three processes of intra- and extra-lexical nature are required for the binary decision (“yes”/ “no”) in a perceptual identification or a lexical decision task. Intra-lexical information is provided by global (overall sum of activation levels in units) and local (activation of the functional unit) activity within the lexicon and serve to generate a word response (“yes”), while, the time from stimulus onset provides extra-lexical information and helps to generate a nonword response (“no”).

Each source of information has a corresponding criterion that, in combination, determine the type (word or nonword) and the speed of a response. While the local criterion is fixed derived from the process of word recognition, the global and the time criteria can be adjusted. The factors that can influence global and time criteria are the distribution of the activation values of words and nonwords in a task, as well as task demands of speed and accuracy.

The speed and accuracy of responses can be explained by the combination of the above-mentioned criteria. For example, slower reaction times will be explained by a high global activation value in early processing that will promote a longer deadline (higher time criterion) and a lower global criterion. When the task stresses speed, both criteria will be lower. However, when the task stresses accuracy, high criteria values are set for time and global activation. Low global activation will set a high global criterion and will result in correct word response (generated by the local criterion) or a correct nonword response (generated by the time criterion). In contrast, high global activation will set a lower average global criterion generating faster correct word responses to words but increasing the number of false positive errors to nonwords.

The model was developed to predict mean RTs and RT distributions, and error percentage of words and nonwords, as well as means and RT distributions of misses (errors to word stimuli) and false alarms (errors to nonword stimuli). Furthermore, this model attempted to provide an integrative account of facilitatory and inhibitory effects of orthographic neighbourhood and the interactivity/additivity of word frequency and nonword lexicality with these neighbourhood effects. Tested through experimental and simulation data, the model provided accurate predictions on their dependent variables in a single experiment in contrast to previous models. Also, it gave a successful explanation regarding the speed-accuracy trade off.

Moreover, the inhibitory influences of simultaneously activated word units that affect the time taken by a given word unit to reach the local activation threshold (neighbourhood frequency), and the sum of word unit activation in early phases of processing influences the relative involvement of the local activation and the time decision criteria in the model (neighborhood density) accounted for the neighbourhood effects.

Interestingly, the global activation decision criterion is hypothesised to be operational only in the lexical decision task. A reduction in nonword lexicality and stressing speed over accuracy in the instructions given to participants would increase the use of the global activation decision criterion, increasing the facilitatory effects of neighborhood density and decreasing the inhibitory effects of neighborhood frequency consequently. Also, the model correctly predicted a facilitatory effect of increasing numbers of high-frequency word neighbours of nonword stimuli. This is particularly important in the light of cross-language neighborhood effects in bilinguals.

Regarding the word frequency effect itself, the model explains this effect in a similar manner to the interactive activation model (see section 1.1.3.1). However, this model further expands on the effect of lexicality by predicting different behavioural responses (speed and accuracy) for pronounceable (pseudowords) and unpronounceable nonwords. Whereas unpronounceable nonwords are easy to reject, pseudowords are more difficult to reject because they generate more activation in the system and can reach the activation threshold compared to unpronounceable nonwords that are quickly identified as nonwords.

Nevertheless, the model does not explicitly account for the effect of repetition. Considering that the parameters are the same as the interactive activation model, it is possible to hypothesise that a larger repetition effect could be found in low frequency words compared to high frequency ones due to their different resting activation levels. Furthermore, unpronounceable nonwords that did not reach an activation level would not show an effect of repetition, in contrast to, pronounceable nonwords that were able to activate word representations.

The interactive activation model and the multiple read-out model have both been developed to understand the mechanisms of lexical access. The multiple read-out model has further included parameters to account for the speed, errors and RT distribution of correct and incorrect response. The next model, the Diffusion model (Ratcliff, 1987), focuses more on the explanation of the wide variety of response patterns in recognition tasks that include dual choices. Among its different implementations, this model has also been implemented to account for the results observed in the lexical decision task (Ratcliff, Gomez & McKoon, 2004). Based on the key proposal of the accumulation of evidence towards a word or nonword criterion over time, this model has been able to account for the effect of word repetition.

1.1.3.3. THE DIFFUSION MODEL

The diffusion model was developed by Ratcliff (1978) to examine components of cognitive processing in two-choice decision tasks. This model is defined as a mathematical model rather than a localist connectionist model. It is based on memory retrieval and uses a resonance metaphor of access to memory traces in which evidence is accumulated in parallel from each probe-memory item comparison, and each comparison is modelled by a continuous random walk process (Ratcliff, 1978).

It has been applied to lexical decision experiments (Ratcliff et al., 2004) and a variety of tasks that require a binary decision (e.g. Ratcliff, 1978, 1981, 1988; Ratcliff & Rouder, 1998, 2000; Ratcliff et al., 1999; Strayer & Kramer, 1994).

In the diffusion model, two-choice decisions (like in the lexical decision task) are explained by the accumulation of noisy information from a stimulus over time. The mechanism underlying these decisions includes the accumulation of noisy information towards one of two decision criteria or boundaries from a starting point in time. The information is accumulated at a specific rate (drift rate*)* that depends on the quality of information produced from the stimulus processing. The drift rate varies around a mean value within the same trial. This variability allows processes with the same rate to reach the same boundary at different times and also allows a process to reach the wrong boundary by mistake, causing an error. The similarity of a letter string to a word ("wordness") influences the amount of accumulated information towards a word or towards a nonword criterion. Larger drift rates are assumed for high-frequency words, followed by low-frequency words, pseudowords, and random letter strings.

The boundaries in this model can be moved further apart, which results in slower but more accurate responses, or move closer together to produce fast and less accurate responses, therefore explaining speed-accuracy trade-offs.

Furthermore, the drift rate across-trials can be fixed or variable in the model. The model predicts that with a fixed drift rate, the speed of the errors and correct responses would be the same. However, with a variable drift rate, errors will be slower than correct responses. Moreover, faster error responses compared to correct responses can also be predicted by varying the starting point across trials, processes starting near the error boundary will have shorter RT and greater probability than processes starting near the correct boundary.

In the implementation of the lexical decision task in the diffusion model, the drift rate is assumed to be normally distributed across trials, with a standard deviation and a starting point that is rectangular distributed in a given range.

Other processing components such as the encoding and response execution are included into a nondecision component of the RT. This nondecision component is also variable and contributes to the leading edge shifts caused by word frequency previously observed in the literature (Balota & Spieler, 1999). In combination with the variable nondecision component, the drift rate can account for such results. For example, the distribution of values of the nondecision component processes can be shorter, longer or equal to the mean value (cumulative RT distribution). If the drift rate is high for each of those values of the distribution, the cumulative RT function of the combination rises rapidly from zero, giving to the nondecision component a small value with no contribution from longer or equal mean values of this component until later in the function. However, when the values of the drift rate are lower, the cumulative RT function includes all processes of the nondecision component. Therefore, only when the values of the drift rate are high and the nondecision component is not variable, the function is shifted toward shorter times in its leading edge.

Importantly, for this model, lexical decision data does not provide a window into the lexicon or the task itself may have nothing to say about lexical representations or lexical processes such as lexical access as pointed out by Ratcliff et al. (2004). Therefore, for these authors, the word frequency effect would be a by-product of the nature of the task itself and not a manifestation of accessibility to the lexicon. As mentioned in the description of the model, the word frequency effect would be explained by the drift rate that it is influenced by the "wordness" of the stimuli. The high frequency words are the most familiar or "wordlike" stimuli and reached the word boundary faster compared to the low frequency words.

The effect of lexicality is also explained by the drift rate parameter; larger drift rate values are produced for nonwords resulting in more reliable identification of its "wordlikeness" compared to pseudowords. The model predicts that words can approach the word boundary faster compared to pseudowords (pronounceable nonwords) approaching the nonword boundary or the word boundary (for an error). However, nonwords would also accumulate evidence towards the nonword boundary faster and more accurately compared to the pseudowords.

The Diffusion model explicitly focuses on the mechanisms behind the decision component of the response time by the accumulation of information towards specific set up thresholds, this would account for the repetition effect in the sense that the accumulation of information could be done within the same task (Ratcliff et al., 2004).

Although this model accounts for a complex pattern of behavioural evidence including reaction times, errors and RT distribution, it does not provide insight regarding lexical representations and how they are accessed. Therefore, the model does not give any account of the process of lexical access or word recognition; rather it focuses on the response mechanisms. Another limitation of this model is that it does not account for the effects of neighbourhood, in contrast to the multiple read-out model, for example. The model that will be described in the following section provides an explanation regarding lexical access and at the same time it incorporates the response mechanisms provided by the diffusion model.

1.1.3.4. THE LEAKY COMPETING ACCUMMULATOR MODEL

The Leaky Competing Accumulator model (Usher and McClelland, 2001), also incorporates the proposal of the accumulation of information from the diffusion model (Ratcliff, 1978). However, this model further specifies the nature of this evidence accumulation. Usher and McClelland (2001) proposed a model of perceptual choice in which information is accumulated in nonlinear decision units in a gradual, leaky, stochastic (intrinsically variable) and competitive way. In this model, leakage and competition work together to account for data from choice tasks using time-controlled and standard reaction time paradigms. This work took into consideration that the human information-processing system may not be a perfect integrator of information but the information accumulation process is influenced by leakage or amplification of differences that can also arise from a partial lateral inhibition between accumulators. The authors concluded that the leakage and competition apply broadly across a wide range of information-processing tasks and can be applied at the psychological and neurophysiological levels.

Dufau, Grainger & Ziegler (2012) applied the leaky competing accumulator (LCA) model of Usher and McClelland (2001) to the understanding of speeded binary decision making in the lexical decision task. The aim was to understand the mechanism that participants use to discriminate words from nonwords and to investigate the role adjustments in response criteria regarding effects of list context within the LCA framework specifically for the lexical decision task.

A dynamic mechanism for nonword decision-making is suggested by Dufau, Grainger & Ziegler (2012). They followed the standard practice regarding the YES response node where a bottom-up input reflects evidence of a word in the stimulus. However, in the case of the "no" response node, the input is a constant value minus the evidence of a word. Different from the multiple read-out model deadline mechanism (Grainger & Jacobs, 1996) that is only based on lexical activity and elapsed time and that, according to Ratcliff et al. (2004) constitutes a meta-level problem because it does not allow the model to produce fast negative responses, especially when the nonwords are random letter strings.

The LCA model considers two sources of lexical influences in the activity of the "no" response node. One of these sources is the total input to the two response nodes that equals to a constant according to Usher and McClelland (2001). The other source has its origins on the mutually inhibitory connections between the two response nodes where higher activity in one of them would automatically cause a reduction in activity on the other. Another very important element of the LCA is the decay of information as represented by a "leak" that is associated with the noisy accumulation of information over time.

In the implementation of the model, the decisions are made based on the accumulation of noisy, leaking and competing information over time. The processing is terminated and a lexical decision is made when the accumulation of activation towards a *YES* or *NO* decision node reaches a criterion value that is trial-specific (dependent of the setting of response thresholds). The response criteria are adjusted trial-by-trial. If a lexical decision emphasises the speed of responses rather than accuracy, the response threshold values decrease by a constant value on each trial if the responses are correct but when an error is made, the thresholds are reset to their initial values. However, when the experiment emphasises accuracy rather than speed, there is a smaller constant value for threshold adjustments.

LCA calculates evidence for nonwords considering the input to the "no" decision node that is equal to a constant value minus the input to the "yes" decision node. The "no" decision node would constitute evidence for a nonword and the "yes" decision node for a word. However, to calculate input to the "no" decision node the model needs to know the amount of lexical activity generated by the stimulus and the total input value that optimises speed and accuracy of response to words and nonwords. This calculation must be done trial-by-trial in order to obtain the total input value (optimal value).

The effects of list context and task instructions, according to this model, are explained in terms of the response criteria adjustments to the "yes" and "no" decision nodes under the principle that participants monitor their performance on a trial by trial basis and try to optimize their performance according to the instructions they received. Based on a "monitor and adjust" principle (similar to that on the conflict monitory theory from Botvinick, Braver, Barch, Carter & Cohen, 2001), the proportion of "yes" and "no" responses does or does not facilitates the threshold and optimisation of responses, then the response criteria adjustments trial by trial become crucial for the performance in the task.

This model attempted to solve the deficiencies of the multiple read-out model identified by Ratcliff et al. (2004) and Wagenmakers, Ratcliff, Gomez & McKoon (2008) regarding the inability of the latter model to produce fast error responses to word target without distorting the RT distribution by generating excessively fast RTs in the first decile of the distribution, the lack of word frequency effect in the error RTs, different RT distributions for correct and incorrect responses, and the incapacity to generate fast correct RTs to nonwords without generating many errors. The LCA model, however, is different from the diffusion model (Ratcliff et al., 2004) regarding the response mechanism because it included an online adjustment of response criteria and provided additional parameters to explain how the accumulation of evidence occurs in the lexical decision task, especially for nonwords. This model was tested in lexical decision experiments and replicated the complex results patterns explained by the Diffusion model (Ratcliff et al., 2004).

1.1.4. SUMMARY OF MONOLINGUAL VISUAL WORD RECOGNITION

Behavioural and electrophysiological findings have shown that responses are more accurate to words compared to pseudowords, and to pseudowords compared to nonwords in recognition tasks. However, in lexical decision tasks, responses are faster and more accurate to words and nonwords compared to pseudowords. Evidence of lexical access can be found even in identification tasks. This distinction between words and pseudowords can be observed in the timing of visual word processing at early and late latencies after stimulus onset.

Responses to high frequency words are usually faster and more accurate than responses to low frequency words in the lexical decision task, although this effect of word frequency can vary in size according to the task at hand, and it can be found across different languages. Even though word frequency is one of the most robust effects in visual word recognition research, its investigation has relied on accounts of frequency that do not reflect the use of the language nowadays. Electrical brain responses have shown that the effect of word frequency can be consistently found in the N400 time window probably reflecting semantic-related or feedback processes in visual word recognition.

Item repetition can facilitate responses to words and inhibit responses to pseudowords. However, facilitated responses to pseudowords under certain experimental conditions probably reflect episodic memory processes. The effect of repetition in behavioural and ERP responses is larger for low frequency words compared to high frequency words.

Finally, the diversity of paradigms in visual word recognition research has allowed the comparison between tasks with behavioural and ERP/MEG measures.

Computational and mathematical models of visual word recognition have succeeded on providing quantitative predictions and simulations of lexical access. Effects of word frequency and lexicality have been replicated; however, the effect of repetition and the role of task demands has not been fully explained. While some models focus on the process of retrieval or access to representations, other models focus more on the response mechanisms.

After describing the most important effects in visual word recognition in monolinguals, the next section will focus on visual word recognition when the system is familiar with two languages. Bilingual visual word recognition will be described in terms of the effects of lexicality, word frequency and repetition. Models of bilingual visual word recognition will be also discussed.

Bilingual visual word recognition research has gained more popularity in recent years with the demands of the present world, mobility across countries and the need to communicate in a lingua franca. The investigations of visual word recognition in bilinguals will help our understanding of how language is processed, how experience with a language can modulate the process of word recognition, how this is different from a word recognition system that only knows one language and what the differences are in lexical access between the first and the second language.

1.2. BILINGUAL VISUAL WORD RECOGNITION

So far, I have focused on monolingual visual word recognition. Lexical access in monolingual visual word recognition has been explored through the effect of lexicality, word frequency and repetition. However, bilingualism is not an exception anymore and is more present in the modern society as many people in the world are able to speak and read more than one language (De Groot, 2011). Understanding the effect of those factors in the first (L1) and the second (L2) language is therefore crucial to understand the process of visual word recognition when the individual can speak two different languages.

Research in bilingualism includes behavioural and electrophysiological studies. In this section I will present behavioural findings regarding the effect of lexicality, word frequency, repetition and task demands in bilinguals. Furthermore, the electrophysiological findings and the neural correlates of these factors in bilinguals will also be explored. Finally, models of bilingual word recognition will be described.

1.2.1. BEHAVIOURAL FINDINGS

The study of visual word recognition in bilinguals has usually focused on the nature of the bilingual lexicon and how this can be accessed. The hypotheses tested in bilingualism have moved from those of monolingual research to test the existence of an independent or integrated lexical access (e.g. Beauvillain & Grainger, 1987; Brysbaert, Van Dyck, & Van de Poel, 1999, De Groot, Delmaar & Lupker, 2000; Dijkstra, Grainger & van Heuven, 1999), as well as a selective (e.g. Scarborough, Gerard, and Cortese, 1984) or a nonselective (e.g. Dijkstra, Timmermans & Schriefers, 2000) access to the lexicon in bilinguals.

In the following sections, I will review some of the findings in visual word recognition in the first (L1) and the second (L2) language in bilinguals. The effect of lexicality, word frequency, repetition and the role of task demands will be discussed.

1.2.1.1. LEXICALITY AND WORD FREQUENCY EFFECTS IN L1 AND L2

Research on bilingual visual word recognition has also involved studying factors that can influence lexical access to understand the process of word recognition. For example, the word superiority effect discussed in the lexicality section of the monolingual behavioural findings (section 1.1.1) has also been observed in bilinguals' L2 (Favreau, Komoda & Segalowitz, 1980).

Favreau et al., (1980) were interested in investigating if the word superiority effect could be found in the bilinguals' L2. They conducted a modified version of the Reicher-Wheeler paradigm with English (L1) – French (L2) bilinguals where words, pseudowords (anagrams of word stimuli) and single letters where presented. Each language (L1 and L2) was tested individually in a pre-cue and a post-cue condition on different days. As previously mentioned in the discussion regarding the effect of lexicality in section 1.1.1, the Reicher-Wheeler paradigm does not require an explicit lexical decision; instead, the task requires the participant to identify whether a specific letter is present or not in a letter string. However, even when this task does not require a lexical decision, an effect of lexicality can be found, indicating different processing for words compared to pseudowords, and therefore the occurrence of lexical access. If the task did not require lexical access, the responses for words and pseudowords will be similar and there will not be an effect of lexicality. Favreau et al. observed a lexicality effect in the pre-cue condition, which was similar for both languages; however, the superiority effect was not found due to many errors to pseudowords. Nevertheless, results from the post-cue condition exhibited a word superiority effect only in L1. No effect of stimulus type was found in L2 for the post-cue condition. To further explore the lack of pseudoword superiority effect in L2, a second experiment was conducted. The same task was used in this experiment, but the procedure attempted to determine the critical durations to achieve a high level of performance on word stimuli in L1 and L2. Results from a subset of participants who had previously performed the first experiment showed no effects of language or stimuli in the pre-cue condition. Whereas, word superiority effects similar in L1 and L2 were found in the post-cue condition. Because the authors had to adjust the durations of the critical stimuli to be able to observe the word superiority effect in L2, the authors suggested that even when bilinguals are proficient in both languages, it might be the case that they use their knowledge of the orthography of their L2 less efficiently in comparison to their L1.

This evidence also suggests that the timing of the lexical access in bilinguals can be different in L2 compared to L1. Interestingly, the effect of lexicality or the difference between the processing of words and pseudowords in bilinguals has also shown differences in the timing of appearance of the effects per languages (e.g. L1 vs. L2).

Grossi, Murphy and Boggan (2009) investigated the lexicality effect in Italian (L1) – English (L2) late bilinguals and native English monolingual speakers. Words, pseudowords and nonwords were presented in a Reicher-Wheeler paradigm. Responses were faster for English stimuli relative to Italian stimuli regardless of the participants' first language (Italian in bilinguals or English in monolinguals). Responses were equally accurate despite participants' group. Interestingly, Italian-English speakers only showed more accurate responses for Italian words compared to pseudowords in Italian (word superiority effect). However, these bilinguals had better performance for pseudowords compared to nonwords in Italian and English. Despite of the lack of a word superiority effect in bilinguals' L2, similar effects of lexicality (main effect of stimulus type) were observed in both languages (no main effect of language) in the accuracy of responses. However, English monolinguals, only showed word and pseudoword superiority effects in English. The comparison of the pseudoword superiority effect (pseudowords vs. nonwords) in bilinguals and monolinguals revealed that the effect was similar in both groups. The authors suggested that no word superiority effects should be expected in individuals unfamiliar with a language but the word and the pseudoword superiority effects might serve as an index of familiarity or orthographic fluency with a language. The authors argued that although it is possibly to shape the visual word recognition system by systematic exposure, the proficiency level might determine the presence or absence of the word superiority effect in the bilinguals' L2.

The study from Grossi et al. (2009) and the pseudoword superiority and lexicality effects in both the bilinguals' languages indicate that lexical access occurred in L1 and L2 even when the task did not require a lexical decision. Nevertheless, the lack of a word superiority effect in bilinguals' L2, as suggested by Grossi et al., can be evidence of a less orthographically fluent L2 compared to the L1 in bilinguals.

Orthographic fluency can be acquired by increasing the experience with a language. The word frequency accounts for words that are encountered more frequently in contrast to words that are encountered less frequently. In a bilingual, the less dominant language had probably been encountered less frequently. Importantly, word frequency has been classified as another index of lexical access. The study of this effect is crucial in bilingual visual word recognition because as was previously discussed in section 1.1.1, the effect of word frequency is one of the best indicators of lexical access. In bilingual visual word recognition, a key question is how frequency and proficiency are related, namely, if the effect would be larger in size in the less proficient language.

Few studies have investigated the effect of word frequency in bilinguals' L1 and L2 using behavioural measures (e.g. Duyck, Vanderelst, Desmet & Hartsuiker, 2008). Due to the lack of research on this topic, those studies based their hypotheses on evidence provided by production studies employing picture naming paradigms. Production studies have revealed larger word frequency effects for the nondominant language compared to the dominant one in unbalanced bilinguals (e.g. Gollan, Montoya, Cera, and Sandoval, 2008).

Duyck et al. (2008) have suggested the possible role of proficiency in L1 and L2 in lexical access. This study was one of the first to explore the effect of frequency in L1 and L2 in lexical decision tasks in bilinguals. In this study, Dutch-English bilinguals performed language-specific lexical decision tasks in their L1 (Dutch) and L2 (English). They compared the size of word frequency effect in the L1 and L2. Also, a group of monolingual English native speakers was included to compare their results to those of bilinguals, although no group differences were observed in genereal task performance. However, a larger word frequency effect was found in L2 compared to L1 for both reaction times and accuracy scores. It was suggested that this size difference of the word frequency effect was due to the lower proficiency in the L2. It is worth mentioning that no objective measures of language proficiency were reported in this study. Therefore, any conclusions regarding language proficiency should be taken with caution.

An important question is whether the size of the word frequency effect is independent of proficiency, modulated by proficiency or if there are additional factors that could modulate it in bilinguals' visual word recognition. For example, the characteristics of the first language might influence the processing of the second language. Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood (2008) investigated this topic with a progressive demasking word identification task. In this task, a mask was presented before and after the target stimulus, and the duration of the target increased gradually across trials, whereas the duration of the mask decreased. Participants had to presss a button as soon as they identified the word and then to type the target word using a computer keyboard. Monosyllabic English words (L2) were presented to bilinguals whose native language was French, German or Dutch. Results revealed very similar responses and an overlap of reaction time patterns across bilinguals. Only cognate status (cognate vs. noncognate) influenced these response patterns, which for the authors was an indication of an activation of the native language and a nonselective lexical access. More importantly, these authors analyse the word frequency effect in L2 in bilinguals and compared it to the effect in monolinguals. They observed that recognition times of bilinguals were affected by written and spoken frequency, whereas native speakers were only affected by spoken frequency. These results were interpreted as more sensitivity to the number of occurrences of a word in bilinguals because of lower subjective frequency of words in L1.

Diependaele, Lemhöfer and Brysbaert (2013) proposed that differences in the word frequency effects found in L1 and L2 could be due to differences in the size of the L1 and L2 lexicons rather than bilinguals' proficiency in the second language. To test this proposal, Diependaele et al. re-analysed the data reported by Lemhöfer et al (2008). In their analysis, they incorporated frequency measures from film subtitles (Brysbaert and New, 2009) to improve the word frequency estimates. Their analysis replicated the interaction between participant group (bilinguals vs. monolinguals) and word frequency found in Lemhöfer et al. (2008). Next, the interaction between frequency and proficiency measured by English vocabulary test scores (LexTALE, Lemhöfer & Broersma, 2012) was included in a nonlinear mixed effects model. This increased the fit of the model and made the interaction between bilinguals' L1 and word frequency nonsignificant. Remarkably, the analysis of the monolingual data with the language proficiency scores also revealed a significant interaction between word frequency and language proficiency. Therefore, the hypothesis that individual skill differences should explain not only group differences across monolingual and bilingual participants but also within each group was confirmed. Language proficiency (measured by vocabulary size) had the same effect in L1 and L2, and the relation between proficiency and frequency effects did not crucially depend on the similarity between L1 and L2 (lexical interference and competition) in the analyses. Therefore, lexical entrenchment refers to extensive practice with words that enhances the entrenchment of lexical representations leading to faster activation and less interference from similar representations (smaller processing differences between high and low frequency words). Better entrenchment correlates with the frequency effect that reflects the vocabulary size, e.g. smaller frequency effects indicate a larger vocabulary size.

This re-analysis of Lemhöfer et al.'s (2008)' data further suggested that the size of the word frequency effect does not exclusively depend on being bilingual and the limited exposure to their L2. Rather, the size of the word frequency effect will depend on the vocabulary size of the bilingual in L1 and L2. Bilinguals with larger vocabulary sizes will have smaller word frequency effects compared to bilinguals with smaller vocabulary sizes. The word frequency effect interacts with the effect of item repetition in monolinguals by increasing the exposure to specific items (see section 1.1.1.2). In the following section I will discuss the impact of item repetition in bilingual visual word recognition.

1.2.1.2. REPETITION EFFECTS IN L1 AND L2 AND THE ROLE OF TASK DEMANDS IN BILINGUAL LEXICAL ACCESS

Repetition can increase the exposure to specific items within an experimental paradigm. Some studies have examined if the effect of repetition in one task can be transferred to a different task. For example, Van Assche, Duyck & Gollan (2016) investigated the effect of repetition across different modalities (recognition and production) with a lexical decision and a picture naming tasks. Bilinguals performed the tasks separately for each language in two different experiments. Words of high and low frequency were repeated 15 times in total on three different sessions that incorporated both experimental tasks. L2 results revealed a decrease in the word frequency effect with repetition in both tasks, although the effect was stronger in picture naming compared to lexical decision. Cross-modal repetition benefited high and low frequency words in picture naming, however, low frequency words benefited more from the cross-modal repetition. L1 results showed a reduction in the size of the word frequency effect because of repetition. However, unlike L2 results, the cross-modal repetition effect was only observed for low frequency words and did not reduce the size of the frequency effect. The authors interpreted these results as evidence of lexical representations in L1 can get activated faster compared to representations in L2.

The role of task demands in bilingualism research has contributed to the debate regarding the existence of a nonselective vs. a selective lexical access. For example, Scarborough, Gerard and Cortese (1984) were interested in investigating if bilinguals have separate lexicons for each language. In the second experiment of this study, Spanish-English bilinguals and English monolinguals were presented with a lexical decision task with words and nonwords based in Spanish (L1) and English (L2). This lexical decision consisted of two parts were stimuli apart from words and nonwords in the target language were presented: a "pure" language condition were nonwords derived from real words from the nontarget language were presented, and a "mixed" language condition were real words from the nontarget language were presented. Participants had to decide if the stimuli were words in a target language or if this was not the case. Half of the bilinguals performed the task with L1 as the target language and the other half with L2 as the target language. Results of bilinguals who performed the lexical decision task in their L2 and monolinguals were compared. Bilinguals rejected words and nonwords of the nontarget language at the same speed, although participants were slower in the "mixed" language condition compared to the "pure" condition. Moreover, word frequency effects were observed in reaction times and accuracy of positive responses (responses to words in the target language) but not in the negative responses, which also included words of the nontarget language. These results were interpreted as bilinguals selectively accessing to their lexicon depending on the target language of the task, consequently processing the nontarget language words as nonwords.

However, other studies have reported that bilinguals are able to exclude effects from the nontarget language only to a limited degree depending on the frequency of the nontarget language words (Dijkstra, Timmermans & Schriefers, 2000). In their study, Dijkstra, Timmermans and Schriefers presented words that share the same written form in two languages (interlingual homographs) to study the effects of task demands and relative word frequency in bilinguals' visual word recognition. Dutch-English bilinguals were presented homographs that were high frequency in English but low frequency in Dutch, high frequency in Dutch but low frequency in English, as well as low frequency in both languages. In the second and third experiments of this study, participants performed two go/no-go tasks where they only had to respond to words in English (English target) or only respond to words in Dutch (Dutch target). Results confirmed that participants were able to exclude effects from the nontarget language only to a limited degree because they also showed slower responses and higher error rates for Dutch/English homographs with high frequency in Dutch (L1). These findings supported evidence for the nonselective lexical access.

The nonselective nature of bilingual lexical access has been discussed elsewhere (e.g. Dijkstra, 2005). However, studies incorporating interlingual homographs (e.g. Dijkstra, van Jaarsveld, ten Brinke, 1998) have suggested the important role of task demands and language intermixing list (list composition).

More recent studies have suggested that bilinguals can use sublexical language membership information to respond to the task at hand (Casaponsa, Carreiras & Duñabeitia, 2014; van Kesteren, Dijkstra & Smedt, 2012). Van Kesteren et al. (2012) investigated bilinguals visual word recognition in a language decision, an L1 lexical decision where items in L2 were also presented, and an L2 lexical decision with L1 items. Norwegian-English bilinguals were presented with words in their L1 and L2 that varied in language-marking orthographic characteristics. The results found that bilinguals use these language-specific characteristics strategically according to the task at hand.

The importance of cross-language interactions is briefly discussed in the following section.

1.2.1.3. CROSS-LANGUAGE INTERACTIONS

As in the case of monolingual visual word recognition and the effect of orthographic similarity on behavioural and electrophysiological responses described in section 1.1.1.5, in bilingual visual word recognition, the similarities across languages can lead to changes in responses caused by cross-language interactions.

To investigate selective and nonselective lexical access in bilinguals, and therefore whether the L1 and L2 in are activated even when the task did not require the specific language information, van Heuven, Dijkstra & Grainger (1998) conducted a study with Dutch-English bilinguals performing progressive demasking and lexical decision tasks. The number of neighbours was orthogonally manipulated. The orthographic neighbourhood density within- and between languages influenced performance in both tasks. As expected, an English monolingual control group did not show a between-languages effect. Also, the effect of between-language neighbourhood was also obtained in pure or mixed language lists. The effect of orthographic neighbourhood size on the nontarget language was interpreted as evidence of a nonselective lexical access, although it was modulated by task demands and stimulus list context. The effects were smaller in the lexical decision task compared to the progressive demasking task. The authors proposed a model of bilingual word recognition that will be further described in section 1.2.3.

Further evidence of cross-language interactions has been reported in behavioural literature (e.g. Dijkstra, Miwa, Brummelhuis, Sappelli & Baayen, 2010; Dijkstra, Timmermans, Schriefers, 2000; Dijkstra, van Jaarsveld & ten Brinke, 1998; Lemhöfer & Dijkstra, 2004), EEG (Christoffels, Firk & Schiller, 2007) and fMRI (van Heuven & Dijkstra, 2010, van Heuven, Schriefers, Dijkstra & Hagoort, 2008). For a further explanation of the integrated nature of the bilingual visual word recognition system see Bultena & Dijkstra (2013).

As has been suggested by monolingual visual word recognition research (section 1.1.2), the investigation of brain responses allow the observation of the effect of lexical factors on the process of visual word recognition prior to an observable response. In the following section I will present the key ERP findings regarding the effects of lexicality, word frequency, repetition and task demands in bilingual visual word recognition.

1.2.2. ELECTROPHYSIOLOGICAL FINDINGS

The impact of the different languages and lexical access in L1 and L2 can be further explored with ERP. Among the advantages of this technique, as it was mentioned in section 1.1.2, is their temporal resolution. The differences in timing on lexical access in L1 and L2 has become crucial in research on bilingual visual word recognition because it can be interpreted as being related to language proficiency as will be discussed in the following section. Furthermore, a key question in bilingual visual word recognition is if the effects of lexicality, word frequency and repetition differ in L1 and L2 in brain responses measured by ERPs.

Language effects are intrinsic to studies with bilinguals; some evidence has indicated that the same brain regions are used for L1 and L2. These studies have also indicated that neural differences in L1 and L2 representations are more related to the specific computational demands that are dependent on age of acquisition, the degree of mastery and the level of exposure to L1 and L2 (see Perani and Abutalebi, 2005, for a further discussion). However, as indicated by Midgley, Holcomb and Grainger (2009), many studies have compared ERP effects like language switching (see Chauncey, Grainger & Holcomb, 2008 for a review), priming or anomaly detection between languages (e.g. Moreno & Kutas 2005), without considering the systematic comparison of ERP responses to words in L1 and L2. This emphasises the need to investigate of the effect of different variables on the process of visual word recognition in bilinguals.

1.2.2.1. LEXICALITY AND WORD FREQUENCY EFFECTS IN L1 AND L2

The few studies that have examined the lexicality effect in bilinguals' ERP responses have used similar paradigms to those used to study the effect of lexicality behaviourally in monolingual visual word recognition (section 1.1.1.1). As mentioned in the introduction of section 1.2.2, some of these studies focused on the investigation of the role of proficiency on lexical access as revealed by the effect of lexicality.

For example, to investigate the timing of brain activation during native and late-acquired languages in simultaneous interpreters, Proverbio, Adorni & Zani (2009) conducted a study in which participants had to perform a letter-search task. Italian-English-German speakers who were simultaneous translators and highly proficient in the three languages were presented with words and pseudowords in Italian, English and German. It is important to note that the letter-search task is similar to other identification studies in which a lexical decision is not required and lexical access or semantic information is not specifically needed to perform the task. In the letter-search task, participants are presented with a target letter followed by a letter string. They have to indicate whether the target letter is present or not. Behaviourally, responses were faster to words compared to pseudowords (words superiority effect) and no language effect was observed, indicating that the participants were highly proficient in the three languages. Interestingly, ERP results showed that only L1 showed early lexicality effects at occipito-temporal sites between 160-180 ms and at fronto-central sites between 175-220 ms. In contrast, the earliest lexicality effect for L2 was found at approx. 260-320 ms (N2 component level), and a frontal effect was observed later at approx. 220-290ms. Finally, the lexicality effect for L3 occurred at posterior sites at approx. 320-380 ms (N3 component level) and was not observable at fronto-central electrode sites (**Error! Reference source not found.**). The comparison between language and target vs. nontarget stimuli, according to the authors, suggested that later lexicality effects might be related to the lengthy processing of longer and less familiar words. Furthermore, the early lexicality effect only observed for L1 indicated a faster or more solid access to word properties for the native language in comparison to languages learned later in life, regardless of proficiency. The authors concluded that early latency mechanisms support automatic access to the lexicon driven by the orthographic appearance of the stimulus.

The duration of the lexicality effects has been suggested to be longer-lasting in bilinguals' L2 relative to their L1. Lehtonen, Hultén, Rodríguez-Fornells, Cunillera, Tuomainen and Laine (2012) specifically investigated the effect of lexicality, frequency and morphology in early and late bilinguals. Finnish (L1) – Swedish (L2) bilinguals who had acquired both languages during childhood, and Finnish monolinguals performed a lexical decision task in Finnish (bilinguals' L2). Behaviourally, the effect of lexicality was significant for both groups, overall monolinguals showed faster responses than bilinguals. ERP results showed an increased negativity from 550 ms onwards (N400-type effect) for pseudowords that was longer-lasting for bilinguals. Although this study did not compare bilinguals' L1 and L2, the longer lasting effects in bilinguals compared to monolinguals suggested different lexicality effects in L1 and L2.

A modulation of the N400 component by word frequency in different languages has also been studied. For example, Aparicio, Midgley, Holcomb, Pu, Lavaur and Grainger (2012) studied the effects of word frequency on ERP responses of French (L1) – English (L2) – Spanish (L3) trilinguals. Words in the three languages were presented in a semantic categorisation task. Participants had to decide if the item referred to an animal in French, English or Spanish. Behaviourally, results indicated that participants more accurately detected animal words in L1 compared to L2 and L3, and that there was no difference between L2 and L3. The ERP data revealed an effect of word frequency (smaller N400 amplitudes for HF words in comparison to LF ones) that was delayed for L2 and L3 compared to L1, which had an earlier peak with a more right posterior distribution. The authors interpreted these results as evidence of different learning mechanisms for L2 and L3 when L1 has already been learned, expressed in the ERP responses.

The word frequency effect in bilinguals has also been studied using go/no-go tasks. Rodríguez-Fornells, Rotte, Heinze, Nösselt and Münte (2002) measured brain potentials of Catalan (L1) – Spanish (L2) bilinguals and Spanish monolinguals to investigate if bilinguals were able to modulate lexical access according to task criteria. In this study, high and low frequency words and pseudowords in Spanish and Catalan words were presented. Participants were instructed to respond with a button press to words in either Spanish or Catalan (according to the target language) and to make a vowel or consonant decision based on the first letter of the letter string. The first experiment was conducted with Spanish as the target language (bilinguals' L2). The results revealed that bilinguals made more errors to high frequency words in L1 (more false positives). However, the reaction times did not differ significantly between groups. Additionally, the Lateralised Readiness Potential (LRP) was calculated to investigate motor preparation to respond in the task (Kornhuber & Deecke, 1965). Results from the LRP showed a slower response preparation for bilinguals compared to monolinguals. Furthermore, the ERPs revealed that both groups were sensitive to the frequency of words in Spanish but not for words in Catalan at centro-parietal electrodes (modulation of N400 component). In order to investigate the effect of word frequency in bilinguals' L1, a second experiment was conducted. Bilinguals were required to respond to words in Catalan (L1). Behavioural results were not reported but ERP responses showed a word frequency effect for Catalan (L2) but not for Spanish (L2). A final control experiment was conducted to rule out the possibility that the lack of a frequency effect for words from the non-target languge in the ERPs could be due to the task characteristics. In this experiment, Spanish monolinguals only responded to pseudowords. The results revealed a frequency effect in the N400 component. The authors interpreted these findings as evidence of a very efficient blocking of the nontarget language in bilinguals, therefore indicating a selective lexical access, which was in contrast to previous ERP findings that had supported the proposal of nonselective lexical access (Proverbio et al. 2009; Aparicio et al. 2012) and previous behavioural findings (e.g. Dijkstra et al., 2010; Dijkstra, Timmermans, Schriefers, 2000; Dijkstra, van Jaarsveld & ten Brinke, 1998; Lemhöfer & Dijkstra, 2004).

The results from Lehtonen et al. (2012) regarding the word frequency effect (study described above) showed larger word frequency effects for bilinguals compared to monolinguals. ERP responses showed a larger negativity for pseudowords compared to real words in the 500-600ms time window that was longer-lasting for bilinguals relative to monolinguals. The word frequency effect in ERPs was also more pronounced and longer-lasting in bilinguals compared to monolinguals in the 250-350ms and 450-550ms time windows. These differences were present for midline and parietal-occipital locations but not in the frontal region of interest. Given that the findings showed effects on the N400 component time-windows, they interpreted these results as indicating bilinguals' lower exposure to Finnish (bilinguals' L2) compared to monolinguals, as bilinguals have divided their language input between two languages. They therefore explained that exposure has an effect on brain responses indirectly through the effect of word frequency. They also mentioned this in contrast to those of Rodríguez-Fornells et al. (2002), who observed similar-sized word frequency effects in Spanish-Catalan bilinguals compared to

Spanish monolinguals. They argued that the Catalan and Spanish are languages that are closely related and have a high proportion of lexical overlap, which is different from the bilinguals in their study. They concluded that the observed ERP results were likely to reflect lower exposure amounts to words for bilinguals relative to monolinguals because bilinguals divide their language input between their two languages.

To determine at what stage language membership affects lexical access or at what stage language membership is not required to allow deep processing, Ng and Wicha (2013) conducted a study that incorporated a language-specific lexical decision task and a language-specific semantic categorisation task. Stimuli in Spanish and English were presented in both tasks but the participants were instructed to only respond to the stimuli in the target language in different sessions. Results from the lexical decision task indicated that balanced Spanish (L1) – English (L2) bilinguals responded faster to high frequency than to low frequency words in Spanish and English. However, they were slower at identifying low frequency words in their L1 compared to their L2. ERPs were analysed separately for target and nontarget L1 and L2 conditions. In the 250-300 ms window a main effect of frequency was found in target and non-target English words. Moreover, in the 350-650 ms time window, larger negative amplitudes for low frequency compared to high frequency words (word frequency effect) was observed across all recording sites for all target words and for nontarget words in L1, whereas the effect was found at medial-posterior sites for L2 nontarget words. These results were interpreted as evidence of lexical access in bilinguals' L1 and L2, regardless of task demands. These findings opposed the findings from Rodríguez-Fornells et al. (2002). Ng and Wicha suggested that the bilinguals in Rodríguez-Fornells et al.' study (Catalan-Spanish) lived in Germany at the time of testing and their L1 was not mentioned, in contrast to their bilingual population that had Spanish as their L1 and lived in the USA at the time of testing, suggesting that the language exposure and the way languages were acquired was different between the groups of bilinguals in both studies. Moreover, task demands used in Rodríguez-Fornells et al.'s study required a vowel-consonant decision that according to Ng and Wicha, might have reduced the cognitive resources available for lexical processing resulting in a weaker word frequency effect in the nontarget conditions. Furthermore, in Rodríguez-Fornells et al's study, Catalan words with language-specific features (e.g. the use of "ç") were not excluded from the stimuli (Grosjean, Li, Münte & Rodríguez-Fornells, 2003). Ng and Wicha explained that even when Catalan and Spanish share more orthographic similarities than Spanish and English words, they found evidence of word frequency effects in nontarget languages that indicated strong support for the nonselective lexical access. The authors concluded that there is a point in time during word processing when words from a nontarget language are treated as potential targets, therefore, allowing the processing of these words.

To summarise, effects of lexicality and word frequency can be found in bilinguals' brain responses as measured by ERPs. Interestingly, it has been suggested that the language proficiency and the age of language acquisition might influence the timing of the lexicality effects on ERPs in highly proficient bilinguals (Proverbio et al., 2009; Aparicio et al., 2012). Language exposure might also play a role in determining bilinguals' ERP responses (Lehtonen et al. 2012). Contrastingly, the effects of word frequency modulating the N400 component have been suggested to dependent on task demands and therefore, indicate some level of selective lexical access as suggested by Rodríguez-Fornells et al. (2002), although the error number and the presence of a higher false positives evidenced the activation of the nontarget language in their first experiment (van Heuven, Schriefers, Dijkstra & Hagoort, 2008). Furthermore, other findings from ERP responses similar to behavioural data (section 1.2.1.3) support the idea that lexical access can be found in nontarget languages (Proverbio et al. 2009, Ng & Wicha, 2013). However, it has also been pointed out that task demands might play an important role in determining the different stages in lexical access (Ng & Wicha, 2013).

Importantly, the effect of repetition can provide further evidence of lexical access. It has been observed to interact with the effects of lexicality and frequency in monolingual visual word recognition (see sections 1.1.1.3 and 1.1.2.3). Evidence regarding the effect of repetition in bilingual word recognition will be described in the following section. Furthermore, the role of task demands in bilingual visual word recognition will also be discussed.

1.2.2.2. REPETITION EFFECTS AND THE ROLE OF TASK DEMANDS IN BILINGUAL VISUAL WORD RECOGNITION

The effect of item repetition on ERP responses of bilinguals' first and second languages has been investigated by Alvarez, Holcomb and Grainger (2003). They looked at the effect of repetition within and between (translation priming) languages in English native speakers enrolled in Spanish courses (beginner and intermediate levels). Using a mixed-language semantic categorisation task, they presented words (non-cognates) in English and Spanish in an immediate repetition paradigm (word *x* presented on trial *n* is repeated, or its translation presented, on trial $n + 1$). Critical items were Spanish and English nouns that did not require an overt response. According to the authors, the comparison between the repetition effects between and within languages would provide information about the relative role of form and meaning overlap. Specifically, the comparison across languages would help determining the amount of semantically driven effects, whereas, the comparison within languages should reveal a greater repetition effect in the second compared to the first language due to bilinguals less experience with words in the second language. Finally, the mixed-language presentation conditions provided information about language switching on ERPs. The results revealed that within-language repetition effects were larger and more prolonged in L2 than in L1. Also, the repetition effects between languages showed that the time course of the repetition was shifted later when the repeated (translated) word was in the second language.

In a similar comparison of within- and between- (translation) languages, Geyer, Holcomb, Midgley and Grainger (2011) examined the organisation and processing of words in the first and second language of Russian (L1) – English (L2) speakers. In this experiment, words and pseudowords in Russian and English were presented in a lexical decision task where participants only responded to pseudowords. Immediate repetition of words was within- and between- (translation) language. Relatedness of the previous word was also manipulated (same word vs. different unrelated word). The behavioural results did not reveal any significant difference between the languages. The ERP results in the window from 150-300 ms revealed a significant interaction between type of priming (repetition vs. translation), relatedness (related vs. urelated) and anterior-posterior (Frontal vs. Central vs. Parietal vs. Occipital), indicating that repeated target words tended to be less positive than unrelated target words at anterior sites but they were more positive at posterior sites. In the N400 time window (300-500ms) repetition priming effects were observed for L1 and L2 targets although the pattern of the responses was more negative for repeated compared to unrelated items at anterior sites in both languages. They interpreted these results as evidence in favour of the proposal that increasing proficiency in L2 modifies the connectivity between form and meaning representations in L1 and L2.

As in monolingual visual word recognition research (see section 1.1.1.4), a variety of tasks have been employed to investigate behavioural (section 1.2.1) and electrophysiological (1.2.2) responses in bilingual visual word recognition. However, to the best of my knowledge, there has not been a study that has compared task effects with the focus on the effects of lexicality, word frequency and repetition on lexical access in L1 and L2.

The next section will focus on models of bilingual visual word recognition.

1.2.3. BILINGUAL MODELS OF VISUAL WORD RECOGNITION

Models of visual word recognition in bilinguals (e.g. Dijkstra & van Heuven, 1998, 2002) focus on how word representations in L1 and L2 are accessed in the mental lexicon, as well as how other influences such as language proficiency and task demands can modulate lexical access. These models will be discussed next. There are other bilingual models. However, these focus on bilingual production (e.g., Revised Hierarchical Model, Kroll & Stewart, 1994) or bilingual inhibitory control (e.g., Green, 1998) and not specifically on visual word recognition.

1.2.3.1. BILINGUAL INTERACTIVE ACTIVATION MODEL (BIA)

The Bilingual Interactive Activation model (BIA, Dijkstra & van Heuven, 1998) is an extension model of the Interactive Activation Model (IAM, McClelland & Rumelhart, 1981). Similar to the IAM, interactive layers according to the different types of representations are implemented (see section 1.1.3.1). This model accounts for bilingual lexical access by incorporating words of two languages at the word level. Unique for this model are the language nodes. The language nodes are activated by the target word and its neighbours and gather activation of all words from one lexicon and these nodes can suppress activated words in the other lexicon.

Similar to the IA model, the BIA model incorporates the notion of lateral inhibition and top-down feedback at the word level, which in bilinguals will function as inhibitory top-down and cross-language feedback. The language nodes work as a language filter that modulates lexical activity not in an all or nothing fashion but gradually dependent on the relative activity of the language nodes.

In the BIA model word frequency differences are implemented as in the IA model in terms of different resting-level activations. Differences in second language proficiency can be implemented in the model by varying the resting-level activations for L2 words relative to L1 words.

An important assumption of this model is that bilingual word processing involves nonselective lexical access. Support for the model comes from the findings of cross-language neighbourhood effects (van Heuven, Dijkstra and Grainger, 1998). Furthermore, effects of the number of neighbours within and between languages have been simulated with the model.

The BIA model implements non-selective bilingual lexical access. However, the authors have allowed the possibility of a "late selection" mechanism (Gernsbacher & Faust, 1991; Gernsbacher & St John, 2001) that would involve "top-down inhibition".

As in the multiple read-out model (Grainger and Jacobs, 1996), the BIA model incorporates context dependence and task demands as dynamic aspects of bilingual visual word recognition. The BIA model accounts for the effect of lexicality and word frequency similar to the IA model. The model has not explained repetition effects explicitly, however, it is possible to hypothesise that the model can potentially explain the effects of repetition by lowering the thresholds of activation levels by repeated exposure, similar to the explanation of different proficiency levels. The next model is an extension of the BIA.

1.2.3.2. BILINGUAL INTERACTIVE ACTIVATION MODEL PLUS (BIA+)

Regardless of successful simulations of the BIA model of the neighbourhood density effect, the model was not able to fully account for phonological or semantic representation and the relationship between word identification and task demands or the representation of interlingual homographs, while a potential confound regarding the representative and functional nature of the language nodes could be observed in the model among other issues. To address these issues the BIA+ (Dijkstra & van Heuven, 2002) model was developed based on the BIA model.

The BIA+ model assumes two main subsystems for bilingual language processing: A word identification system and a task/decision system. The word identification component has integrated bilingual lexicon across languages and the lexicon is accessed in a language-independent way or parallel activated regardless the language. Moreover, the word activation is affected by language exposure and the task system is governed by an executive control system (Dijkstra & van Heuven, 2002).

One of the principal features of this model is the “temporal delay assumption”, which assumes that when orthographic lexical representations are activated, this activation triggers a cascade of phonological and semantic representations activations. Importantly, the activation of L2 lexical representations will be weaker and further delayed in relation to L1 representations if the bilingual is less proficient in L2 than in L1, due to the lower resting-level activations of L2. If the task demands allow it, the decision process could be based on orthographic lexical representations and do not require semantic and phonological representations. To be observable at a behavioural level, the temporal delay of L2 representations would depend on a combination of bilinguals' proficiency in L2, the language and stimuli characteristics, and the decision criteria for the task at hand (Dijkstra & van Heuven, 2012).

Many findings from different methods and techniques have contributed to the support of the BIA+ model (see Dijkstra & van Heuven, 2012, van Heuven & Dijkstra 2010). In particular, this model can explain the results that support a nonselective lexical access as reviewed in sections 1.2.1 and 1.2.2. This model accounts for the factors of lexicality, word frequency, repetition and task in a similar manner to the IA and BIA models.

1.2.4. SUMMARY OF BILINGUAL VISUAL WORD RECOGNITION

Bilingual visual word recognition has coincided with monolingual visual word recognition in the evidence of lexicality, word frequency and repetition effects in identification and lexical decision tasks behaviourally. While these effects can affect various components of the ERPs, changes in the N400 time window associated with the effect of lexicality, frequency and repetition have been observed. Moreover, differences in the timing of the lexicality effect on ERP responses have been associated with language exposure (either in terms of language acquisition or language proficiency). In contrast to the observed differences in timing in the lexicality effect related to language exposure, the effect of word frequency might be more dependent on task demands. The role of task demands has been less studied in bilingual visual word recognition. The study of the selective and nonselective lexical access has provided the structure to make predictions regarding the effect of task demands on lexical access in L1 and L2.

Research focusing on bilingual visual word recognition has usually compared the effect of lexicality and word frequency between bilinguals and monolinguals. Few studies have compared these effects in bilinguals' L1 and L2. This comparison can be very valuable in the explanation of the structure of the visual word recognition system and the mental lexicon of bilinguals. Moreover, the effect of repetition and task demands has been less explored in terms of visual word recognition, although, they have been instrumental factors in the investigation of the nature of lexical access (selective vs. nonselective). Models of visual word recognition in bilinguals have allowed the interpretation of the findings and have established the basis to make specific predictions regarding the effect of lexical variables in bilingual visual word recognition.

The present thesis focused on the word frequency, lexicality and repetition effects in bilinguals and monolinguals and the role of task demands using behavioural and ERP responses. The aims of this thesis are presented in the following section.

1.3. THE PRESENT THESIS

This thesis investigates visual word recognition in monolinguals and bilinguals and focuses on word frequency, lexicality and repetition effects in different tasks. Word frequency and lexicality (pronounceable and nonpronounceable letter strings) were manipulated as well as repetition. Task demands were manipulated by incorporating tasks that involve different criteria (further described in section 1.3.2.1). The role of list composition was explored because of the observed differences between the word frequency and lexicality effects in the bilingual and monolingual experiments. Six experiments investigated the above-mentioned factors in Spanish (L1) – English (L2) bilinguals and English monolinguals with behavioural (sections 1.3.2.3, 1.3.2.4) and ERP responses (section 1.3.2.2).

1.3.1. PREDICTIONS

Overall topic of this thesis

Lexical access in bilinguals is investigated through the effects of lexicality and word frequency in brain and behavioural responses, as well as repetition (only behaviourally). The aim is to understand the interactions between lexical access, language and task demands, to contrast the empirical results with models of bilingual visual word recognition, and to further explain the mechanisms of lexical access. Furthermore, this thesis aims to investigate lexical access in monolinguals and to study the impact of task demands on lexicality, frequency and repetition effects. The findings will be interpreted using models of visual word recognition that have made specific predictions regarding lexical access. The specific questions that were addressed throughout the thesis are presented below.

- **Does lexical access occur in the nontarget language of bilinguals?**

Rodríguez-Fornells et al. (2002) suggested that bilinguals could inhibit the nontarget language. In their study, two bilingual groups performed a go/no-go task where participants responded only to the target language (see section 1.2.1.1). The lack of a word frequency effect in the ERP responses to the nontarget language was interpreted as evidence of bilinguals' ability to inhibit the nontarget language if the task does not require it. Chapter 2 reports a study that used the same paradigm as Rodríguez-Fornells et al (2002) but improved the design to investigate lexical access in L1 and L2.

- **Is lexical access in bilinguals' L1 and L2 task-dependent?**

Chapters 2 and 3 will further explore this question using ERP (chapter 2) and behavioural (chapter 3) measures.

- **What are the differences between lexical access in L1 and L2?**

Theoretical models of bilingual visual word recognition (see section 1.2.3) suggested that there would be differences in the bilinguals' lexical access to their L1 and L2 (van Heuven & Dijkstra, 2002). The effects of lexicality and word frequency were used as indices of lexical access in bilinguals. Chapter 2 will provide electrophysiological evidence, whereas, Chapter 3 will provide behavioural evidence to answer this question.

- **Is lexical access in English monolinguals task-dependent?**

As discussed in section 1.1.1, it is still unclear whether task demands can influence lexical access. Chapter 4 will provide data to answer this question.

- **Can the effect of repetition be found across two different tasks?**

These questions were explored in chapter 3 in bilinguals (section 1.2.1.2) and in chapter 4 in monolinguals (section 1.1.1.4).

- **Can the effect of repetition be found within the same task?**

Chapter 5 explored the effect of repetition (discussed in section 1.1.1.3) using the same task. Potential factors were explored by modifying stimuli material. The implications for lexical processing are discussed in the above-mentioned chapter.

1.3.2. METHODS USED IN THIS THESIS

1.3.2.1. Tasks

Chapter 2 is a replication and extension of Rodríguez-Fornells et al. (2002) study (described in section 1.2.2.1). Improvements were made in terms of the experimental design (within-subjects) and the stimuli. However, the go/no-go with an orthographic, lexical and language decision task was still used. This task used by Rodríguez Fornells et al. was a modified version of the task employed by Van Turennout, Hagoort & Brown (1997) and Schmitt, Münte & Kutas (2000) to investigate language interference in bilinguals. Because the interest was on whether lexical access (word frequency and lexicality effects) in bilinguals' L1 and L2 is language selective, the go/no-go task involved a lexical (go for words, no-go for nonwords) and a language decision (only respond to words in the target language), as in the task used by Rodríguez-Fornells et al. (2002). However, the onset decision or orthographic level (vowel or consonant decision) was kept. A more detailed description of the task can be found in chapter 2.

To avoid a task that involves multiple levels of task demands, a simplified version of the paradigm used by Rodríguez-Fornells et al. (2002) was needed. The task criteria (orthographic, lexical and language decision) in the go/no-go task was decomposed by testing each language separately in two different tasks in chapters 3 and 4: an onset decision (ODT) and a lexical decision (LDT) tasks. The only difference between these two tasks was the task criteria. In the ODT participants were instructed to make a vowel or consonant decision, whereas, in the LDT participants made a word or nonword decision. Further details of these tasks can be found chapter 3. Umansky and Chambers (1980) employed a similar approach to the ODT. Using a "same-different" task they varied the response criteria by instructing the participants to make a response based on either the first letter or the whole letter string. Umansky and Chambers did not observe an effect of word frequency or lexicality when participants used the "first-letter" criterion; however, the effects were observed when the participants decided on the "whole letter string" criterion. These results are consistent with models of word recognition that suggest different processing levels for letters and words in visual word recognition (see section 1.1.3).

1.3.2.2. ERPs

As mentioned in sections 1.1.2 and 1.2.2, the use of EEG measures can provide important information about the influence of different psycholinguistic variables on the timing of brain responses. This information is useful to indicate the presence and the timing of lexical access. An important question of this thesis is whether lexical access can vary according to the task at hand in bilinguals (sections 1.2.1.2 and 1.2.2.4) and monolinguals (sections 1.1.1.4 and 1.1.2.4). Because the ERPs can be recorded from the time when the participant sees the stimulus until the time when this participant makes a behavioural response, it is possible to identify if lexical access occurs in a given task as revealed by the effect of lexical variables (e.g. lexicality and word frequency). The point at which these lexical factors have an influence on the process of visual word recognition can also be investigated with ERPs (sections 1.1.2 and 1.2.2). Different ERP components have been identified in previous research during visual word recognition. The present thesis focused on changes observed in the time-window of the N400 component because this component has been associated with the effect of lexicality and word frequency, indicating lexical access in monolingual and bilingual visual word recognition (section 1.1.2).

Previous literature has incorporated a variety of analysis techniques of the ERPs (e.g. Independent Component Analyses, Source localisation, Regression of the ERP responses). However, the most common analysis is the analysis of the ERPs amplitude means by time-windows of usually 100 ms in specific regions of interest (ROIs). This will be explained in more detail in the Methods section of each chapter.

1.3.2.3. Mixed effects modelling

In chapters 3, 4 and 5, linear mixed effects modelling was used in the analysis of reaction times and errors. This approach was used due to the possibility of introducing random intercepts for subjects and items (Baayen et al., 2008), as well as to increase in statistical power and better protection against type II errors (Baayen & Milin, 2010). Mixed-effects models consist of fixed and random factors, where more than one random factor can be incorporated. The fixed factors are the explanatory variables responsible for systematic variation, whereas the random factors consist of the sampling structure of the design that contributes to random variability in responses. Similar approaches have been adopted and recommended in research in psychology and psycholinguistics (e.g. Diependaele et al., 2013, Lo & Andrews, 2015). Model construction for this thesis data analysis is described in chapter 3.

1.3.2.4. Reaction Times Distribution

As mentioned in sections 1.1.1.3 and 1.1.3.3, the analysis of the reaction times distribution can contribute to the understanding of the effect of lexical factors on behavioural responses. Balota and Yap (2011) suggested three approaches in the understanding of influences of variables on RT distributions: the evaluation of computationally explicit models that makes specific predictions about RT distributions, the fit of a mathematical function to empirically obtained RT distribution and the visual inspection of the RT distribution to determine the influence of a factor over different regions of the distributions. In chapters 3, 4, and 5 the RT distributions were fitted to the ex-Gaussian distribution as suggested by Balota and Spieler (1999), and recommended by Balota and Yap (2011). The details of this fit are provided in chapter 3.

1.3.2.5. THESIS OUTLINE

Four experimental chapters are included in this thesis. Two chapters focus on bilingual visual word recognition and two focus on monolingual visual word recognition. The chapters focusing on monolingual visual word recognition each report two behavioural experiments. In contrast, the chapters focusing on bilingual visual word recognition each report a large experiment with either electrophysiological or behavioural measures. As mentioned in section 1.3.1, each experimental chapter answers one or more research questions. To present an overview of this thesis, chapter 2 tests the presence or absence of lexical access (lexicality and word frequency effects) in the nontarget language of bilinguals through a go/no-go task. Chapter 3 uses the onset decision task (ODT) along with the lexical decision task (LDT) to investigate lexical access through the effect of word frequency, lexicality and repetition in bilinguals' L1 and L2, and the role of task demands in bilinguals' lexical access. Due to the high number of errors in bilinguals' responses, the same paradigm (ODT and LDT) were employed to investigate lexical access and behavioural responses of English monolinguals (chapter 4). Interestingly, the errors were dependent on the stimulus categories included in the tasks and the results of each experiment are discussed in chapter 4. Because the effect of repetition was not observed in the previous experiments (bilinguals and monolinguals), two behavioural experiments with LDT explored the effect of repetition in monolingual participants (chapter 5). In the General Discussion (chapter 6), the results of these experiments are summarised and their theoretical implications are discussed in light of current models of bilingual and monolingual visual word recognition. Limitations and future research are also presented in Chapter 6.

Chapter 2. Lexicality and Word Frequency Effects in Target and Nontarget Languages in Bilinguals

2.1. Introduction

As discussed in chapter 1 (section 1.1.2.2), Rodriguez-Fornells et al. (2002) investigated whether bilinguals can prevent interference from the non-target language while identifying words in a target language. The investigation of indices of lexical access such as the lexicality and the word frequency effects in a task that does not require the language information of both languages can yield further evidence for the debate surrounding selective or a nonselective lexical access. In this chapter, the focus will be on whether it is possible to find an effect of lexicality and word frequency in the nontarget language, which would be evidence in favour of nonselective lexical access.

In Rodríguez-Fornells' et al. (2002) study participants were presented with words in Catalan (bilinguals' L1) and Spanish (bilinguals' L2, monolinguals' L1), and pseudowords in two go/no-go lexical decision tasks. In the first experiment participants were instructed only to respond to Spanish words and withhold responses to Catalan words and pseudowords. Reaction times were similar for bilinguals and monolinguals although bilinguals showed more false positive responses to high frequent words in their L1, indicating language interference from L1 on the task in L2, which is consistent with the findings of, for example, van Heuven et al. (2008). Importantly, a word frequency effect was observed in ERPs of Spanish (bilinguals' L2) but not in Catalan (bilinguals' L1) words in both bilinguals and monolinguals. The authors interpreted these results as evidence of a language blocking mechanism in the bilinguals for the language that was not required for the task. In order to investigate the generalisability of these effects, a second experiment was conducted with a subset of the bilinguals. In this experiment, bilinguals were only required to respond to words in their L1 (Catalan). Again, the word frequency effect was found for the target language (L1) but not for the nontarget language (L2). Unfortunately, behavioural data were not reported. To investigate the possibility that the lack of a word frequency effect on the ERPs in the nontarget language could be due to task characteristics, the final experiment was conducted with Spanish monolinguals who were required to respond only to pseudowords. Monolinguals ERPs showed a word frequency effect (N400 modulation) for Spanish. The authors interpreted these results as indicating that this effect was independent of task requirements.

Important limitations of this study have been pointed out and discussed in the literature (see Grosjean, Li, Münte & Rodríguez-Fornells, 2003). Firstly, the monolingual speakers used in Rodríguez-Fornells et al. (2002) study were probably bilingual, and the bilingual group was probably trilingual, since the experiment was conducted in Germany and the participants were foreign students of two German universities. Some knowledge of German as a second and third language could have played some role in the observed results. Secondly, some bilingual participants took part in the main and the first control experiments. Thus, previous exposure to the stimuli might have played a role in the second experiment. Thirdly, some language interference was found because bilingual participants responded incorrectly to L1 words when the task required responses to L2 words. Fourth, the analysis of the control experiments (second and third) was conducted with a very small group of participants (four bilinguals in the second experiment and 12 monolinguals in the third experiment), usually not recommended in ERP studies (DeBoer, Scott & Nelson, 2005). Finally, the stimuli included Catalan words with language specific-features (e.g. words with a grave accent and letters like “ç”. In Grosjean, Li, Münte & Rodríguez-Fornells (2003), Grosjean and Li also commented that the bilingual population used by Rodríguez-Fornells et al. was very specific; Lehtonen et al. (2012) further explained that because these languages (Catalan and Spanish) have a high proportion of lexical overlap, these bilinguals might exhibit differences in word frequency effects.

Furthermore, Ng and Wicha (2013) have pointed out a couple of additional points to consider regarding Rodríguez-Fornells’ et al. (2002) study. They emphasised that in that study's task, the requirement of lexical, language (target word on a specific language) and phonetic (vowel or consonant) judgments might have impacted an additional attention requirement to phonology. The result of that would have been a reduction of cognitive resources for lexical processing, and a weaker word frequency effect for the nontarget language.

The above-mentioned criticisms on Rodríguez-Fornells et al. (2002) study suggest that the evidence for the blocking of the nontarget language might not be strong. In fact, there are a few studies that found evidence that participants are not able to block the nontarget language. For example, Ng and Wicha (2013) conducted a similar ERP study with balanced Spanish (L1) – English (L2) bilinguals. In this study, participants performed two lexical decision tasks in either L1 or L2 as the target language (a language-specific lexical decision task). Behavioural responses revealed a main effect of word frequency; interestingly, the responses were slower for LF words in L1 than in L2. ERPs revealed a widespread word frequency effect in the N400 time window for L1 and L2 target words, and L1 non-target words. However, the word frequency effect for L2 non-target words was found at more posterior sites. According to the authors these results supported non-selective lexical access.

Moreover, Aparicio et al. (2012) studied French-English-Spanish speakers who performed a detection task with words in French, English and Spanish. Participants were required to decide if words referred to an animal in the target language or not. Word frequency effects were found in ERPs (smaller N400 amplitudes for HF words in comparison to LF ones) for L1, L2 and L3. The only difference between languages was that the distribution of the brain potentials was more right posterior for L2 and L3 compared to L1. These results also provided evidence of a word frequency effect in the language that is not required to perform the task.

In bilinguals, the more frequent usage of words in one language would reflect higher proficiency in that language (Dijkstra & van Heuven, 2002). Duyck et al. (2008) investigated Dutch (L1) – English (L2) bilinguals and English monolinguals in language-specific lexical decision tasks in their L1 and L2. Larger word frequency effects in L2 compared to L1 for both reaction times and accuracy scores of bilinguals' responses were reported, and it was suggested that this size difference of the word frequency effect was due to less proficiency in the L2.

The present chapter investigated whether bilinguals can block the nontarget language. To address this question, indices of lexical access such as the effect of lexicality and frequency were investigated in bilinguals' L1 and L2 as target and nontarget conditions. If these effects are observed, the next question is whether the effects are the same or different between L1 and L2.

The same task as Rodriguez-Fornells et al. (2002) was used. However, similar to Ng and Wicha (2013), the bilingual population consisted of 19 Spanish (L1) – English (L2) speakers who were highly proficient in their L2, because they were studying in England at the time of testing and were not fluent in another language. Additionally, instead of conducting comparisons between experiments as in Rodriguez-Fornells et al. (2012), a within-subjects' design was adopted in which the same group of bilinguals performed both tasks with either L1 or L2 as target language. Also, language-specific features such as diacritics or letters like "ñ" in Spanish were not included in the stimuli, and the word frequencies were similar in both languages, unlike Rodríguez-Fornells et al.'s study in which Spanish words covered a wider frequency range than Catalan words. Moreover, lexicality effects were investigated and reported in more detail than Rodríguez-Fornells et al.'s study. The analysis of the ERPs also included specific regions of interest (ROIs). A similar analysis to that of Rodríguez-Fornells et al. was conducted at centro-parietal electrodes and using the same time window. Furthermore, an analysis in 100 ms time windows from 100 to 700ms was conducted in ROIs to investigate the effect of frequency and lexicality in the different areas across the brain.

Two dual choice go/no-go tasks were conducted given that the "go" trials would allow the investigation of the word frequency effect in behavioural responses and ERPs where a response is required for the target language; while, "no-go" trials makes it possible to investigate frequency and lexicality effects in the nontarget language.

Based on previous findings that supported nonselective lexical access (see sections 1.2.1 and 1.2.2), word frequency and lexicality effects were expected in both languages. Furthermore, based on Duyck et al. (2008) a larger word frequency effect was expected in L2 compared to L1 and a delay of the lexicality effect for the L2 relative to the L1 was expected (Favreau, Komoda and Segalowitz, 1980, Proverbio et al., 2009). These predictions are in line with those of the BIA+ model (Dijkstra & van Heuven, 2002), which proposes slower activation of L2 representations relative to L1 representations (see description of BIA+ in section 1.2.3.2).

2.2. Experiment 1

2.2.1. Methods

2.2.1.1. Participants

Twenty-three participants were recruited from the University of Nottingham, United Kingdom, student population. All participants were native Spanish (L1) speakers from Latin America countries (Chile: n=3, Colombia: n=2, Guatemala: n=1, Mexico: n=12, Venezuela: n=1) who had acquired English (L2) at the age of 14 years old (*SD* = 7.3). The first contact with English was at approx. 9 years old (*SD* = 4.5). The bilinguals were living and studying in England at the time of testing and had had 19 years (*SD* = 7.7) of previous experience with English. Proficiency in L2 and L1 was measured using self-ratings (1- to 7-point-scale from very poor to very good/fluent in reading, writing, speaking and listening) (see Table 2.1). Furthermore, English proficiency was also measured using the British Picture Vocabulary Scale (BPVS, *M* = 119, *SD* = 6.6), and LexTALE (Lemhöfer & Broersma, 2012, *M* = 73, *SD* = 10.6). According to Lemhöfer and Broersma, LexTALE scores of 60-80% are associated with upper intermediate (B2), while scores of 80-100% correspond to upper and lower advanced/proficient user levels in the Common European Framework (CEF).

Participants rated their daily use of L1 and L2 on a scale from 1 (never) to 5 (always) (Table 2.2). Nine participants reported basic knowledge of other languages in addition to Spanish and English but no fluency in those languages. All participants were right-handed (Edinburgh Handedness Inventory-Oldfield, 1971, mean score=+0.9, SD=0.08) and had normal or corrected-to-normal vision. Four participants were excluded from the analysis because they did not complete some part of the proficiency tests (n=1), or they had a high error rate in one of the go/no-go tasks (n=2) or had a poor recording of the EEG with a high amount of artefacts due to muscular activity (n=1). The analysis was based on the data of 19 Spanish-English speakers (9 female; mean age=30.3 years, SD=5.9).

Table 2.1 Mean Score and Standard Deviation of Proficiency in L2, Subjective Measures of Language Proficiency, and Language Use of L1 and L2 in Bilinguals

L2 Proficiency					
British Picture Vocabulary Scale (BPVS)				118.9 (6.6)	
LexTALE				73.1 (10.6)	
Subjective Language Proficiency					
	Speaking	Listening	Reading	Writing	Overall
L1 Spanish	7 (0)	7 (0)	7 (0)	6.9 (0.2)	7 (0.1)
L2 English	5.6 (1)	5.3 (1.4)	6.3 (0.7)	5.7 (1)	5.7 (1.1)
Language Use					
	Home	Friends	Course mates	Other social	Overall
L1 Spanish	2.9 (1.7)	3.1 (1)	1.5 (0.8)	2.7 (1.1)	2.6 (1.3)
L2 English	3.2 (1.6)	3.6 (0.9)	5 (0.7)	4.7 (0.8)	3.9 (1.2)

2.2.1.2. Stimuli

The complete set of stimuli consisted of 600 letter strings. 480 were words (240 Spanish, 240 English), 60 were pseudo-words (30 Spanish, 30 English) and 60 were pure letter strings (30 consonant, 30 vowel). Half of the stimuli had a vowel onset whereas the other half had a consonant onset (Table 2.2).

Table 2.2 Characteristics of the Complete Stimulus Set

Item	Onset	Language	Characteristics
480 Words	Vowel	Spanish	High frequency
			Low frequency
		English	High frequency
			Low frequency
	Consonant	Spanish	High frequency
			Low frequency
		English	High frequency
			Low frequency
60 Pseudo-words PW	Vowel	Spanish	NA
		English	
	Consonant	Spanish	NA
		English	
60 Letter Strings LS	Vowel	NA	NA
	Consonant		

The word stimuli (length: four to six letters) were mostly nouns that were selected from the subtitle-based corpus SUBTLEX-ESP (Cuetos, 2011) for Spanish and from SUBTLEX-UK (van Heuven et al., 2013) for English. Half of the words in both languages were of high frequency (HF: 3.9 – 5.8 Zipf values) and the other half was of low frequency (LF: 2 – 3.8 Zipf values). Zipf values were considered instead of frequency per million because Zipf values are easier to interpret and can be compared across different-sized corpora (van Heuven et al, 2013). The Zipf scale is a word frequency scale that goes from 1 to 7. Its calculation is based on a logarithm 10 of the frequency per billion/million taking into consideration the total number of the analysed corpus (van Heuven et al., 2013). Emotional and taboo words were avoided, as well as Spanish-English cognates, homographs and homophones.

Pseudowords (4-6 letters) consisted of pronounceable legal letter combinations generated by randomisation combinations of legal Spanish and English bigrams and trigrams. To make sure that the pseudowords were not real words; these stimuli were contrasted to the words included in SUBTLEX-UK and SUBTLEX-ESP. Letter strings (5 letters) were generated by randomising vowels and consonants to create pure vowel and pure consonant letter strings. The pseudowords and letter strings were generated with the Pseudo-word generator v. 2.04 (van Heuven, 2013).

All the stimuli were matched in terms of neighbourhood density within the same and between languages, as well as for length and bigram frequency (Table 2.3).

Table 2.3 Lexical Characteristics of the Stimuli

	Zipf values	ND Within	ND Between	Bigram frequency	Length
Spanish (L1)					
Pseudoword	NA	2.9 (0.3)	2.2 (0.4)	NA	5.3 (0.1)
Low frequency words	3.2 (0.4)	2.9 (0.3)	5.5 (0.7)	2.7 (0.04)	5.2 (0.08)
High frequency words	4.7 (0.5)	3.9 (0.4)	6.5 (0.8)	4.3 (0.05)	5.1 (0.08)
English (L2)					
Pseudoword	NA	4.3 (0.6)	0.8 (0.2)	NA	5.3 (0.1)
Low frequency words	3.4 (0.4)	7.0 (0.7)	0.7 (0.1)	2.9 (0.03)	5.3 (0.07)
High frequency words	4.7 (0.4)	11.2 (1.0)	1.0 (0.2)	4.3 (0.04)	5.0 (0.08)

From these stimuli, two main lists per language were created. Each list contained 480 stimuli; one of them was predominant for English and the other for Spanish.

2.2.1.3. Design

The experiment consisted of two dual choice go/no-go tasks (one with English as the target language and one with Spanish as the target language). In each task, half of the trials required a go-response, whereas the other half did not require any response (no-go trials). The English (L2) go/no-go task (Figure 2.2) required the participant only to respond to words in English, while the Spanish (L1) task required responses to words in Spanish (Figure 2.1). In the English task, no-go trials included 120 words in Spanish, 60 pseudo-words and 60 consonant/vowel strings (240 items in total) and 240 words in English (120 HF and 120 LF words) were included for the go trials. In the Spanish task, no-go trials consisted of 120 words in English, 60 pseudo-words and 60 consonant/vowel strings (240 items in total). For this task, the go trials included 120 HF and 120 LF words in Spanish.

Go trials required that responses were made based on the first letter of the word (vowel or consonant) with the correspondent hand (left or right). No-go trials did not require any response.

Two versions of each list (in each task) were created and counterbalanced across participants. Items were presented in 16 different lists using different pseudorandom orders for each subject (Pseudorandom list generator v. 1.28, van Heuven, 2013). The randomisation avoided more than three repetitions of items of the same language (Spanish or English), frequency (High or Low), onset (vowel/consonant) and response (go/no-go).

The English and the Spanish tasks were presented in the same experimental session. The language of the task was counterbalanced across participants (eight participants started with Spanish and 11 participants started with English). The response hand (left or right), determined by the first letter of the string (vowel or consonant) of the word on the screen was also counterbalanced across participants.

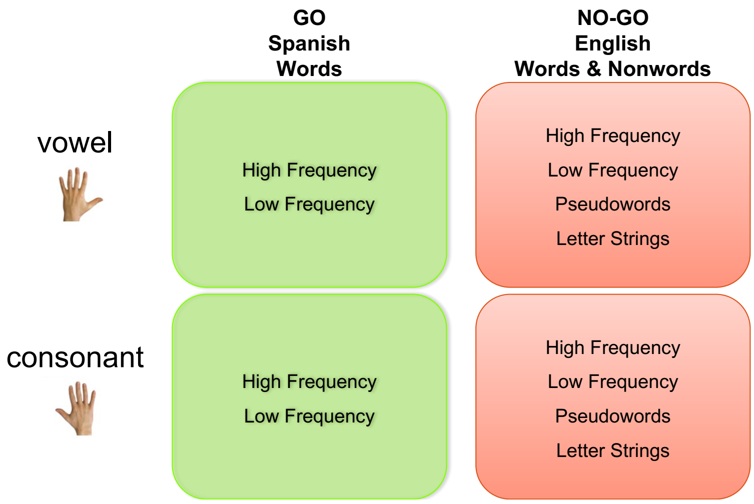

Figure 2.1 Dual choice go/no-go task in Spanish (bilinguals' L1)

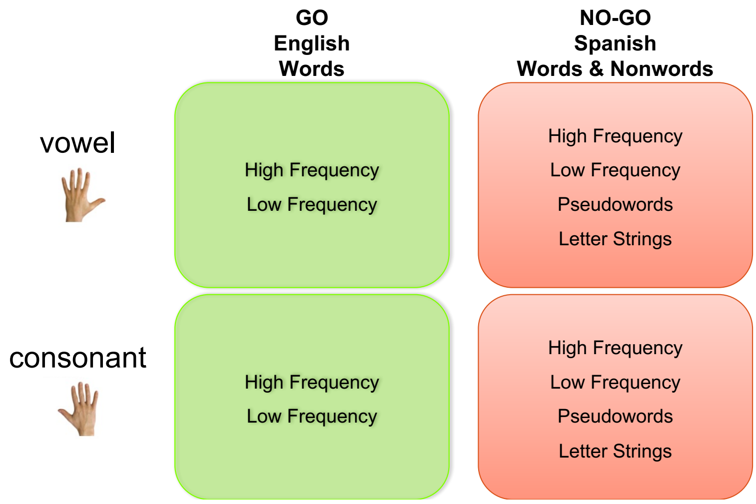

Figure 2.2 Dual choice go/no-go task in English (bilinguals' L2)

2.2.1.4. Procedure

The Research Ethics Committee of the School of Psychology, University of Nottingham, granted ethics approval for the experiment. Prior the experiment participants were informed of the procedure and they provided their informed consent.

Participants were seated in a comfortable position in a sound and light attenuating room and after head measurement, 64 electrodes were placed over the surface of the scalp of participants through a head cap, according to the head size of each participant. Six additional electrodes were placed: four over the eye cantus of the right and left eyes to monitor for eye-related artefacts (blinks and vertical or horizontal eye movement) and two electrodes over the right and left mastoids for reference. Participants were instructed to minimize movements during the recording session and task performance.

Task instructions and 10 practice trials were presented before each task. Participants were instructed only to respond to a word in the target language of the task (Spanish or English). They had to give a button press with the right hand when the word started with a vowel (or consonant) and press the button with their left hand when the word began with a consonant (or vowel). Individuals were also reminded to minimize movements during task performance. Psychopy (version 1.77, Peirce, 2007) was used to present the stimuli on a LCD screen (width: 51.2 cm) at 68cm from the participants and to collect the behavioural data.

The stimuli were presented in black Courier New font in the centre of a grey rectangle on a black background (Barber et al., 2013). In each trial, a small fixation cross was shown in the centre of the screen (700 ms), followed by a blank screen (300 ms), then the presentation of the word/pseudo-word/letter string (400 ms) to finalise with another blank screen (2100 ms) (see Figure 2.3). The participants' EEG was recorded during both tasks. Each task (Spanish or English) was divided into four blocks (three breaks) and lasted approximately 30 mins. Participants were free to control the duration of the break time before continuing with the next block. Another break took place between each task when the experimenter provided water or additional resting time for the participants.

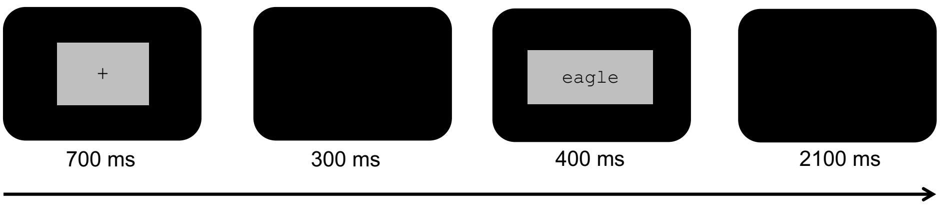

Figure 2.3 Sequence of stimuli presentation on each trial

Upon completion of the EEG recording session, individuals performed a computer-based version of the British Picture Vocabulary Scale (BPVS), as well as LexTALE (Lemhöfer & Broersma, 2012).

At the end of the experimental session participants received an inconvenience allowance. The complete experiment lasted in total approximately 2.5 hours.

2.2.1.5. EEG data collection, pre-processing and analysis of ERPs

Electrophysiological signals were collected using a 64-channel BioSemi Active Two system with a 512 Hz sampling rate. Impedances were kept under 20 kΩ, where possible. BioSemi system incorporates the “ground” electrodes in two separated electrodes: a Common Mode Sense (CMS) active electrode and a Driven Right Leg (DRL) passive electrode.

Data was pre-processed in EEGlab version 12.0.2.5b toolbox (Delorme & Makeig, 2004) and ERPlab (Lopez-Calderon & Luck, 2014) version 4.0.2.1 (plug in) in Matlab version 2013a. The data was filtered with a band-pass filter from 0.1 to 30 Hz and re-referenced to the average of the mastoids. After filtering and re-referencing, incorrect trials were rejected. Manual rejection of non-systematic artefacts and drifts in the signal was then performed on the continuous signal for each participant in each task, followed by Independent Component Analysis (ICA) to identify 32 principal components (PCA). Once the components were identified, those related to eye movements and muscular artefacts were removed. Next, time-locked epochs from -200 to 1000 ms, according to the onset of the stimuli, were extracted. Bad epochs were identified and rejected using the ERP artefact detection for differences in peak amplitude and step-like changes in voltage. The average percentage of retained epochs for both tasks was 80% (equivalent to 384 trials per participant).

Epochs were sorted by item condition and averages per condition were calculated per subject. The grand average across participants was then calculated.

Two different analyses of the ERPs were conducted. The first one involved 12 regions of interest (ROIs) and the analysis of the midline (Filik, Sanford & Leuthold, 2008). The factors included in the ROIs were hemisphere (Left and Right), anterior-central-posterior and dorsal-ventral. The possible combinations of these factors resulted in a total of 12 regions. The midline was analyzed separately and divided into three additional regions: anterior, central and posterior (Fig 3). Mean amplitudes every 100 ms time-windows were calculated for each region in each condition; starting from 100 ms up to 700 ms. Analyses of variance were computed using Rstudio (Version 1.0.136). The effects of language (Spanish vs English) and frequency (high vs. low) were calculated in each task for target and non-target words. The effect of lexicality was calculated in the no-go trials by comparing nontarget words with letters strings (Figure 2.4).

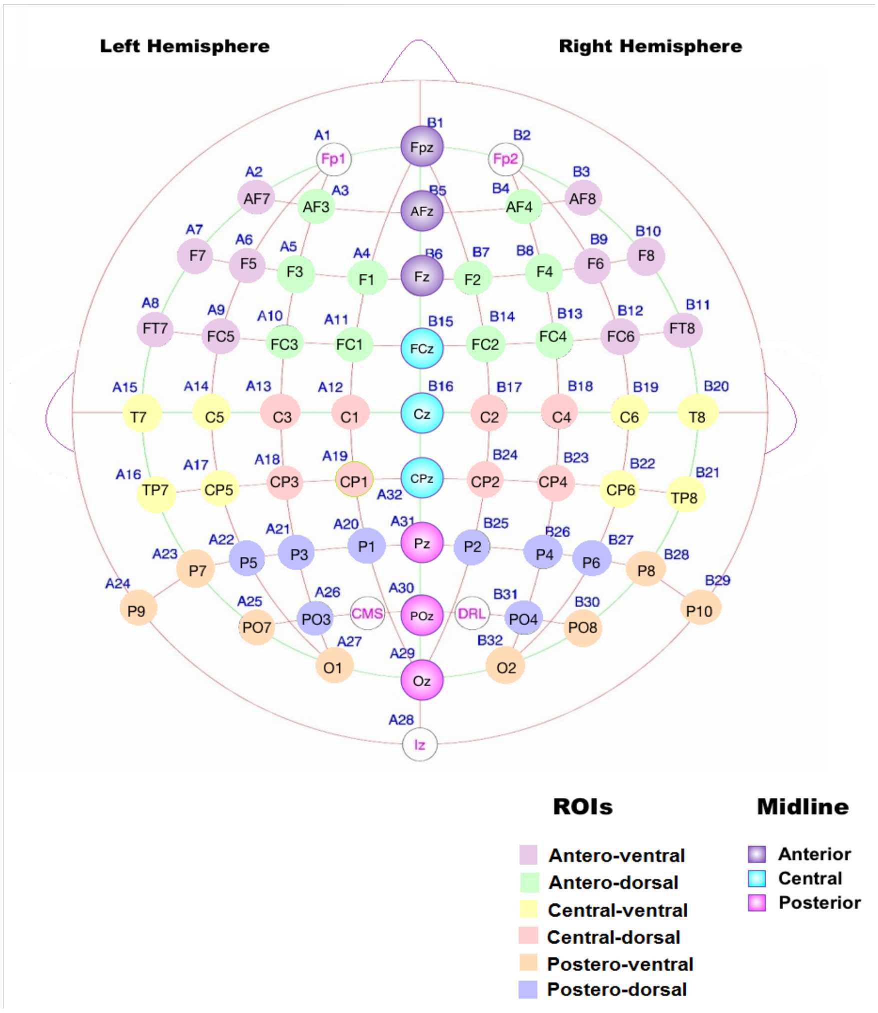

Figure 2.4 Regions of Interest (ROIs) per hemisphere and Midline division

2.2.2. Results

2.2.2.1. Behavioural data

The total number of collected behavioural trials was 18,240. Responses faster than 3000 ms were treated as outliers (4.4%). The percentage of correct responses was 93.3%. The analysis of the reaction times (RT) only included correct responses to go trials.

The analysis of the frequency effect was conducted via 2 x 2 repeated measures ANOVAs with the factors language (Spanish L1 vs. English L2) and

Frequency (high vs. low frequency words) using the reaction times of go trials, as well as the accuracy of go and no-go trials.

The lexicality effect was investigated using 2 x 2 repeated measures ANOVAs with the factors language (L1 vs. L2) and lexicality (words vs. pseudowords of the same language) in no-go trials.

I. Language and Frequency effects: go trials

The analysis of the reaction times of the go trials revealed that participants responded 83 ms faster, $p < .001$, to words in Spanish (L1) than to words in English (L2), F_1 (1,18) = 17.268, $p < .0006$, F_2 (1,476) = 74.945, $p < .0001$. Responses were also 93 ms faster to high frequency words than to low frequency words, F_1 (1,18) = 81.154, $p < .0001$, F_2 (1,476) = 101.113, $p < .0001$. Importantly, no interaction was found between language and frequency, $F < 1$, indicating that the word frequency effect in L1 did not differ from L2 (91 ms vs. 95 ms) (Figure 2.5).

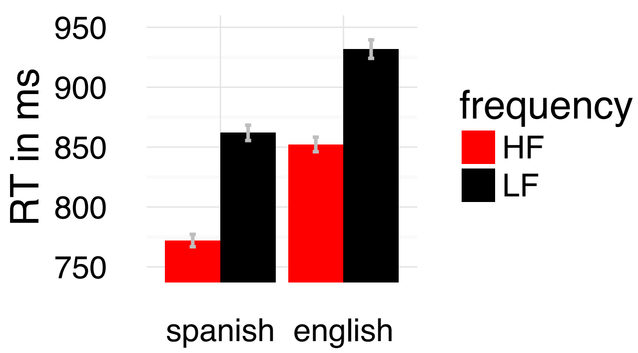

Figure 2.5 Frequency Effect in the reaction times to Spanish (L1) and English (L2) words

The accuracy scores of go trials also revealed significant main effects of language, F_1 (1,18) = 17.0002, $p = .0006$, F_2 (1,476) = 52.048, $p < .0001$, and frequency, F_1 (1,18) = 23.024, $p = .0001$, F_2 (1,476) = 79.432, $p < .0001$. Responses were 7% more accurate in Spanish (L1) than in English (L2) and 8% less accurate in low frequency words compared to high frequency words. More importantly, a significant interaction was observed between language and frequency, F_1 (1,18) = 16.515, $p = .0007$, F_2 (1,476) = 37.457, $p < .0001$.

Paired t-tests indicated that Low frequency L2 words had 15% more errors than high frequency L2 words, t (18) = 4.486, p = .0003, whereas, low frequency L1 words had 3% more errors compared to high frequency L1 words, t (18) = 5.709, p < .0001 (Figure 2.6).

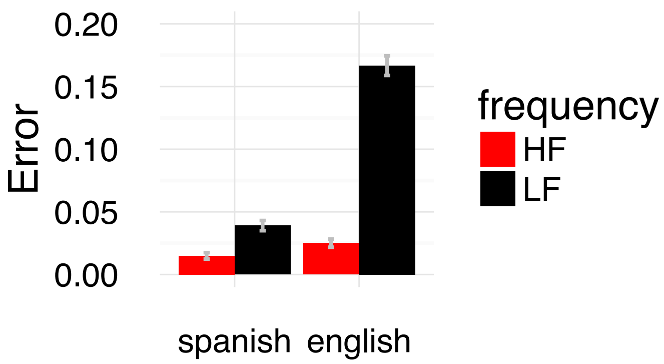

Figure 2.6 Frequency Effect on Accuracy Scores in Spanish (L1) and English (L2) words in go trials.

II. Language and Frequency effects: no-go trials

The analysis of accuracy scores of no-go trials revealed no effects of either language, $F < 1$, frequency, F_1 (1,18) = 1.975, $p = .177$, F_2 (1,476) = 1.869, $p = .172$, or an interaction between these factors, F_1 (1,18) = 2.228, $p = .153$, $F_2 < 1$.

III. Language and Lexicality effects: no-go trials

The accuracy scores of the no-go trials revealed significant main effects of language, F_1 (1,18) = 20.166, $p = .0003$, F_2 (1,534) = 3.953, $p = .047$, and lexicality, F_1 (1,18) = 14.924, $p = .001$, F_2 (1,534) = 17.407, $p < .0001$. Participants were 2% more accurate in withholding responses when the language of the items was in English (L2) than in Spanish (L1). Also, participants were 7% more successful in withholding responses to words compared to pseudowords. Interestingly, a significant interaction between language and lexicality was found, F_1 (1,18) = 17.573, $p = .0005$, F_2 (1,534) = 16.438, $p < .0001$, indicated that pseudowords in L1 were 9% more difficult to reject than words in L1, t (18) = 4.426, p = .0003. However, no difference was observed in L2 (0.3%), $t < 1$ (Figure 2.7).

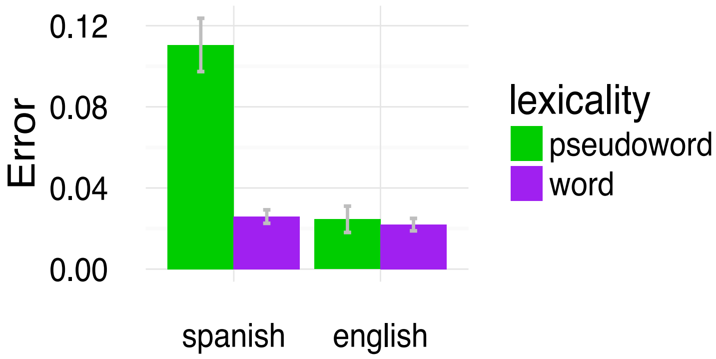

Figure 2.7 Lexicality Effect on Accuracy Scores in Spanish (L1) and English (L2) items in no go trials.

2.2.2.2. Electrophysiological data

To directly compare our results to those of Rodríguez-Fornells et al. (2002), mean amplitudes were calculated for centro-parietal electrodes (e.g. CP1, CP2, CP3, CP4, CP5, CP6, CP7, CPz) in the time window 350-500ms. These amplitudes were analysed in 2 x 2 repeated measures ANOVAs with language (Spanish vs. English) and frequency (high vs. low frequency words).

Next, similar to Ng and Wicha (2013), mean amplitudes were calculated every 100 ms starting from 100ms to 700ms. 2 x 2 x 2 x 3 x 2 ANOVAs included all electrode locations divided in Regions of Interest (ROIs) to investigate the effect of language (Spanish vs. English) and frequency (high vs. low), in brain regions divided by hemisphere (left vs. right), antero-posterior (anterior vs. central vs. posterior) and dorsal-ventral (dorsal Vs. ventral). Separate 2 x 2 x 3 ANOVAs were conducted in ROIs of the midline since these ROIs do not have dorsal and ventral factors. The factors for this analysis were: language (Spanish vs. English), frequency (high vs. low), antero-posterior (anterior vs. central vs. posterior). Huynh-Feldt epsilon correction was applied as necessary.

The analysis of the lexicality effect was conducted in ERP responses of no-go items. 2 x 2 x 3 x 2 ANOVAs were conducted with lexicality (word vs.

pseudoword), hemisphere, antero-posterior and dorsal-ventral factors for the nontarget language in each of the tasks: Spanish task (English nontarget) and English task (Spanish nontarget). 2 x 3 ANOVAs were separately conducted in the midline with the factors: lexicality and antero-posterior. Huynh-Feldt epsilon correction was applied as necessary.

For the 100 ms time windows analysis from 100 to 700ms, only significant results ($p < .05$) on the crucial factors language and frequency or language, and lexicality are reported.

I. Spanish Task (Spanish go and English no-go)

I.I. Language x Frequency between 350-500ms at centro-parietal electrodes

No significant effects of language (Spanish vs. English), $F < 1$, frequency (high vs. low), $F < 1$, or its interaction, $F < 1$, were found.

I.II. Language x Frequency in 100ms time windows

The F values and significances of the main effects and interactions for each time window are presented in Table 2.4.

100-200ms: The significant interaction between language and dorsal-ventral revealed no effect of language on ventral regions but a tendency towards significance in dorsal regions of the hemispheres, t (18) = -1.910, p = .072. The analysis of the midline regions showed a main effect of language, F (1,18) = 4.581, p = .046, indicating more negative mean amplitude values for English (L2: -.458 μV) compared to Spanish (L1: -.122 μV).

***200-300ms*:** Only the analysis of the midline revealed a main effect of language, indicating more negative amplitude values for Spanish (L1 = 2.532 μV) than for English (L2 = 2.840 μV).

300-400ms**:** The significant interaction between frequency and antero-posterior indicated no significant effects of frequency in anterior, t (18) = 1.692, p = .108, central and posterior regions of the hemispheres, $t < 1$. This interaction in regions of the midline, also showed no frequency effects in any of the regions: central and posterior regions, $t < 1$; anterior, t (18) = 1.094, p = .289.

400-500ms: A significant interaction between language and hemisphere, revealed no significant language effects in the left or right hemispheres, $t < 1$. The analysis of the midline revealed a significant interaction between language and antero-posterior, whereas further analyses showed no effects of language in anterior, $t < 1$, central, t (18) = -1.208, p = .243, and posterior, $t < 1$, regions of the midline.

500-600ms: Significant interactions were found between language and antero-posterior in the regions of the hemispheres and the midline. In the hemispheres analysis, more negative amplitudes were observed for Spanish (L1 = 2.274 μV) relative to English (L2 = 3.511 μV) in posterior regions, t (18) = .006, but no language effect was found in central, t (18) = 1.133, p = .272, or anterior, $t < 1$, regions. Other significant interactions observed in the hemispheres analyses were: language, hemisphere and antero-posterior; language, antero-posterior and dorsal-ventral.

600-700ms: Main effects of frequency were found in the hemispheres analysis. Significant interactions were found: language and antero-posterior; language, hemisphere and antero-posterior; language, antero-posterior and dorsal-ventral; The analysis of the midline showed significant interactions between language and antero-posterior, as well as frequency and antero-posterior The latter interaction was broken down by antero-posterior. Anterior regions did not show any significant frequency effect, $t < 1$, while central regions showed a tendency towards significance, t (18) = 1.536, p = .142. Nevertheless, posterior regions show a significant frequency effect (more negative amplitudes for low frequency words compared to high frequency words) regardless of language, t (18) = 2.556, p = .020.

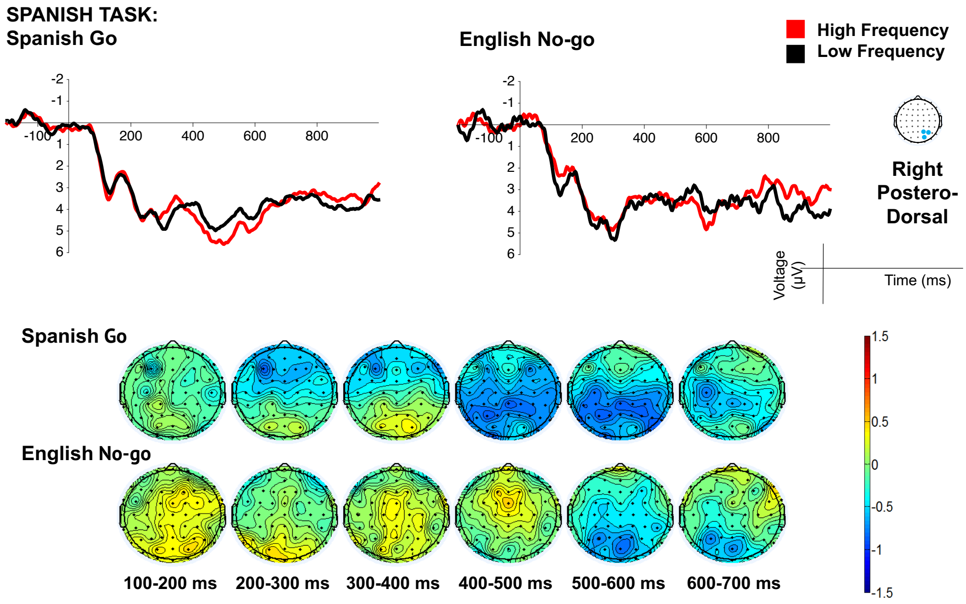

Figure 2.8 Frequency effect on ERP waveforms and mean amplitudes every 100 ms in the Spanish Task

Table 2.4 F and p values of the Language and Frequency Analysis of the Spanish Task (L1)

Hemispheres						
	100-200ms	200-300ms	300-400ms	400-500ms	500-600ms	600-700ms
Frequency						4.551*
Frequency * antero-posterior			7.19**			
Language * hemisphere				5.175*		
Language * dorsal-ventral	8.002*					
Language * antero-posterior					31.321****	30.806****
Language * hemisphere * antero-posterior					4.48*	11.376***
Language * antero-posterior * dorsal-ventral					4.814*	12.185****
Midline						
	100-200ms	200-300ms	300-400ms	400-500ms	500-600ms	600-700ms
Frequency	4.581*	4.517*				
Language			5.056*			3.844*
Language * dorsal-ventral				6.265***	21.03****	22.739****
Language * antero-posterior	4.581*	4.517*				

p < .05, p < .01**, p < .001***, p < .0001*****

I.III. Lexicality (no-go trials) in 100ms time windows

The *F* values and significances of the main effects and significant interactions are presented in Table 2.5.

***100-500ms*:** No main effects or interactions were observed in the analysis of the hemispheres or the midline.

500-600ms: The analysis of the hemispheres revealed a main effect of lexicality, as well as significant interactions between lexicality and dorsal-ventral and between lexicality and antero-posterior. This two-way interaction was broken down by the antero-posterior revealing more positive mean amplitudes for letter strings compared to words in anterior, t (18) = 2.775, p = .0125, and central, t (18) = 2.616, p = .018, regions. However, this effect of lexicality was not significant in posterior regions, t (18) = 1. 311, p = .201. The analysis of the midline also showed a main effect of lexicality, F (1,18) = 4.475, p = .048 (Figure 2.9).

600-700ms: The significant three-way interaction between lexicality, antero-posterior, and dorsal-ventral was broken down by antero-posterior.

Anterior regions showed no effects of lexicality, $F < 1$, or the interaction between lexicality and dorsal-ventral, $F < 1$. Central regions had no main effect of lexicality, $F < 1$, but a significant interaction between lexicality and dorsal-ventral was found, F (1,18) = 5.397, p = .032. Further comparisons showed no significant effects of lexicality in dorsal or ventral regions, $t < 1$. Posterior regions did not show any effect of lexicality or its interaction with dorsal ventral. The analysis of the midline revealed no significant effects of lexicality.

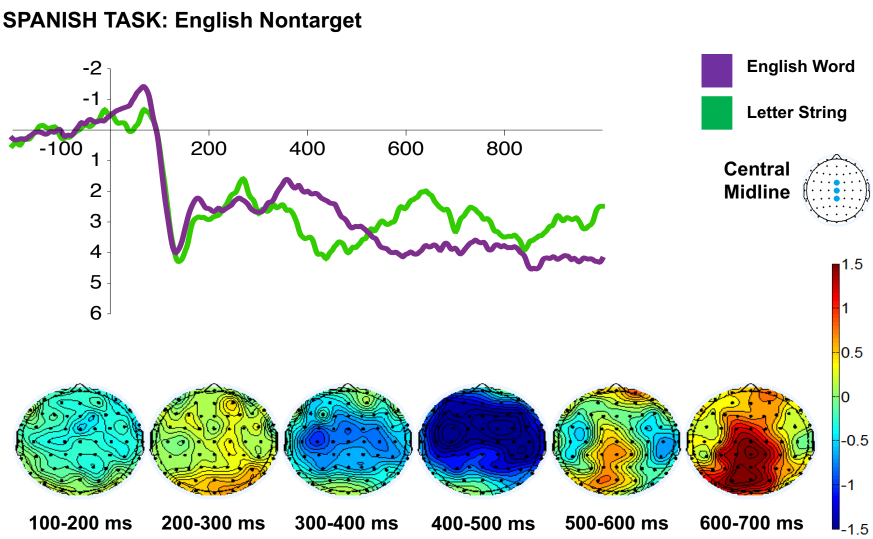

Figure 2.9 Lexicality effects on ERP waveforms and mean amplitudes every 100 ms of the no-go trials (L2) in the Spanish Task (L1).

Table 2.5 F and p values of the Lexicality Analysis (no-go trials) of the Spanish Task (L1)

	500-600ms		**600-700ms**	
	Hemispheres	Midline	Hemispheres	Midline
Lexicality	6 6.042*	4.475*		
Lexicality * antero-posterior	4.683*			
Lexicality * dorsal-ventral	4.921*			
Lexicality * antero-posterior * dorsal-ventral			4.719*	

p < .05, p < .01**, p < .001***, p < .0001*****

II. English Task (English go and Spanish no-go):

I.I. Language x Frequency between 350-500ms at centro-parietal electrodes

A significant effect of language was observed, F (1,18) = 7.278, p = .015. The effect of frequency approached significance, F (1,18) = 4.294, p = .053 but the interaction between language and frequency was not significant, $F < 1$.

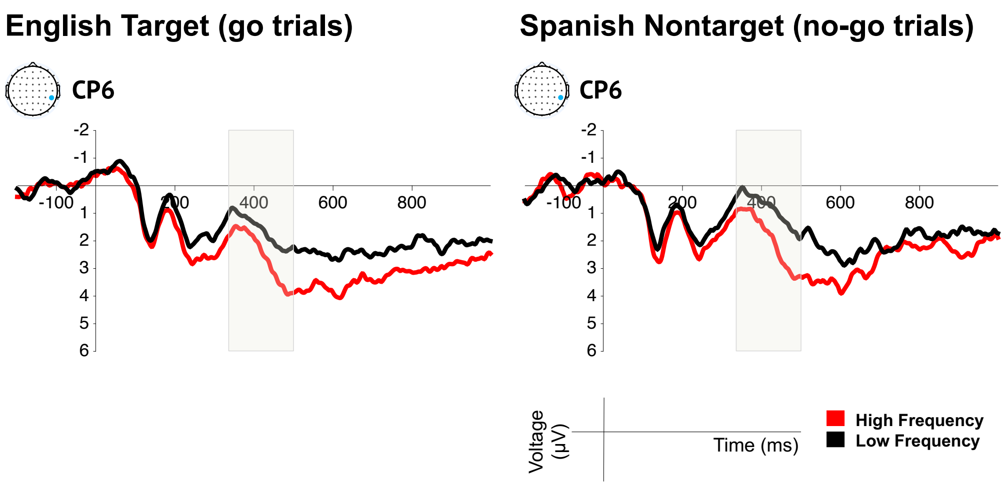

Figure 2.10 Word frequency Effect at centro-parietal electrode (CP6). The time window from 350-500ms is highlighted.

II.I. Language x Frequency in 100ms time windows

The F values and significances of the main effects and interactions for each time window are presented in Table 2.6.

***100-200ms*:** The analysis of the hemispheres revealed a main effect of language. However, in the analysis of the midline, the main effect of language, $p = .057$, and the interaction between frequency and antero-posterior, $p = .072$ approached significance.

200-300ms: Significant interactions between language and hemisphere, as well as frequency and hemisphere were observed in the hemispheres analysis. More importantly, the interaction between language, frequency, antero-posterior and dorsal-ventral was significant. This four-way interaction was broken down by language.

Results for Spanish (L1) showed a significant interaction between frequency, antero-posterior and dorsal-ventral, F (2,36) = 6.956, $p = .003$. This interaction was broken down by dorsal-ventral. No significant effects were observed in dorsal regions, $p > .05$ or ventral regions, $F < 1$. Results for English (L2) revealed no significant effects.

The analysis of the midline did not find any significant main effects or interactions $F < 1$.

***300-400ms*:** Interactions between frequency and hemisphere; language, antero-posterior and dorsal ventral; as well as language, hemisphere and antero-posterior, were significant. The interaction between frequency and hemisphere was broken down by hemisphere. T-tests between high and low frequency words in each hemisphere revealed more negative amplitudes for low frequency compared to high frequency words in the right hemisphere, $t(18) = 2.135$, $p = .046$, but this frequency effect was not found on the left hemisphere, $t < 1$.

The analysis of the midline showed a main effect of language, $F(1,18) = 6.316$, $p = .022$.

400-500ms: A significant main effect of language was observed. Importantly, significant interactions between language and hemisphere; language and dorsal-ventral; language, hemisphere, and dorsal ventral; as well as frequency, antero-posterior and dorsal-ventral, were found. Furthermore, the four-way interaction between language, frequency, hemisphere and antero-posterior was significant, $F(2,36) = 4.893$, $p = .021$.

This four-way interaction was broken down by antero-posterior. Anterior regions showed main effects of language, $F(1,18) = 10.797$, $p = .004$, and hemisphere, $F(1,18) = 5.419$, $p = .032$. Importantly, a significant interaction between language and hemisphere was observed in anterior regions, $F(1,18) = 7.034$, $p = .016$. Interestingly, the three-way interaction between language, frequency and hemisphere was very close to significance, $F(1,18) = 4.152$, $p = .057$. This three-way interaction was broken down by language. No significant main effects or interactions of frequency, $F < 1$, hemisphere, $F(1,18) = 2.773$, $p = .113$, or frequency and hemisphere, $F(1,18) = 1.175$, $p = .293$ were observed in English (L2). However, main effects of frequency, $F(1,18) = 5.764$, $p = .027$, hemisphere, $F(1,18) = 7.469$, $p = .014$, and the interaction between frequency and hemisphere, $F(1,18) = 5.234$, $p = .035$, were significant in Spanish (L1). Further t-tests comparisons revealed a significant frequency effect in the right hemisphere, $t\,(18) = 2.864, p = .010$, but no frequency effect in the left hemisphere, $t\,(18) = 1.796, p = .089$ (Figure 2.11).

Central regions exhibited similar results supporting a main effect of language, $F\,(1,18) = 6.262$, $p = .022$, and hemisphere, $F\,(1,18) = 5.395$, $p = .032$. The interaction between language and hemisphere was also significant, $F\,(1,18) = 7.991$, $p = .011$. Posterior regions only showed a significant main effect of language, $F\,(1,18) = 10.646$, $p = .004$, and other main effects or interactions were not significant, $p < .05$.

The analysis of the midline only revealed a main effect of language, $F\,(1,18) = 14.855, p = .001$.

***500-600ms*:** A main effect of frequency was found in the analysis of the hemispheres. Importantly, significant interactions were observed between language and antero-posterior; frequency and antero-posterior; frequency and dorsal-ventral; language, antero-posterior, and dorsal-ventral. Crucially, the four-way interaction between language, frequency, hemisphere and antero-posterior was also significant. This four-way interaction was broken down by the antero-posterior factor. Anterior regions showed a main effect of frequency, $F\,(1,18) = 11.310$, $p = .003$, and hemisphere, $F\,(1,18) = 5.407$, $p = .032$. However, there was no effect of language, $F < 1$ or other significant interactions, $p > .05$. Central regions also revealed a significant main effect of frequency, $F\,(1,18) = 14.648$, $p = .001$, and no other main effects or interactions ($p < .05$).

Interestingly, posterior regions also showed main effects of language, $F\,(1,18) = 11.567, p = .003$, and frequency, $F\,(1,18) = 16.106, p = .0008$. Crucially, the interaction between language, frequency and hemisphere was significant, $F\,(1,18) = 5.813, p = .03$. Further comparisons by language showed no effects of frequency, $F < 1$, hemisphere, $F\,(1,18) = 3.468$, $p = .079$ or significant interaction between frequency and hemisphere, $F < 1$, in English (L2). However, significant main effect of frequency, $F\,(1,18) = 10.168$, $p = .005$, hemisphere, F (1,18) = 5.609, p = .029, and interaction between frequency and hemisphere, F (1,18) = 4.545, p = .047, were observed. T-test comparisons showed that the effect of frequency was significant in both hemispheres: left, t (18) = 2.939, p = .009, and right, t (18) = 3.285, p = .004.

The analysis of the midline revealed a main effect of frequency. Significant interactions between language and antero-posterior, as well as frequency and antero-posterior were found. The latter interaction was broken down by the factor antero-posterior. Further analyses showed that the effect is significant at anterior regions, t (18) = 2.827, p = .011, and it becomes stronger at central regions, t (18) = 3.734, p = .002, having its maximum effect at posterior regions of the midline, t (18) = 4.215, p = .0005 (see topoplots and ERPs from Figure 2.11 from 500-600ms).

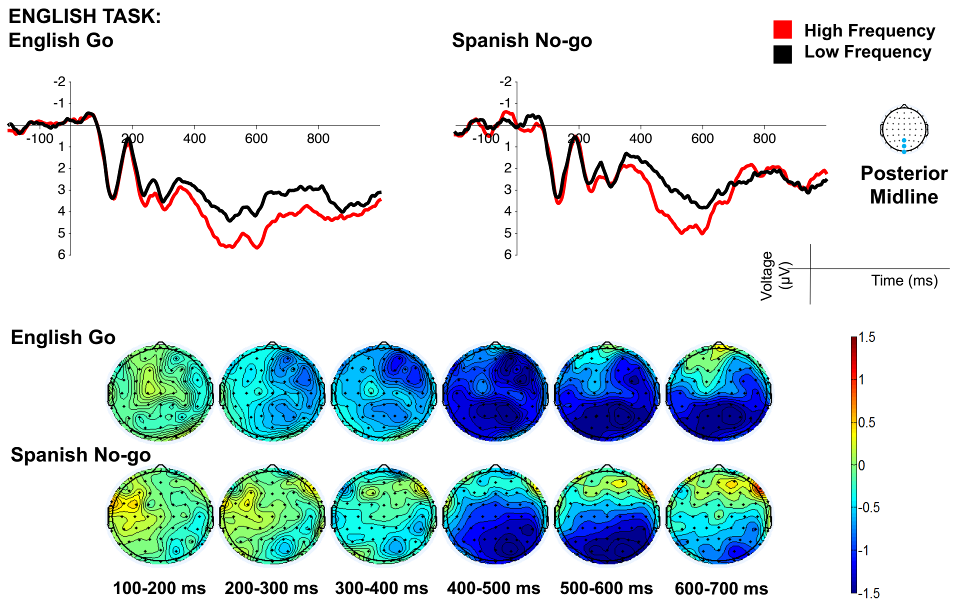

Figure 2.11 Frequency effect on ERP waveforms and mean amplitudes every 100 ms in the English Task.

600-700ms: The analysis of the hemispheres showed a main effect of frequency. Significant interactions were observed between language and antero-posterior; frequency and antero-posterior; frequency and dorsal-ventral; language, hemisphere and antero-posterior; frequency, hemisphere and dorsal-ventral; language, antero-posterior and dorsal-ventral; frequency, antero-posterior and dorsal-ventral. Crucially, the four-way interaction between language, frequency, hemisphere and antero-posterior observed from 500-600ms was again significant in the 600-700ms time window.

This four-way interaction was broken down by the antero-posterior factor. No effects were found in anterior regions, $p < .05$. However, a main effect of frequency was observed in central regions, F (1,18) = 8.018, p = .011. Interestingly, a stronger main effect of frequency was found in posterior regions, F (1,18) = 17.359, p = .0005. Remarkably, the interaction between language, frequency and hemisphere was significant, F (1,18) = 7.653, p = .013. This three-way interaction was broken down by language. No effects were found for English (L2). However, in Spanish (L1), effects of frequency, F (1,18) = 3.821, p = .066 or hemisphere, F (1,18) = 3.500, p = .077, approached significance, and the interaction between frequency and hemisphere was significant, F (1,18) = 7.719, p = .012. Further t-tests by hemisphere revealed that there was no frequency effect in the left hemisphere for Spanish, t (18) = 1.513, p = .148, whereas, the effect was significant in the right hemisphere, t (18) = 2.290, p = .034 (Figure 2.11).

The analysis of the midline also showed a main effect of frequency. Interestingly, interactions between language and antero-posterior, and between frequency and antero-posterior, were significant. The interaction between frequency and antero-posterior was further explored and t-tests revealed that the effect of frequency was not significant in this time window, $t < 1$ for anterior regions. However, the effect was significant for the central, t (18) = 2.182, p = .043, and posterior, t (18) = 4.214, p = .0005, regions of the midline across languages (see topoplots and ERPs from Figure 2.11 from 600-700ms).

Table 2.6 F and p values of the Language and Frequency Analysis of the English Task (L2)

Hemispheres						
	100-200ms	200-300ms	300-400ms	400-500ms	500-600ms	600-700ms
Frequency					15.288***	7.659*
Frequency * antero-posterior					5.54*	2.829****
Frequency * hemisphere		10.066**	7.295*		10.187***	5.795*
Frequency * dorsal-ventral						
Frequency * hemisphere * dorsal-ventral						5.146*
Frequency * antero-posterior * dorsal-ventral						4.948*
Language	4.485*			9.871**		
Language * hemisphere		5.235*		7.168*		
Language * dorsal-ventral				27.321****		
Language * antero-posterior					11.016**	4.236*
Language * hemisphere * antero-posterior			3.462*			4.539*
Language * hemisphere * dorsal-ventral				4.896*		
Language * antero-posterior * dorsal-ventral			6.411**		3.667*	1.201****
Language * frequency * hemisphere * antero-posterior				4.893*	5.568***	7.475**
Language * frequency * antero-posterior * dorsal-ventral		3.500*				
Midline						
	100-200ms	200-300ms	300-400ms	400-500ms	500-600ms	600-700ms
Frequency					16.44***	5.605*
Frequency * antero-posterior	3.168				4.44*	19.88****
Language	4.142		6.316*	14.855***		
Language * antero-posterior					16.186****	8.206**

p < .05, p < .01**, p < .001***, p < .0001*****

II.II. Lexicality (no-go trials) in 100ms time windows

The *F* values and significances of the main effects and interactions are presented in Table 2.7.

100-300ms: No main effects or interactions were observed in the analysis of the hemispheres or the midline.

***300-400ms*:** A significant interaction was found between lexicality and dorsal-ventral. This interaction was broken down by dorsal-ventral and no significant lexicality effects were found in any of these regions. The analysis of the midline only showed that the effect of lexicality approached significance, p = .087. Further exploration of this effect showed a tendency towards significance in anterior, t (18) = 1.857 p = .079, and central, t (18) = 1.761, p = .095, but not in posterior regions, t (18) = 1.3521, p = .193.

400-500ms: A significant interaction between lexicality and dorsal-ventral was found. This two-way interaction was broken by dorsal-ventral. More negative amplitudes were found for words compared to letter strings in dorsal regions, t (18) = 2.499, p = .022. However, this lexicality effect was not found in ventral regions, t (18) = 1.309, p = .207 (Figure 2.12)

The analysis of the midline showed a significant main effect of lexicality. The interaction between lexicality and antero-posterior approached significance, p = .052. This interaction was explored by antero-posterior. Lexicality was not significant in anterior regions, t (18) = 1.950, p = .067. However, a significant lexicality effect was found in central regions, t (18) = 2.616, p = .018, and it was strongly significant in posterior regions, t (18) = 3.082, p = .006.

500-600ms: A main effect of lexicality was found. Significant interactions were observed between lexicality and dorsal-ventral, as well as between lexicality, hemisphere and antero-posterior. This three-way interaction was broken down by hemisphere.

In the left hemisphere, main effects of lexicality, F (1,18) = 6.286, p = .022, antero-posterior, F (2,36) = 4.442, p = .037, and the interaction between these factors, F (2,36) = 4.343, p = .040, were found. Further analyses revealed a significant lexicality effect in anterior, t (18) = 2.637, p = .017, and central, t

(18) = 2.631, p = .017, regions. However, in posterior regions no effect of lexicality was observed, t (18) = 1.916, p = .072.

In the right hemisphere, main effects of lexicality, F (1,18) = 5.770, p = .027, antero-posterior, F (2,36) = 5.214, p = .027, were observed. However, the interaction between these factors was not significant, F (2,36) = 1.953, p = .176.

The analysis of the midline regions only revealed a main effect of lexicality.

***600-700ms*:** Significant interactions between lexicality and dorsal-ventral, as well as between lexicality, hemisphere and antero-posterior, were observed. This three-way interaction was broken down by hemisphere.

Results for the left hemisphere showed a trend towards significance for the main effect of lexicality, F (1,18) = 3.616, p = .073, and antero-posterior, F (2,36) = 2.599, p = .088. However, a significant interaction between lexicality and antero-posterior was found, F (2,36) = 4.474, p = .038. Further analyses revealed significantly more negative mean amplitudes for words relative to letter strings in anterior regions, t (18) = 2.337, p = .031, and no effects in central, t (18) = 1.871, p = .078, and posterior, t (18) = 1.211, p = .242, regions.

In the right hemisphere, only a main effect of antero-posterior was found, F (2,36) = 4.611, p = .038. No effect of lexicality, F (1,18) = 3.082, p = .096, or a significant interaction between lexicality and antero-posterior, F (2,36) = 1.835, p = .175, were observed.

The analysis of the midline revealed no significant main effects of lexicality or interactions with other brain regions.

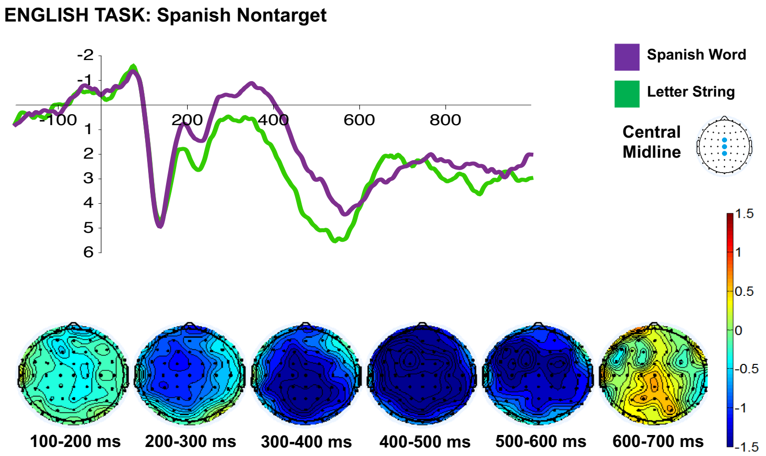

Figure 2.12 Lexicality effects on ERP waveforms and mean amplitudes every 100 ms of the no-go trials (L1) in the English Task (L2).

Table 2.7 F and p values of the Lexicality Analysis (no-go trials) of the English Task (L2)

Hemispheres				
	300-400ms	400-500ms	500-600ms	600-700ms
Lexicality			6.191*	
Lexicality * antero-posterior				
Lexicality * dorsal-ventral	5.981*		25.5****	7.103*
Lexicality * antero-posterior * dorsal-ventral		27.778****		
Lexicality * hemisphere * antero-posterior		3.357*		4.337*
Midline				
	300-400ms	400-500ms	500-600ms	600-700ms
Lexicality	3.275	6.896*	8.94**	
Lexicality * antero-posterior		3.206		

p < .05, p < .01**, p < .001***, p < .0001*****

2.3. Discussion

The aim of the present chapter was to investigate whether effects of word frequency and lexicality could be found in bilinguals' first (L1) and second languages (L2) in target or nontarget language conditions.

Behavioural results of the go-trials from the Spanish (L1) and the English (L2) tasks showed a main effect of language, indicating that the responses to L1 words were significantly faster than the responses to L2 words. More importantly, a similar-sized word frequency effect was found in the bilinguals'

L1 and L2 reaction times (91 ms vs. 95 ms). Thus, no interaction was found between language and word frequency.

However, the error rates revealed a significant interaction between language and frequency for these trials (go trials), a larger word frequency effect was observed in L2 compared to L1, although these effects were significant for both languages.

The effect of lexicality (no-go trials) on behavioural responses was investigated by comparing the error rates between nontarget words and pseudowords in L1 and L2. The results showed a lexicality effect in L1, pseudowords were more difficult to reject than words when these items were in L1. By contrast, no effect of lexicality was observed in the error rates of L2 nontarget words and pseudowords.

The ERP analysis in the time window 350-500ms revealed no effects of language, frequency or its interaction in the L1 task (L1 go, L2 no-go). However, in the L2 task (L2 go, L1 no-go), a main effect of language was found and the effect of frequency approached significance ($p = .053$) indicating that the effect was similarly strong in target and nontarget languages. The lack of an interaction between language and frequency confirmed this interpretation, in contrast to Rodríguez-Fornells et al. (2002)'s findings.

Furthermore, the time window analyses (100 ms time windows from 100 to 700ms) also revealed main effects of word frequency and interactions with different brain ROIs, regardless of language (target and nontarget). No interactions between word frequency and language were found at any of the time windows.

In the L1 task, the effect of frequency was prominent in anterior regions of the hemispheres and the midline from 300-400 ms. However, in the following time windows a main effect of frequency was not observed, from 600-700ms there was a main effect of frequency in the analysis of the hemispheres. However, this frequency effect was only present in posterior regions of the midline.

Results from the L2 task revealed significant interactions of word frequency with hemisphere and anterior-posterior and dorsal-ventral regions from 200-300ms. However, from 300-400ms an effect of word frequency was found in the right hemisphere but not in the left hemisphere. In the 400-500 ms time-window, the effect of word frequency was significant for L1 (nontarget) but not for L2 (target) in anterior regions of the right hemisphere. Main effects of frequency were observed from 500-600 ms. While, in anterior and central regions this effect remained significant despite the language, in the posterior regions, the word frequency effect was only significant for L1 (nontarget) in both hemispheres. Regions of the midline showed a main effect of frequency that was stronger in the posterior midline. In the time window from 600-700 ms main effects of frequency were observed in the hemispheres and in the midline. The effect was localised in posterior regions of the right hemisphere for L1, as well as in central and posterior regions of the midline.

Interestingly, the word frequency effects were stronger in the L2 task from 300-700 ms, whereas in the L1 task these effects were observed at the early and late latencies of the N400 time window.

The analysis of the effect of lexicality (in no-go trials) revealed main effects of lexicality in the ERPs of nontarget trials in both tasks. In the L1 task, effects were found from 500-600 ms in anterior and central regions of the hemispheres and in all regions of the midline. In the L2 task, the lexicality effect was found in anterior and central regions of the hemispheres from 300-400 ms, as well as in dorsal regions of the hemispheres from 400-500 ms. From 500-600 ms, a main effect of lexicality was observed in both hemispheres and at the midline, this effect interacted with the factor dorsal-ventral showing a significant main effect in dorsal regions. In the 600-700ms time-window the effect of lexicality was observed in posterior but not in central and anterior regions. This lexicality effect supports the notion of lexical access in the nontarget language.

The present results are not in line with the findings from Rodríguez-Fornells et al. (2002) who did not find a word frequency effect in the nontarget language. Although the same task was used, improvements were made regarding the bilingual population that was only fluent in Spanish (L1) and English (L2), also the comparisons were made within-subjects, language-specific features were avoided and word frequencies were similar in both languages. Furthermore, lexicality effects were investigated and reported in more detail.

The results of the present chapter are consistent with those of Ng and Wicha (2013) who found word frequency effects in the nontarget language. Moreover, the present results also revealed a lexicality effect in the nontarget language. Therefore, it is more likely that there was no suppression of the nontarget languages as had been previously suggested in behavioural and ERP findings (see chapter 1 sections 1.2.1 and 1.2.2).

In contrast to Rodríguez-Fornells et al. (2002), the analysis of brain potentials at centro-parietal electrodes revealed a word frequency effect in both target and nontarget languages in the L2 task. Interestingly, this was not the case in the L1 task.

The analysis by 100 ms time windows in the different ROIs supported these findings by identifying main effects of frequency in regions of the left and right hemisphere and midline from 300 to 700 ms. Similar to the effects in centro-parietal electrodes, the effects were found in a larger number of regions in the L2 task, whereas in the L1 task, the effects were only found in anterior regions in the 300-400 time-window, no main effect of frequency was observed from 400-500 ms and a frequency effect was observed from 600-700 ms, suggesting a stronger effect when the L1 is the nontarget language. Interestingly, the effect observed from 300-500ms was found in anterior and central regions of the right hemisphere, indicating a N400-type effect usually associated with lexical access; however, from 500 to 700 the effect was found in posterior regions of both hemispheres, similar to the results of nontarget trials in L2 and L3 by Aparicio et al. (2012)

The N400 component (discussed in section 1.2.2 of chapter 1) has been suggested as an index of information access within long-term semantic memory (Kutas & Federmeier, 2000) so the effects of frequency and lexicality correspondent to lexical access in this time window possibly provide evidence of the automaticity of the lexical access. The data of the time-window analyses showed language effects across different time windows in both tasks, which probably suggest different task demands for go and no-go trials according to the target or nontarget languages. Crucially, the fact that a word frequency effect was also found suggests that lexical access occured regardless of the task demands, as had previously been suggested by Ng and Wicha (2013), who also found word frequency effects in nontarget items. Ng and Wicha also studied Spanish-English bilinguals who were immersed in an L2 environment. However, in their experiment, they used language-specific lexical decision tasks and they did not report the effects of lexicality. Of special interest was the effect of lexicality in nontarget trials, which in this experiment supported the hypothesis of lexical access in the nontarget language. Moreover, the lexicality effect occurred at later time windows in L2 compared to L1, supporting the proposal of slower activation of L2 representations relative to L1 representations (Dijkstra & van Heuven, 2002).

The observed language effects (target vs. nontarget) probably reflect an effortful response to the target language of the task, in part influenced by an additional effort withholding responses for the other language, especially in L2 task. Although lexical access was observed in L1 and L2 when these languages were presented in no-go trials (nontarget language), the strength of the effects seems to depend on the language exposure as previously suggested by previous ERP studies (e.g. Lehtonen et al, 2012).

The behavioral results of the present experiment showed a similar-sized word frequency effect for go trials. This finding is different from those reported by Duyck et al. (2008) who found a larger frequency effect in L2 than in L1. The similar-sized word frequency effects observed in L1 and L2 suggest that balanced bilinguals (highly proficient in L2), would have similar activation speed for L1 and L2. However, an interaction between language and frequency was found in the error rates to target words and this could be evidence of different activation levels of L1 and L2. For example, the less available low frequency words in L2 exhibit a higher error rate compared to L2 high frequency and L1 words (high and low frequency) in the present results.

The task used in this experiment was, however, different from the one that was used by Duyck et al. (2008). They used a lexical decision task performed by Dutch-English bilinguals. It has been argued that the languages of the bilinguals might play an important role in determining differences in the size of the word frequency effect in L1 and L2 processing, according to language proficiency. In that study, bilinguals showed larger word frequency effect in their L2 (English) compared to their L1 (Dutch).

The observed lexicality effect in the nontarget L1 and the lack of a lexicality effect in L2 nontarget items are consistent with the results reported by Dijkstra, Timmermans and Schriefer (2000). Similar to Dijkstra, Timmermans and Schriefer results, the present findings showed that bilinguals found it difficult to withhold their responses to L1 words but not to L2 pseudowords.

In agreement to the results reported by Dijkstra, Timmermands and Schriefers, 2000 and Rodríguez-Fornells et al., 2002 of a high rate of false positive responses or false alarms. A further error analysis per stimulus was conducted.

As mentioned before, apart from only considering words in the target language to give a response, the task used in this experiment also required that the participants used either their left or right hand according to the onset (first letter) of the word (vowel/consonant). Difficulty with the vowel/consonant decision will reflect task difficulty, whereas responding in the non-target language would reflect a control issue with withholding responses to this language. Three types of errors could be made in the present experiment: (1) participant used the opposite (nonrequired) hand (i.e. right when left was required and vice versa), (2) participants made a response in a no-go trial (false positive), or (3) participants failed to respond in a go-trial.

Table 2.8 summarises the different types of errors for each condition and onset type in the present experiment. The low rate of error type (1) and the high rate of error types (2) and (3) in the specific condition according to the task indicates that participants had more item-related difficulties than onset-related ones. Due to the considerable number of errors in the no-go trials for pseudowords in both tasks (*Spanish:* 25%; *English:* 56%), these conditions were excluded from the ERP analyses.

Table 2.8 Error Type per condition. Error Rates were calculated based on the total number of data points in each stimuli condition

		Error by using the opposite hand	Error by giving an unrequired response	Error by failing to give a required response
Spanish Task				
Spanish (target)	HF	1.1	0	1.1
	LF	1.3	0	1.3
	PW	0	25.4	0
English (nontarget)	HF	0	2.1	0
	LF	0	2.3	0
	PW	0	2.5	0
English Task				
Spanish (nontarget)	HF	0	1.7	0
	LF	0	3.0	0
	PW	0	11.1	0
English (target)	HF	0.9	0	1.1
	LF	1.1	0	15.0
	PW	0	56.3	0

Overall, the analysis of the error types revealed that bilinguals had an increased error rate for L1 and L2 pseudowords when these items agreed with the target language of the task.

The present study investigated whether bilinguals can suppress the nonrequired language in a go/no-go task; the results presented in this chapter provided evidence of lexical access in nontarget languages. One issue worth mentioning was the high number of errors that were found in the no-go trials. Thus, bilinguals had more difficulty withholding responses to pseudowords in the target language (either L1 or L2) in the task at hand. The analysis of the types of errors suggests that the vowel and consonant decision did not increase the task difficulty. However, it might be the case that performing the task with stimuli from both languages could have added more difficulty to the tasks even if the target language was only one of those languages. The present go/no-go vowel decision task required three different components: orthographic (vowel or consonant), lexical (word or nonword) and language (L1 or L2). The next chapter disentangles this complex task by using different tasks that focus either on orthographic or lexical components. Also, separating the performance in L1 and L2 in different sessions per language eliminated the language decision. In order to compare the frequency and lexicality effects in bilinguals' L1 and L2, the next chapter focuses on behavioural responses in an experiment with the above-mentioned tasks in another group of Spanish-English bilinguals.

Chapter 3. Frequency and Lexicality effects in Bilinguals: The role of Language, Task and Repetition

3.1. Introduction

In the previous experiment, I investigated if lexical access occurs in L1 and L2 when bilinguals only need to respond to the target language in a go/no-go onset decision task. The ERP data revealed that lexical access occurred in both the target and nontarget language. Furthermore, a similar-sized word frequency effect in L1 and L2 was observed in the behavioural data, although responses in L2 were significantly slower than in L1. These behavioural findings are different from those reported by Duyck et al. (2008) who found a larger word frequency effect in L2 compared to the word frequency effect in L1. However, the findings of Chapter 2 are consistent with the suggestions of Diependaele et al. (2013) and Yap et al. (2011) that the effect of word frequency could be better explained by the lexical precision or lexical quality of the representations.

In this chapter, a different approach was used to investigate lexical access in bilinguals by simplifying the response criteria within the experimental task. Separate tasks that focused on the decision-levels of the task in chapter 2 were used in this chapter. These tasks were an Onset Decision Task (ODT) focused on the identification of the first letter of the presented letter string (vowel or consonant decision), and a Lexical Decision Task (LDT), which focuses on the word membership of the letter string (word/nonword decision). Because the interest was on the lexical access by language, tasks were conducted in different sessions per language and the language decision was not required anymore. Lexical access was investigated in behavioural responses through the effects of word frequency and lexicality. Due to the fact that the the word frequency effect reflects the frequency of encountering specific words and that this can also be manipulated within an experimental setting by item repetition, in the present experiment half of the items were repeated to examine whether the repetition effect would interact with word frequency and lexicality, and if responses would be similar or different in bilinguals' L1 and L2. Therefore, it is expected to show effects on indices of lexical access (word frequency and lexicality).

This chapter further investigates lexical access in bilinguals and focuses on frequency, lexicality, and repetition effects, as well as on the influence of the task demands. The lexical decision task was used to investigate if lexical access (word frequency and lexicality effects) is similar to those observed in the go/no-go task. In the previous chapter participants had to make a complex go/no-go decision that required them to focus on language membership (only respond to the target language), lexicality (word or nonword) and the orthographic onset of the letter string (vowel or consonant). Tasks that incorporate multiple decision levels would probably require several overlapping processes complicating the study of lexical access. For example, in the go/no-go task with Spanish (L1) as target language (chapter 2), the word "casa" required an orthographic decision (response with the right hand to a consonant onset), a lexical decision (only respond to words) and a language decision (only respond to words in the target language), whereas the Spanish pseudoword "erite" would need no response because is not a real word, as well as the English (L2) word "pickle" or an English-based pseudoword "urist".

According to the BIA+ model (Dijkstra & van Heuven, 2002) discussed in section 1.2.3.2, bilingual visual word recognition requires different levels of processing. These levels are the feature level, the letter level, the lexical level and the language level. The lexical level is one of the highest order level where the effect of word frequency takes place and could be explained by different resting-activation levels for the word representations according to their frequency of usage: high frequency words possess low resting levels of activation while low frequency words have higher resting levels. The tasks considered in this experiment focus on either the letter level (onset decision task) or the lexical level (lexical decision task). Based on the model predictions we would expect to see a word frequency and a lexicality effect in the lexical decision task. The onset decision task would allow the investigation of the presence of lexical access when the task demands do not require a lexical decision, which in turn will help to explore the influence of the lexical level on the letter level in the visual word recognition process, which can be explained by feedback mechanisms from the lexical to the letter level and could potentially predict a word frequency effect according to the BIA+ model.

The use of tasks that involve the same task sequence but only differ in the participant's required response will allow the investigation of task demands in lexical access, consistent with the proposal of a flexible lexical-processing system that relies on attentional mechanisms to optimise information processing for accomplishing the goals of any given lexical-processing task (Balota & Yap, 2006). The discussion regarding the role of task demands in bilingual visual word recognition (section 1.1.2.4) and monolingual visual word recognition (section 1.1.1.4) suggests that lexical access reflected by the word frequency and the lexicality effects can be modulated or influenced by task demands.

Moreover, word frequency and lexicality effects can be modulated by repetition in bilinguals' visual word recognition. As discussed in chapter 1 (section 1.2.1.2 and section 1.1.1.3) repeated exposure to word stimuli increase the speed of responses to those stimuli, especially if they are of low word frequency compared to high frequency words. However, the effect is less clear for nonwords as item repetition can result in slower or faster responses to these stimuli in monolinguals. Because the experimental design and the task used can be important factors in determining the direction of the repetition effect for nonwords, repetition was incorporated in this experiment where we varied task demands. Moreover, it would be interesting to investigate the repetition effect in bilinguals to see whether repeated exposure to stimuli can strengthen the word representations in the second language.

As mentioned above, the BIA+ (Dijkstra & van Heuven, 2002) proposes different activation resting-levels in bilinguals' L1 and L2, which would predict a word frequency effect either delayed or larger for L2 due to weaker lexical representations in L2 compared to those in L1, as discussed in section 1.2.3.2.

The effect of word frequency in the lexical decision task in Dutch–English (L2) bilinguals revealed a larger word frequency effect in L2 (103 ms) than in L1 (46 ms) (Duyck et al., 2008). Evidence from eye-movements has supported the notion of bilinguals' lower exposure to words in L2 compared to words in L1 by observing larger word frequency effects in L2 compared to the effect in the L1 when bilinguals read an entire novel (Cop et al., 2015). The importance of language exposure has been emphasised by Diependaele et al. (2013) who proposed that language proficiency increases lexical entrenchment (lexical "precision" or "lexical quality"), leading to a reduced frequency effect regardless of bilingualism, language dominance or language similarity. Monaghan, Chang, Welbourne & Brysbaert (2017) have been able to demonstrate through computer simulations that word frequency effect is a function of the individual vocabulary size. Furthermore, this lexical entrenchment hypothesis has been tested in the lexical decision task (Brysbaert, Lagrou & Stevens, 2017) and, in accordance with the lexical entrenchment hypothesis they concluded that the word frequency effect is related to the vocabulary size (larger frequency effects in less exposure) more than the difficulty of processing the L2.

Additionally, the role of proficiency has also been suggested as an important factor for the effect of lexicality. Grossi, Murphy and Boggan (2009) noted a relationship between the proficiency level and the pseudoword superiority effect, probably reflecting the influence of the native language on the second one. Recently, the effect of repetition has been investigated in Dutch-English bilinguals through a training paradigm to examine shared representations in lexical access in production and recognition (Van Assche, Duyck & Gollan, 2016). Results from the lexical decision task showed a decrease in response times when comparing first to second presentations in both languages tested in two different experiments. Although this study was mainly focused on cross-transfer effects with lexical decision and naming tasks, repetition effects were found in bilinguals.

In this chapter word frequency, lexicality and repetition effects were investigated in bilinguals in an ODT and a LDT. Repetition effects have rarely been studied in bilinguals within the lexical decision task (section 1.2.1.2) However, it has been found that different levels of exposure could impact the size of the word frequency (Diependaele et al., 2013) and lexicality effects (Van Assche, Duyck & Gollan, 2016).

Mixed-effects modelling of reaction times and accuracy of responses was conducted. The advantages of this approach over ANOVAs were discussed in section 1.3.2.3. Furthermore, the RT distribution was also analysed due to its contribution to the understanding of lexical factors on behavioural responses beyond the mean reaction times and accuracy scores (section 1.3.2.4). Response times are generally positively skewed at the faster end of the scale (Balota & Spieler, 1999). In order to understand the influence of word frequency and lexicality on task, language and repetition, fitting a mathematical function and plotting the distribution for the different stimuli conditions could be conducted according to Balota and Yap (2011).

Regarding the shape of the reaction times distribution, it has been found that the effect of word frequency shifts and increases the tail of the distribution (e.g., Balota & Spieler, 1999). This effect of word frequency also interacts with that of repetition in the tau parameters of the distribution where the effect of repetition is larger for low frequency than for high frequency words, while the effect of repetition for nonwords is shown in mu and tau parameters, according to Balota and Spieler (1999).

Based on previous findings, word frequency effects are expected in the lexical decision task only. The ODT requires only the letter level and not the lexical level. Therefore, no lexical access would be expected in this task and interactions between the effects of word frequency or lexicality with task will be predicted. In Chapter 1, the sizes of the word frequency effect in L1 and L2 did not differ significantly so no interaction between the word frequency and language is predicted in this experiment either. If language (L1 vs. L2) determines the size of the effect of word frequency, a larger effect for L2 compared to L1 will be found similar to Duyck et al. (2008). However, if language does not determine the size of the effect of word frequency in bilinguals as in our previous study, only the interaction between word frequency and task will be found. Similar predictions can be made regarding the effect of lexicality: a larger effect would be found in the L2 compared to the L1 if language determines the size of the effect.

Considering the effect of repetition (section 1.1.1.3 and section 1.2.1.2), a decrease in the word frequency effect and an increase in the lexicality effect in the LDT can be predicted. However, this might not be the case in the ODT if this task does not require lexical access. Interactions between repetition, word frequency, language and task would be expected. Regarding the RT distribution, we expect word frequency effects in the mean (mu) and tail (tau) of the distribution and an interaction between word frequency and repetition in the tail of the distribution (tau parameters) as previously reported by Balota and Spieler, (1999).

3.2. Experiment 2

3.2.1. Methods

3.2.1.1. Participants

Twenty-four Spanish-English speakers (8 females) were recruited from the University of Nottingham student population and they received an inconvenience allowance for their participation. Participants were born in Spanish-speaking countries (i.e. Mexico, Colombia, Chile, Spain), and they had Spanish as their first and dominant language. Participants were postgraduate students in the UK at the time of testing and were between 23 and 35 years old ($M = 28$, $SD = 3.3$). All participants were right-handed and did not report any language problems. Language proficiency in Spanish (L1) and English (L2) was measured objectively using a vocabulary task that consists of a un-speeded visual lexical decision task to test vocabulary knowledge for medium to highly proficient second language speakers. For Spanish, the Lextale-Esp (Izura, Cuetos & Brysbaert, 2014) vocabulary task was used. Participants' scores in this task were above 90% ($M = 92.21$, $SD = .04$). For English, LexTALE (Lemhöfer & Broersma, 2012) was used and scores were on average above 70% (*M* = 74.67, *SD* = .07). Participants also provided information regarding their language background through a language questionnaire. Their first contact with L2 was at 9 years old (*SD* = 3.9) and they had at least 15 years of experience with the language (*SD* = 6.7). Participants evaluated their own ability in speaking, listening, reading and writing for each language on a scale from 1 (very poor) to 7 (very good/fluent). In L1 (Spanish) the overall score was 6.8 (*SD* = 0.52) and in L2 (English) it was 5.5 (*SD* = 1). The participants also described their daily language use at various social situations on a scale from 1 (never) to 5 (always). The overall L1 use was 2.8 (*SD* = 1.3) and the L2 use was 3.7 (*SD* = 1.1). The scores for individual categories of subjective language proficiency and language use is summarised in Table 3.1.

Table 3.1 Subjective Language Proficiency and Language Use Scores

Subjective Language Proficiency					
	Speaking	Listening	Reading	Writing	Overall
L1 Spanish	6.8 (0.5)	6.9 (0.3)	6.9 (0.4)	6.7 (0.8)	6.8 (0.5)
L2 English	5.1 (1.0)	5.8 (1.1)	5.9 (0.8)	5.3 (0.9)	5.5 (1.0)
Language Use					
	Home	Friends	Course mates	Other social	Overall
L1 Spanish	3.1 (1.6)	3.5 (0.8)	1.7 (1.0)	2.8 (0.9)	2.8 (1.3)
L2 English	3.3 (1.5)	3.3 (0.9)	4.6 (0.9)	3.5 (0.8)	3.7 (1.1)

3.2.1.2. Stimuli

The stimuli in Spanish consisted of 480 letter strings of 4 to 6 letters. 240 items were words, 120 were pseudowords (pronounceable nonwords, e.g. gruzo) and 120 were pure consonant (e.g. hrcjr) or pure vowel (e.g. aueia) letter strings. One half of the stimuli started with a vowel while the other half started with a consonant letter. The words were high (HF) and low (LF) frequency nouns selected from SUBTLEX-Esp (Cuetos et al., 2011). High frequency words had Zipf values of 3.9 to 6 Zipf (10 to 1000 fpm) and low frequency words had Zipf values of 2.1 to 3.9 Zipf (0.1-10fpm). The pseudowords (PW) were constructed by combining legal bi-grams and tri-grams of words in SUBTLEX-ESP. Frequency, length and number of high frequency neighbours were matched within and between languages (see Table 3.2 for a summary).

A similar set of 480 letter strings of 4 to 6 letters was created for English. In total, 240 items were words, 120 were pseudowords (e.g. *idgest*) and 120 were pure consonant (e.g. *nrthv*) or pure vowel (e.g. *eiuoi*) letter strings. One half of the stimuli started with a vowel while the other half started with a consonant letter. The words were high (HF) and low (LF) frequency nouns selected from SUBTLEX-UK (van Heuven et al., 2014). High frequency words had Zipf values of 3.9 to 6 Zipf (10 to 1000 fpm) and low frequency words had Zipf values of 2 to 3.9 Zipf (0.1-10 fpm). The pseudowords (PW) were selected from the British Lexicon Project (BLP, Keuleers et al., 2012). Stimuli characteristics such as frequency, length and number of high frequency neighbours were matched within and between languages (see Table 3.2 for a summary).

The pure consonant or vowel letter strings (LS) were constructed based on randomizations of consonants (b, c, d, f, g, h, j, k, l, m, n, p, q, r, s, t, v, w, x, y, z) or vowels (a, e, i, o, u). These LS included no more than two repetitions per letter, and followed the same construction criteria in Spanish and English.

Cognates and language-specific characters were avoided (e.g. ñ) in Spanish and English. The vowel and consonant onsets were the same as Spanish and English: a, e, i, o, u, b, c, d, f, g, h, j, l, m, n, p, r, s, t, v. For each language, items were divided into three matched lists (A, B, C), each of them consisted of 80 words (40 HF and 40 LF), 40 PW and 40 LS (see Table 3.2). Half of the stimuli in each list started with a vowel while the other half started with a consonant letter (the complete set of stimuli can be found in Appendices I, III, IV and VI).

Table 3.2 Stimuli Characteristics

	Zipf values	ND Within	ND Between	Length
Spanish (L1)				
Letter String	NA	0 (0)	0.008 (0.9)	5.3 (0.7)
Pseudoword	NA	0.6 (1.1)	0.3 (0.6)	5.3 (0.7)
Low frequency words	3.1 (0.5)	0.5 (0.9)	0.1 (0.3)	5.3 (0.7)
High frequency words	4.7 (0.5)	0.7 (0.9)	0.1 (0.3)	5.3 (0.7)
English (L2)				
Letter String	NA	0.03 (0.2)	0.03 (0.2)	5.3 (0.7)
Pseudoword	NA	0.4 (0.7)	0.4 (0.7)	5.3 (0.7)
Low frequency words	3.2 (0.4)	0.5 (1)	0.5 (1)	5.3 (0.7)
High frequency words	4.7 (0.4)	0.7 (1.1)	0.7 (1.1)	5.3 (0.7)

ND between/ within= Neighbourhood density with high-frequent words between languages or within the same language

3.2.1.3. Design

The experiment consisted of two sessions (one per language). In each session participants conducted an onset decision task (ODT) and a lexical decision task (LDT). The order of the tasks was counterbalanced across subjects; one half of the participants started with the ODT followed by the LDT, whereas the other half started with the LDT followed by the ODT.

Two of the stimulus lists were presented in the first task (e.g. A, B) and the remaining list (e.g. C) was presented with a previously seen stimulus list (e.g. B) in the second task. The order of the lists was counterbalanced across subjects and all participants were exposed to the three stimulus lists. Each list per language contained high and low frequency words as well as pseudowords and letter strings. Thus, language (Spanish vs. English), frequency (HF vs. LF), lexicality (words vs. pseudowords) and repetition (repeated vs. nonrepeated), were within-subjects factors, and task (ODT and LDT) was a between-subjects factor.

3.2.1.4. Procedure

Participants took part in two sessions: one in Spanish (L1) and the other in English (L2) separated by at least 24 hours. Each session took approximately 45 mins. In the first session, participants read the study information sheet. After providing participants with the opportunity to ask questions about the study they were asked to sign a consent form and then complete an online version of the Edinburgh Handedness Questionnaire (Oldfield, 1971).

In both sessions, participants conducted two tasks while sitting in a comfortable position in front of a computer screen. In the ODT, individuals had to respond with either their left or right index finger on an external response button box according to the first letter of the item (i.e. right hand for the vowel onset and left hand for the consonant one). In the LDT participants responded with their left or right index if the presented item was a word or not (i.e. right hand for words and left hand for non-words: pseudo-words and letter strings). The task instructions were provided on paper and also presented on screen at the beginning of each task followed by 12 practice trials so that participants could familiarise themselves with the task.

The order of the tasks and the response hand were counterbalanced across participants. All stimuli were presented on a CRT monitor (refresh rate 11.7 ms) at approximately 60 cm distance. Each trial started with a small fixation cross at the center of the screen presented for 500 ms, followed by a blank screen of 300 ms and then the stimulus presentation in lowercase for 500 ms. Breaks were provided during and between the tasks.

After the completion of the ODT and LDT tasks in each session, language proficiency was measured with vocabulary tasks according to the language of the session. For English, LexTALE (Lemhöfer & Broersma, 2012) was used and for Spanish, Lextale-Esp (Izura, Cuetos, Brysbaert, 2014) was used. At the end of the second session, participants also completed a language background questionnaire. Each session took approx. 45 mins.

3.2.2. Results

The following section includes two types of analysis. The first one is mixed effects modelling while the second one is the analysis of the RT distribution. All analyses only considered responses in the tasks performed, as in the second task, given that repetition is one of the factors of interest and this was only observable in the second tasks. Within-subjects' factors were frequency (HF vs. LF), lexicality (Word vs. Pseudoword) and repetition (Nonrepeated vs. Repeated), whereas, between-subjects' factors consisted of language (L1 vs. L2) and task (ODT vs. LDT). Separate analyses were conducted for Frequency and Lexicality in conjunction with the other factors mentioned.

3.2.2.1. Mixed effects modeling

The total number of collected data points was 30,720. Outliers were considered as responses slower than 300 ms or faster than 1500 (0.78%). Reaction times analyses included only correct responses (91%).

Mixed-effects modelling was conducted using the lme4 package (Bates et al., 2014) in R version 3.3.0 (R Development Core Team, 2010). Similar to Perea et al. (2016) and in order to account for the positive asymmetry of the data while maintaining the direction of the effects, an Inverse-Gaussian transformation of the reaction times (-1000/RT) was used (Baayen & Milin, 2010). The *glmer* function of the *lmer4* package was used to analyse accuracy due to the binary values of that variable (1 = correct, 0 = incorrect). In order to examine the effects of language, frequency and lexicality in relation to task and repetition, separate models were conducted for language (two levels: Spanish, English), frequency (two levels: high, low), task (two levels: ODT, LDT) and repetition (two levels: repeated, non-repeated); and for language, lexicality (two levels: word, nonword), task and repetition.

The initial models were the full models, incorporating random intercepts for subjects and items, as well as random slopes by subjects incorporating the interaction of the analysed factors (Barr et al., 2013). However, the random structure was in some comparisons simplified to achieve convergence of the models. After achieving convergence, the models were then simplified in a step-by-step backward model selection procedure. To further explore significant interactions in the final model, chi-squared tests with Bonfenroni adjustment were conducted using the package *phia* (function *testInteractions*).

Mean reaction times and accuracy scores were calculated by frequency and repetition (see Table 3.3).

Table 3.3 Mean and SE Reaction Times and Accuracy

	Onset Decision Task		Lexical Decision Task	
Reaction Times	*Nonrepeated*	*Repeated*	*Nonrepeated*	*Repeated*
L1 Spanish				
High Frequency	459 (5.4)	451 (4.6)	518 (6.4)	516 (6.4)
Low Frequency	459 (4.4)	467 (5.3)	593 (8.4)	577 (7.9)
L2 English				
High Frequency	472 (5.5)	461 (4.6)	532 (6.9)	522 (6.6)
Low Frequency	464 (4.9)	474 (5.7)	621 (10.3)	613 (11)
Accuracy				
	Onset Decision Task		Lexical Decision Task	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
L1 Spanish				
High Frequency	0.96 (0.01)	0.97 (0.01)	0.98 (0.01)	0.98 (0.01)
Low Frequency	0.98 (0.01)	0.98 (0.01)	0.94 (0.01)	0.94 (0.01)
L2 English				
High Frequency	0.96 (0.01)	0.96 (0.01)	0.96 (0.01)	0.97 (0.01)
Low Frequency	0.97 (0.01)	0.97 (0.01)	0.82 (0.02)	0.83 (0.02)

Reaction Times: The final model included language, task, frequency, repetition, and the interaction between task and frequency (Table 3.4). Main effects of language, task, frequency and repetition were observed. Responses were faster to words in Spanish (L1) relative to words in English (L2, $t = -4.14$, $p < .0001$). Also, faster responses were observed in the ODT compared to the LDT, $t = -3.19$, $p < .01$. Furthermore, responses were slower to low frequency words relative to high frequency words, $t = 16.12$, $p < .0001$. Finally, faster responses were found for repeated words compared to nonrepeated words, $t = -2.02$, $p < .05$. Importantly, a significant interaction between frequency and task was observed, $t = -11.46$, $p < .0001$, Figure 3.1. This interaction was due to the absence of a frequency effect in the ODT (5 ms, $p = .273$) and a significant frequency effect of 78 ms in the LDT ($p < .0001$).

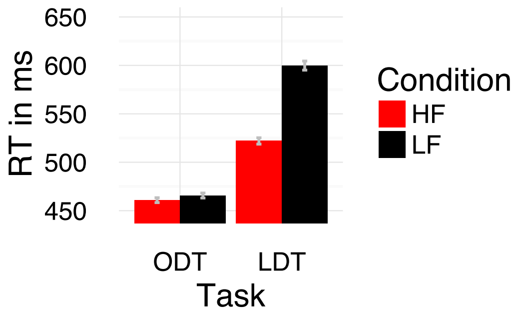

Figure 3.1 Frequency by Task Interaction of RT

Table 3.4 Final model of reaction times Language, Task, Frequency and Repetition

	Estimate	SE	t-value
Fixed effects			
(Intercept)	1.986	0.05667	-35.055
Language	0.0432	0.01045	-4.136
Task	0.2424	0.07935	-3.055
Frequency	2.231	0.01386	16.101
Repetition	0.0178	0.00884	-2.015
Frequency * Task	0.2029	0.01771	-11.458
	Variance	SD	
Random effects			
Item (Intercept)	0.003634	0.06029	
Participant (Intercept)	0.140856	0.37531	

Accuracy: The final model only included the main factors of language, task and frequency (Table 3.5). Responses to Spanish items were more accurate than responses to English items, $z = 5.02$, $p < .0001$. Also, responses in the ODT revealed fewer errors than responses in the LDT, $z = 3.42$, $p < .001$. Finally, responses to high frequency words had a higher accuracy compared to low frequency words, $z = -5.48$, $p < .0001$.

Table 3.5 Final model of accuracy Language, Task, Frequency and Repetition

	Estimate	SE	z-value
Fixed effects			
(Intercept)	3.1838	0.2390	13.321
Language	0.7539	0.1503	5.016
Task	1.0081	0.2950	3.417
Frequency	-0.8249	0.1506	-5.478
	Variance	SD	
Random effects			
Item (Intercept)	0.8730	0.9344	
Participant (Intercept)	0.4184	0.6468	

II. Language, Task, Lexicality and Repetition Effects

Mean reaction times and accuracy scores were calculated for words and pseudowords by language and task (Table 3.6).

Table 3.6 Mean and SE Reaction Times and Accuracy

	Reaction Times			
	Onset Decision Task		Lexical Decision Task	
	Not Repeated	*Repeated*	*Not Repeated*	*Repeated*
L1 Spanish				
Word	459 (3.5)	459 (3.5)	555 (5.4)	546 (5.2)
Pseudoword	460 (4.6)	460 (5.1)	803 (12.1)	824 (12)
L2 English				
Word	468 (3.7)	467 (3.7)	572 (6.2)	564 (6.4)
Pseudoword	473 (5.2)	479 (6.3)	820 (18.7)	813 (19.6)
	Accuracy			
	Onset Decision Task		Lexical Decision Task	
	Not Repeated	*Repeated*	*Not Repeated*	*Repeated*
L1 Spanish				
Word	0.97 (0.01)	0.97 (0.01)	0.96 (0.01)	0.96 (0.01)
Pseudoword	0.97 (0.01)	0.97 (0.01)	0.64 (0.02)	0.66 (0.02)
L2 English				
Word	0.96 (0.01)	0.97 (0.01)	0.89 (0.01)	0.90 (0.01)
Pseudoword	0.97 (0.01)	0.97 (0.01)	0.50 (0.02)	0.45 (0.02)

Reaction times: The final model included the main factors of language, task, lexicality and repetition and the interactions between language, task and lexicality (Table 3.7).

Responses to Spanish items were faster than responses to English items, $t = 3.79$, $p < .001$. Also, faster responses were found in the ODT relative to LDT ($t = -10.07$, $p < .0001$. Moreover, faster responses to words compared to pseudowords were found, $t = -21.05$, $p < .0001$. Faster responses to repeated relative to nonrepeated words, $t = -1.51$, $p < .0001$, were also observed. Furthermore, the following interactions included in the model were significant: language * task, $t = -5.29$, $p < .0001$, language * lexicality, $t = -4.88$, $p < .0001$, task * lexicality, $t = 17.21$, $p < .0001$, and importantly, the interaction between language, task and lexicality, $t = 4.91$, $p < .0001$.

The 3-way interaction between language, task and lexicality was broken down by language and separate models for each language were created (Figure 3.2).

Spanish (L1): The final model included task, lexicality and the interaction between these factors. Main effects of task, $t = -12.69$, $p < .0001$, and lexicality $t = -30.93$, $p < .0001$, were observed. Importantly, the interaction between task and lexicality was significant, $t = 25.96$, $p < .0001$, because of a lexicality effect of 264 ms in the LDT ($p < .0001$) and not in the ODT ($p = 1$). In general, responses to words (91 ms, $p < .0001$) and pseudowords (354 ms, $p < .0001$) were faster in the ODT relative to the LDT.

English (L2): The final model for English words included the main factors and interactions between task and lexicality. Main effects of task, $t = -7.010$, $p < .0001$ and lexicality, $t = -10.037$, $p < .0001$ were found. Crucially, the interaction between task and lexicality was significant, $t = 10.7$, $p < .0001$, because of a lexicality effect of 248ms in the LDT ($p < .0001$) and not in the ODT (difference 9ms, $p = .934$). Furthermore, responses to words were 101ms faster in the ODT compared to the LDT ($p < .0001$), and responses to nonwords were 342ms faster in the ODT relative to the LDT ($p < .0001$).

Table 3.7 Final model of reaction times Language, Task, Lexicality and Repetition

	Estimate	SE	t-value
Fixed effects			
(Intercept)	-1.406	0.05694	-24.687
Language	0.0997	0.02630	3.791
Task	-0.7911	0.07853	-10.074
Lexicality	-0.4760	0.02261	-21.054
Repetition	-0.0114	0.00757	-1.511
Language * task	-0.1591	0.03010	-5.287
Language * lexicality	-0.1469	0.03012	-4.879
Task * lexicality	0.4462	0.02593	17.209
Language * task * lexicality	0.1722	0.03505	4.914
	Variance	SD	
Random effects			
Item (Intercept)	0.005846	0.07646	
Participant (Intercept)	0.033963	0.18429	

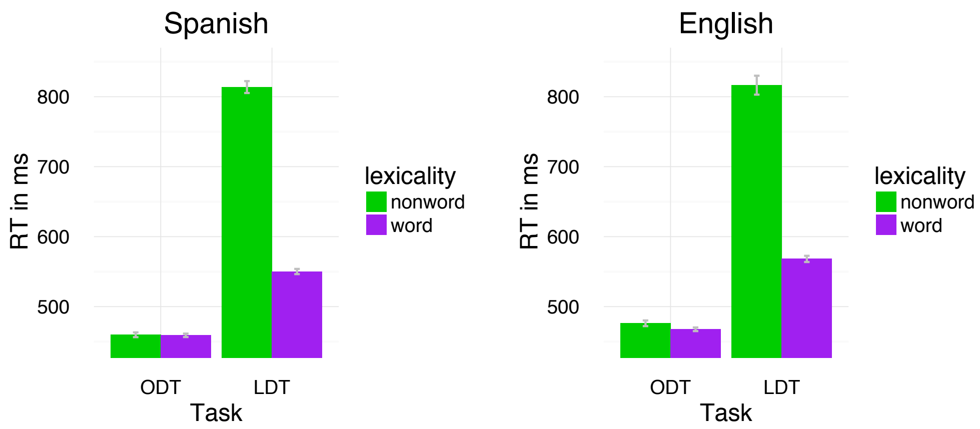

Figure 3.2 Language, Task and Lexicality interaction of RT

Accuracy: The final model included language, task, lexicality and the interaction between language and task (Table 3.8). Significant main effects of language, z = 8.04, p < .0001, task, z = 11.06, p < .0001, and lexicality, z = 20.82, p < .0001, were found. Notably, the interaction between language and task was significant, z = -3.5, p < .001. Responses to Spanish (L1) items were 9% more accurate relative to those for English (L2) items in the LDT (p < .0001) but no language effect was found in ODT (-.5%, p < .5).

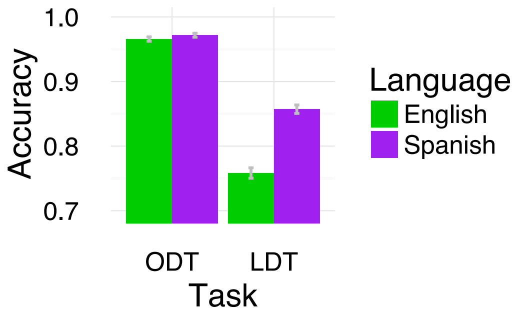

Figure 3.3 Lexicality by Task interaction of accuracy

Table 3.8 Final model of accuracy Language, Task, Lexicality and Repetition

	Estimate	SE	z-value
Fixed effects			
(Intercept)	0.09201	0.17179	0.536
Language	0.83747	0.10417	8.039
Task	2.71956	0.24582	11.063
Lexicality	2.15015	0.10329	20.816
Language * Task	0.62924	0.17973	3.501
	Variance	SD	
Random effects			
Item (Intercept)	0.6541	0.8088	
Participant (Intercept)	0.2608	0.5107	

3.2.2.2. Reaction Times Distribution Analysis

Responses shorter than 250 ms or longer than 3000 ms (0.7 % of the data) and incorrect responses (9 %) were excluded from the analysis. One of the most commonly used mathematical functions to fit an RT distribution is the ex-Gaussian function that according to Ratcliff and Murdock (1976) and Heathcote et al. (1991) provides an excellent fit for empirically obtained RT distributions and its parameters algebraically map onto the mean of the RT distribution (Balota & Yap, 2011). The method used by Balota & Spieler (1999) was followed to fit the ex-Gaussian distribution to the observations from a small participants' sample. The data was divided into a set of 20 quantiles for each participant and super-subjects were generated. Vincent averages for every 4 subjects (6 super subjects) were calculated for the quantiles per participant, because the fit of the ex-Gaussian distribution requires approximately 100 observations per condition (Ratcliff, 1979, Vincent, 1912). The parameters of the ex-Gaussian distribution (mu, sigma, tau) were calculated for each super subject and condition (frequency: high, low; repetition: nonrepeated, repeated) with the R package ‘retimes’ (function *mexgauss)*. Mixed 2x2x2x2 ANOVAs were calculated with each of the parameters of the RT distribution.

I. Language, Task, Frequency and Repetition

The *F* and *p* values of the statistical analyses are summarised in Table 3.9. The group parameter estimates [1]are shown in Table 3.10. The RT distribution of the frequency effect across quantiles is presented in Figure 3.4.

Mu: Main effects of task and frequency were observed. Mu values were 73 ms higher in the LDT relative to the ODT. The mu values were also 29 ms higher for low frequency words compared to high frequency words. No effects of language or repetition were found. Importantly, a significant interaction between task and frequency and paired t-tests revealed that the effect of word frequency was significant in the LDT (59 ms), t (11) = -7.598, $p < .0001$, whereas, in ODT (0.2 ms) it was not significant, $t < 1$. Moreover, responses to high frequency (43 ms), t (11) = -13.932, $p < .0001$, and low frequency words (101 ms), t (5) = -10.227, $p < .0001$, had lower Mu values in the ODT relative to the LDT.

Sigma: A main effect of frequency was observed indicating that values of sigma were 15ms higher for low frequency words than for high frequency words. No effects of task, language, or repetition were found. However, the interaction between task and frequency revealed that the frequency effect was significant in the LDT (30 ms), t (11) = -7.068, $p < .0001$, but not in the ODT

[1] The vincentiles for the whole group without dividing by super subjects do not deviate more than 2 ms from the ones reported in Table 3.10.

(-1 ms), t (11) = 0.882, p = .397. Furthermore, the interaction between language and frequency was significant. Crucially, a significant interaction between task, language and frequency was also found. This three-way interaction was broken down by language.

The results for L1 (Spanish) showed a significant effect of frequency, F (1, 4) = 13.446, p = .021, and a significant interaction between frequency and task, F (1, 4) = 11.636, p = .023, but no effect of task, F (1, 4) = 2.835, p = .168. Further comparisons revealed that responses to high frequency words were 22 ms faster than responses to low frequency words in the LDT, t (5) = -5.158, p = .004. In contrast, there was no effect of frequency in the ODT (1 ms), t (5) = -0.881, p = .419.

The results for L2 (English) revealed a similar pattern: no effect of Task, F (1, 4) = 2.381, p = .198, whereas the main effect of Frequency, F (1, 4) = 15.867, p = .016, and the interaction between Task and Frequency, F (1, 4) = 22.374, p = .009, were significant. Again, no frequency effect was found in the ODT (-3 ms), t (5) = 1.297, p = .251, whereas a word frequency effect was found in the LDT (39 ms), t (5) = -6.595, p = .001.

The interaction between task, language and repetition was also significant. This interaction was due to an effect of language for repeated words, F (1, 4) = 25.649, p = .007, and not for nonrepeated words, F (1, 4) = 2.461, p = .192. Other effects were not significant (Repeated words: task (F (1, 4) = 2.272, p = .206; task * language, F (1, 4) = 1.881, p = .242; nonrpeated words: task, F (1, 4) = 2.787, p = .170; task * language, $F < 1$).

Tau: The main effects of task, language and repetition failed to reach significance. However, there was a main effect of frequency, as well as a significant interaction between task and frequency. Paired t-tests revealed a significant word frequency effect in the LDT (25 ms), t (11) = -6.617, $p <$ .0001, but not in ODT (4 ms), t (11) = -1.649, p = .127. Other interactions failed to reach significance.

Table 3.9 F and p values of the ANOVAs for Mu, Sigma and Tau means

Interaction	*Mu*		*Sigma*		*Tau*	
	F	*P*	*F*	*p*	*F*	*p*
Task	45.044	.003	2.608	.182	< 1	
Frequency	43.048	.003	15.050	.018	20.939	.010
Language	3.099	.153	6.501	.063	< 1	
Repetition	1.567	.279	< 1		< 1	
Task * frequency	42.450	.003	17.785	.014	11.881	.026
Task * language	1.180	.339	< 1		< 1	
Task * repetition	1.885	.242	< 1		< 1	
Language * frequency	2.149	.217	15.698	.017	< 1	
Language * repetition	< 1		< 1		< 1	
Frequency * repetition	< 1		< 1		< 1	
Task * frequency * repetition	1.737	.252	< 1		4.851	.092
Language * frequency * repetition	< 1		< 1		< 1	
Task * language * frequency	6.133	.069	42.478	.003	< 1	
Task * language * repetition	< 1		9.654	.036	< 1	
Task * language * frequency * repetition	1.107	.352	< 1		2.486	.190

Table 3.10 Means of Parameter Estimates from the ex-Gaussian analysis for super subjects

	Onset Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
L1: Spanish				
Mu	416 (5)	412 (8)	415 (8)	422 (7)
Sigma	41 (2)	41 (4)	41 (3)	43 (3)
Tau	28 (4)	28 (3)	33 (3)	31 (0)
L2: English				
Mu	425 (11)	420 (10)	417 (7)	420 915)
Sigma	47 (9)	46 (4)	41 (5)	45 (5)
Tau	38 (7)	32 (7)	35 (5)	40 (2)
	Lexical Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
L1: Spanish				
Mu	463 (8)	458 (9)	512 (18)	493 (9)
Sigma	48 (8)	48 (6)	73 (13)	67 (13)
Tau	41 (7)	44 (15)	67 (9)	69 (17)
L2: English				
Mu	467 (3)	459 (3)	540 (18)	536 (16)
Sigma	45 (7)	45 (8)	86 (17)	82 (14)
Tau	52 (17)	54 (16)	83 (16)	70 (15)

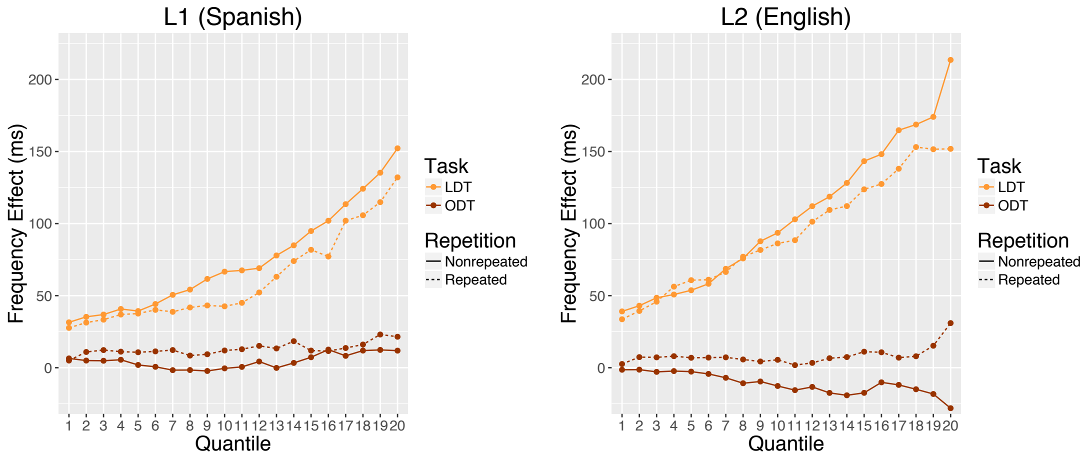

Figure 3.4 Quantile Distribution of the Frequency Effect by Language, Task and Repetition

II. Language, Task, Lexicality and Repetition

The *F* and *p* values of the statistical analyses are summarised in Table 3.11. The group parameter estimates[2] for Mu, Sigma and Tau (dependent variables) are presented in Table 3.12. The lexicality effect across quantiles is shown in Figure 3.5.

Mu: Main effects of task and lexicality were found. There were no effects of language or repetition. The values of this parameter were larger (49 ms) in the LDT relative to the ODT. Importantly, a significant interaction between task and lexicality was observed. Further paired t-tests revealed no lexicality effect in the ODT (2 ms), t (11) = 0.598, p = .562, whereas a lexicality effect of 290 ms was found in the LDT, t (11) = 12.049, p < .0001. Task effects were observed for words (61 ms), t (11) = -11.567, p < .0001, and pseudowords (349 ms), t (11) = -13.495, p < .0001. Other interactions failed to reach significance.

Sigma: A main effect of lexicality was observed. No effect of language, task or

[2] The vincentiles for the whole group without dividing by super subjects showed very similar results, the parameters do not deviate more than 2 ms from the ones reported in Table 3.12.

repetition was found. Again, the interaction between task and lexicality was significant. Similar to mu values, further comparisons showed a lexicality effect only in LDT (43 ms), *t* (5) = 5.771, *p* = .0001, and not in ODT (2 ms), *t* (5) = 1.159, *p* = .271. Also, sigma values were higher for LDT compared to ODT for words (19 ms), *t* (5) = -31.138, *p* = .005, and pseudowords (60 ms), *t* (5) = -87.043, *p* = .0005. Other interactions failed to reach significance.

Tau: Tau values were 9 ms larger for English (L2) words than for Spanish (L1) words. The effect of Task showed a trend towards significance (*p* = .053), while other main effects and interactions were not significant.

Table 3.11 F and p values of the ANOVAs for Mu, Sigma and Tau means

Interaction	*Mu*		*Sigma*		*Tau*	
	F	*P*	*F*	*p*	*F*	*p*
Task	48.513	.002	5.742	.075	7.429	.053
Lexicality	32.590	.005	16.614	.015	< 1	
Language	1.190	.337	1.300	.318	10.701	.031
Repetition	< 1		< 1		< 1	
Task * lexicality	31.807	.005	13.881	.020	< 1	
Task * language	< 1		< 1		< 1	
Task * repetition	< 1		< 1		< 1	
Language * lexicality	< 1		< 1		1.568	.279
Language * repetition	< 1		3.002	.158	< 1	
Lexicality * repetition	< 1		1.597	.274	< 1	
Task * lexicality * repetition	1.252	.326	< 1		1.547	.281
Language * lexicality * repetition	< 1		1.676	.265	< 1	
Task * language * lexicality	1.835	.247	< 1		< 1	
Task * language * repetition	< 1		2.000	.230	< 1	
Task * language * lexicality * repetition	< 1		1.222	.331	< 1	

Table 3.12 Means of Parameter Estimates from the ex-Gaussian analysis for super subjects

	Onset Decision Task			
	Word		Pseudoword	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
L1: Spanish				
Mu	414 (6)	415 (7)	416 (5)	407 (3)
Sigma	42 (2)	43 (3)	41 (3)	43 (2)
Tau	32 (3)	31 (2)	32 (4)	42 (9)
L2: English				
Mu	419 (8)	420 (13)	426 (5)	427 (12)
Sigma	45 (6)	46 (5)	48 (4)	52 (9)
Tau	38 (6)	37 (3)	36 (7)	39 (9)
	Lexical Decision Task			
	Word		Pseudoword	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
L1: Spanish				
Mu	477 (12)	468 (11)	762 (66)	772 (52)
Sigma	63 (11)	58 (9)	102 (23)	91 (12)
Tau	62 (10)	62 (19)	75 (9)	63 (12)
L2: English				
Mu	488 (9)	480 (6)	757 (66)	781 (47)
Sigma	68 (13)	64 (12)	107 (30)	123 (33)
Tau	74 (15)	72 (17)	68 (16)	69 (13)

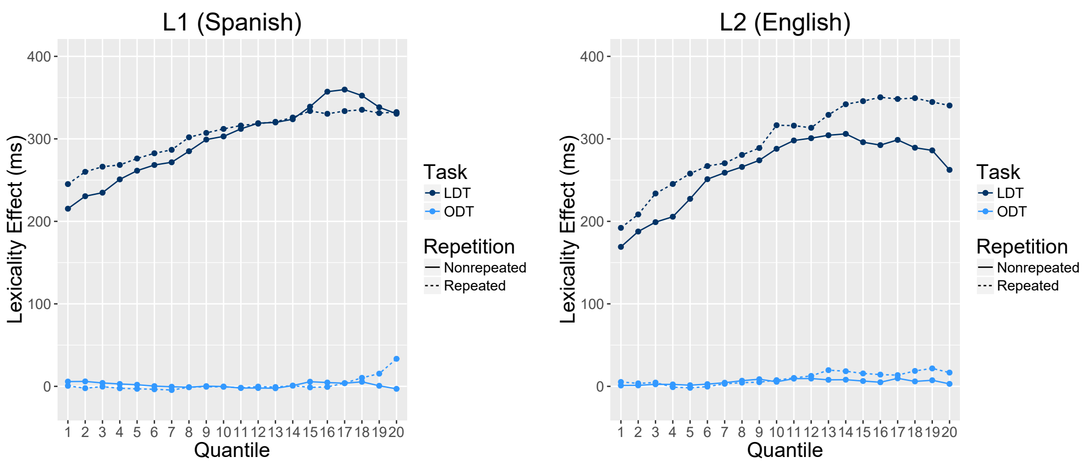

Figure 3.5 Quantile Distribution of the Lexicality Effect by Language, Task and Repetition

3.3. Discussion

Lexical access in the L1 (Spanish) and L2 (English) of bilinguals was investigated through the effects of frequency, lexicality, and repetition.

Moreover, the influence of the task demands was explored using an Onset Decision Task (ODT) that focused on the identification of the first letter of the visually presented letter string (vowel or consonant decision), and a Lexical Decision Task (LDT) focused on the word membership of the letter string (word/nonword decision).

The reaction time results revealed word frequency effects in the LDT but not in the ODT. Although previous literature has reported lexical access in tasks that do not require a lexical decision (e.g. Barron & Pittenger, 1974, Reicher, 1969, Wheeler, 1970), these results can be related to the different stages involved in the process of visual word recognition as proposed by previous models of word recognition (e.g. Interactive Activation Model, McClelland and Rumelhart, 1981) and the task demands (Umansky and Chambers, 1980). As in chapter 1, the effect of word frequency in the LDT, did not interact with language, indicating similar word frequency effects in L1 and L2. However, main effects of language and repetition were found. Overall, responses were slower to L2 words compared to L1 words. Also, responses were faster to repeated relative to nonrepeated words. The effect of lexicality interacted with the effect of language and task. Only the LDT showed an effect of lexicality that was larger in the L1 (264 ms) relative to the L2 (248 ms).

The analyses of word frequency in the accuracy of responses revealed a general effect of language where responses were more accurate to L1 compared to responses to L2. Additionally, fewer errors were observed in the ODT compared to the LDT. Finally, responses to high frequency words were more accurate than responses to low frequency words, while, the analyses of lexicality showed main effects of language and lexicality. Responses were faster to words and pseudowords in L1 compared to responses to words and pseudowords in L2. Also, quicker responses were made to words compared to pseudowords. Interestingly, a significant interaction between language and task was found, indicating that responses to words and pseudowords were faster when these stimuli were in L1 compared to L2 only in the LDT but not in the ODT.

The distributional analyses showed a word frequency effect only in the LDT (59 ms) but not in the ODT for Mu parameters. Interestingly, the sigma parameter also revealed a significant word frequency effect in LDT but not in ODT in L1 and L2. Furthermore, the effect was larger in L2 (39 ms) relative to L1 (22 ms), reflecting a more skewed RT distribution in the L2 compared to the L1. Tau showed the same interaction between task and frequency found in the Mu parameter, the effect was of 25 ms in the LDT but of 4 ms in the ODT.

The lexicality effect was only observed in LDT (290 ms) and no effect was found in the ODT for the Mu parameter. Sigma followed the same pattern, a 43 ms effect was found in the LDT and no effect was found in the ODT. In Tau, only an effect of language was found and this did not interact with any factors. Tau values were larger for L2 than for L1 indicating a longer tail of the distribution for L2 compared to L1.

Taken together, these findings indicate that the word frequency effect was similar in L1 and L2 reaction times, however, this effect was modulated by language in terms of the accuracy of responses. The present study similar to Duyck et al. (2008) employed a lexical decision task. In contrast to the results reported by Duyck et al. of a larger frequency effect in L2 (103ms) with that of L1 (46ms), the results of the present study (LDT) showed effect sizes in L1 (68ms) and L2 (90ms) that did not differ significantly. Duyck et al. compared bilingual results to those of monolingual participants and reported similar effect sizes in bilinguals' L1 (46ms) and monolingual (52ms) responses. Due to the incorporation of stimuli from the BLP, it is possible to predict the effect size of monolinguals for the stimulus set used in the present study. The effect of word frequency on reaction times, according to the BLP, would be 72ms in English monolinguals. The effect observed in bilinguals' L2 was of 90ms; however, this effect did not significantly differ from the effect in L1 (68ms), which in turn was similar to that predicted in monolinguals' L1 by the BLP (Figure 3.6). In accuracy, the BLP predicted a frequency effect on error rates of 8% in monolinguals. The observed effect in bilinguals' L2 was of 14%, twice as much as that predicted by the BLP for English monolinguals. Nevertheless, in bilinguals' L1, the word frequency effect on error rates was of 4%.

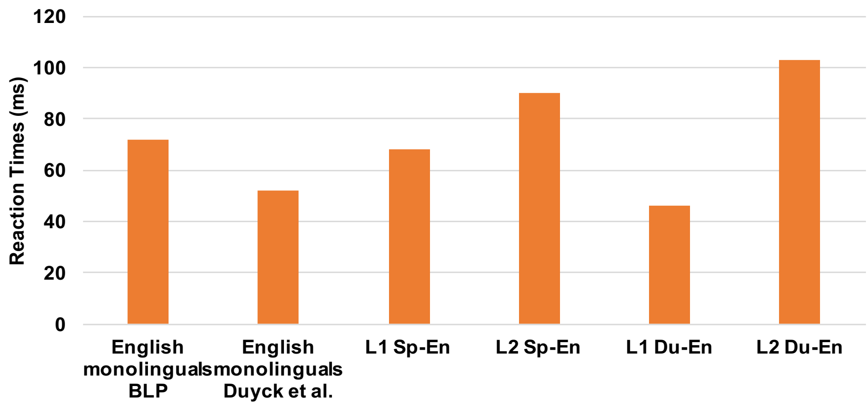

Figure 3.6 Word frequency effect in BLP, Spanish-English bilinguals (Sp-En, the present study), Dutch-English (Du-En) bilinguals and English monolinguals (Duyck et al., 2008)

Moreover, according to Diependaele et al. (2013), the vocabulary size and not the fact of being bilingual can influence the size of the word frequency effect, resulting in larger frequency effects for smaller vocabulary sizes. Bilinguals in Duyck et al.'s study were undergraduate participants, while in the present study, postgraduate students who had studied in England at the time of testing and actively used their L2 in everyday life were tested. In this respect, postgraduate students could have larger vocabulary sizes compared to undergraduate students. However, Duyck et al. (2008) did not report any measure of vocabulary size or language proficiency in their study.

Although in the present study language did not interact with task and frequency, the finding of main effects of this factor reflects the fact that bilinguals still have a dominant L1. In fact, the RT distribution analyses showed that the word frequency effect increases more at higher quantiles in L2 than it increases in the dominant language (L1). This was supported by the parameters of the exGaussian distribution with higher values of the sigma parameter for the L2 relative to the L1.

The lexicality effect was expressed by slower responses for L2 stimuli (~20 ms) compared to L1 stimuli, suggesting that participants are less able to identify L2 pseudowords. Compared to monolingual effects predicted by the BLP, the lexicality effect would be of 60 ms in reaction times and 3% in accuracy. Bilinguals in the present study showed an effect of lexicality on reaction times of 248 ms in reaction times to L2 items, which is twice as large as the effect predicted by the BLP. The accuracy of responses showed a lexicality effect of 42% for bilinguals' L2. Surprisingly, the lexicality effect in L1 was also larger compared to that predicted for monolinguals in reaction times (264ms) and error rate (31%).

Interestingly, the plot of the quantiles of the RT distribution (see Figure 3.5) shows different repetition effects for L1 and L2. In L1, the effect of repetition increases the lexicality effect at lower quantiles but decreases it at higher quantiles, whereas in L2, repetition increases the effect of lexicality across all the distribution.

The present findings support Diependaele's et al. (2013) proposal of lexical entrenchment since we observe similar sized effects of word frequency in L1 and L2 (90 ms vs 68 ms). Nevertheless, the main effect of language on reaction times supports the notion that the frequency of exposure could strengthen the representations in L1 compared to those in L2, therefore, showing slower responses to L2 relative to L1 and further supporting the hypothesis of different resting-level activation of the representations in L1 and L2 in late (or unbalanced) bilinguals by the BIA+ model. It seems that the overall speed of the responses might reflect these differences in resting-levels rather than the size of the word frequency effect.

Importantly, the word frequency and the lexicality effects behave in a different manner. While the analysis of the mean RTs did not show any interaction with language, frequency and task, the analysis of lexicality showed this interaction. The lexicality effect was larger in the less dominant but proficient language (L2). This effect might be due to the participants being less familiar with the vocabulary in the L2 that caused them to give slower responses to L2 pseudowords compared to pseudowords in L1. The overall accuracy score confirmed a lower performance in L2 relative to L1.

Crucially, the accuracy scores for pseudowords reflected a low performance for these items. In the L2, accuracy was 48%, and even in the L1 the accuracy for pseudowords was only 65%. An important question is why the accuracy for pseudowords was so poor relative to the words (L1 = 96%, L2 = 90%). A possible explanation is that the pure consonant or vowel letter strings included in the experiment impacted the decision strategy in the experiment (in particular the LDT). Potentially, participants failed to process the stimuli sufficiently to correctly distinguish words from pseudowords. As a consequence, error rates were high because participants simply made a decision between a letter string and a word or 'wordlike' stimulus rather than distinguishing between a word and a nonword. This change in decision criteria could have impacted the overall findings of the experiment. Therefore, the next chapter investigates the same paradigm only including English stimuli with English monolinguals, and tests whether the stimulus list composition (letter strings included in the list or not) might have an influence on the frequency, lexicality and repetition effects in the ODT and LDT tasks.

Chapter 4. Effects of Frequency, Lexicality and Repetition across tasks in English monolinguals

4.1. Introduction

The previous chapter investigated word frequency, lexicality and repetition effects in Spanish-English bilinguals in a task that focused on orthographic information (onset decision: vowel or consonant) and on lexical information (lexical decision: word or nonword). The effects of word frequency and lexicality were only found in the lexical decision task (LDT) but not in the onset decision task (ODT) for both L1 and L2. Also, word frequency did not interact with language (L1 and L2) in the speed of responses, while this interaction was observed in the accuracy of responses. Although, the plots of the RT distribution suggested that the effect of repetition might impact the lexicality effect in L1 and L2 differently, repetition effects were not observed in the analysis of reaction times, accuracy or mean values of the RT distribution.

Faster responses to L1 compared to L2 were observed in the LDT; this language effect interacted with task and frequency in the parameters of the RT distribution (sigma), indicating smaller frequency effects in the lower quantiles that increased at higher quantiles of the L2 distribution compared to L1, where the effect is similar across the distribution. These results indicated that language might determine the speed of responses more than the size of the word frequency effect, which can be interpreted as reflecting different activation resting-levels for L1 and L2. In the case of the effect of lexicality, more accurate responses were found in L1 compared to L2. The overall accuracy in nonrepeated L2 pseudowords (50%), which decreased in repeated items to 45%, was significantly less accurate than responses to nonrepeated and repeated L1 pseudowords. This high level of errors in L2 suggests that participants might have been guessing the correct answer when performing the LDT in the L2 due to the presence of stimuli that were easy to reject as a nonwords.

Although a decrease in accuracy for pseudowords was observed in repeated pseudowords, this effect of repetition did not interact with the effect of frequency, lexicality or language.

This chapter investigated whether the stimulus list composition influenced the effects of frequency, lexicality and repetition. In the previous chapter, it was suggested that the use of letter strings as part of the stimulus set had made bilinguals' performance in the LDT difficult. To investigate whether this low performance was specific to bilinguals, probably due to a lower proficiency in L2, in this chapter the performance of monolingual participants is explored only with the English items (bilinguals' L2). Additionally, no effect of repetition was found in bilinguals although the plots of the RT distribution showed different lexicality effects in repeated items of L2 compared to those in L1. Because of the lack of repetition effects in bilinguals' responses, investigating the effect of repetition in monolingual participants can help to clarify whether the lack of an effect was only observed in bilinguals, whether this effect is due to the fact that repetition was conducted across tasks with different task demands or whether the presence of letter strings in the stimulus list might have affected the decision strategy in the experiment causing a high error rate for pseudowords.

In monolingual visual word recognition, different effect sizes across tasks with diverse task criteria have suggested that task demands play an important role in lexical access. As it has been discussed in sections 1.1.1.2 and 1.1.1.4, the effect of word frequency varies with task. For example, Balota and Chumbley (1984) found the largest word frequency effect in the lexical decision task (100 ms), a smaller-sized effect in a pronunciation task (50 ms) and no effect in a category verification task (24 ms). These authors proposed that the word frequency effect was closely related to the lexical decision task and concluded that word frequency has different effects depending on the task used to assess lexical access.

Although the tasks compared in that study differed not only in the decision criteria but also in the task procedure and task stimuli, the observation of different sizes of word frequency effects according to the task has been also reported by Monsell, Doyle, and Haggard (1989). They found similar sizes of the word frequency effect when comparing a semantic categorisation (person or thing decision) and a lexical decision task. However, a smaller effect was observed in the comparison between a syntactic categorisation (noun or adjective decision) or naming tasks with the effect of the lexical decision task; this effect even disappeared in delayed naming conditions (a detailed description of this study can be found in section 1.1.1.2).

The lexicality effect has also been observed to vary in different tasks (as discussed in sections 1.1.1.1 and 1.1.1.4). In identification tasks, responses to real words are faster than responses to pseudowords, which in turn are also faster than responses to nonwords (nonpronounceable letter strings). However, the lexical decision task, responses are usually faster to nonwords and words but significantly slower to pseudowords. Therefore, the direction of the effects will vary according to the task decision or task demands.

The repeated exposure to the stimuli can reduce word frequency and lexicality effects (Balota & Spieler, 1999; Scarborough, Cortese & Scarborough, 1977). Although it has been proposed that written words elicit automatic recognition processes in the brain, it has also been suggested that these processes can be modulated in speed and quality according to the top-down intention of the individual to engage in a linguistic task (Chen, Davis, Pulvermüller and Hauk, 2015; Strijkers, Bertrand & Grainger, 2015).

The key question would be if lexical access could be found in tasks that require earlier stages of visual word recognition, such as a letter identification task. As mentioned in the Introduction to chapter 3, the word frequency effect has been found when the task requires the whole letter string identification rather than only the first letter of the string (Umansky and Chambers, 1980).

Models of visual word recognition have incorporated the notion of different levels of processing of letter strings. The Interactive Activation Model (IAM, McClelland & Rumelhart, 1981), as further described in section 1.1.3.1, includes: a visual feature level, a letter level and a word level. The model incorporates spatial parallel processing that also trigger the occurrence of processing at the same time. Based on the Interactive Activation Model, Grainger and Jacobs (1996) developed the Multiple Read-Out Model (MROM). According to this model, a lexical decision does not necessarily require (complete) identification of the word stimuli and therefore would involve the influence of intra- and extra-lexical sources of information in order to generate a binary lexical decision response ('yes' or 'no'). Intra-lexical sources of information in this model are the overall (global) activity in the orthographic lexicon and the (local) activity of functional units within the lexicon, to generate a 'yes' response. The extra-lexical source of information is the time from stimulus onset. These sources of information interact with each other to produce different response patterns in a lexical decision. According to this model, errors generated by making positive responses to pseudowords (false positive) are the result of either a short time criterion, or the generation of high local lexical activation in combination with a low global activation criterion. This would generate faster correct responses for words and a higher number of false positive errors for nonwords (for further discussion see section 1.1.3.2).

In experiment 3, English monolinguals performed the same tasks as bilinguals (ODT and LDT) with the English stimuli used in experiment 2 (Chapter 3). In the case that being bilingual was the reason for the high number of errors for English (bilinguals' L2) pseudowords, English monolinguals would have more accurate scores for these items. In chapter 3, stimuli from the BLP were used. The word effect observed by the BLP reaction times for English monolinguals was similar to the effect observed in bilinguals' L2 and L1, although the word frequency effect in accuracy was higher in bilinguals' L2 (14%) relative to the effect observed by the BLP (8%). Moreover, the observed effects of lexicality were very high (248ms, 42%) in comparison to those in the BLP for reaction times (60ms) and accuracy scores (3%).

In experiment 4, a different group of English monolinguals performed the same tasks as in experiment 3 (ODT and LDT). However, pure consonant or pure vowel letter strings were excluded from the stimulus list and pseudoword fillers were used instead. This experiment was conducted in order to investigate whether the stimulus set would explain a higher number of errors in bilingual participants. To further investigate the role of list composition, results from experiment 4 were contrasted with the results of experiment 3. According to the MROM (Grainger and Jacobs, 1996), the presentation of letter strings that are less similar to words (e.g. pure consonant or pure vowel letter strings) in a visual word recognition task would reduce the global lexical activity, which would facilitate responses to words and those letter strings. In contrast, a higher number of false positive responses would be predicted to pseudowords (see section 1.1.3.2 for a detailed description of the model). The exclusion of pure consonant or pure vowel letter strings and the inclusion of pseudoword fillers would increase the global lexical activity and responses to pseudowords would exhibit a lower number of false positive responses.

The repetition effect across tasks has been previously found in a number of studies in monolingual participants (see section 1.1.1.3). According to these studies it can be predicted that the effect of repetition interacts with word frequency and lexicality effects because the effect of frequency would decrease in repeated items and low frequency words would benefit more from repetition. The effect of lexicality, however, would increase with repetition, and the repetition effect for words would be positive facilitating responses to repeated words while for pseudowords the effect would be negative inhibiting responses to repeated pseudowords (e.g. Balota & Spieler, 1999, Perea et al., 2016). In the present study the analysis of the RT distribution was incorporated in order to explore how the different variables impact the shape of the response distribution and to determine whether these are in agreement with our predictions.

4.2. Experiment 3

4.2.1. Methods

4.2.1.1. Participants

Twenty-four English native speakers (8 males) were recruited from the student population at the University of Nottingham. They were between 17 and 35 years old (*M* = 22, *SD* = 4). All participants were right-handed (*M* = 0.9, *SD* = 0.19), as confirmed with an online version of the Edinburgh handedness questionnaire (Oldfield, 1971). Fluency in another language and language problems were considered as the exclusion criteria. The score in vocabulary size measures (LexTale, Lemhöfer & Broersma, 2012) above 80% was considered (*M* = 93%, *SD* = .06) as inclusion criteria. Participants rated their proficiency in English in speaking (*M* = 7, *SD* = .8), listening (*M* = 7, *SD* = .6), reading (*M* = 7, *SD* = .9) and writing (*M* = 6, *SD* = 1) on a scale of 1 (very poor) to 7 (very good) scale. Course credits or an inconvenience allowance were provided to participants.

4.2.1.2. Stimuli

The same stimuli in English and the pure consonant and pure vowel letter strings used in experiment 2, were employed in this experiment.

4.2.1.3. Design & Procedure

The design and procedure were the same as in experiment 2. Participants performed both tasks: ODT and LDT in only one session of approx. 45 min.

4.2.2. Results

Only the responses from the second ODT and LDT were analysed. Responses shorter than 300ms or longer than 1500ms were considered as outliers and excluded from the analyses (2.4%). Only correct responses (91.6%) were included in the analysis of reaction times (RT).

Mixed-effects modelling was conducted in the same way as in experiment 2.

4.2.2.1. Frequency, Task and Repetition

The reaction times and accuracy means are presented in **Table 4.1**.

Table 4.1 Mean and SE of Reaction Times and Accuracy

	Onset Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	488 (7.2)	480 (6.4)	474 (6.1)	490 (7.3)
Accuracy	0.95 (0.01)	0.96 (0.01)	0.94 (0.01)	0.93 (0.01)
	Lexical Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	459 (5.9)	452 (6)	512 (7.6)	489 (7.1)
Accuracy	0.97 (0.01)	0.97 (0.01)	0.87 (0.02)	0.91 (0.01)

The final model of RT included the main effects and the interactions between frequency, task and repetition (**Table 4.2**). Responses to high frequency words were faster than responses to low frequency words, $t = 7.68$, $p < .0001$. The effects of task, $t = 0.74$, $p = .4$, and repetition were not significant, $t = -1.47$, $p = .1$. However, a significant interaction between frequency and task was found (**Figure 4.1**) because a significant frequency effect of 45 ms was found in the LDT ($p < .0001$), whereas there was no frequency effect in the ODT (-2 ms, $p = 1$). Other interactions failed to reach significance, *t's* < 1; however, a trend for interaction was observed in the three-way interaction between frequency, task and repetition, $t = 1.768$, $p = .077$.

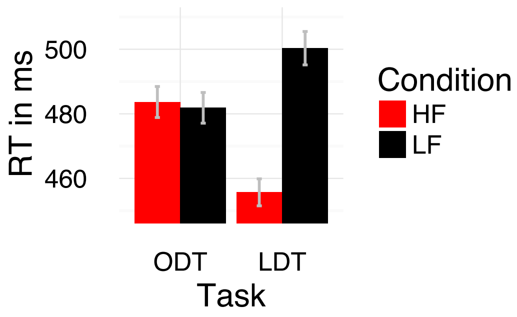

Figure 4.1 Frequency by Task Interaction in Reaction Times

Table 4.2 Final model of reaction times Frequency, Task and Repetition

	Estimate	SE	t-value
Fixed effects			
(Intercept)	-2.30347	0.09060	-25.424
Frequency	0.20462	0.02855	7.167
Task	0.09440	0.12794	0.738
Repetition	-0.03936	0.02681	-1.468
Frequency * Task	-0.23718	0.03857	-6.149
Frequency * Repetition	-0.04830	0.03869	-1.248
Task * Repetition	0.03295	0.03809	0.865
Frequency * Task * Repetition	0.09634	0.05448	1.768
	Variance	SD	
Random effects			
Item (Intercept)	0.0056720	0.07531	
Participant (Intercept)	0.0636778	0.25234	

The final model of accuracy (**Table 4.3**) included the main effects of frequency, task and repetition, as well as the interaction between frequency and task. Responses to high frequency words were significantly more accurate than responses to low frequency words, t = -5.94, $p < .0001$. However, no effects were found for task, t = -1.18, p = .2, or repetition, t = - 1.42, p = .1. Importantly, the interaction between frequency and task was significant, t = 3.41, $p < .001$ (**Figure 4.2**). Response to low frequency words had 8% more errors than responses to high frequency words in the LDT ($p < .0001$) but there was no difference in accuracy in the ODT (p = .3). In addition, the accuracy of responses to high frequency words was similar in the ODT and LDT task (1%, p = .5) whereas the accuracy of responses to low frequency words was 5% more accurate in the ODT than in the LDT ($p < .05$).

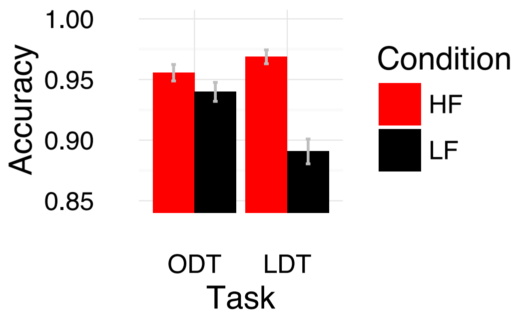

Figure 4.2 Frequency by Task Interaction in Accuracy

Table 4.3 Final model of accuracy Frequency, Task and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	3.5599	0.2522	14.115
Frequency	-0.3670	0.3101	-1.184
Task	-1.3726	0.2310	-5.943
Repetition	0.2007	0.1411	1.422
Frequency * task	1.0446	0.3061	3.412
	Variance	SD	
Random effects			
Item (intercept)	0.2880	0.5366	
Participant (intercept)	0.1928	0.4391	

4.2.2.2. Lexicality, Task and Repetition Effects

The reaction times and accuracy means are presented in **Table 4.4**

Table 4.4 Mean and SE of Reaction Times and Accuracy

	Onset Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	481 (4.7)	485 (4.8)	489 (6.8)	495 (7.4)
Accuracy	0.95 (0.01)	0.95 (0.01)	0.95 (0.01)	0.97 (0.01)
	Lexical Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	484 (4.8)	470 (4.6)	611 (10.7)	624 (11.7)
Accuracy	0.92 (0.01)	0.94 (0.01)	0.67 (0.02)	0.61 (0.02)

The final model of RT included Lexicality, Task, Repetition and the interaction between these factors (see **Table 4.5**). Responses to words were faster than responses to pseudowords, $t = -12.94$, $p < .0001$. Also, quicker responses were observed in the ODT compared to the LDT, $t = -2.99$, $p < .01$. No effect of repetition was found, $t < 1$. More importantly, the interaction between lexicality and task, $t = 8.981$, $p < .0001$, and the interaction between lexicality and repetition, $t = -2.44$, $p < .05$, were significant (see Table 6).

The interaction between lexicality and task was broken down by task. A lexicality effect of 140 ms was found in the LDT ($p < .0001$) but not in the ODT ($p = .09$). Likewise, responses to pseudowords were 125 ms faster in the ODT relative to the LDT ($p < .01$), whereas there was no difference in the responses to words between the ODT and LDT ($p = 1$).

The interaction between lexicality and repetition was broken down by repetition. A significant lexicality effect was found for repeated (57 ms, $p < .0001$) and nonrepeated (67 ms, $p < .0001$) items. Importantly, the effect of repetition was not significant for words (5 ms, $p = .2$) or nonwords (-6 ms, $p = .6$).

The interaction between task and repetition did not reach significance, $t = -0.46$, $p = .7$, but a trend was observed in the interaction between lexicality, task and repetition, $t = 1.96$, $p = .0506$. This trend was investigated by task. Separate models were conducted for ODT and LDT.

The final model for ODT only included the random factors indicating that none of the effects could explain the observed responses. However, the final model for LDT included lexicality, repetition and the interaction between these factors. A significant main effect of lexicality, $t = -13.187$, $p < .0001$, was found. The main effect of repetition was not significant, $t = 1.018$, $p = .309$. Nevertheless, the interaction between lexicality and repetition was significant, $t = -2.569$, $p = .010$, indicating that although the lexicality effect was significant for both repeated and nonrepeated items, this was larger for repeated items (154 ms, $p < .0001$) compared to nonrepeated ones (126ms, $p < .0001$).

Table 4.5 Final model of reaction times Lexicality, Task and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	-1.80156	0.09170	-19.646
Lexicality	-0.40226	0.03108	-12.941
Task	-0.38422	0.12870	-2.985
Repetition	0.03166	0.03299	0.960
Lexicality * task	0.36289	0.04041	8.981
Lexicality * repetition	-0.09303	0.03814	-2.439
Task * repetition	-0.01928	0.04233	-0.455
Lexicality * task * repetition	0.09813	0.05018	1.956
	Variance	SD	
Random effects			
Item (intercept)	0.01989	0.1410	
Task	0.03047	0.1745	
Participant (intercept)	0.1745	0.3042	

The final model for accuracy included the factors: lexicality, task, repetition and the interaction between task and lexicality (see Table 4.6).

Responses to words had fewer errors than responses to pseudowords, $z = 4.132$, $p < .0001$. Also, more accurate responses were observed in ODT compared to LDT, $z = 5.286$, $p < .0001$. However, responses to repeated and nonrepeated items did not differ significantly, $z = -0.08$, $p = .9$. Importantly, the interaction between lexicality and task was significant, $z = -10.71$, $p < .0001$, (**Figure 4.3**) because the effect of lexicality was 29% in the LDT ($p < .0001$) and there was no effect of lexicality in the ODT ($p = .4$). Responses to nonwords were 31% more accurate in the ODT than in the LDT ($p < .0001$), while responses to words were only 2% more accurate in the ODT than in the LDT ($p = .3$).

Figure 4.3 Interaction Lexicality by Task in Accuracy

Table 4.6 Final model of accuracy Lexicality, Task and Repetition

	Estimate	SE	z-value
Fixed effects			
(Intercept)	2.1965	0.2520	8.714
Lexicality	0.6563	0.1588	4.132
Task	2.0233	0.3828	5.286
Task * Lexicality	-0.8157	0.2747	-2.968
	Variance	SD	
Random effects			
Item (Intercept)	0.6596	0.8121	
Participant (Intercept)	0.5510	0.7423	

I. RT distribution analysis

Only the responses for the second tasks (LDT and ODT) were incorporated in this analysis. Responses shorter than 250 ms or longer than 3000 ms (.12 % of the data) and incorrect responses (8.4%) were excluded from the analysis. The analysis of the RT distribution was conducted in the same way as reported in experiment 2.

I.I. Frequency, Task and Repetition

Task (ODT and LDT) was a between-subjects factors, and frequency (high and low) and repetition (nonrepeated and repeated) were within subjects factors.

Mu: The main effect of frequency was significant, F (1, 4) = 8.585, p = .042, the values of this parameter were 17 ms larger for low frequency words compared to high frequency words. No significant effect of either task or repetition (F's < 1) was found. Importantly, a significant interaction between task and frequency was observed, F (1, 4) = 9.318, p = .038. Paired t-tests revealed that the effect of word frequency was significant in the LDT (-34 ms), t (5) = -5.068, p = .004, whereas the effect in ODT (.7 ms) was not significant, t < 1. Other interactions failed to reach significance (F's < 1).

Sigma: A significant main effect of frequency, F (1, 4) = 11.273, p = .028, showed that the values for this parameter were smaller (6 ms) for high frequency words relative to low frequency words. Sigma values were also smaller (5 ms) for nonrepeated words compared to repeated ones as revealed by a main effect of repetition, F (1, 4) = 8.173, p = .046. Importantly, again a significant interaction between task and frequency was observed, F (1, 4) = 11.766, p = .027. Further comparisons with paired t-tests indicated that the effect of frequency in the values of the parameter sigma was significant only in the LDT (-12 ms), t (5) = -3.509, p = .017, and not in the ODT (.1 ms), t < 1. No significant effect of task or other interactions was found (F's < 1).

Tau: The main effects of task, frequency and repetition failed to reach significance, as well as the interaction between these factors (F's < 1).

The group parameter estimates [3] are shown in **Table 4.7**.

Table 4.7 Means of Parameter Estimates from the ex-Gaussian analysis of Frequency, Task and Repetition for super subjects

	Onset Decision Task			
	High frequency		Low frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	427 (13)	421 (5)	421 (18)	426 (12)
Sigma	53 (5)	58 (9)	49 (12)	62 (8)
Tau	42 (10)	54 (25)	43 (6)	46 (9)
	Lexical Decision Task			
	High frequency		Low frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	412 (7)	409 (11)	454 (12)	434 (6)
Sigma	41 (4)	46 (6)	57 (4)	54 (4)
Tau	32 (5)	28 (2)	38 (2)	41 (7)

[3] The vincentiles for the whole group without dividing by super subjects do not deviate more than 2 ms from the ones reported in **Table 4.7**.

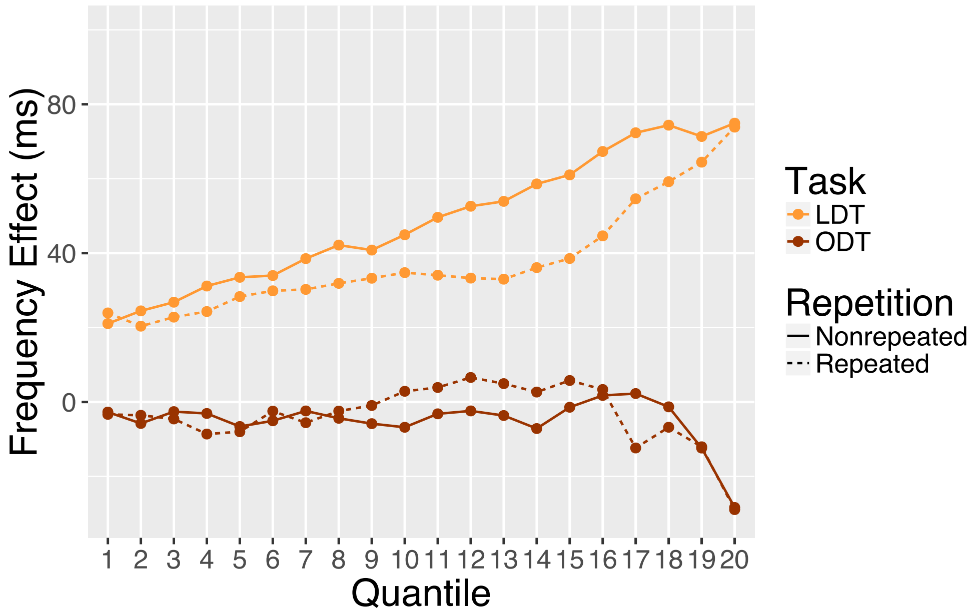

Figure 4.4 RT Distribution of the Frequency Effect by Quantile

I.II. Lexicality, Task and Repetition

Mu: Main effects of task, F (1, 4) = 16.325, p = .016 and lexicality, F (1, 4) = 151.567, p = .0003, but not of repetition, F < 1, were found. The values of this parameter were larger (49 ms) in the LDT relative to the ODT. Mu values were also 61 ms larger for pseudowords compared to words. A significant interaction between task and lexicality was observed, F (1, 4) = 114.994, p = .0004. Further analyses showed that the effect of lexicality was of 114 ms, t (5) = 16.985, p < .0001, in the LDT. This effect was only of 8 ms in the ODT, t (5) = 1.204, p < .283. Mu values for words were not affected by task (4 ms), t (5) = 0.633, p = .555, whereas, Mu values for pseudowords were larger in the LDT relative to ODT (-102 ms), t (5) = -7.405, p < .001. There was no main effect of repetition (F < 1) and other interactions failed to reach significance, p's > .107).

Sigma: A main effect of lexicality was observed, F (1, 4) = 11.411, p = .028, indicating that sigma values were 16 ms larger for pseudowords relative to words. No effect of task or repetition was found, F's < 1. Again, the interaction between task and lexicality was significant, F (1, 4) = 14.324, p = .019. Similar to the values of mu, the values of the sigma parameter showed a significant effect of lexicality only in the LDT (35 ms), *t* (5) = 5.27, *p* = .003, and not in the ODT (-2 ms), *t* (5) = -.798, *p* = .461. The effect of task was significant for pseudowords (-29 ms), *t* (5) = -3.773, *p* = .013; however, the effect was no significant for words (8 ms), *t* (5) = 2.061, *p* = .094. Other interactions failed to reach significance, *F's* < 1.

Tau: The main effect of lexicality was significant, *F* (1, 4) = 9.986, *p* = .034. Tau values were larger for pseudowords than for words (10 ms). The effect of task and repetition, as well as the interactions between task, lexicality and repetition were not significant, *F's* < 1.

The group parameter estimates[4] are shown in **Table 4.8**.

Table 4.8 Means of Parameter Estimates from the ex-Gaussian analysis of Lexicality, Task and Repetition for super subjects

	Onset Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	430 (11)	423 (2)	435 (13)	433 (16)
Sigma	56 (6)	60 (8)	55 (8)	57 (12)
Tau	36 (12)	50 (17)	41 (12)	51 (15)
	Lexical Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	427 (7)	417 (6)	528 (5)	542 (9)
Sigma	51 (4)	50 (4)	81 (9)	89 (5)
Tau	39 (4)	38 (6)	56 (3)	56 (8)

[4] The vincentiles for the whole group without dividing by super subjects showed very similar results, the parameters do not deviate more than 2 ms from the ones reported in **Table 4.8**.

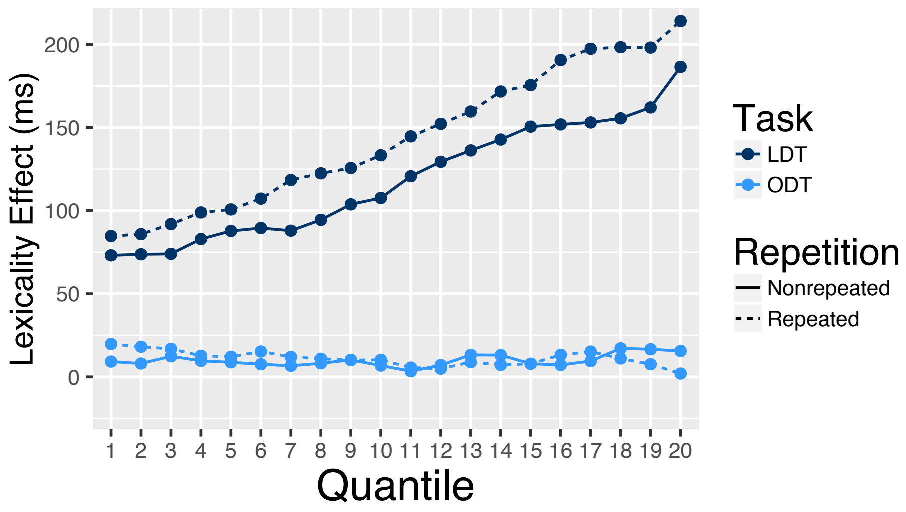

Figure 4.5 RT Distribution of the Lexicality Effect by Quantile

4.2.3. Discussion

Experiment 3 was conducted to investigate the effects of frequency, lexicality and repetition in monolingual participants performing an ODT and an LDT. This experiment used the same stimuli and paradigm used in rxperiment 2 with Spanish-English bilinguals. This experiment explored whether a high number of errors and a lack of the effect of repetition will be found for English monolinguals, as it was the case for bilinguals.

The results of experiment 3 replicated with English monolinguals the English findings reported in chapter 3 for English (L2) in bilinguals. The effect of word frequency was only found in the LDT but not in the ODT. In the LDT, the effect of word frequency was 30 ms smaller than that observed by the BLP for English monolinguals (experiment 3: 45 ms vs. BLP: 72 ms). Nevertheless, the frequency effect in the LDT was similar (8%) to the one observed by the BLP (8%). Importantly, no effect of repetition was observed in the frequency analysis in experiment 3, although a trend towards significance was observed in the interaction between word frequency, task and repetition (p = .0771).

Lexicality effects were also found exclusively in the LDT and not in the ODT. The size of the lexicality effect on reaction times was larger (140ms) than the effect observed by the BLP (60ms). The significant interaction between lexicality and task also revealed that responses to pseudowords were 125 ms slower in LDT compared to the ODT, however, no difference between tasks was observed for words. The lexicality effect on accuracy scores was only significant in the LDT (29% vs. 3% in BLP) but there was no effect in the ODT. Importantly, responses to pseudowords were 31% more accurate in the ODT compared to the LDT, while, responses to words only differed by 2% between tasks.

RT distribution analyses revealed an interaction between task and frequency in the mu and sigma parameters, and further tests revealed similar patterns to those observed in the analyses of reaction times and accuracy: a frequency effect in the LDT but not in the ODT. No word frequency effects were found in tau. The quantiles plot show that the effect of word frequency increases in the later quantiles during the lexical decision task, while it increases and becomes negative in the later quantiles for the onset decision task.

The lexicality effect interacted with task in mu and sigma parameters of the RT distribution, the effect of lexicality was only observed in the LDT but not in the ODT. Responses to pseudowords significantly differed between tasks but responses for words did not show any significant difference. The parameter tau showed a main effect of lexicality: values were larger for pseudowords relative to words. The distribution plot of the lexicality effect showed that this effect increases in the later quantiles for the LDT but it remains nonsignificant in the ODT across quantiles.

The smaller word frequency effects and the larger lexicality effects observed in this experiment compared to those predicted by the BLP could be indicators of low local lexical activity and high global threshold according to MROM. Thus, the number of false positives would be higher and probably similar to the results observed in a bilingual population. In fact, the results from this experiment with monolinguals showed a high error percentage in the identification of pseudowords (around 20% within the stimuli category). However, this error rate was not as high as the one observed in bilinguals' responses (around 50%). The high error rates in experiments 3 and 2 were probably due to the presence of letter strings in the stimuli. Therefore, a subsequent experiment was conducted in which the pure consonant and vowel letter strings were removed. Furthermore, pseudoword fillers were included in the experiment to facilitate participants word and nonword identification without the confound of 'easy to reject' nonwords compared to pseudowords. In the case that the list composition has an impact on the global activation level of the word recognition system, the inclusion of pseudowords will increase global lexical activation of representations and decrease the global threshold of activation, reducing the error rate for pseudoword target stimuli. Therefore, the effect of lexicality will be also reduced.

4.3. Experiment 4

4.3.1. Methods

4.3.1.1. Participants

Twenty-four English native speakers (6 males) took part in this experiment. Participants were recruited from the student population at the University of Nottingham and were between 18 and 33 years old (M = 23, SD = 4). Inclusion criteria into the study involved being right handed according to an online version of the Edinburgh handedness questionnaire (Oldfield, 1971), as well as a score above 80% in vocabulary size measures (LexTale, Lemhöfer & Broersma, 2012), M = 94%, SD = .07. Participants were also asked to rate their proficiency in English in speaking (M = 7, SD = .2), listening (M = 7, SD = 0), reading (M = 7, SD = .4) and writing (M = 7, SD = .7) in a scale from 0 to 7. Fluency in another language and language problems were considered as the exclusion criteria. By taking part, individuals were entered into a monetary prize draw.

4.3.1.2. Stimuli

The word stimuli were the same as the one used in experiment 3. Pseudowords from experiment 3 that had less than 85% of accuracy (*n* = 40) in the BLP (Keuleers et al., 2012) were replaced by pseudowords with accuracy above 85% in the BLP. Additionally, pseudoword fillers were included instead of pure consonant and vowel letter strings. These pseudoword fillers were also selected from the BLP with accuracy above 90%. The final stimulus set consisted of 480 letter strings of 4 to 6 letters where 240 items were words (120 of high and 120 of low frequency) and 240 were pseudowords (120 were target stimuli and 120 were fillers). Stimuli were controlled for frequency, length and number of high frequency neighbours within the same language, for a summary see **Table 4.9**. Items were also divided into three equivalent lists (A, B, C), each of them consisted of 80 words (HF and LF) and 80 pseudo-words (target and fillers). One half of the stimuli in each list started with a vowel while the other half started with a consonant letter.

Table 4.9 Summary of lexical characteristics of the stimuli

Condition	Frequency (Zipf values)	Neighborhood Density	Orthographic Levenshtein's Distance (OLD 20)	Length
Pseudoword	NA	0.4 (0.7)	2.3 (0.4)	5.3 (0.7)
Low frequency	3.2 (0.4)	0.5 (1.0)	2.3 (0.5)	5.3 (0.7)
High frequency	4.7 (0.4)	0.7 (1.1)	2.2 (0.4)	5.3 (0.7)

4.3.1.3. Design & Procedure

The design and procedure was the same as that employed in experiment 3.

4.3.2. Results

The responses from the first tasks (ODT or LDT) were not considered in this analysis. Only the responses from the second ODT and LDT were included. Responses shorter than 300ms or longer than 1500ms were considered as outliers and excluded from the analyses (1.2%). Only correct responses were included in the analysis of reaction times (RT, 93.5%).

Mixed-effects modelling was conducted in a similar way as in experiment 3.

4.3.2.1. Mixed-effects modelling

I. Frequency, Task and Repetition

The reaction times and accuracy means are presented in **Table 4.10**

Table 4.10 Mean and SE of Reaction Times and Accuracy

	Onset Decision Task			
	High frequency		Low frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction Times	514 (7)	497 (6)	494 (6.3)	505 (6)
Accuracy	0.97 (0.01)	0.97 (0.01)	0.98 (0.01)	0.97 (0.01)
	Lexical Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction Times	546 (6.8)	532 (6.9)	621 (9)	607 (9.8)
Accuracy	0.95 (0.01)	0.98 (0.01)	0.84 (0.02)	0.87 (0.02)

The final model of RT included the main effects and the interactions between frequency, task and repetition (Table 4.11). Significant main effects of frequency and repetition were found. Responses to high frequency words were faster than responses to low frequency words, t = 7.35, $p < .0001$. Likewise, quicker responses were made for repeated compared to nonrepeated words, t = - 2.08, $p < .01$. Additionally, the interaction between frequency and task was significant, t = - 7.09, $p < .0001$. Crucially, the trend observed in Experiment 3 was found as a significant interaction between frequency, task and repetition, t = 2.29, $p < .05$ in experiment 4. In order to explore this interaction, the responses from each task were analysed separately (**Figure 4.6**).

The ODT final model included the factors frequency and repetition and the interaction between them. Significant main effects of frequency and repetition, as well as a significant interaction between frequency and repetition were found. Across tasks, responses to high frequency words were faster in comparison to low frequency words, $t = -2.46$, $p < .01$. Also, responses to repeated words were faster than to nonrepeated ones, $t = -2.92$, $p < .01$. Importantly, there was an interaction between frequency and repetition. This interaction was due to a reversed effect of frequency for nonrepeated words (20 ms, $p < .05$): responses to high frequency words were slower than responses to low frequency words, whereas there was no effect of word frequency on repeated words (9 ms, $p = .4$). Furthermore, the repetition effect was significant for high frequency words (17 ms, $p < .01$) but not for low frequency words (-11 ms, $p = .6$).

The LDT final model included the factors frequency, repetition and the interaction between frequency and repetition. Responses to high frequency words were faster than responses to low frequency words (75ms), $t = 6.68$, $p < .0001$. Likewise, quicker responses were made to repeated words compared to nonrepeated ones (14 ms), $t = -2.28$, $p < .05$. The interaction between frequency and repetition was not significant, $t = -0.19$, $p = .85$.

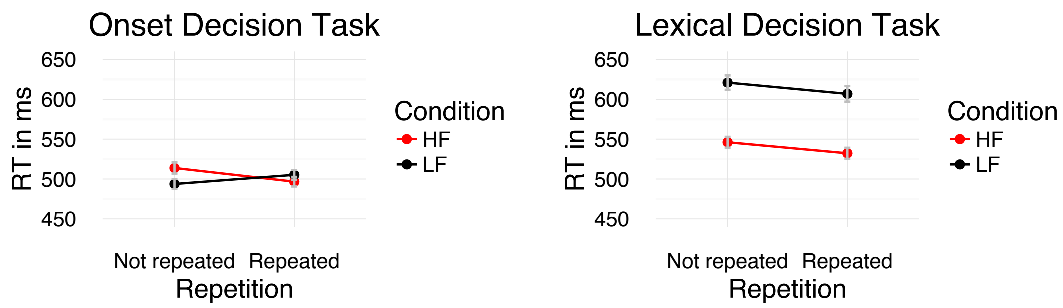

Figure 4.6 Interaction Frequency by Task by Repetition in Reaction Times

Table 4.11 Final model of reaction times Frequency, Task and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	-1.942	0.07518	-25.826
Frequency	0.2062	0.02805	7.351
Task	-0.1141	0.1064	-1.073
Repetition	-0.0505	0.02425	-2.080
Frequency * task	-0.2785	0.03928	-7.090
Frequency * repetition	-0.0071	0.03549	-0.200
Task * repetition	-0.2663	0.03449	-0.772
Frequency * task * repetition	0.1130	0.04935	2.290
	Variance	SD	
Random effects			
Item (intercept)	0.0056720	0.07531	
Task	0.0099977	0.09999	
Participant (intercept)	0.0636778	0.25234	
Frequency	0.0006336	0.02517	

The final model for accuracy scores included the main factors of frequency, task and repetition, as well as the interaction between frequency and task (**Table 4.12**). The results revealed a significant main effect of frequency, $z = -7.3$, $p < .0001$, but not of task, $z = -0.4$, $p = .7$, or repetition, $z = 1.6$, $p = .1$. Again, a significant interaction between task and frequency was found, $z = 5.65$, $p < .0001$ (**Figure 4.7**). Further analyses indicated that responses to high frequency words were more accurate than responses to low frequency words in the LDT (11%, $p < .0001$) but not in the ODT (1%, $p = .7$). Additionally, the accuracy to low frequency words was 12% higher in the LDT than in the ODT ($p < .0001$), whereas there was no difference in accuracy for the high frequency words in either the LDT or ODT ($p = 1$).

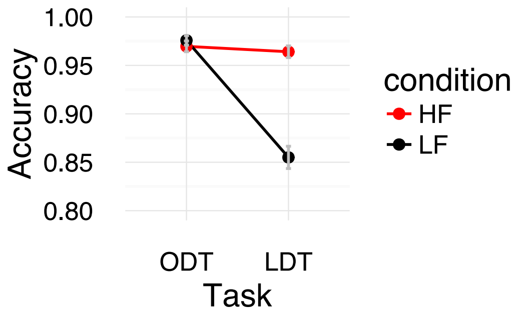

Figure 4.7 Interaction Frequency by Task in Accuracy

Table 4.12 Final model of accuracy Frequency, Task and Repetition

	Estimate	SE	z-value
Fixed effects			
(intercept)	3.9900	0.3584	11.133
Frequency	-1.7833	0.2446	-7.289
Task	-0.1713	0.4637	-0.369
Repetition	0.2480	0.1562	1.588
Task * frequency	2.0536	0.3636	5.649
	Variance	SD	
Random effects			
Item (intercept)	0.6305	0.7941	
Participant (intercept)	0.7910	0.8894	

II. Lexicality, Task and Repetition Effects

The reaction times and accuracy means are presented in **Table 4.13**

Table 4.13 Mean and SE of Reaction Times and Accuracy

	Onset Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	504 (4.7)	501 (4.2)	496 (6.3)	503 (5.7)
Accuracy	0.97 (0.01)	0.97 (0.01)	0.98 (0.01)	0.97 (0.01)
	Lexical Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	581 (5.7)	567 (6)	672 (10.2)	693 (10.4)
Accuracy	0.90 (0.01)	0.92 (0.01)	0.87 (0.02)	0.83 (0.02)

The final model of RT included lexicality, task, repetition and the interaction between these factors (**Table 4.14**). Responses to words were faster than responses to nonwords, $t = -6.32$, $p < .0001$. Also, responses in the ODT were faster than responses in the LDT, t = -5.1, $p < .0001$. There was no main effect of Repetition. More importantly, the interactions between lexicality and task, t = 4.98, $p < .0001$, and between lexicality and repetition, t = -2.93, $p < .01$, were significant (**Figure 4.8**). The interaction between task and repetition, t = -0.58, p = .6 or between lexicality, task and repetition, t = 1.2, p = .2, failed to reach significance.

A breakdown of the interaction between lexicality and task revealed that the effect of lexicality was only significant in the LDT (108 ms, $p < .0001$) and not in the ODT (-3 ms, p = 1). A breakdown of the interaction between lexicality and repetition showed that the effect of repetition was only significant for words (11 ms, $p < .05$) but not for nonwords (-5 ms, p = .3).

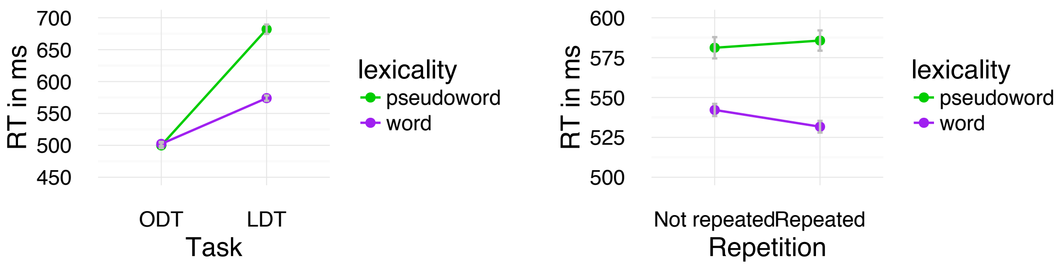

Figure 4.8 Interactions Lexicality by Task and Lexicality by Repetition in Reaction Times

Table 4.14 Final model of reaction times Lexicality, Task and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	-1.62028	0.06843	-23.676
Lexicality	-0.22406	0.03547	-6.318
Task	-0.49162	0.09642	-5.099
Repetition	0.03880	0.02815	1.378
Lexicality * task	0.24443	0.04913	4.975
Lexicality * repetition	-0.09235	0.03156	-2.926
Task * repetition	-0.02267	0.03878	-0.584
Lexicality * task * repetition	0.05211	0.04353	1.197
	Variance	SD	
Random effects			
Item (intercept)	0.011450	0.10701	
Task	0.016150	0.12708	
Participant (intercept)	0.051022	0.22588	
Lexicality	0.007427	0.08618	
Repetition	0.001306	0.03614	

The final model for accuracy included lexicality, task and the interaction between task and lexicality (Table 4.15). Responses to words were more accurate than responses to nonwords, z = 4.13, p < .0001. Also, responses in the ODT contained fewer errors relative to responses in LDT, z = 5.29, p < .0001. Crucially, the interaction between task and lexicality was significant, z = -2.97, p < .01 (**Figure 4.9**). The effect of lexicality was significant in the LDT (5%, p < .0001) but not in the ODT (-0.4%, p = 1). Furthermore, responses to nonwords were 12% (p < .0001) more accurate in the ODT compared to the LDT (task effect) but responses to words were only 6% (p > .001) more accurate in the ODT relative to the LDT.

Figure 4.9 Interaction Lexicality by Task in Accuracy

Table 4.15 Final model of accuracy Lexicality, Task and Repetition

	Estimate	SE	z-value
Fixed effects			
(Intercept)	2.1965	0.2520	8.714
Lexicality	0.6563	0.1588	4.132
Task	2.0233	0.3828	5.286
Task * Lexicality	-0.8157	0.2747	-2.968
	Variance	SD	
Random effects			
Item (Intercept)	0.6596	0.8121	
Participant (Intercept)	0.5510	0.7423	

4.3.2.2. RT distribution analysis

The RT distribution analysis was conducted in a similar manner as in experiment 3. Responses shorter than 250 ms or longer than 3000 ms (.09 % of the data) and incorrect responses (6.5%) were excluded from the analysis.

I. Frequency, Task and Repetition

The results from the 2x2 ANOVAs included Task (ODT vs. LDT) as a between-subjects factors, as well as Lexicality (word vs. pseudoword) and repetition (nonrepeated vs. repeated) as within subjects factors. The means of the parameter estimates are shown in **Table 4.16**.

Mu: Significant main effects of task, F (1, 4) = 7.864, p = .049, frequency, F (1, 4) = 32.942, p = .005, and repetition, F (1, 4) = 10.24, p = .033, were found. Mu values were 57 ms larger in the LDT compared to the ODT. Also, these parameter values were larger (23 ms) for low frequency words relative to high frequency ones. Finally, repeated words showed smaller mu values (15 ms) than nonrepeated words. Importantly, only the interaction between task and frequency was significant, F (1, 4) = 37.753, p = .004, indicating that the frequency effect was significant only for the LDT (-47ms), t (5) = -8.418, p < .001, and not for the ODT (2ms), t (5) = .267, p = .8. Other interactions failed to reach significance, *F's* < 1.

Sigma: The main effect of frequency was significant (12ms), F (1, 4) = 21.404, p = .010. As expected, the interaction between task and frequency was significant, F (1, 4) = 13.357, p = .022, because the frequency effect was significant in the LDT (-21ms), t (5) = -5.762, p = .002, and not in the ODT (-3 ms), t (5) = -.563, p = .598. The effects of task, repetition and other interactions failed to reach significance, *F's* < 1.

Tau: Similar to the results of Sigma, the effect of frequency (10ms), F (1, 4) = 9.115, p = .039, and the interaction between task and frequency, F (1, 4) = 14.702, p = .019, were significant. However, further analyses by task showed no frequency effect on the tau value in ODT, t < 1, but a significant frequency effect in LDT, t (5) = -6.038, p = .002. No other effects of task, repetition or interactions reached significance, *F's* < 1.

Table 4.16 Means of Parameter Estimates from the ex-Gaussian analysis of Frequency, Task and Repetition for super subjects

	Onset Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	456 (1)	440 (10)	450 (12)	442 (6)
Sigma	56 (4)	49 (3)	55 (5)	56 (0)
Tau	47 (11)	41 (5)	35 (4)	47 (5)
	Lexical Decision Task			
	High Frequency		Low Frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	488 (21)	471 (18)	538 (21)	516 (21)
Sigma	46 (5)	54 (10)	72 (11)	69 (11)
Tau	40 (12)	53 (23)	66 (7)	73 (28)

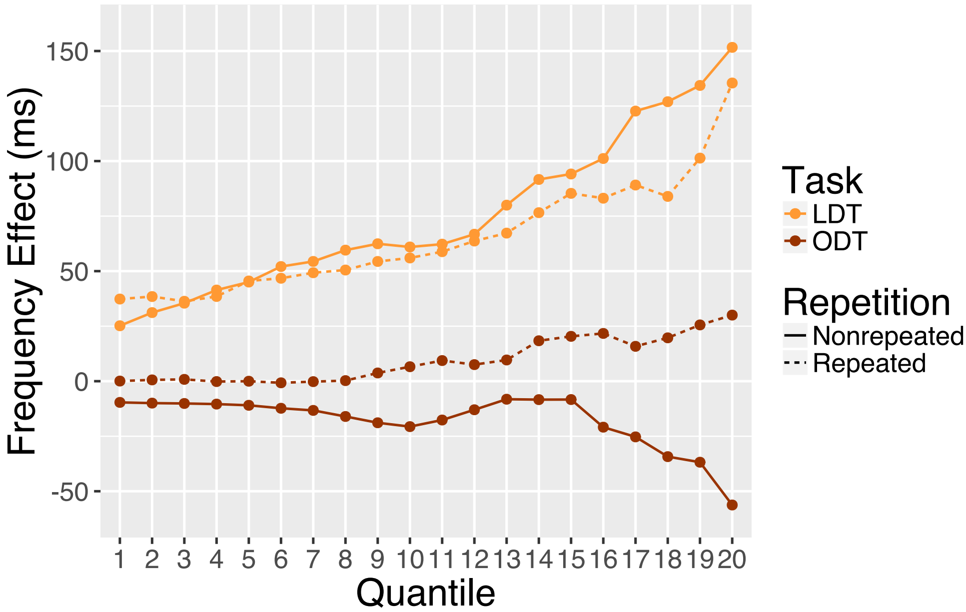

Figure 4.10 RT Distribution of the Frequency Effect by Quantile

II. Lexicality,Task and Repetition

Means of the parameter estimates are shown in Table 4.17.

Mu: The values of the mu parameter were 98 ms larger in the LDT relative to the ODT, F (1, 4) = 17.014, p = .015. Also, these values were 45 ms larger for pseudowords compared to words, F (1, 4) = 60.107, p = .002. Repetition did not have any significant effect, F < 1. Importantly, a significant interaction between task and lexicality was found, F (1, 4) = 70.55, p = .001. Pairedsamples t-tests revealed that the effect of Lexicality was significant in the LDT (94 ms), t (5) = 10.4, p = .0001, and not in the ODT (-4 ms), t (5) = -.648, p = .546. Other interactions failed to reach significance, F's < 1.

Sigma: The values of sigma were larger for pseudowords relative to words (6 ms), F (1, 4) = 17.132, p = .014. No significant main effects of task or repetition were found, F's < 1. However, the interaction between task and lexicality was again significant, F (1, 4) = 48.362, p = .002. Further comparisons revealed a trend of a reversed lexicality effect in the ODT (-4 ms), t (5) = -2.155, p = .083, whereas a significant lexicality effect was found in the LDT (17 ms), t (5) = -2.579, p = .049. No other interactions were significant F's < 1; lexicality and repetition, F (1, 4) = 1.510, p = .286.

Tau: No significant effects of task, lexicality, repetition or the interaction between these factors was found, F's < 1.

Table 4.17 Means of Parameter Estimates from the ex-Gaussian analysis of Lexicality, Task and Repetition for super subjects

	Onset Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	452 (8)	441 (8)	440 (8)	445 (6)
Sigma	56 (2)	53 (2)	50 (2)	50 (1)
Tau	41 (6)	45 (4)	47 (12)	45 (4)
	Lexical Decision Task			
	Words		Pseudowords	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	501 (21)	489 (18)	590 (31)	589 (30)
Sigma	60 (9)	65 (10)	83 (17)	75 (3)
Tau	61 (11)	64 (27)	78 (25)	97 (36)

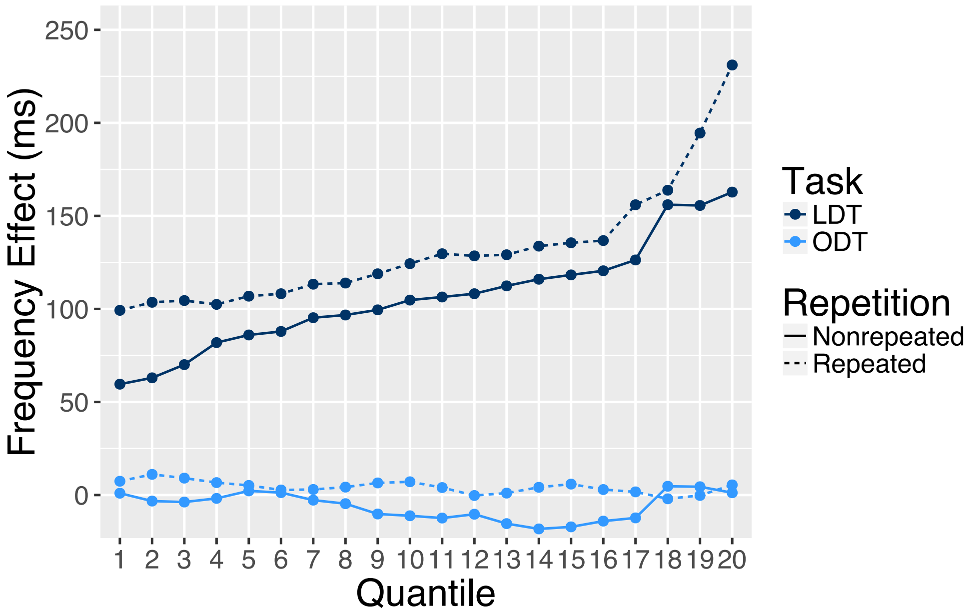

Figure 4.11 RT Distribution of the Lexicality Effect by Quantile

4.3.3. Discussion

Similar to experiment 3, a word frequency effect was only found in LDT and not in the ODT in the analysis of mean reaction times and the RT distribution. However, in contrast to experiment 3, an interaction between task, frequency and repetition was observed in mean reaction times. Further analyses by task revealed that nonrepeated words in the ODT actually showed a reversed frequency effect (responses to high frequency words were slower than responses to low frequency words) that was not found in the repeated words. Moreover, the effect of repetition was only significant for high frequency words (17ms) but no effect was observed for the low frequency words. In the LDT, a main effect of frequency (75ms) and a main effect of repetition (14ms) was found and these factors did not interact.

The word frequency effect in this experiment was similar to that predicted by the BLP (75 vs. 72 ms). The exclusion of the letter strings might have influenced the size of the word frequency effect that was of 45ms in experiment 3 when the stimulus list included the pure consonant and pure vowel letter strings, therefore suggesting that the list composition play an important role in determining the size of the word frequency effect.

Regarding the accuracy of responses, no effect of word frequency was observed in ODT; however, an effect of 11% was observed in the LDT and was similar to that predicted in the BLP (8%). An analysis per frequency revealed that only low frequency words showed slower responses in the LDT relative to the ODT, whereas the high frequency words did not show any difference in the accuracy between the two tasks.

The plot of the RT distribution showed a higher increase of the word frequency effect in the later quantiles during the LDT and a smaller negative increase during the ODT.

The effect of lexicality was similar to the one observed in experiment 3, no lexicality effect was found in the ODT but it was in the LDT (108ms). The size of the lexicality effect was smaller than the one observed in experiment 3 (140ms) but still larger than what was predicted based on the BLP (60ms). A repetition effect was also observed for words (11ms) but not for pseudowords (lexicality by repetition interaction). Interestingly, the effect of lexicality increased in repeated items (15ms).

Additionally, more accurate responses were given to words than pseudowords only in the LDT (5% similar to the 3% predicted by BLP) but no significant difference was observed in the ODT. Pseudoword responses were 12% more accurate in the ODT compared to the LDT, whereas word responses were only 6% more accurate in the ODT relative to the LDT.

The effect of lexicality showed a similar pattern of results in mu and sigma; however, the effect of task was significant for both pseudowords and words in mu but only for pseudowords in sigma, and no effects were found in tau. The RT quantile plot of the lexicality effect confirms these results.

The implications of these findings will be further discussed in the General Discussion section.

4.4. General Discussion

The present chapter investigated the influence of list composition on the effects of frequency, lexicality and repetition. Based on previous findings from experiment 2 with bilinguals, experiment 3 investigated whether a high error rate for pseudowords and a lack of repetition effects were due to bilingualism, task demands or list composition (the presence of pure consonant or pure vowel letter strings) using the same stimuli (only stimuli in English) and paradigm with English monolinguals. Experiment 4 further investigated low performance to pseudowords by replacing letter strings with pseudoword fillers in the stimulus set, and therefore allowing the comparison between experiment 3 and 4 regarding the size of the different lexical effects.

In experiment 3, word frequency and lexicality effects were only found in LDT but not in ODT in reaction times, accuracy and RT distribution analyses. In the LDT, the word frequency effect was smaller than the one predicted by the BLP in reaction times but similar in accuracy. An increase of the effect of word frequency was found in higher quantiles of the RT distribution. However, no effect of repetition was observed in the frequency analysis. The effect of lexicality was larger in size to that predicted by the BLP in reaction times and accuracy. A main effect of lexicality was observed in tau, larger tau values were found for pseudowords compared to words, and the effect of lexicality increases in higher quantiles.

The data of experiment 4 revealed word frequency effects in reaction times and accuracy that were similar to those observed in the BLP, which suggests that list composition plays a role in the word frequency effect, therefore influencing lexical access. The effect of word frequency increased in the higher quantiles of the distribution for LDT only. The effect of lexicality was reduced in this experiment compared to experiment 3 but was still larger than the one predicted by the BLP on reaction times. Importantly, a repetition effect for words, as well as an increase in the lexicality effect in repeated items was found on reaction times. The lack of an effect of lexicality in accuracy was similar to that predicted by the BLP. Pseudowords showed a task effect on the sigma value of the RT distribution.

The overall results revealed a modulation of the effects of word frequency, lexicality and repetition by task demands. Whereas the effects were observed in a task that requires a lexical decision, there was no effect of those variables when the individuals performed an onset decision task, even though the only change was made in the stimulus list by replacing the filler stimuli.

The tendency towards interaction between frequency, task and repetition observed in the experiment 3, became significant by excluding the pure consonant and pure vowel letter strings from the stimuli in experiment 4. Thus, the effect of repetition was directly affected by the list composition.

Moreover, the effect of word frequency interacted with task and repetition. In the ODT a reversed pattern of the usual word frequency effect was observed in nonrepeated items and no effect was observed in the repeated ones. However, in the case of LDT, main effects of frequency and repetition were found.

Furthermore, when the letter strings were excluded from the stimulus list, the size of the word frequency effect in the LDT increased from 45 ms to 75 ms. Interestingly, this latter size is similar to what was predicted by the BLP.

Also, the accuracy of responses for pseudoword target stimuli increased, and the lexicality effect in accuracy became similar to that predicted by the BLP.

The different findings between experiment 3 and experiment 4 indicate that stimulus list composition plays an important role in determining the impact on word frequency, lexicality and repetition. The presence or absence of letter strings as part of the stimulus list in these two experiments varied the threshold of the global lexical activity as proposed by the MROM (Grainger and Jacobs, 1996). As expected by the model, the inclusion of letter strings that are less similar to words had an impact on the reaction times and the accuracy of responses by facilitating responses to words but increasing the number of false positive errors to pseudowords. In fact, more false positive responses to pseudowords were given in experiment 3 (accuracy: 64%) relative to experiment 4 (accuracy: 85%). Moreover, the inclusion of more 'wordlike' stimuli generated a significant change in the tail of the RT distribution (tau) for word frequency, which is in line with the increase in the size of the effect on reaction times in experiment 4. This tau parameter might reflect the increased global lexical activity in experiment 4 compared to experiment 3. However, further studies should be conducted to confirm these hypotheses.

In summary, lexical access as reflected by the effect of word frequency and lexicality is modulated by task and list composition. In the ODT the decision based on the orthographic level did not require any lexical access and so no effects of word frequency and lexicality were observed. Moreover, these effects are also influenced by the global activation of the lexicon that can be manipulated by the list composition within an experiment. Finally, the mu and sigma parameters of the RT distribution could be reflecting local activation of the lexicon while the tau parameter might reflect global activation of the lexicon.

An effect of repetition was found when items were repeated across tasks in experiment 4. These findings are consistent with the data reported by Monsell (1985). It was expected that the effect of word frequency would interact with that of repetition in the LDT. The results of experiment 4 revealed, however, main effects of frequency and repetition only, replicating the findings observed in experiment 3 (Chapter 2). In the following chapter we will further investigate the impact of repetition on word frequency and lexicality effects by repeating items across blocks that involve the same LDT task.

Chapter 5. Repetition Effects in Lexical Decisions: the Role of List Composition

5.1. Introduction

In the previous chapter, the effects of word frequency, lexicality and repetition were investigated in monolingual participants using an onset decision (ODT) and a lexical decision task (LDT). The word frequency and lexicality effects were only found in LDT. Interestingly, repetition effects for words were found in LDT only when the pure consonant and pure vowel letter strings were excluded from the stimulus list. However, no repetition effect was found for pseudowords although the lexicality effect increased with repetition. In that Chapter, items were repeated across tasks so that half of the items previously seen in the first task (either ODT or LDT) were also presented in the second task (LDT or ODT). It has been previously proposed that when pseudowords are repeated in a task other than the lexical decision task, no effects are found (Duchek & Neely, 1989; Feustel, Shiffrin & Salasoo, 1983; McKoon & Ratcliff, 1979), suggesting repetition effects occur mainly in the LDT.

The present chapter explores whether repeated exposure to words impacts the word processing system so that words encountered more often are recognised faster than word encountered rarely. As discussed in section 1.1.1.2, the word frequency effect reflects the difference between words that have a high level compared to words that have lower level of exposure. How exactly this repeated exposure impacts the visual word recognition system is still not entirely clear. For example, repeated exposure to letter strings that are not part of the mental lexicon (e.g., pseudowords) has a different impact than letter strings that exist in the mental lexicon (words) because they do not contain any meaning, and therefore these pseudowords are not able to access the lexicon.

The effects of frequency and repetition as manifestations of the same phenomenon induced experimentally or naturally were suggested by Morton (1969). The interactive activation model (McClelland and Rumelhart (1981) is able to explain the effect of repetition by an activation level that slowly returns towards its resting level after the unit is accessed. Therefore, predicting larger repetition effects for low frequency words compared to high frequency words. The level of activations also predicts the effect of word frequency in this model.

As pointed out in section 1.1.1.2, word frequency is the strongest predictor of the speed of visual word recognition (Scarborough, Cortese, & Scarborough, 1977; Balota et al., 2007; Brysbaert et al., 2011). The frequency of exposure can also be manipulated within an experiment through stimuli repetition. Balota and Chumbley (1984) suggested that familiarity and lexicality effects are on the same dimension when evaluating stimuli in the lexical decision task. This dimension, defined by the "wordiness" or similarity of a letter string with a word, requires a global assessment of the item's familiarity or meaningfulness and would result in a faster identification of words and nonwords. However, for low frequency or less familiar words this categorisation would take more time.

According to this hypothesis of a familiarity/meaningfulness dimension, letter strings that are less similar to real words are quickly discarded (Balota & Chumbley, 1984). Interestingly, Stanners and Forbach (1973) found that letter strings with a structure similar to that of words (e.g. consonant-consonant-vowel-consonant-consonant) took more time to be discarded than pure consonant letter strings. Therefore, pronounceability of nonwords affects responses to these items so that pronounceable nonwords are responded to more slowly than nonpronounceable nonwords (Scarborough, Cortese & Scarborough, 1977, Balota & Spieler, 1999, Perea et al., 2016).

In the lexical decision task, responses to low frequency words can be as fast as those of pronounceable nonwords (Balota and Chumbley, 1984). The question would be whether it is possible to repeat a nonword such that it becomes more familiar and become part of the lexicon. The repetition of a letter string potentially increases its familiarity within the experimental task; it would therefore be relevant to explore the mechanisms behind slower response times of repeated pseudowords (pronounceable letter strings). Pseudowords are not familiar to individuals who have not been exposed to these items before. Furthermore, pseudowords do not have meaning and therefore these items are not part of the mental lexicon. This means they require different processing mechanisms that result in longer recognition times when they are more similar to words and less time when they are less similar to words, as explained by the MROM model (see section 1.1.3.2).

Forbach, Stanners and Hochhaus (1974) found that responses became faster across blocks for repeated words but slower for repeated pseudowords (first vs. second presentations). Practice effects were identified in the first presentation of the items across presentation blocks (faster mean latencies as the block number increased) for pseudowords but not for words. They argued that in the case of words a previously activated representation would show faster activation in subsequent presentations. Because pseudowords do not have a representation in memory, there would be no repetition effects for these items but practice effects would occur in an additional corroboration in the mental lexicon that is different from stimuli encoding.

In order to provide more evidence regarding the stage at which the repetition effect for words and pseudowords/nonwords occur, Scarborough, Cortese and Scarborough (1977) investigated the impact of repetition on frequency and lexicality effects in lexical decision. In their first lexical decision task (experiment 1), overall findings revealed faster responses for repeated words and nonwords relative to non-repeated items (first presentation). They observed an effect of repetition that was larger for low-frequency words than for high frequency words. In their second lexical decision task (experiment 2) word frequency and pseudoword pronounceability were manipulated. Consistent with the first lexical decision task, a significant interaction was found between frequency and repetition, and between repetition and pronounceability. It was concluded that these three factors: frequency, repetition and pronounceability would occur at a common stage during encoding of the stimuli in word processing. Some limitations on the experimental design of this study are discussed in section 1.1.1.3.

Further studies improved upon the experimental design from Scarborough, Cortese and Scarborough, (1977) by repeating the items across blocks, allowing more time between repetitions and dissociating it from the practice effects (e.g. Balota & Spieler, 1999; Perea et al., 2016).

Balota and Spieler (1999) investigated the effect of repetition on word frequency and lexicality effects by analysing the RT distributions in a blocked design. They found different results for words and nonwords in a lexical decision task that followed from a rhyme judgment task. Faster reaction times were observed for repeated compared to nonrepeated words and this repetition effect was larger for low frequency words than for high frequency words. The reaction time distribution analysis revealed that word frequency shifted the distribution and increased the tail of the distribution. Moreover, only the estimates of tau showed an interaction between word frequency and repetition; this interaction was driven by the low frequency words. In contrast, the data of the nonwords revealed slower responses to repeated nonwords relative to norepeated ones. Repetition effects of nonwords in the RT distribution were found in the estimates of mu and tau. A limitation of this study, as pointed out by Perea et al (2016), was the use of a rhyming task followed by a lexical decision task, which might have created associations between nonwords and words, increasing the familiarity/wordness of nonwords, and therefore the repetition effects. These results suggested the existence of different processes underlying words and nonwords repetition effects.

This repetition effect of words (facilitatory) and nonwords (inhibitory) was further investigated by Wagenmakers et al. (2004). In a block design, they manipulated the deadline to make a lexical decision across three experiments. The comparison between the first and the second presentation in the first experiment revealed a facilitatory repetition effect for nonwords and words, which was stronger for low frequency words. The facilitative repetition effect for nonwords disappeared in their second (short deadline) and third experiments (short and systematically increased deadlines) but was still found for words in both experiments. The authors explained that, under the condition of what they referred to as extreme speed-stress, where a short time is allowed to give a response within an experimental task, the contribution of a facilitatory episodic process is reduced but an inhibitory repetition priming effect is enhanced by increasing the participant's reliance on familiarity.

More recently, Perea et al. (2016) examined the dissociative effects of repetition for words and nonwords to test the predictions of "familiarity/wordness" in the context of the diffusion model (Ratcliff et al., 2004; see section 1.1.3.3 for a detailed description). Perea et al.'s study consisted of a lexical decision task with two blocks. The first block incorporated high frequency words and nonwords. The second block contained half of the items presented in the first block (repeated items) and new items (non-repeated). Similar to previous literature (Balota and Spieler, 1999), the results revealed that responses to repeated words were faster and responses to repeated nonwords were slower than responses to non-repeated items. This study also explored the impact of repetition on the reaction time distributions. The RT distribution analysis revealed that responses in lower quantiles showed facilitation for repeated items, while responses in higher quantiles exhibited an inhibition for repeated items. The authors concluded that the dissociative repetition effect for words and nonwords depended on the degree of wordness of the strings (as defined in the diffusion model), and further supported the notion of dissociation between encoding and discriminability in the decision process.

Gordon et al. (2013) also used a block design; however, they investigated novel memory representations over time (from encoding to test phase in memory tasks) to determine whether excluding the interference from the intervening stimuli would help to investigate the effect of list context in the nonword repetition effect. The inclusion of items that have not been presented before might affect the encoding of the previously seen stimuli by modifying the resting level values of these items (according to the interactive activation account, McClelland & Rumelhart, 1981).

In fact, the "Leaky Competing Accumulator Model of Lexical Decision (LCA)" model (Dufau, Grainger & Ziegler, 2012) has emphasised the importance of the list composition. This model described in section 1.1.3.4 proposed trial-by-trial adjustments of response criteria that are adjusted as a function of response accuracy. This constant adjustment of response criteria could potentially explain both the facilitatory and the inhibitory repetition effect when only the stimulus list context differs because the accumulation of the evidence towards a word would be supported by the stimulus list presented within the task (list composition).

The present study attempts to further investigate the repetition effect on words and pseudowords in a blocked design within a lexical decision task, considering the analysis of the RT distribution and including words of high and low frequency to further explore the interaction between word frequency and repetition.

In two experiments, words and pronounceable nonwords were presented. Experiment 5, similar to that of Perea et al. (2016), incorporated two blocks of lexical decision tasks. Half of the items presented in the first block were repeated during the second block along with the presentation of non-previously seen items. In this experiment, the list composition is varied in the second block by including the non-previously seen items. Due to a very similar design to that used by Perea et al., it is possible to compare the present results to Perea et al.'s by comparing high frequency words with pseudowords. Overall the effect of lexicality was explored through three different comparisons: words (high and low frequency) and pseudowords; high frequency words and pseudowords (same as Perea et al.); and low frequency words and pseudowords.

Furthermore, experiment 6 was conducted to compare the role of list composition when the stimulus list is not varied. This experiment involved four blocks of lexical decision task where the same item list was presented in each block. The present study extended on Perea et al. (2016) findings by incorporating an additional experiment to investigate the role of list composition on the repetition effect. We hypothesise that the effect of word frequency effect will be reduced through repetition (e.g. Balota and Spieler, 1999, Perea et al., 2016). Thus, the effect of word frequency will be larger for nonrepeated words than for repeated words. Low frequency words are expected to show a larger effect of repetition than high frequency words through a significant interaction between frequency and repetition. The effect of lexicality would also be modulated by repetition such that the effect would be larger for repeated items and positive for words while negative for pseudowords. These effects will be expressed in a significant interaction between lexicality and repetition. Specifically, a larger decrease in the reaction times of responses to repeated low frequency words would be observed in contrast to the decrease in the responses to repeated high frequency words. Repetition is expected to slow down response times to pseudowords but facilitate responses to words.

In addition, the RT distribution will also reveal an interaction between the effect of word frequency and the effect of repetition in the mean of the distribution, indicating that the effect of repetition was driven by low-frequency words (Balota and Spieler, 1999). The effect of repetition will also interact with the effect of lexicality. According to Perea et al. (2016), this interaction will result in an inhibitory effect in higher quantiles of the distribution but facilitatory effects in the lower quantiles.

5.2. Experiment 5

5.2.1. Methods

5.2.1.1. Participants

Twenty-four English native speakers (three males) from 18 to 24 years old (*M* = 19, *SD* = 1.3) were recruited from the University of Nottingham student population. Participants were right-handed and reported not having fluency in another language or any language reading disorder. For their participation, participants received course credits.

5.2.1.2. Stimuli

The stimuli were similar to that used in experiment 4. The only difference is that this experiment only included pseudowords with an accuracy of more than 90%. The stimuli were controlled for frequency, length (mean = 5.3, *SD* = 0.7), number of high frequency neighbours (mean = 0.7, *SD* = 1.1), and orthographic Levenshtein's Distance (OLD20) (mean = 2.3, *SD* = 0.4). For a summary of the controlled characteristics see Table 5.1.

Table 5.1 Stimuli Characteristics

Condition	Frequency (Zipf values)	Neighborhood Density	Orthographic Levenshtein Distance (OLD 20)	Length
High frequency	4.65 (0.42)	0.65 (1.10)	2.22 (0.42)	5.31 (0.70)
Low frequency	3.24 (0.43)	0.50 (1.0)	2.30 (0.45)	5.32 (0.71)
Pseudowords	NA	0.38 (0.76)	2.31 (0.42)	5.27 (0.74)
Pseudoword fillers	NA	0.32 (0.72)	2.37 (0.44)	5.26 (0.74)

5.2.1.3. Design & Procedure

Same as experiment 4, except that in this Experiment the repetition was between blocks of the LDT instead of across tasks (ODT and LDT).

5.2.2. Results

5.2.2.1. Mixed effects modelling

Only the second lexical decision task was analysed. Responses shorter than 300 ms or longer than 1500 ms (1.6 % of the data) as well as incorrect responses (11%) were excluded from the RT analysis.

Mixed-effects modelling was conducted in the same way as in experiment 4.

I. Frequency and Repetition

Mean reaction times, accuracy scores and standard errors are presented in Table 5.2.

Table 5.2 Mean and SE of Reaction Times and Accuracy

	High frequency		Low frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	527 (5.4)	509 (4.3)	606 (7.3)	571 (6.3)
Accuracy	0.93 (.01)	0.95 (.01)	0.74 (.01)	0.83 (.01)

The final model for reaction times included the main effects of frequency, repetition and the interaction between these factors (see Table 5.3)[5]. The results revealed that responses to high frequency words were significantly faster than responses to low frequency words (70 ms), t = 11.5, $p < .0001$. Furthermore, responses to repeated words were significantly faster than to non-repeated words (24 ms), t = - 2.4, $p < .05$. Importantly, the interaction between frequency and repetition was significant, t = -2.4, $p < .05$. The effect of frequency was similar for nonrepeated (79 ms, $p < .0001$), and repeated words (62 ms, $p < .0001$). The repetition effect for low frequency words was larger (35 ms, $p < .0001$) than for high frequency words (18 ms, $p < .05$) (Figure 5.1).

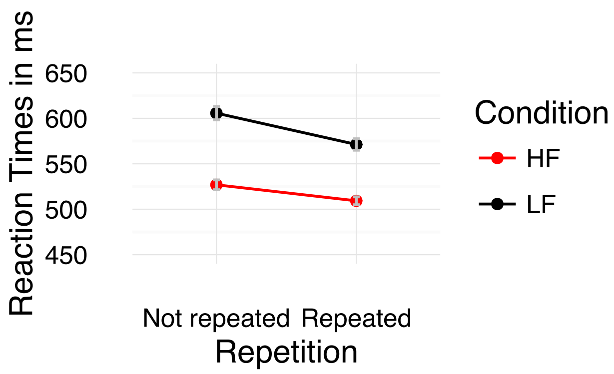

Figure 5.1 Word Frequency by Repetition Interaction in Reaction Times

[5] A model including trial number and previous RT find similar results and main effects of trial number and previous RT.

Table 5.3 Final model of reaction times Frequency and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	-2.02699	0.05571	- 36.385
Frequency	0.25443	0.02207	11.526
Repetition	- 0.04131	0.01703	- 2.426
Frequency * repetition	- 0.06076	0.02535	- 2.397
	Variance	SD	
Random effects			
Item (intercept)	0.008874	0.0942	
Participant (intercept)	0.069140	0.2629	

The final model for accuracy scores only included frequency and repetition (see Table 5.4). The results revealed significant fewer errors for high frequency words than for low frequency words, $z = -8.66$, $p < .0001$. Furthermore, responses to repeated words were significantly more accurate than responses to nonrepeated words, $z = 5.61$, $p < .0001$.

Table 5.4 Final model of accuracy Frequency and Repetition

	Estimate	SE	z-value
Fixed effects			
(intercept)	3.0793	0.2304	13.365
Frequency	-1.7680	0.2041	-8.663
Repetition	0.6089	0.1086	5.607
	Variance	SD	
Random effects			
Item (intercept)	0.94376	0.9715	
Participant (intercept)	0.57459	0.7580	
Frequency	0.07834	0.2799	

II. Lexicality and Repetition

Mean reaction times, accuracy scores, and standard errors for words and pseudowords are reported in Table 5.

Table 5.5 Mean and SE of Reaction Times and Accuracy

	Word		Pseudoword	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Reaction times	562 (4.5)	538 (3.8)	600 (6.1)	617 (6.2)
Accuracy	0.83 (0.1)	0.89 (0.1)	0.91 (0.1)	0.87 (0.1)

The final model for reaction times included lexicality, repetition and the interaction between lexicality and repetition (see Table 5.6)[6]. Results indicated main effects of lexicality, t = -3.5, p < .001, and repetition, t = 2.57, p < .01. More important, the interaction between lexicality and repetition was significant, t = -5.49, p < .0001. Post-hoc analyses showed that the lexicality effect of nonrepeated items was smaller (38 ms, p < .0001) than of repeated items (79 ms, p < .0001). Importantly, the repetition effect was positive (24 ms) for words (p < .0001) and negative (-17 ms) for pseudowords (p < .01).

Table 5.6 Final model of reaction times Lexicality and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	-1.78147	0.06337	-28.111
Lexicality	-0.12282	0.03511	-3.499
Repetition	0.04625	0.01797	2.574
Lexicality * repetition	-0.11376	0.02071	-5.493
	Variance	SD	
Random effects			
Item (intercept)	0.0167160	0.12929	
Participant (intercept)	0.0897188	0.29953	
Lexicality	0.0193786	0.13921	
Repetition	0.0009504	0.03083	

The final model for accuracy included lexicality, repetition and the interaction between lexicality and repetition (Table 5.7). There were significantly more accurate responses to words compared to pseudowords (86% vs. 89%), z = -3.5, p < .0001. Furthermore, responses to repeated items led to significantly more errors relative to responses to nonrepeated items (1%), z = -3.002, p <

6 A model with trial number and previous RT find similar results except for the main effect of trial number and previous RT.

.001. Similar to the model of reaction times, the interaction between lexicality and repetition was significant, $z = 5.7$, $p < .0001$. The effect of repetition showed fewer errors for repeated words (6%, $p < .0001$), and more errors for repeated pseudowords (4%, $p < .001$). Moreover, the lexicality effect was significant for nonrepeated items (8%, $p < .0001$) but not for repeated items (2%, $p = .9$) (Figure 5.2).

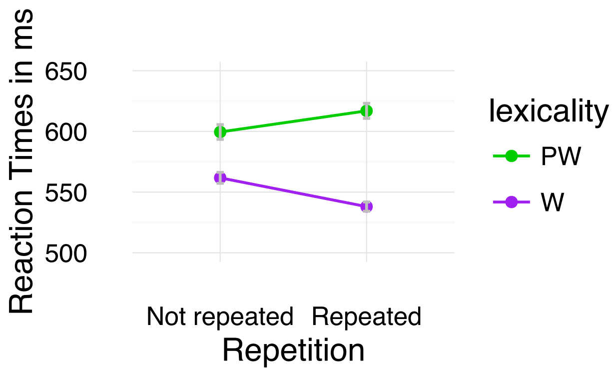

Figure 5.2 Lexicality by Repetition Interaction in Reaction Times

Table 5.7 Final model of accuracy Lexicality and Repetition

	Estimate	SE	z-value
Fixed effects			
(intercept)	2.9616	0.2629	11.263
Lexicality	-0.8846	0.2538	-3.486
Repetition	-0.4633	0.1543	-3.002
Lexicality * repetition	1.0558	0.1855	5.693
	Variance	SD	
Random effects			
Item (intercept)	1.2238	1.1062	
Participant (intercept)	0.9737	0.9868	
Lexicality	0.6297	0.7935	

To directly compare our results to those of Perea et al. (2016), the effect of lexicality was investigated with separate mixed-effects models for high and low frequency words compared to pseudowords.

High frequency words: the final model included lexicality, repetition and the interaction between lexicality and repetition. Significant main effects of lexicality, $t = -7.2$, $p < .0001$, and repetition, $t = 2.5$, $p = .016$, were found. Similar to the analysis of all words (HF and LF), the interaction between lexicality and repetition was significant, t = -3.8, p = .0002. Further analyses revealed again that the effect of repetition was positive for high frequency words (18 ms, p = .021) but negative for pseudowords (-17 ms, p = .013). This indicates that responses were faster for repeated high frequency words, whereas, responses for repeated pseudowords were slower relative to nonrepeated items. Furthermore, the lexicality effect was significant for nonrepeated (73 ms, $p < .0001$) and this effect was larger for repeated items (108 ms, $p < .0001$) (Figure 5.3).

Low frequency words: the final model included lexicality, repetition and the interaction between these variables. A significant main effect of repetition was observed, t = -2.8, p = .006, but no effect of lexicality, $t < 1$, p = .764. Similar to the results of the high frequency words, the interaction between lexicality and repetition was significant, t = -6.3, $p < .0001$. Further comparisons showed a similar pattern to the one observed for high frequency words: the effect was positive for low frequency words and larger than that observed for high frequency words (35 ms, $p < .0001$), while the effect of repetition was negative for pseudowords (-17 ms, p = .006). Interestingly, the effect of lexicality was not significant for nonrepeated items (-6 ms, p = .762) but it was significant for repeated items (46 ms, p = .0003) (Figure 5.4).

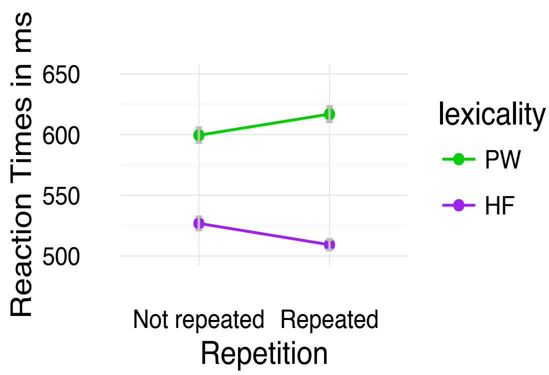

Figure 5.3 Lexicality (high frequency words vs. pseudowords) by Repetition Interaction in Reaction Times

Figure 5.4 Lexicality (low frequency words vs. pseudowords) by Repetition Interaction in Reaction Times

5.2.2.2. RT distribution analysis

The analysis of the reaction times distribution incorporated only the responses of the second lexical decision task. Responses shorter than 250 ms or longer than 3000 ms (.07 % of the data) and incorrect responses (11%) were excluded from the analysis. Similar to Balota & Spieler (1999), the data were divided into a set of 20 quantiles for each participant. Vincent averages for every four subjects (six super subjects) were calculated based on the quantiles per participant because the fit of the ex-Gaussian distribution requires approximately 100 observations per condition (Ratcliff, 1979; Vincent, 1912). The parameters of the ex-Gaussian distribution (mu, sigma, tau) were calculated for each super subject and condition (frequency: high and low; repetition: nonrepeated and repeated) with the R package ‘retimes’ (function *mexgauss)*. The 2x2 ANOVAs were calculated for each of the parameters of the RT distribution with the data of the super subjects.

I. Frequency, Task and Repetition

The group parameter estimates[7] are presented in Table 5.8. The frequency effect across quantiles of the RT distribution are shown in Figure 5.5. The

[7] The vincentiles for the whole group without dividing by super subjects do not deviate more than 2 ms from the ones reported in Table 5.8.

ANOVA included frequency (high vs. low) and repetition (nonrepeated vs. repeated) for the parameters mu, sigma and tau (dependent variables) are presented below.

Mu: significant effects of frequency and repetition were found. The mu parameter was larger (51 ms) for low frequency words than for high frequency words, F (1, 5) = 73.409, p = .0004. Repeated words also had smaller mu values (19 ms) than nonrepeated words, F (1, 5) = 8.747, p = .031. The interaction between frequency and repetition was not significant, $F < 1$.

Sigma: sigma was significantly larger for low frequency words compared to high frequency words (18 ms), F (1, 5) = 13.521, p = .014, and for nonrepeated words compared to repeated ones (14 ms), F (1, 5) = 10.719, p = .022. No interaction between these factors was found, $F < 1$.

Tau: no effects were observed of frequency, F (1, 5) = 4.465, p = .088, repetition, F (1, 5) = 2.527, p = .173, and their interaction, $F < 1$.

Table 5.8 Means of Parameter Estimates from the ex-Gaussian analysis for super subjects

	High frequency		Low frequency	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	467 (14)	459 (9)	529 (16)	499 (11)
Sigma	61 (8)	48 (4)	79 (9)	65 (7)
Tau	51 (12)	39 (6)	69 (12)	61 (12)

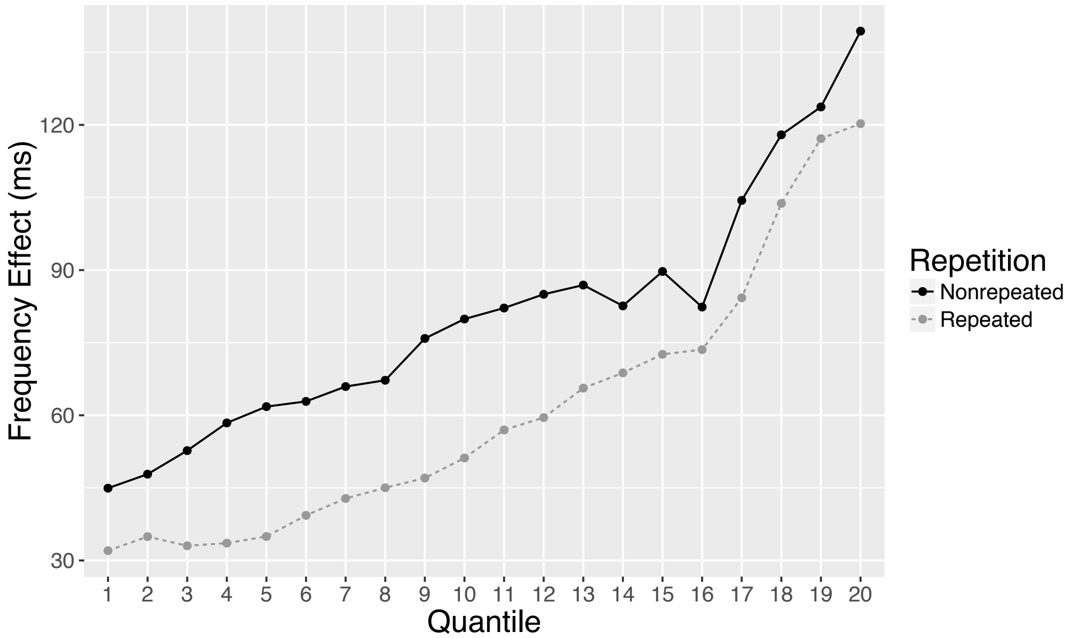

Figure 5.5 Frequency Effect by Repetition in the Distribution of Reaction Times

II. Lexicality and Repetition

The 2x2 ANOVAs including lexicality (word and pseudoword) and block (first and second) were conducted for the mu, sigma and tau parameters. The group parameter estimates[8] are presented in Table 5.9. The effect of lexicality across quantiles of the RT distribution are shown in Figure 5.6.

[8] The vincentiles for the whole group without dividing by super subjects showed very similar results, the parameters do not deviate more than 2 ms from the ones reported in Table 5.9

Mu: a significant effect of lexicality was found, $F\ (1, 5) = 27.413$, $p = .003$, but no effect of repetition, $F\ (1, 5) < 1$. Importantly, a significant interaction between lexicality and repetition was found, $F\ (1, 5) = 17.478$, $p = .008$. Further paired t-tests indicated that the effect of lexicality, although significant for both, was larger for repeated items (71 ms), $t\ (5) = 5.489$, $p = .003$, relative to nonrepeated items (56 ms), $t\ (5) = 4.84$, $p = .005$. The analysis of the effect of repetition by lexicality revealed a trend for words (13 ms), $t\ (5) = 2.303$, $p = .069$, and no significant repetition effect for pseudowords (-3 ms), $t\ (5) = -0.526$, $p = .621$.

Sigma: a significant effect of repetition was observed, $F\ (1, 5) = 8.515$, $p = .033$, but no effect of lexicality, $F\ (1, 5) < 1$, and no interaction, $F\ (1, 5) = 4.397$, $p = .0901$.

Tau: no significant effects of lexicality, $F\ (1, 5) < 1$ and repetition, $F\ (1, 5) < 1$, were found. However, a significant interaction between lexicality and repetition was found, $F\ (1, 5) = 16.955$, $p = .009$. Further analyses showed no effect of repetition for nonrepeated items (-12 ms), $t\ (5) = 1.921$, $p = .113$, whereas the effect of repetition was significant for repeated items (9 ms), $t\ (5) = 3.738$, $p = .014$. The analysis of the effect of repetition by lexicality showed no effect of repetition in either words (14 ms), $t\ (5) = 1.978$, $p = .105$, or pseudowords (-8 ms), $t\ (5) = -1.59$, $p = .173$.

Table 5.9 Means of Parameter Estimates from the ex-Gaussian analysis for super subjects

	Word		Pseudoword	
	Nonrepeated	*Repeated*	*Nonrepeated*	*Repeated*
Mu	484 (13)	471 (10)	540 (21)	543 (20)
Sigma	71 (7)	57 (4)	64 (6)	65 (8)
Tau	67 (12)	53 (7)	54 (10)	62 (8)

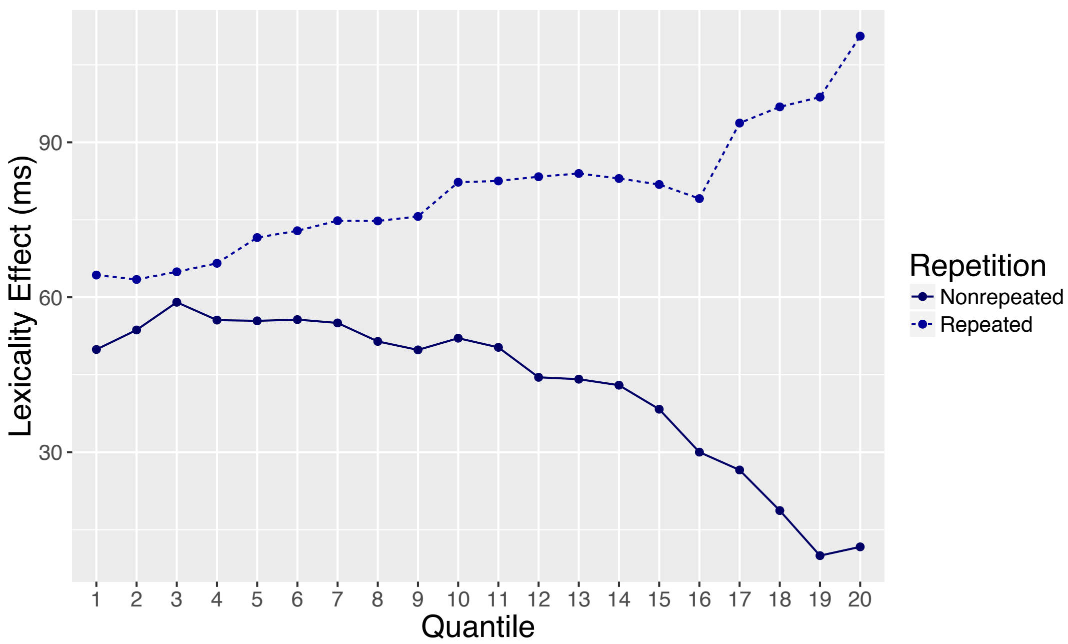

Figure 5.6 Lexicality Effect by Repetition in the Distribution of Reaction Times

5.2.3. Discussion

The results from experiment 5 revealed repetition effects on reaction times to words. Consistent with our hypothesis, this effect of repetition interacted with word frequency. Although the effect was strongly significant in nonrepeated and repeated words (79 ms vs. 62 ms), the effect of repetition was larger for low frequency relative to high frequency words (35 ms vs. 18 ms). Responses to repeated words were faster than responses to nonrepeated words, but the interaction indicated that this facilitation in responses was larger for low frequency words compared to high frequency words.

The error rate also revealed effects of word frequency and repetition. Responses were more accurate overall for high frequency words relative to low frequency words, and to repeated relative to nonrepeated words.

Furthermore, as was predicted, the effect of lexicality increased with repetition. This increase occurred from 38 ms in nonrepeated items to 79 ms in repeated items. A different direction of the effects was observed for words and pseudowords. While repetition facilitated responses for words (faster responses in repeated vs. nonrepeated items), this effect of repetition inhibited pseudowords responses (slower responses to repeated vs. nonrepeated items). The accuracy of responses showed a significant lexicality effect for nonrepeated items (8%) that disappeared for repeated items (2%). Interestingly, the same direction of effects for repeated words (more accurate responses) and repeated pseudowords (less accurate responses) was observed.

The RT distribution analyses revealed main effects of word frequency and repetition in the estimates of mu and sigma indicating an impact of these factors on the mean and standard deviation of the distribution (mu and sigma) but not in the tail (tau). Interestingly, the analysis of lexicality and repetition showed larger lexicality effects in repeated items compared to the effect in nonrepeated items in the mean of the distribution (mu). A similar pattern was observed for the tail of the distribution (tau) where the effect of lexicality was only significant for repeated items. This interaction between lexicality and repetition in the parameters of the distribution are similar to those observed in reaction times, where an increase in the effect of lexicality was observed in repeated items relative to nonrepeated ones. The decrease in accuracy scores might also be related to the shape of the distribution, where the lexicality effect for repeated items is more 'wordlike' (e.g. resembles more the shape of the word frequency).

These results support previous hypothesis regarding an influence of word frequency, lexicality and repetition at a common processing stage (Scarborough, Cortese, & Scarborough, 1977). The interactions between word frequency and repetition, as well as between lexicality and repetition are evidence of this, and are in line with previous studies that have proposed a continuum between these factors (Balota & Chumbley, 1984). The larger repetition effect for low frequency words indicates that less familiar words benefit more from repetition than high frequency words. However, words in general benefit from repetition. In contrast to, a negative (or inhibitory) repetition effect for nonwords, which suggests that even though these items are not part of the mental lexicon, they are affected by repetition. Therefore, repeated presentations of pseudowords might have increased their degree of familiarity for the visual word recognition system. The pattern of responses show that while the system becomes faster and more accurate in responding to words it becomes slower and less accurate in responding to pseudowords with repetition. Therefore, the visual word recognition system could have some sort of storage for information related to pseudowords.

Findings from experiment 5 are similar to those reported by Perea et al. (2016). Perea et al. also found that the effect of lexicality was increased by repetition and that the direction of the repetition effect was different for words (positive/facilitative) than pseudowords (negative/inhibitory) in reaction times. However, unlike Perea et al.'s study, in the present experiment, the effect of word frequency was also investigated by including words of high and low frequency, while in Perea et al.'s only high frequency words were included. Therefore, in the present experiment more information regarding how repeated exposure of words can improve recognition for less-encountered words (low frequency words) compared to more-encountered words (high frequency words) was provided.

Perea et al. (2016) focused more on the effect of lexicality. To compare our results directly to those of Perea et al., lexicality analyses only comparing high frequency words to pseudowords were conducted. However, the effect of lexicality was also explored comparing responses to low frequency words with responses to pseudowords. The results of both comparisons were similar in showing the same facilitation-inhibition pattern for words (high or low frequency) and pseudowords. Interestingly, the comparison between low frequency and pseudowords only showed a lexicality effect when the items were repeated. Therefore, fewer differences are observed between low frequency words and pseudowords when the items are not repeated, in contrast to, the comparison the lexicality effect observed for high frequency words compared to pseudowords in nonrepeated items.

From the observed interactions of the repetition with word frequency and lexicality, we can conclude that repetition influences the degree of familiarity of words and nonwords facilitating word processing and inhibiting pseudoword processing. If responses to low frequency words are initially similar to pseudoword responses as shown by the lack of a lexicality effect in the comparison of those items, the question would be if it is possible to find similar repetition effects between words and pseudowords.

The LCA model explains (Dufau, Grainger & Ziegler, 2012) the potential mechanism behind the repetition effect. The LCA model (discussed in section 1.1.3.4), similar to the diffusion model (Ratcliff, 1978, described in section 1.1.3.3), explains a lexical decision by incorporating two response nodes ('yes' and 'no'). In the case of words, 'yes' responses only depend on the accumulation of evidence towards a word. However, 'no' responses to pseudowords (evidence towards a nonword), depend on the accumulation of evidence towards a word and mutually inhibitory connections between the two response nodes (the rise in activity in one automatically causes a reduction in activity in the other and vice versa). Repetition increases the evidence accumulation for a word, facilitating responses for these items. This rise in activity of the 'yes' node will cause inhibition on the 'no' responses, therefore inhibiting responses for pseudowords with repetition.

Moreover, the LCA model considers the evidence towards a word not only for each trial but also the contribution of this evidence trial-by-trial as an adjustment of the response criteria within the lexical decision task. Because the initial input value can be adjusted to optimise performance in the same way as it can the response criteria, modifying the list context in each task would modify the task context reducing the time to give a 'No' response and modifying any inhibitory link between the 'yes' and 'no' responses (response nodes according to the LCA). We hypothesise that list compositions that generate less lexical activity by their elements due to the incorporation of only previously seen items would contribute to a facilitatory effect for pseudowords, given that such a list would not provoke the accumulation of additional evidence towards word representations and therefore the mutually inhibitory connections between the 'yes' and 'no' nodes would be reduced.

The results of the experiment 5 confirmed that the effect of repetition has a different impact on words and pseudowords (e.g. Perea et al., 2016), which can be explained by the LCA model. However, previous research has also found similar facilitatory repetition effects for words and nonwords in lexical decision (Logan, 1990). By manipulating the list composition or the list context in a way that increases the familiarity of all the stimuli and not only half of them (as in experiment 5), we should be able to increase the familiarity of both, words and nonwords. Experiment 6 investigated the role of the list composition in order to test the trial-by-trial adjustment of response criteria proposed by the LCA model. If as the LCA model proposes, the thresholds of the "yes" and "no" decision nodes are adjusted according to the list composition, increasing the familiarity context would reduce the inhibition towards the 'no' response and repetition would result in facilitatory effects for words and pseudowords. To further manipulate the increase of the familiarity context effects in experiment 6, four presentation blocks were included and the same stimulus list was presented in each block.

5.3. Experiment 6

5.3.1. Methods

5.3.1.1. Participants

Twenty-four right-handed English native speakers (6 males) were recruited from the University of Nottingham student population. Participants were between 18 to 20 years old (M = 19, SD = 0.6) and reported not being proficient in other languages than English and having no reading problems. For their participation, participants received a course credit.

5.3.1.2. Stimuli and Design

The stimuli were identical to those used in experiment 5. This experiment consisted of a lexical decision task involving four blocks. A stimulus list (A, B or C) was presented four times to each participant in separated blocks. An equal number of participants were exposed to each list.

5.3.1.3. Procedure

The procedure was the same as in experiment 1. A short break was provided between blocks. Participants conducted a practice session with 24 practice trials (six of each stimuli condition) before the first block.

5.3.2. Results

5.3.2.1. Mixed effects modelling

Responses shorter than 300 ms or longer than 1500 ms were excluded from reaction times and accuracy analyses (1.2%). Furthermore, only correct responses were included in the reaction times analysis (91.4%). Mixed-effects modeling was conducted in a similar way as in experiment 1. In order to explore the effect of the block, the data collected in all the blocks were kept and included in the analyses.

I. Frequency and Block Effects

Mean reaction times and accuracy scores were calculated by frequency and block (see Table 5.10).

Table 5.10 Mean and SE of Reaction Times and Accuracy

	High Frequency				Low Frequency			
	Block 1	*Block 2*	*Block 3*	*Block 4*	*Block 1*	*Block 2*	*Block 3*	*Block 4*
Reaction Times	514	516	521	525	594	570	576	569
	(4.5)	(4.4)	(5.2)	(5.6)	(6.3)	(5.7)	(6.1)	(6.2)
Accuracy	0.97	0.96	0.96	0.95	0.84	0.85	0.84	0.83
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)

The final model for reaction times included the main effects and interactions between frequency and block (contrasts of interest) (see Table 5.11)[9]. The model revealed significantly faster responses to high frequency words than to low frequency words (58 ms), $t = 9.6$, $p < .0001$. The main effect of the block was not significant (Block 1 vs. block 2: $p = .6$; block 2 vs. block 3: $p = .6$; block 3 vs. block 4: $p = .9$). However, the interaction between frequency and block 1 vs. block 2 was significant, $t = -3.1$, $p < .01$. Other interactions such as between frequency and block 2 vs. block 3, $t = 0.6$, $p = .6$, as well as between frequency and block 3 vs. block 4, $t = -1.01$, $p = .3$, were not significant.

Further analyses revealed that repetition had no effect on low (24 ms, $p = .3$) or high (-1 ms, $p = 1$) frequency words in block 1 vs. block 2 (Table 5.11). However, the reduction in speed of low frequency words, although non-significant, could have driven a reduction in the effect of frequency from 79 ms in block 1 ($p < .0001$) to 54 ms in block 2 ($p < .0001$) (Figure 5.7).

[9] A model that incorporated trial number and previous RT revealed similar findings.

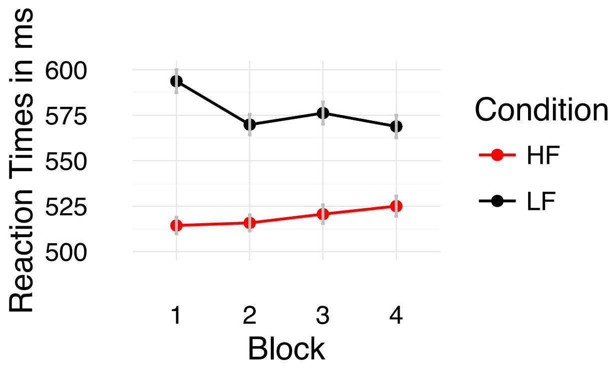

Figure 5.7 Frequency by Block Interaction in Reaction Times

Table 5.11 Final model of reaction times Frequency and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	-2.050	0.06725	-30.479
Frequency	0.1984	0.02081	9.535
Block 1 vs. Block 2	0.01707	0.02963	0.576
Block 2 vs. Block 3	-0.01316	0.02374	-0.554
Block 3 vs. Block 4	0.003269	0.01886	0.173
Frequency * Block 1 vs. Block 2	-0.06754	0.02209	-3.057
Frequency * Block 2 vs. Block 3	0.01293	0.02212	0.585
Frequency * Block 3 vs. Block 4	- 0.02242	0.02224	-1.008
	Variance	SD	
Random effects			
Item (intercept)	0.011766	0.10847	
Participant (intercept)	0.094161	0.30686	
Frequency	0.004148	0.06441	
Block 1 vs. Block 2	0.015619	0.12498	
Block 2 vs. Block 3	0.028764	0.16960	
Block 3 vs. Block 4	0.025543	0.15982	

The final model for accuracy only included frequency (Table 5.12), indicating that fewer errors were made to high frequency words than to low frequency words, $z = -8.67$, $p < .0001$.

Table 5.12 Final model of accuracy Frequency and Repetition

	Estimate	SE	z-value
Fixed effects			
(Intercept)	3.6690	0.1718	21.36
Frequency	- 1.5392	0.1775	-8.67
	Variance	SD	
Random effects			
Item (Intercept)	1.1300	1.0630	
Participant (Intercept)	0.2193	0.4683	

II. Lexicality and Repetition Effects

Mean reaction times and accuracy scores for words and pseudowords are presented in Table 5.13.

Table 5.13 Mean and SE of Reaction Times and Accuracy

	Word				Pseudoword			
	Block 1	*Block 2*	*Block 3*	*Block 4*	*Block 1*	*Block 2*	*Block 3*	*Block 4*
Reaction Times	551 (3.9)	541 (3.6)	547 (4.0)	545 (4.2)	639 (6.1)	610 (5.5)	597 (6.0)	594 (6.0)
Accuracy	0.90 (0.1)	0.91 (0.1)	0.90 (0.1)	0.89 (0.1)	0.90 (0.1)	0.92 (0.1)	0.92 (0.1)	0.92 (0.1)

The final model for reaction times included lexicality and block, as well as an interaction between these factors (see Table 5.14)[10]. Results showed that participants responded significantly faster to words than pseudowords (64 ms), $t = -8.1$, $p < .0001$. Responses were quicker in block 2 compared to block 1 (20 ms), $t = -2.2$, $p < .05$ and in block 3 compared to block 2 (4 ms), $t = -2.7$, $p < .01$, but response times were similar in block 3 and block 4 (3 ms), $t = -.6$, $p = .6$.

Importantly, the interaction between lexicality and block 1 vs. block 2, $t = 2.04$, $p < .05$, and lexicality and block 2 vs. block 3, $t = 2.97$, $p < .0001$, were significant (Figure 5.8). However, the interaction between lexicality and block

[10] Similar results were observed in a model that included trial number and previous RT.

3 vs. block 4, $t = .2$, $p = .8$, was not significant. The effect of block was significant for pseudowords ($p < .001$) but not for words ($p = 1$). The pseudoword repetition effect in block 1 vs. block 2 was of 29 ms ($p = .1$) and in block 2 vs. block 3 of 13 ms ($p < .05$). The repetition effect for words was not significant in block 1 vs. block 2 (10 ms, $p = .9$) and block 2 vs. block 3 (-6 ms, $p = 1$). The lexicality effect was significant in each block. However, the size of the lexicality effect decreased across blocks: block 1 (88 ms, $p < .0001$), block 2 (69 ms, $p < .0001$), block 3 (50 ms, $p < .0001$).

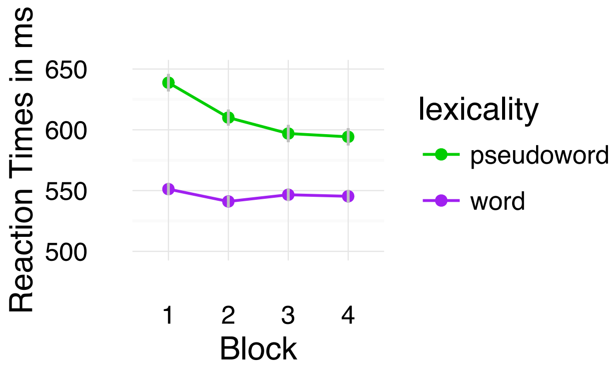

Figure 5.8 Lexicality by Block Interaction of Reaction Times

Table 5.14 Final model of reaction times Lexicality and Repetition

	Estimate	SE	t-value
Fixed effects			
(intercept)	- 1.753	0.05875	- 29.844
Lexicality	- 0.1984	0.02459	-8.068
Block 1 vs. Block 2	-0.05748	0.02579	-2.229
Block 2 vs. Block 3	-0.06364	0.02320	-2.744
Block 3 vs. Block 4	-0.01220	0.02173	-0.561
Lexicality * Block 1 vs. Block 2	0.03976	0.01954	2.035
Lexicality * Block 2 vs. Block 3	0.05674	0.01910	2.970
Lexicality * Block 3 vs. Block 4	0.003875	0.01913	0.203
	Variance	SD	
Random effects			
Item (intercept)	0.026837	0.16382	
Block 2	0.001308	0.03616	
Block 3	0.001476	0.03842	
Block 4	0.002157	0.04644	
Participant (intercept)	0.069895	0.26438	
Lexicality	0.007999	0.08944	
Block 2	0.009853	0.09926	
Block 3	0.025233	0.15885	
Block 4	0.027420	0.16559	

In order to investigate whether the interaction between lexicality and block was driven by high or low frequency words, separate analyses were conducted for low and high frequency words.

High frequency words: The final model revealed a significant effect of lexicality (91 ms, $t = -11.7$, $p < .0001$), block 1 vs. block 2 (13 ms, $t = -3.6$, $p < .0001$), and block 2 vs. block 3 (4 ms, $t = -4.1$, $p < .0001$) but not of block 3 vs. block 4 (-1 ms, $t = -0.7$, $p = .5$). Importantly, the interactions between lexicality and block 1 vs. block 2, $t = -3.3$, $p < .01$, as well as lexicality and block 2 vs. block 3, $t = 2.3$, $p < .05$, were significant. Further comparisons indicated that the effect of repetition was significant for pseudowords in block 1 vs. block 2 (29 ms, $p < .01$) and block 2 vs. block 3 (13 ms, $p < .001$). In contrast, there was no effect of repetition for high frequency words: block 1 vs. block 2 (-1 ms, $p = .1$), block 2 vs. block 3 (-5 ms, $p = .1$).

Low frequency words: The final model revealed significant main effects of lexicality (33 ms, $t = -5.4$, $p < .0001$), block 1 vs. block 2 (26 ms, $t = -2.3$, $p < .01$), and block 2 vs. block 3 (4 ms, but not of block 3 vs. block 4 (5 ms, $t =$ -

0.5, p = .7). Crucially, only the interaction between lexicality and block 2 vs. block 3, t = 2.8, p < .01, was significant. Further comparisons showed a marginal effect of repetition on pseudowords in the block 2 vs. block 3 (13 ms, p = .07) and no effect of repetition for low frequency words in block 2 vs. block 3 (-6 ms, p = 1).

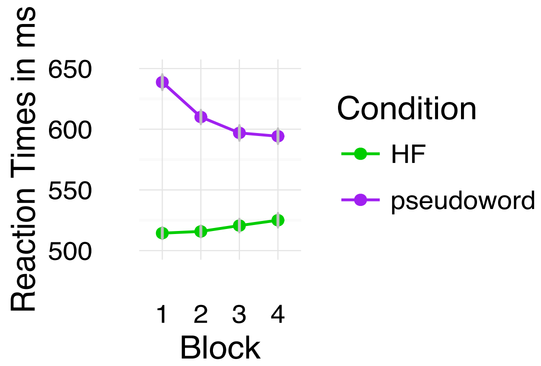

Figure 5.9 Lexicality (HF vs. PW) by Block Interaction of Reaction Times

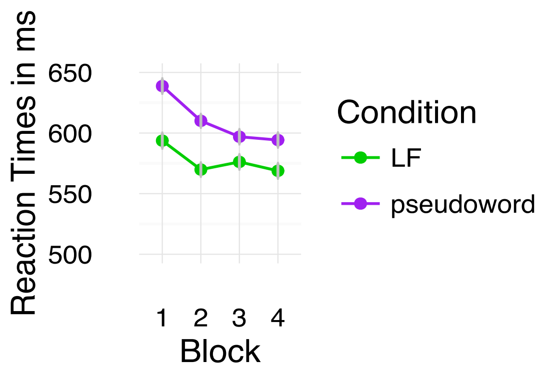

Figure 5.10 Lexicality (LF vs. PW) by Block Interaction of Reaction Times

The final model for accuracy only included the random effects (Table 5.15). Thus, no effects of lexicality or repetition were observed in the accuracy data.

Table 5.15 Final model of accuracy Lexicality and Repetition

	Estimate	SE	z-value
Fixed effects			
(intercept)	2.8717	0.1287	22.31
	Variance	SD	
Random effects			
Item (intercept)	1.3950	1.1811	
Participant (intercept)	0.2486	0.4986	

5.3.2.2. RT distribution analysis

The RT distribution analysis was conducted in a similar way as in experiment 5. Responses shorter than 250 ms or longer than 3000 ms (.06 % of the data) and incorrect responses (8.6%) were excluded from the analysis.

I. Frequency, Task and Repetition

The results from the 2x2 ANOVAs including frequency (word and nonword) and block (first and second) for the parameters mu, sigma and tau (dependent variables) are presented below. The group parameter estimates[11] are shown in Table 5.16. The frequency effect across quantiles is shown in Figure 5.11.

A significant main effect of frequency was found in the parameters mu, F (1, 5) =95.696, p = .002, sigma, F (1, 5) = 30.962, p = .002, and tau, F (1, 5) = 24.009, p = .005. The effect of repetition was not significant for any of the parameters, $F's < 1$, neither was the interaction between frequency and repetition (mu and sigma $F's$ < 1, tau: F (1, 5) = 1.089, p = .384).

[11] The vincentiles for the whole group without dividing by super subjects showed very similar results, the parameters do not deviate more than 2 ms from the ones reported in Table 5.16.

Table 5.16 Means of Parameter Estimates from the ex-Gaussian analysis

	High frequency				Low frequency			
	Block 1	*Block 2*	*Block 3*	*Block 4*	*Block 1*	*Block 2*	*Block 3*	*Block 4*
Mu	473 (17)	477 (23)	474 (20)	477 (24)	518 (22)	517 (29)	514 (28)	505 (16)
Sigma	45 (4)	44 (4)	47 (4)	52 (5)	61 (6)	57 (9)	60 (8)	59 (3)
Tau	31 (7)	32 (4)	36 (6)	41 (8)	60 (9)	45 (5)	54 (5)	60 (19)

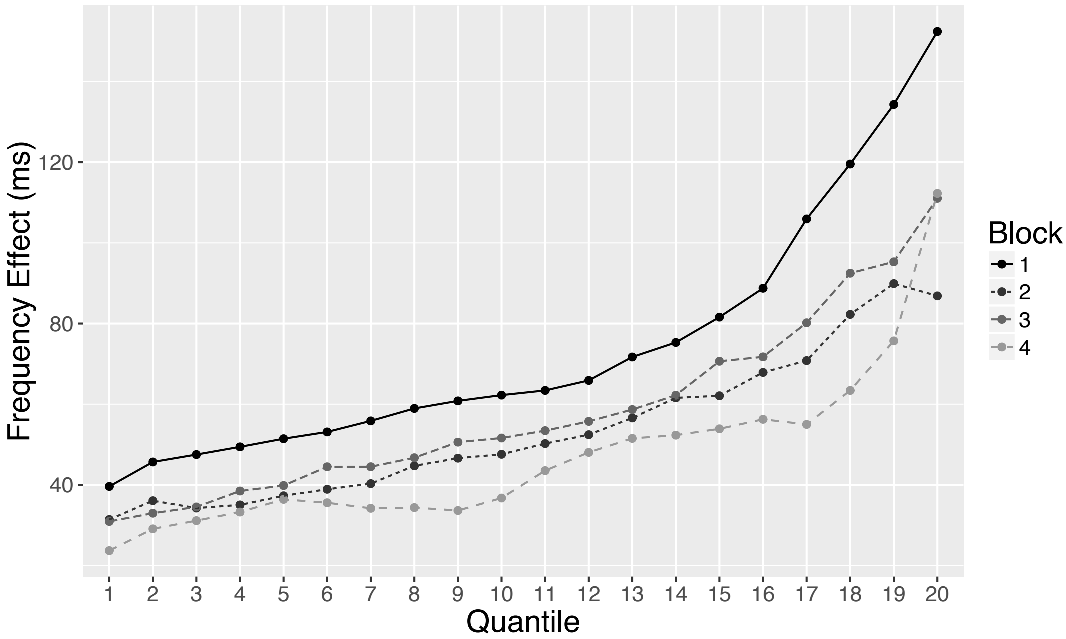

Figure 5.11 Frequency Effect by Block in the Distribution of Reaction Times

II. Lexicality, Task and Repetition

The 2x2 ANOVAs including lexicality (word and pseudoword) and block (nonrepeated and repeated) for the parameters mu, sigma and tau revealed a significant main effect of lexicality for mu, F (1, 5) =106.91, p = .0001, and sigma, F (1, 5) =47.743, p = .0009, but not for tau, F (1, 5) < 1. The main effect of repetition (first vs. second vs. third vs. forth block) was not significant in mu, F (1, 5) = 1.814, p = .188, sigma, F (1, 5) = 1.236, p = .325, or tau, F (1, 5) < 1. The interaction between lexicality and repetition was only significant in sigma, F (1, 5) = 5.03, p = .013, but not in tau, F (1, 5) < 1, although it was a trend in mu, F (1, 5) = 3.208, p = .054.

Further paired t-test revealed that the effect of lexicality decreased with repetitions. In the first block the lexicality effect was 16 ms (t (5) = 4.529, p = .006), in the second the effect was 12 ms, t (5) = 4.122, p = .009, while in the third block it was 6 ms, t (5) = 2.797, p = .038, but in the fourth block there was no effect of lexicality, t (5) = 0.274, p = .795. The repetition (block) effect was not significant for words, F (1,3) = 1.283, p = .316, but showed a trend for pseudowords, F (1,3) = 2.938, p = .067.

The group parameter estimates[12] are shown in Table 5.17. The lexicality effect across quantiles of the RT distribution are presented in Figure 5.12.

Table 5.17 Means of Parameter Estimates from the ex-Gaussian analysis

	Word				Pseudoword			
	Block 1	*Block 2*	*Block 3*	*Block 4*	*Block 1*	*Block 2*	*Block 3*	*Block 4*
Mu	487 (19)	489 (23)	485 (23)	488 (21)	573 (30)	555 (18)	540 (33)	536 (23)
Sigma	56 (5)	52 (6)	54 (6)	59 (5)	71 (8)	65 (4)	60 (7)	60 (6)
Tau	49 (8)	44 (6)	51 (6)	50 (11)	51 (6)	41 (9)	51 (6)	45 (6)

[12] The vincentiles for the whole group without dividing by super subjects showed very similar results, the parameters do not deviate more than 2 ms from the ones reported in Table 5.17

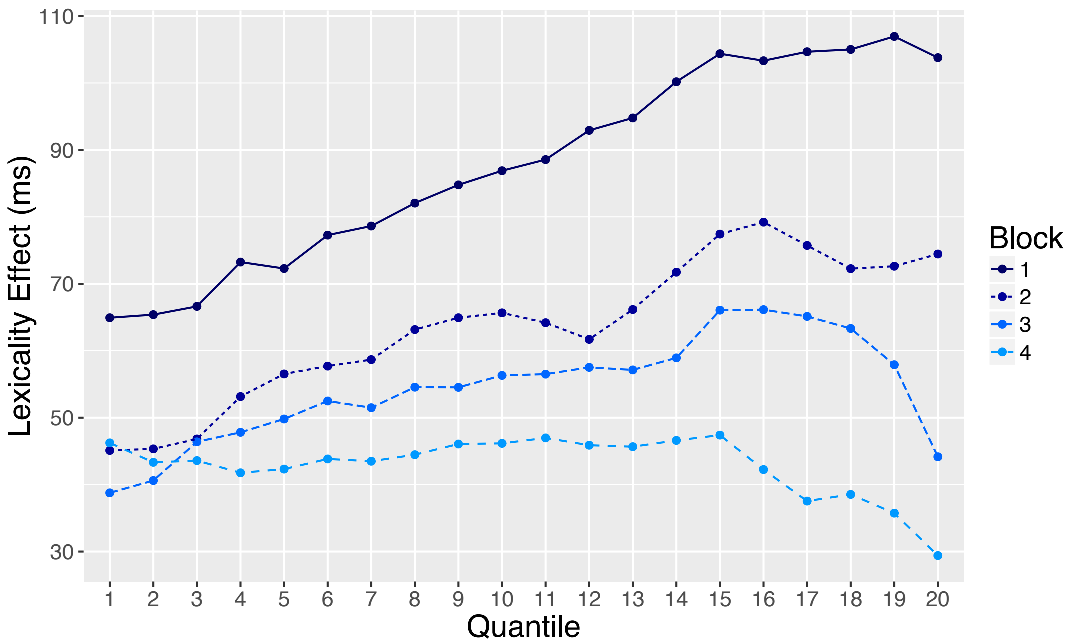

Figure 5.12 Lexicality Effect by Block in the Distribution of Reaction Times

5.3.3. Discussion

The aim of experiment 6 was to investigate whether similar facilitative (faster) responses could be found for repeated words and pseudowords by repeating the same stimulus list in four blocks during a LDT.

Results from the analyses of frequency and repetition on reaction times revealed a main frequency effect that significantly decreased by 25 ms from the first to the second block, although no further significant decreases were observed in the following blocks in reaction times. The error analyses showed more accurate responses to high frequency relative to low frequency words, but these were not modulated by repetition. Therefore, the increase of the stimulus familiarity only reduced the effect of frequency on reaction times from the first to the second presentation. The lack of interaction between frequency and repetition in subsequent repetitions showed that responses to high and low frequency words are more stable across further repetitions. This was confirmed by the lack of an interaction with repetition in the accuracy of the responses.

The effect of lexicality was influenced by repetition. A decrease on the lexicality was observed from the first to the third block (88 ms vs. 69 ms vs. 50 ms). This decrease was driven by a significant repetition effect in pseudowords because words did not show any effect of repetition, as was revealed by a significant interaction between lexicality and block in reaction times. However, no lexicality effects were observed in the accuracy of responses.

The RT distribution analyses revealed main effects of frequency in all the parameters of the distribution (mu, sigma, tau). However, this effect did not interact with repetition, which was consistent with the reaction times findings from blocks 3 and 4 but not with the interaction observed in blocks 1 and 2. In the case of lexicality, a main effect of this variable was found for the mean of the distribution (mu) and its standard deviation (sigma) but not for the tail of the distribution (tau). However, values of sigma revealed a similar pattern to that observed in reaction times: a decrease of the lexicality effect with repetition from block 1 to block 3 (16 ms vs. 12 ms vs. 6 ms) and no lexicality effect in block 4. Interestingly, these differences in the shape of the distribution can be observed in the plot by quantiles (Figure 5.12). This shows that in higher quantiles of the distribution the lexicality effect is normally larger in nonrepeated trials (block 1), but the effect decreases in those quantiles with repetition in subsequent blocks (2 and 3). These sigma values were consistent with those found in the analysis of reaction times and it seems to be driven by the trend in the effect of repetition for pseudowords relative to no effect for words.

These results confirm that a facilitative repetition effect can be found for pseudowords when the stimuli is kept the same across repetitions. In contrast to the inhibitory effect observed for pseudowords in experiment 5, where non-previously seen stimuli were presented along with the repeated stimuli. Therefore, the results of experiment 5 compared to those of experiment 6 emphasise the role of list composition on the direction (inhibitory or facilitatory) of the effect of repetition on pseudowords. Interestingly, list composition also played a role in the repetition effect for words by showing no repetition effect when the stimuli were kept the same (experiment 6), but a facilitatory effect when non previously seen stimuli were incorporated (experiment 5). Moreover, the effect of word frequency interacted with the effect of repetition only in the first repetition when the stimuli was kept the same across blocks; however, no effect of repetition was found in subsequent blocks. Furthermore, no repetition effect was found for low or high frequency words in experiment 6, in contrast to Experiment 5 where the effect was significant for these items, and stronger for low frequency words.

The implication of the findings mentioned above is further discussed in the General Discussion section.

5.4. General Discussion

This chapter investigated whether the effect of repetition could be found for pseudowords and whether list composition would play a role in determining the direction (facilitatory/inhibitory) of these repetition effects. In the previous chapter (chapter 4) repetition was manipulated across tasks with different task demands (ODT and LDT), while in this chapter (chapter 5), repetition was manipulated across blocks of the LDT.

According to the predictions for experiment 5 and similar to previous findings (e.g. Balota and Spieler, 1999; Perea et al., 2016), a facilitatory-inhibitory pattern of repetition effects was observed for words and pseudowords when a second block included stimuli that had not been previously seen in the first block. By contrast, when the stimulus list was repeated in each consecutive block (4 times), facilitatory effects were observed for pseudowords according to our predictions based on the LCA model of word recognition (Dufau, Grainger & Ziegler, 2012).

Unlike Perea et al., 2016, experiment 5 included both high and low frequency words to investigate how repetition affected the word frequency effect. In line with previous studies (Balota & Spieler, 1999; Scarborough, Cortese & Scarborough, 1977; Wagenmakers et al., 2004) we observed larger repetition effects for low frequency words compared to high frequency words. Moreover, the size of the word frequency and the lexicality effects were modulated by repetition: the word frequency effect was reduced for repeated words and the lexicality effect was increased for repeated items.

In terms of accuracy, the effect of word frequency was not modulated by repetition, in contrast to the results observed in reaction times. However, the effect of lexicality was influenced by repetition, indicating a larger facilitative repetition effect for words and a negative effect for pseudowords. Additionally, the repetition effect eliminated the lexicality effect on repeated items. These results are in line with the reaction times results that also showed a facilitative-inhibitory effect in words and pseudowords.

Therefore, evidence towards the LCA model (Dufau, Grainger & Ziegler, 2012) and the diffusion model (Ratcliff, 1978) that state that repetition would increase the familiarity of words and nonwords are supported in experiment 5. However, the results from experiment 6 illustrated the importance of the list context. In this experiment, the word frequency effect was not modulated by repetition in the main interaction but the effect of word frequency significantly decreased from the first to the second block (presentations) and remained stable in subsequent blocks as revealed in the analysis of reaction times. No effect of repetition was observed when analysing the high and low frequency words separately.

The lexicality effect was reduced by repetition from the first to the second block and from the second to the third block, and this pattern was observed in reaction times and the reaction times distribution analyses. Remarkably, the main effect of repetition was significant for pseudowords but not for words in the analysis of reaction times. Additional analyses revealed that the interaction between lexicality and repetition was driven by the high frequency words. When only high frequency words were included, the analysis exposed significant repetition (block) effects from the first to the second, and from the second to the third block for pseudoword but not for high frequency words. The analysis only including low frequency words showed no effects of block for either the pseudowords or the low frequency words.

The accuracy of responses in experiment 6 only revealed main effects of frequency and repetition when these measures where included in the analysis and no effect when the lexicality and repetition were analysed. However, the analysis of the RT distribution revealed that the effect of repetition by lexicality is due to the differences in the shape of the distribution as revealed by the observed pattern in the parameter of sigma as it was discussed in section 5.3.3.

In this chapter, repetition was manipulated across blocks in a LDT. In experiment 5, two blocks were used where half of the items were repeated in the second block while the other half were novel items. Conversely, experiment 6 did not incorporate any novel items, and the same stimulus list was presented in four consecutive blocks. Therefore, list composition was manipulated across experiments indicating that this factor can influence the impact of repetition.

As predicted, a facilitative-inhibitory pattern of responses for repeated words and pseudowords can be observed when the repetition occurs within blocks of the same task (LDT). Also, the direction of the effects for pseudowords can be modulated by list composition. Although the exclusion of non-previously presented items eliminated the effect of repetition for words, it resulted in a facilitative effect for pseudowords. This would in fact support the proposal of the LCA model (Dufau, Grainger, Ziegler, 2012) of trial-by-trial adjustments in stimuli input and response criteria as a function of list context.

The analyses of the RT distributions supported the observed patterns in the reaction times analyses and provided additional information regarding the shape of distribution of the responses. Our results of experiment 5 are similar to those of Balota and Spieler (1999) who found an effect of word frequency in the mu parameter. In relation to the lexicality effect modulated by repetition, results from experiment 5 are in agreement with results from Balota and Spieler that observed different repetition effects for words and pseudowords in the estimates of mu and tau, supporting the notion of different processes behind the processing of words and nonwords. Perea et al. (2016), pointed out that this different repetition effect of words and pseudowords could be exhibited in the higher quantiles of the distribution, which is concurrent with the current findings that observed a significant interaction in the sigma parameter of the distribution, revealing different distribution shapes in the higher quantiles of the distribution.

Nevertheless, the present results are different from Balota and Spieler's (1999) in the observation of an interaction between frequency and repetition in the values of sigma and the lack of effects on tau values. In this chapter, repetition was conducted across blocks within the same LDT, whereas Balota and Spieler (1999) used a rhyming judgment task followed by a lexical decision task. Therefore, the task switch in Balota and Spieler could have impacted their findings.

The results of experiment 6 provided further information regarding the facilitative effect of repetition on pseudowords. Perea et al. (2016) suggested that this facilitative effect would be reflecting encoding processes. In our results of experiment 6, were we observed a facilitatory effect on the reaction times analyses that decreased in size as the block number increased. This pattern was also found in the parameter of sigma, indicating shape variations of the RT distribution caused by the interaction between lexicality and repetition. The effect of frequency, however, did not interact with the effect of repetition although main effects of word frequency were found in mu, sigma and tau further supporting the notion that the effect of word frequency remained stable through repetitions when all the stimuli in the list were repeated.

The experiments presented in this chapter provided evidence that confirm that repetition increases the familiarity of the items facilitating responses to words and inhibiting responses to pseudowords but only when the repeated items are presented along with nonrepeated ones in the same block. Repetition of the same stimulus list in consecutive blocks eliminates the repetition effect for words and facilitates responses to pseudowords. This study added further information to the effect of repetition and its interaction with lexicality and word frequency by demonstrating that these effects can be modified by the list composition. This is a key factor that should be considered in the models of visual word recognition that attempt to explain the effect of word frequency, lexicality and repetition as is the case for the LCA model (Dufau, Grainger and Ziegler (2012). Repetition would increase the familiarity of words as long as new stimuli (not previously seen) are included in the stimulus list but this inclusion of new stimuli will contribute to an inhibitory effect of repetition for pseudowords in the mechanisms discussed in section 5.2.3. However, when all the items are repeated in subsequent blocks, there is no increase in familiarity with words and the familiarity with pseudowords is increased, probably reflecting encoding processes.

Therefore, the role of list composition not only impacts the size of the lexicality effect as previously observed in chapter 4, but also impacts the effect of repetition, which in turn is also task-dependent because no repetition effects were observed across tasks with different task demands (ODT and LDT). List composition is also responsible for the high number of errors observed in responses to pseudowords, whereas, in conjunction with task demands, this could also explain the lack of repetition effects in monolinguals' responses and probably also in bilinguals' responses. A summare of all the findings presented in this thesis, the implications of these findings and how models of word recognition previously discussed (sections 1.1.3 and 1.2.3) can explain them are presented in the following chapter.

Chapter 6. General Discussion

6.1. Summary of the thesis

This thesis investigated visual word recognition in monolinguals and bilinguals through the effects of lexicality, word frequency and repetition. In bilinguals, brain and behavioural responses were investigated in chapter 2 to identify whether bilinguals are able to suppress lexical access to the nontarget language. Due to the task complexity, which might have led to a high number of errors to pseudowords, the role of task demands was investigated in Chapter 3. In this chapter, the effect of repetition was also investigated across tasks. Because the error rate was again high for pseudowords in L1 and L2 and the lack of an effect of repetition, chapter 4 explored whether these results were specific to bilinguals by conducting the same experimental design in English with English monolinguals. In experiment 3, monolinguals also showed a high error rate for pseudowords and a lack of repetition effects when the stimuli included pure consonant or pure vowel letter strings. However, the error rate decreased and a repetition effect was observed when these items were excluded from the stimulus list in experiment 4, therefore evidencing the role of list composition. Interestingly, the repetition effect was only observed in words but not in pseudowords. Chapter 5 further investigated if the repetition effect on pseudowords depended on whether the repetition occurred across tasks or on the list composition. Repetition within the same task in chapter 5 revealed repetition effects for pseudowords, which were inhibitory or facilitatory depending on list composition. These findings from bilinguals and monolinguals will be interpreted in the context of models of visual word recognition that have made specific predictions regarding lexical access. Before discussing the implication for the models, in the following sections the research questions addressed by this thesis are presented.

- **Does lexical access occur in the nontarget language of bilinguals?**

Chapter 2 investigated whether bilinguals can block lexical access in the nontarget language using the same paradigm as Rodríguez-Fornells et al. (2002) who have previously suggested that bilinguals can suppress the nontarget language. Improvements in the design were implemented (presented in section 2.1) based on previous limitations observed in Rodríguez-Fornells et al.'s study. The ERP analysis between 350-500 ms at centro-parietal locations (same as Rodríguez-Fornells et al.) in the L1 task (L1 go, L2 no-go) revealed no effects of language, frequency or their interaction. However, in the L2 task (L2 go, L1 no-go), a main effect of language was found and the effect of frequency approached significance (p = .053), indicating that the effect was present in target and nontarget languages.

Furthermore, the ERP analysis on 100 ms time also revealed main effects of word frequency that in some cases were localised in specific brain regions, regardless of language (target and nontarget). More importantly, the effect of language (target and nontarget) did not interact with the effect of frequency.

These results evidencing main effects of frequency and a lack of interaction between language and frequency are in contrast to Rodríguez-Fornells' et al. (2002) findings, and support the nonselective lexical access perspective of bilingual lexical access previously observed in a variety of behavioural findings (section 1.2).

The timing and location of the effect was not considered in our initial predictions that focused on the issue of language non-selective lexical access. However, the findings of the timing and location of the word frequency effects in target and nontarget languages are in line with previous research. For example, the word frequency effect was observed around the N400 component time window (300-400 ms) in anterior regions and at later time windows (600-700 ms) in posterior regions of the midline during the L1 task. However, this effect was found in regions of the right hemisphere from 300-400ms; in anterior and central regions from 500-600ms; and in posterior regions from 600-700 ms, during the L2 task. Previous research has observed “early” effects of word frequency (280-380ms) in anterior regions and “late” (380-500 ms) effects in posterior (Dambacher et al., 2006) or widespread brain regions (Dufau et al., 2015).

Although a significant effect of word frequency was observed in the late time windows, no word frequency effect was found in the 400-500ms time window when the L2 was the nontarget language. However, the effect of word frequency was significant in anterior regions of the right hemisphere from 400-500 ms when L1 was the nontarget language. Previous findings in bilinguals have observed delayed word frequency effects for L2 compared to L1 (Aparicio et al., 2012, Lehtonen et al., 2012) and early effects in nontarget L1 (Ng & Wicha, 2013).

Regarding the effect of lexicality in nontarget languages, L1 lexicality effect in the L2 task was observed in anterior and central regions from 300-400ms, and in dorsal regions from 400-500ms. This effect was also found to be particularly stronger in dorsal regions from 500-600 ms and became more posterior from 600-700ms. By contrast, the L2 lexicality effects in the L1 task were only observed from 500-600 ms in anterior and central regions of the hemispheres and in all regions of the midline. The effect of lexicality in nontarget L1 follows a similar pattern of effects reported in monolinguals. Hauk et al. (2006) found stronger lexicality effects in centro-parietal electrodes from 425 to 500 ms and late effects of lexicality in occipital electrodes. In the present study the effects for L1 nontarget were found in dorsal regions from 400-600 and in posterior regions from 600-700, similar to the effects observed in monolinguals. Nevertheless, the effects were found later for L2 nontarget (e.g. 500-600 ms) and no effect was identified in later time windows (600-700 ms). These findings are consistent with previous research that reported late lexicality effects for bilinguals’ L2, starting from 550 ms (Lehtonen et al., 2012). This is also consistent with the proposal that language dominance (Midgley, Holcomb & Grainger, 2009) or vocabulary size (Moreno & Kutas, 2005) might play a role on the timing of lexicality effects in L1 and L2.

Behavioural findings confirmed the ERP results in showing no interaction between language and word frequency on reaction times indicating similar effect sizes, although more errors were made for L2 words. More errors were also made for pseudowords in L1 when the target language was L2. In contrast, no effect of lexicality was observed in the error rates of L2 pseudowords in the L1 task. Dijkstra, Timmermands and Schriefers, 2000 and Rodríguez-Fornells et al., 2002 also reported a high rate of false positive responses or false alarms for L1 stimuli in nontarget conditions. This probably reflects a bilinguals' more dominant L1, while, also providing evidence of a nonselective lexical access.

In conclusion, it was demonstrated that lexical access occurs in both languages of bilinguals, regardless of target or nontarget conditions. Interestingly, the timing and error rate of the lexical effects might reflect bilinguals' dominance towards L1.

- **Is lexical access in bilinguals' L1 and L2 task-dependent?**

Chapter 2 demonstrated that lexical access occurs in both languages despite the fact of one language not being needed to perform the task. However, in L1 nontarget, the effects of word frequency and lexicality on ERPs were consistent with those reported in monolingual literature. In L2 nontarget, these effects appeared delayed probably indicating a language dominance of the bilinguals towards L1 (see discussion of the previous question).

Chapter 3 further investigated lexical access in bilinguals and the role of task demands by simplifying the task criteria used in chapter 2. Separate tasks that included the previously used decision-levels were incorporated. An Onset Decision (ODT) and a Lexical Decision Task (LDT) were used to explore the role of the task demands on bilinguals L1 and L2. Conducting the two tasks on separate days per language eliminated language decision. This time the focus was on behavioural responses to investigate if task demands could modulate lexical access in this level of response.

The effects of word frequency were only observed when the task required a lexical decision but not when the task required an orthographic onset decision (vowel or consonant) in reaction times, accuracy scores and the RT distribution. However, the effect of lexicality on reaction times was larger in L1 compared to L2 only in the LDT but no effects of lexicality or language were found in the ODT. No interaction between task, lexicality and language was observed in the accuracy scores but the lexicality effect was only significant in LDT relative to ODT. The RT distribution only varied as a function of lexicality in the LDT but not in the ODT.

These results are similar to those by Umansky and Chambers (1980) who observed effects of word frequency in a task that required a decision based on the whole letter string but not when the decision was based only on the first letter of the string. This task effect in bilinguals was similar for L1 and L2, as we did not find any interaction between task, word frequency and language. Nevertheless, the present findings extend on previous findings regarding the effect of lexicality by pointing out that the effect of lexicality is more sensitive to language differences. Furthermore, to our knowledge, no similar studies have been conducted in bilinguals where the stimuli and task sequence remain constant across tasks that only differ in the task decision. Although it has been concluded that lexical access occurs in both languages regardless of task demands, here I also found evidence of task criteria modulating the observation of word frequency and lexicality effects behaviourally. Whether lexical access is in fact occurring should be further explored with the use of more sensitive techniques (e.g. ERPs). To this extent, we can conclude that lexical access observed in behavioural responses can be modulated by task. However, these task modulations impact words in L1 and L2 in a similar manner (word frequency effect), while the larger lexicality effects in L2 compared to L1 on response times might be explained by particular mechanisms in the word and pseudoword processing that caused a delay in responses to items in L2. This will be further discussed in the implications of the findings for the models of visual word recognition.

- **What are the differences between lexical access in L1 and L2?**

Chapters 2 and 3 indicated similar-sized word frequency effects in behavioural responses to L1 and L2 (chapter 2: 91ms vs 95ms; chapter 3: 90ms vs 68ms). In contrast to Duyck et al. (2008) who suggested that larger word frequency effects in L2 compared to L1, should be expected in bilinguals due to the lower proficiency in the L2. However, Diependaele et al. (2013)'s propose that lexical entrenchment could explain similar sized effects of word frequency in L1 and L2. According to Diependaele et al. (2013), the vocabulary size and not the fact of being bilingual can influence the size of the word frequency effect, resulting in larger frequency effects for smaller vocabulary sizes. Bilinguals in Duyck et al.'s study were undergraduate participants, while in the present study, postgraduate students who have studied in England at the time of testing and actively used their L2 in everyday life were tested. In this respect, postgraduate students could have larger vocabulary sizes compared to those of undergraduate students. However, whether bilinguals are accurate in identifying more (high) or less (low) frequent words could reflect language dominance towards L1. In chapter 2, more errors were observed to low frequency compared to high frequency words in L2 relative to L1. However, in chapter 3, only main effects of word frequency and language were observed.

Moreover, participants are slower in discriminating pseudowords and words (lexicality effect) in L2 compared to L1. Chapter 3 provided evidence that the lexicality effect was larger in the less dominant but proficient language (L2). This effect might be due to the participants being less familiar with the vocabulary in the L2 that caused them to give slower responses to L2 pseudowords compared to pseudowords in L1. This was not confirmed in the accuracy analysis because no interaction between language, lexicality and task was found. However, looking at the accuracy scores in each category, the accuracy for pseudowords was just below chance (48%). Even in the L1, the accuracy for pseudowords was very low (65%) compared to responses to words (L1 = 96%, L2 = 90%). This issue was further explored in monolinguals (chapter 4) indicating that the presence of the letter strings might have resulted in a poor performance in this task and therefore, providing evidence of the flexibility of the effect of lexicality in L1 and L2 to the list composition.

In terms of brain responses, lexical access occurs for both languages and is not blocked when the language is not required for the task, therefore evidencing a non-selective lexical access in L1 and L2 (section 1.2.1). However, L1 nontarget showed more similar patterns (timing and location) of the word frequency and lexicality effects to those observed in monolinguals (see question "Does lexical access occur in the nontarget language of bilinguals?" for a further description of the results). By contrast, delayed effects of word frequency and lexicality were observed in L2 compared to L2. Moreno and Kutas (2005) have proposed that vocabulary size might be an important factor in ERPs responses, while, Midgley, Holcomb & Grainger (2009) have proposed that early language effects could be explained by language dominance.

Language effects were also observed in the results from brain responses reported in chapter 2. Because this language effect did not interact with word frequency, this effect might not be reflecting differences in lexical access in L1 and L2 but instead, different cognitive requirements to respond in L1 and L2 or less language exposure.

It has been proposed that the more frequent usage of words in one language would result in higher proficiency in that language (Dijkstra & van Heuven, 2002). If this is the case, proficient bilinguals in L1 and L2 would have a high level of exposure to both languages but this will not guarantee less language dominance towards their L1 if they learned the L2 later in life. Research in bilingual visual word recognition has used the terms of vocabulary size, language exposure, language proficiency or language dominance interchangeably. Further clarification or delimitation of these concepts will be needed to be able to more precisely elucidate the differences in lexical access in L1 and L2.

- **Is lexical access in English monolinguals task-dependent?**

- **Can the effect of repetition be found across two different tasks?**

Chapter 4 provided further evidence that the word frequency and lexicality effects can be modulated by task demands in behavioural responses. In monolingual research, a variety of tasks that include identification tasks and lexical decision tasks have found variations in the word frequency and lexicality effects across tasks (sections 1.1.1.4 and 1.1.2.4) indicating that lexical access might depend on task demands.

In chapter 4 an ODT and a LDT were used. Experiment 3 and 4 only found the effects of word frequency, lexicality and repetition in the LDT, which provided evidence in reaction times, accuracy and RT distribution analyses that these effects are not found in tasks that do not require a lexical decision. Moreover, these experiments also revealed that these lexical effects are sensitive to list composition within the experimental task.

For example, in experiment 3, results from the LDT observed a word frequency effect that was smaller than the effect observed by the British Lexicon Project (BLP) for the same stimulus set in reaction times (45 ms vs. 72 ms). However, this word frequency effect was similar in accuracy to the one observed by the BLP (8% vs. 8%). In contrast, the findings from experiment 4 showed a similar word frequency effect to that observed by the BLP in the LDT reaction times (75 ms vs. 72 ms) and accuracy scores (11% vs. 8%). In relation to the lexicality effect, this was larger in experiment 3 compared to the effect observed in the BLP for reaction times (140 ms vs. 60 ms) and accuracy (29% vs. 3%). Although, the lexicality effect was still larger in experiment 4 compared to the effect observed in the BLP for reaction times (108 ms vs. 60 ms), this was reduced compared to the effect observed in experiment 3. Importantly, the high number of errors exhibit in experiment 3 was reduced in experiment 4, showing similar effects between the results of experiment 4 and the results reported in the BLP for accuracy scores (5% vs. 3%).

These results suggest that task demands and list composition play an important role in modulating the word frequency effect and lexicality effects, therefore influencing lexical access. The RT distribution analyses confirmed this proposal by showing significant interactions between task and word frequency in the mean (mu) and standard deviation (sigma) of the distribution in Experiments 3 and 4, but also indicating that this interaction between task and word frequency became significant for the tail of the distribution in Experiment 4 when the letter strings were excluded from the analysis. Although, RT distributions obtained in experiments 3 and 4 showed similar interactions of task and lexicality in mu and sigma parameters of the distribution but not in tau parameters, pseudowords showed a task effect on the sigma value of the RT distribution in experiment 4 only.

Furthermore, a tendency towards significance was observed in the interaction between frequency, task and repetition in Experiment 3. This tendency was found significant when the pure consonant and pure vowel letter strings were excluded from the stimuli in experiment 4. Thus, the effect of repetition was directly affected by the list composition.

Interestingly, a significant interaction between the effect of word frequency, task and repetition in experiment 4 indicated a reversed pattern of the word frequency effect (faster responses to low frequency words compared to high frequency words) in the ODT and main effects of frequency and repetition in LDT. These results in the ODT might indicate a process different to lexical access, as previous literature in identification tasks have reported faster responses to high frequency words compared to low frequency words, and not the opposite pattern (section 1.1.1.2).

In summary, lexical access as reflected by the effect of word frequency and lexicality is modulated by task and list composition. In the ODT the decision based on the orthographic level did not require any lexical access, and no effects of word frequency and lexicality were therefore observed. Moreover, these effects are also influenced by the global activation of the lexicon that can be manipulated by the list composition within an experiment. Finally, the mu and sigma parameters of the RT distribution could be reflecting local activation of the lexicon since they consistently showed similar result patterns across experiments. However, the tau parameter might reflect global activation of the lexicon as this was the factor directly affected by the list composition change from experiment 3 to experiment 4.

- **Can the effect of repetition be found within the same task?**

Chapter 4 explored the effect of repetition across tasks, while chapter 5 explored the effect of repetition using the same task. Based on the results of chapter 4, potential factors modulating the effect of repetition were also explored by modifying stimuli material. Chapter 5 investigated whether the effect of repetition could be found for pseudowords and whether list composition would play a role in determining the direction (facilitatory/inhibitory) of these repetition effects. Using a block design in a LDT, the effect of repetition was investigated including non-previously seen stimuli in the second block (experiment 5) and the same stimulus list repeated in four consecutive blocks (experiment 6).

In line with previous findings from Balota and Spieler, (1999) and Perea et al., (2016), a facilitatory-inhibitory pattern of repetition effects for words and pseudowords, respectively, was observed in experiment 5. Faster responses were found for repeated words compared to slower responses for repeated pseudowords. The investigation of the word frequency effect revealed larger repetition effects for low frequency words compared to high frequency words and a reduction in the size of the word frequency effect in repeated words. The effect of lexicality was also modulated by repetition but showing an increase in the size of this effect for repeated items.

In contrast, when the stimulus list was repeated in each consecutive block (4 times), the exclusion of non-previously presented items eliminated the effect of repetition for words and also resulted in a facilitative effect for pseudowords.

The analyses of the RT distributions supported the observed patterns in the reaction times analyses and provided additional information regarding the shape of distribution of the response times. Our results of experiment 5 are similar to those of Balota and Spieler (1999) who found an effect of word frequency in the mu parameter. In relation to the lexicality effect modulated by repetition, results from experiment 5 are in agreement with results from Balota and Spieler that observed different repetition effects for words and pseudowords in the estimates of mu and tau, supporting the notion of different processes behind the processing of words and nonwords. Perea et al. (2016), pointed out that this different repetition effect of words and pseudowords could be exhibited in the higher quantiles of the distribution, which is concurrent with the current findings that observed a significant interaction in the sigma parameter of the distribution revealing different shapes of the RT distribution in the higher quantiles.

Nevertheless, the present results are different from Balota and Spieler's (1999) in the observation of an interaction between frequency and repetition in the values of sigma and the lack of effects on tau values. In this chapter repetition was conducted across blocks within the same LDT, whereas Balota and Spieler (1999) used a rhyming judgment task followed by a lexical decision task. Therefore, the task switch in Balota and Spieler could have impacted their findings.

The results of experiment 6 provided further information regarding the facilitative effect of repetition on pseudowords. Perea et al. (2016) suggested that this facilitative effect would be reflecting encoding processes. In the results of experiment 6 a facilitatory effect was observed on the reaction times analyses that decreased in size as the block number increased. This pattern was also found in the parameter of sigma, indicating shape variations of the RT distribution caused by the interaction between lexicality and repetition. The effect of frequency, however, did not interact with the effect of repetition although main effects of word frequency were found in mu, sigma and tau further supporting the notion that the effect of word frequency remained stable through repetitions when all the stimuli in the list were repeated.

In summary, the effect of repetition can be found within blocks of the same task if the task employed requires a lexical decision. However, the role of list composition might modulate the presence and magnitude of the repetition effects and its interaction with word frequency and lexicality.

6.2. Further Implications

Previous findings have incorporated some predictions based on bilingual and monolingual models of word recognition. The implications of the findings in terms of the models discussed in sections 1.1.3 and 1.2.3 will be presented below.

According to the Bilingual Interactive Activation model (BIA+, Dijkstra & van Heuven, 2002), the bilingual visual word recognition requires an integrated lexicon that is accessed in a nonselective manner. This proposal was demonstrated in chapter 2 where word frequency and lexicality effects were found in the nontarget language, which is also consistent with the BIA+ proposal of the word identification system not being controlled by task demands.

BIA+ proposes that bilingual visual word recognition requires different levels of processing. These levels are the feature level, the letter level and the lexical level. The lexical level is the highest order level where the effect of word frequency takes place and could be explained by different resting-activation levels for the word representations according to their frequency of usage: high frequency words possess low resting levels of activation while low frequency words have higher resting levels. In this context, the fact that the size of the word frequency effect did not vary significantly by language in chapters 2 and 3 would reflect similar strength of the representations between L1 and L2. Nevertheless, main effects of language on reaction times support the notion that the frequency of exposure could strengthen the representations in L1 compared to those in L2, therefore, showing slower responses to L2 relative to L1 and further supporting the hypothesis of different resting-level activation of the representations in L1 and L2 in late (or unbalanced) bilinguals. It seems that the overall speed of the responses might reflect these differences in resting-levels rather than the size of the word frequency effect, in agreement with the assumption of a temporal delay for weaker representations.

BIA+ have proposed that the global language context does not affect activation in the word recognition system, however, the model does not account for global language activation within the same language and concepts such as global activation as proposed by the Multiple Read-Out Model (MROM, Grainger and Jacobs, 1996) or a trial-by-trial adjustments of the response criteria like the Leaky Competing Accumulator Model (LCA, Dufau, Grainger & Ziegler, 2012). Therefore, it is not able to predict high error rates for pseudowords when letter strings are included in the stimulus list or the role of list composition. Also, the model does not explain any mechanisms behind the effect of repetition that were not found when letter strings were included in the stimuli, similar to experiment 3 in monolinguals.

Regarding the monolingual models, the MROM can account for the high number of errors observed in experiments 3 by explaining that a lexical decision does not necessarily require (complete) identification of the word stimuli and therefore would involve the influence of intra- and extra-lexical sources of information in order to generate a binary lexical decision response ('yes' or 'no'). Intra-lexical sources of information in this model are the overall (global) activity in the orthographic lexicon and the (local) activity of functional units within the lexicon, to generate a 'yes' response. The extra-lexical source of information is the time from stimulus onset. These interact with each other to produce different response patterns in a lexical decision. Errors generated by making positive responses to pseudowords (false positive) are the result of either a short time criterion, or because stimuli generate high local activation and in combination with a low global activation criterion. This would generate faster correct responses for words and a higher number of false positive errors for nonwords (for further discussion see section 1.1.3.2).

Although this model correctly predicts reaction times and error rates, it does not predict RT distribution results (see section 1.1.3.3). Furthermore, the model does not make any predictions regarding the effects of repetition for words and nonwords as is the case with models based on the diffusion model (Ratcliff, 1978). Therefore, a model based on the evidence of accumulation over time would help to explain the pattern of results.

The potential mechanism behind the repetition effect of nonwords is explained by the LCA model (Dufau, Grainger & Ziegler, 2012). The LCA model (discussed in section 1.1.3.4), similar to the diffusion model (Ratcliff, 1978, described in section 1.1.3.3), explains a lexical decision by incorporating two response nodes ('yes' and 'no'). In the case of words, 'yes' responses only depend on the accumulation of evidence towards a word. However, 'no' responses to pseudowords (evidence towards a nonword) depend on the accumulation of evidence towards a word and mutually inhibitory connections between the two response nodes (the rise in activity in one automatically causes a reduction in activity in the other and vice versa). Repetition increases the evidence accumulation for a word, facilitating responses for these items. This rise in activity of the 'yes' node will cause inhibition on the 'no' responses, therefore inhibiting responses for pseudowords with repetition.

The LCA model considers the evidence towards a word not only for each trial but also the contribution of this evidence trial-by-trial as an adjustment of the response criteria within the lexical decision task. Because the initial input value can be adjusted to optimise performance in the same way as it can the response criteria, modifying the list context in each task would modify the task context reducing the time to give a 'No' response and modifying any inhibitory link between the 'yes' and 'no' responses (response nodes according to the LCA). Although this model does well in explaining the repetition and list composition effects, it is limited to the lexical decision in relation to the role of task demands.

In summary, some concepts incorporated in monolingual models are needed in the bilingual models to better describe the visual word recognition process. Research in bilingualism has focused on different questions regarding the visual word recognition system, which have left questions unanswered regarding basic mechanisms in visual word recognition that have already been explored in monolingual research. Although bilinguals and monolinguals visual word recognition require different mechanisms, factors such as word frequency, lexicality and repetition have been found in bilingual and monolingual research, as well as the role of task demands and repetition. Therefore, models of bilingual word recognition can be developed to include an explanation of these mechanisms to explore the decision system within a specific task (e.g. diffusion model) and other factors such as list composition influencing the responses in visual word recognition (e.g. LCA).

The present thesis has shown that there is limited research in monolinguals that investigated the effect of word frequency, lexicality and repetition with the focus on task demands and list composition. The data presented in this thesis demonstrated that the latter factors were crucial in modulating different lexical effects in the process of visual word recognition in monolinguals. Given that previous research has involved a variety of task instructions and stimulus lists, the conclusions drawn by such studies could only be presenting a partial picture of the mechanisms behind the process of visual word recognition and therefore, future research needs to account for these variations. Although some of the recent models of monolingual visual word recognition have incorporated these factors, their implementation and comparison with participants' real data are lacking.

Furthermore, research in bilingual visual word recognition has been even less focused on the investigation of the role of task demands and list composition. This thesis shows that high error rates observed in bilingual when compared to monolingual participants could be due to the effect of the list composition rather than being bilingual. Moreover, studies have not considered the effects that different task variations have in lexical access before concluding that bilinguals are able or not able to block lexical access in their nontarget language. Therefore, there is a strong need for the investigation of the word frequency and the lexicality effects in bilinguals considering these aspects that are present in the research process and the decision of a paradigm and stimulus list. Moreover, investigating the process of visual word recognition in bilinguals under a similar perspective that some models of monolingual visual word recognition has adopted will not only be beneficial in the understanding of this process based on the findings of research in monolingual visual word recognition but it will also guide the development of current models visual word recognition in bilinguals. Bilingual models of visual word recognition have been developed based on the results from behavioural responses in different paradigms and stimulus sets, that in turn have been chosen based on classic but limited measures of word frequency. This thesis shows that using more broad and updated measures of word frequency, investigating the response time distribution and the brain responses, as well as considering the role of task demands and list composition should be essential to improve current models so that the conclusions obtained based on those models can be clearer and contribute to a better understanding of the differences and similarities between bilingual and monolingual visual word recognition. Future research and models of visual word recognition should then incorporate these elements to better describe the monolingual and bilingual visual word recognition systems and to better explain how bilingualism shapes this process from the starting point of monolingual visual word recognition.

6.3. Limitations

The present findings can present some limitations including the high error rate for pseudowords in experiment 2 and 3. Previously, I have explained that I consider these high error rates to be a reflection of the function of the visual word recognition and the role of list composition, as evidenced by findings in monolingual participants in experiments 3-6. However, further experiments will need to be conducted in bilinguals to corroborate this.

In the present thesis Spanish-English bilinguals were studied. Although, I do not consider this to be a strong limitation, previous results that suggested larger word frequency effects in bilinguals' L2 were observed in different bilingual populations (e.g. Dutch-English in Duyck et al, 2008, and Catalan-Spanish in Rodríguez-Fornells et al., 2002). However, similar results to those reported in chapter 2 have been found in a similar population of Spanish-English bilinguals by Ng and Wicha (2013).

Initially, I was also interested in conducting experiments that required decisions at semantic and language levels in order to fully delineate time differences in visual word recognition in bilinguals and monolinguals. Furthermore, the role of task demands was also intended to be investigated with ERPs to further clarify if lexical access occurs even in the ODT. However, time constraints did not allow me to conduct experiments with semantic and language decisions or to finalise the ERP experiment with the same paradigm used in chapter 4.

6.4. Future research

The present thesis has explored word frequency and lexicality in bilinguals highlighting the nonselective nature of lexical access in bilinguals, the similar word frequency effects sizes in bilinguals' L1 and L2 but the delayed responses in L2 compared to L1. Also, in monolinguals it has been observed that list composition plays an important role in determining lexicality and repetition effects, especially for pseudowords. However, some unanswered questions remain as to what the mechanism is in brain responses of an orthographic identification task, and whether lexical access is triggered by only reading a single letter in the beginning of a letter string as it had been predicted by some models of visual word recognition that state a parallel activation of letters and letters strings. Future research will explore this possibility with ERPs in order to have a more sensitive measure that could clarify this question in different decision levels including an orthographic, lexical, semantic and language (in bilinguals) levels.

Another important question regards the effect of repetition in bilinguals and whether it is possible to observe facilitative and inhibitory repetition effects in L1 and L2. Combining the effect of repetition with orthographic, lexical and semantic tasks will help understanding the mechanisms of language acquisition and the incorporation of low frequency words into the bilinguals' lexicon.

Future research will also investigate whether list compositions that incorporate a high global lexical activation help incorporate low frequency L2 words into bilinguals' mental lexicon.

6.5. Conclusions

Lexical access occurs in both languages of bilinguals, regardless of target or nontarget conditions. Interestingly, the timing and error rate of the lexical effects might reflect bilinguals' dominance towards L1. Task criteria modulate the observation of word frequency and lexicality effects behaviourally, whether lexical access is in fact occurring should be further explored. However, task modulations impact words in L1 and L2 in a similar manner (word frequency effect), while the larger lexicality effects in L2 compared to L1 on response times might be explained by particular mechanisms in the word and pseudoword processing that delay responses in L2.

In monolinguals, lexical access as reflected by the effect of word frequency and lexicality is modulated by task and list composition, as revealed by behavioural responses. Word frequency, lexicality and repetition effects are influenced by the global activation of the lexicon that can be manipulated by the list composition within an experiment. The tau parameter of the RT distribution might reflect global activation of the lexicon. While the effect of repetition can be found within blocks of the same task if the task employed requires a lexical decision, the role of list composition might modulate the presence and magnitude of the repetition effects and its interaction with word frequency and lexicality.

Bilingual models that incorporate the role of repetition, task demands and list composition are needed. Monolingual models can provide successful conceptualisation of those factors and contribute to the development of bilingual models.

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Appendices

Appendix I. Stimuli in Spanish (L1) used in Experiment 1 and 2

Item	Zipf value	Neighbourhood Density with words of 4-6 letters N Within-Language	Neighbourhood Density with words with Zipf values above 2 Within-Language	Neighbourhood Density with high frequency words Within-Language	Neighbourhood Density with words of 4-6 letters N Between-Languages	Neighbourhood Density with words with Zipf values above 2 Between-Languages	Neighbourhood Density with high frequency words Between-Languages	Condition	Onset: vowel (v) or consonant (c)	Length
abrazo	4.3	1	1	0	0	0	0	HF	v	6
abrigo	4.4	1	1	0	1	0	0	HF	v	6
abuelo	4.9	1	1	1	1	0	0	HF	v	6
aceite	4.3	2	2	0	0	0	0	HF	v	6
acero	4.2	3	3	0	3	1	0	HF	v	5
afecto	3.9	4	4	2	0	0	0	HF	v	6
agosto	4.1	0	0	0	0	0	0	HF	v	6
agrado	4.0	4	4	1	0	0	0	HF	v	6
agua	5.4	0	0	0	7	4	0	HF	v	4
aguja	4.1	1	1	0	2	2	0	HF	v	5
aldea	4.2	0	0	0	2	1	0	HF	v	5
alivio	4.2	2	2	0	1	0	0	HF	v	6
alma	4.9	7	7	3	20	8	0	HF	v	4
alteza	4.0	1	1	0	0	0	0	HF	v	6
altura	4.5	1	1	0	0	0	0	HF	v	6
alumno	3.9	1	1	0	2	1	0	HF	v	6

amante	4.5	3	3	0	2	1	0	HF	v	6
amigo	5.8	2	1	1	3	1	0	HF	v	5
amor	5.6	2	2	1	14	6	0	HF	v	4
anillo	4.8	1	0	0	1	0	0	HF	v	6
ante	4.9	5	4	1	14	8	2	HF	v	4
apodo	3.9	2	2	2	1	0	0	HF	v	5
apoyo	4.7	4	4	2	1	0	0	HF	v	5
apuro	3.9	2	2	0	2	0	0	HF	v	5
arena	4.4	6	6	0	7	1	0	HF	v	5
arroz	4.1	1	1	0	3	2	0	HF	v	5
asalto	4.3	1	1	0	0	0	0	HF	v	6
asco	4.5	3	3	1	8	1	0	HF	v	4
asunto	5.1	2	2	0	0	0	0	HF	v	6
ataque	5.0	0	0	0	0	0	0	HF	v	6
aviso	4.4	2	2	0	0	0	0	HF	v	5
ayuda	5.5	5	4	2	0	0	0	HF	v	5
azar	4.1	6	6	1	16	7	0	HF	v	4
basura	5.1	1	1	0	0	0	0	HF	c	6
bicho	4.0	3	2	1	0	0	0	HF	c	5
bolsa	4.9	2	2	1	3	2	0	HF	c	5
bosque	4.7	1	1	1	3	3	0	HF	c	6
broma	4.9	5	5	0	9	1	0	HF	c	5
cabeza	5.6	0	0	0	0	0	0	HF	c	6
cabra	4.0	3	3	0	7	3	0	HF	c	5

celda	4.5	3	3	0	4	2	0	HF	c	5
cielo	5.2	5	5	3	2	0	0	HF	c	5
cueva	4.1	5	5	2	3	0	0	HF	c	5
deuda	4.4	0	0	0	0	0	0	HF	c	5
dibujo	4.1	2	2	0	0	0	0	HF	c	6
dicho	5.4	6	5	1	1	0	0	HF	c	5
dinero	5.9	1	1	0	2	1	0	HF	c	6
edad	5.1	0	0	0	7	1	0	HF	v	4
empleo	4.8	2	1	0	0	0	0	HF	v	6
enano	4.0	1	1	0	2	0	0	HF	v	5
enero	4.1	1	1	1	3	0	0	HF	v	5
enlace	4.0	0	0	0	1	0	0	HF	v	6
ensayo	4.4	2	2	0	0	0	0	HF	v	6
equipo	5.4	1	1	0	1	0	0	HF	v	6
escena	4.9	0	0	0	0	0	0	HF	v	6
escudo	4.0	1	1	0	0	0	0	HF	v	6
espada	4.5	0	0	0	1	1	0	HF	v	6
espejo	4.5	2	2	1	0	0	0	HF	v	6
espera	5.8	7	7	2	2	0	0	HF	v	6
esposo	5.1	3	3	1	1	0	0	HF	v	6
estado	5.8	1	0	0	0	0	0	HF	v	6
etapa	4.1	0	0	0	1	1	0	HF	v	5
feria	4.2	2	2	2	4	1	0	HF	c	5
fiesta	5.4	1	1	1	2	1	0	HF	c	6

fuego	5.1	4	4	3	3	1	0	HF	c	5
fuerza	5.0	2	1	0	0	0	0	HF	c	6
golpe	4.8	0	0	0	2	0	0	HF	c	5
granja	4.5	1	1	0	4	1	0	HF	c	6
grito	4.0	5	5	2	6	1	0	HF	c	5
hambre	5.0	1	1	0	3	2	0	HF	c	6
hielo	4.8	4	3	2	2	1	0	HF	c	5
hogar	4.9	1	1	0	5	2	0	HF	c	5
horno	4.1	2	2	1	7	4	1	HF	c	5
hueso	4.2	4	4	4	2	1	0	HF	c	5
jaula	4.1	2	1	1	1	1	1	HF	c	5
jefe	5.3	1	1	1	6	2	1	HF	c	4
juego	5.4	5	5	4	2	2	0	HF	c	5
juicio	4.8	1	1	0	0	0	0	HF	c	6
leche	4.7	2	2	0	4	0	0	HF	c	5
lengua	4.6	1	0	0	1	1	0	HF	c	6
letra	4.3	2	1	0	3	1	0	HF	c	5
libro	5.2	3	3	1	4	2	0	HF	c	5
mitad	5.1	2	2	0	0	0	0	HF	c	5
mujer	5.7	0	0	0	2	0	0	HF	c	5
multa	4.0	4	4	0	6	2	1	HF	c	5
mundo	5.8	3	3	1	10	6	0	HF	c	5
nieve	4.5	2	2	1	7	3	0	HF	c	5
noche	5.9	2	2	1	7	2	0	HF	c	5

nombre	5.7	3	3	0	2	2	0	HF	c	6
novio	5.1	1	1	1	2	1	0	HF	c	5
obra	4.8	4	3	2	5	2	0	HF	v	4
ocho	5.0	2	2	1	10	4	0	HF	v	4
odio	5.2	5	5	2	7	4	0	HF	v	4
oeste	4.7	2	2	0	8	0	0	HF	v	5
oferta	4.7	1	1	0	1	0	0	HF	v	6
ojos	5.4	2	2	1	0	0	0	HF	v	4
olas	4.2	6	5	1	15	6	1	HF	v	4
olor	4.6	2	2	2	6	1	0	HF	v	4
olvido	4.2	2	2	2	0	0	0	HF	v	6
onda	4.4	2	2	1	8	2	0	HF	v	4
oreja	4.2	1	1	0	0	0	0	HF	v	5
pecho	4.6	5	5	2	3	0	0	HF	c	5
polvo	4.6	3	3	1	3	3	0	HF	c	5
prueba	5.2	2	2	0	1	0	0	HF	c	6
pueblo	5.2	1	1	0	1	0	0	HF	c	6
regalo	5.0	5	4	0	4	1	0	HF	c	6
reina	4.8	4	4	1	6	3	0	HF	c	5
ruido	4.7	4	4	0	1	1	0	HF	c	5
sabor	4.3	3	3	1	6	4	0	HF	c	5
salud	4.9	1	1	0	4	2	1	HF	c	5
siglo	4.5	2	2	1	0	0	0	HF	c	5
sonido	4.7	1	1	0	0	0	0	HF	c	6

techo	4.6	5	5	2	4	2	0	HF	c	5
tejido	4.1	4	4	1	0	0	0	HF	c	6
tienda	5.0	4	4	0	0	0	0	HF	c	6
trozo	4.2	3	2	1	3	1	0	HF	c	5
unidad	4.7	1	1	0	0	0	0	HF	v	6
verano	4.9	1	1	0	2	0	0	HF	c	6
viaje	5.2	2	2	0	1	0	0	HF	c	5
vuelo	4.9	6	6	3	0	0	0	HF	c	5
abeja	3.9	1	1	0	1	1	0	LF	v	5
abono	3.3	1	0	0	2	1	0	LF	v	5
acecho	3.2	1	1	0	0	0	0	LF	v	6
acera	3.8	2	2	1	4	2	0	LF	v	5
acorde	3.4	2	0	0	0	0	0	LF	v	6
aduana	3.6	0	0	0	0	0	0	LF	v	6
alba	3.5	5	5	3	19	8	0	LF	v	4
aleta	3.1	3	3	0	4	1	0	LF	v	5
almeja	3.3	0	0	0	0	0	0	LF	v	6
apio	3.1	3	3	0	10	0	0	LF	v	4
arado	2.6	7	7	3	3	1	0	LF	v	5
arce	3.2	7	7	2	15	8	1	LF	v	4
arete	3.2	1	1	0	5	1	0	LF	v	5
arroyo	3.7	1	1	0	0	0	0	LF	v	6
asesor	3.8	0	0	0	0	0	0	LF	v	6
auge	2.8	1	1	0	12	4	1	LF	v	4

aula	3.5	4	4	0	20	10	0	LF	v	4
aval	2.7	2	2	0	11	4	0	LF	v	4
balde	3.8	1	1	0	7	1	0	LF	c	5
bocina	3.6	5	4	1	1	0	0	LF	c	6
bolero	2.7	3	3	1	1	0	0	LF	c	6
borla	2.3	3	3	0	3	0	0	LF	c	5
bulto	3.5	4	4	1	2	1	0	LF	c	5
canela	3.6	0	0	0	2	0	0	LF	c	6
cerco	3.0	5	5	3	7	2	0	LF	c	5
chispa	3.8	1	1	0	1	1	0	LF	c	6
clavo	3.8	4	4	2	2	0	0	LF	c	5
cofre	3.7	3	3	1	3	0	0	LF	c	5
dedal	2.4	2	2	0	5	2	1	LF	c	5
desliz	3.1	0	0	0	0	0	0	LF	c	6
divisa	2.7	3	2	1	2	0	0	LF	c	6
dureza	3.1	1	1	0	0	0	0	LF	c	6
ejes	2.7	5	4	0	10	6	1	LF	v	4
elenco	3.6	0	0	0	0	0	0	LF	v	6
elogio	3.2	2	1	0	0	0	0	LF	v	6
embudo	2.9	0	0	0	0	0	0	LF	v	6
emisor	3.0	0	0	0	0	0	0	LF	v	6
empate	3.6	2	2	0	2	0	0	LF	v	6
encaje	3.5	4	3	1	1	1	0	LF	v	6
encino	2.7	0	0	0	0	0	0	LF	v	6

enredo	3.2	2	2	0	0	0	0	LF	v	6
ente	3.2	4	3	1	16	3	0	LF	v	4
erizo	2.9	1	1	0	0	0	0	LF	v	5
esbozo	2.5	0	0	0	0	0	0	LF	v	6
escama	2.7	3	3	2	0	0	0	LF	v	6
escoba	3.7	1	1	0	0	0	0	LF	v	6
escote	3.4	1	1	0	1	0	0	LF	v	6
espina	3.7	3	2	0	1	1	0	LF	v	6
espuma	3.8	1	1	0	0	0	0	LF	v	6
estufa	3.5	1	1	1	0	0	0	LF	v	6
faena	2.8	2	2	0	2	1	0	LF	c	5
fleco	2.2	1	1	0	3	1	0	LF	c	5
flora	3.5	3	3	2	4	0	0	LF	c	5
franja	3.1	2	2	1	2	1	0	LF	c	6
gaita	2.8	3	3	1	3	1	0	LF	c	5
garfio	3.2	0	0	0	1	0	0	LF	c	6
gruta	3.1	4	4	2	5	1	0	LF	c	5
hebra	2.6	1	1	0	5	2	0	LF	c	5
hiedra	3.1	1	1	1	0	0	0	LF	c	6
hiena	2.8	4	4	0	5	2	0	LF	c	5
hongo	3.5	6	5	1	9	4	0	LF	c	5
huerta	3.0	4	4	2	2	0	0	LF	c	6
ingle	3.2	1	1	0	4	3	1	LF	v	5
jalea	3.6	4	4	0	3	1	0	LF	c	5

jarabe	3.7	0	0	0	0	0	0	LF	c	6
jarro	3.1	5	5	1	7	3	0	LF	c	5
jinete	3.8	0	0	0	0	0	0	LF	c	6
labio	3.7	3	3	1	4	3	0	LF	c	5
lavabo	3.7	2	2	1	0	0	0	LF	c	6
lirio	2.8	3	3	0	1	0	0	LF	c	5
llaga	2.8	4	4	3	3	1	0	LF	c	5
maceta	3.1	3	3	1	1	0	0	LF	c	6
madeja	2.2	2	2	2	2	0	0	LF	c	6
matiz	2.8	0	0	0	5	1	0	LF	c	5
meseta	2.7	3	3	0	1	0	0	LF	c	6
naipe	2.3	0	0	0	3	1	0	LF	c	5
navaja	3.9	1	1	0	1	1	0	LF	c	6
nogal	2.8	0	0	0	3	0	0	LF	c	5
nutria	3.0	1	1	0	0	0	0	LF	c	6
obrero	3.4	1	1	0	0	0	0	LF	v	6
ocaso	3.3	1	1	1	1	0	0	LF	v	5
ocio	3.1	4	4	3	4	4	0	LF	v	4
oficio	3.9	2	0	0	0	0	0	LF	v	6
ojal	2.6	2	2	0	4	3	0	LF	v	4
ojeada	3.2	2	2	0	0	0	0	LF	v	6
oleaje	2.9	0	0	0	0	0	0	LF	v	6
olfato	3.5	0	0	0	0	0	0	LF	v	6
olla	3.7	3	3	0	13	6	0	LF	v	4

olmo	2.6	0	0	0	3	2	0	LF	v	4
onza	3.1	1	1	1	3	0	0	LF	v	4
orilla	3.8	2	2	0	0	0	0	LF	v	6
oropel	2.2	1	1	0	1	1	0	LF	v	6
ortiga	2.1	1	1	0	1	0	0	LF	v	6
oruga	3.2	0	0	0	0	0	0	LF	v	5
osezno	2.3	0	0	0	0	0	0	LF	v	6
oveja	3.8	1	1	1	1	0	0	LF	v	5
ovillo	2.7	0	0	0	0	0	0	LF	v	6
palco	3.4	4	2	0	6	1	0	LF	c	5
peaje	3.3	0	0	0	4	3	1	LF	c	5
pepino	3.4	0	0	0	0	0	0	LF	c	6
perno	2.9	4	4	2	2	1	0	LF	c	5
resina	3.0	3	2	0	4	3	0	LF	c	6
roble	3.6	2	2	2	11	3	1	LF	c	5
rosal	2.5	1	1	0	5	1	1	LF	c	5
siena	2.9	4	3	1	5	0	0	LF	c	5
sigilo	2.9	1	1	0	0	0	0	LF	c	6
sismo	2.4	1	1	1	6	2	0	LF	c	5
sutura	3.2	4	2	1	2	1	0	LF	c	6
tambor	3.7	0	0	0	0	0	0	LF	c	6
tapiz	3.0	1	1	0	3	1	0	LF	c	5
tejado	3.8	4	3	2	0	0	0	LF	c	6
toldo	2.8	0	0	0	3	1	0	LF	c	5

ubre	2.4	2	2	0	1	0	0	LF	v	4
umbral	3.5	0	0	0	0	0	0	LF	v	6
urna	3.3	0	0	0	8	4	0	LF	v	4
urraca	2.5	0	0	0	0	0	0	LF	v	6
uvas	3.6	2	2	2	4	1	0	LF	v	4
vaho	2.2	4	4	3	2	0	0	LF	c	4
vasija	3.2	1	1	0	0	0	0	LF	c	6
vejez	3.4	0	0	0	2	0	0	LF	c	5
aaeeao	NA	0	0	0	0	0	0	nonword	v	6
aaoi	NA	0	0	0	5	1	0	nonword	v	4
aeeooe	NA	0	0	0	0	0	0	nonword	v	6
aeieou	NA	0	0	0	0	0	0	nonword	v	6
aeiiie	NA	0	0	0	0	0	0	nonword	v	6
aeioea	NA	0	0	0	0	0	0	nonword	v	6
aeiuu	NA	0	0	0	0	0	0	nonword	v	5
aeoie	NA	0	0	0	0	0	0	nonword	v	5
aeooie	NA	0	0	0	0	0	0	nonword	v	6
aeueui	NA	0	0	0	0	0	0	nonword	v	6
aeuuee	NA	0	0	0	0	0	0	nonword	v	6
aiao	NA	1	1	0	10	4	0	nonword	v	4
aieiei	NA	0	0	0	0	0	0	nonword	v	6
aioea	NA	1	0	0	0	0	0	nonword	v	5
aioeu	NA	0	0	0	0	0	0	nonword	v	5
aiueue	NA	0	0	0	0	0	0	nonword	v	6

aiui	NA	0	0	0	3	2	0	nonword	v	4
aiuie	NA	0	0	0	1	0	0	nonword	v	5
aiuiee	NA	0	0	0	0	0	0	nonword	v	6
aoaiua	NA	0	0	0	0	0	0	nonword	v	6
aoee	NA	0	0	0	13	0	0	nonword	v	4
aoiu	NA	0	0	0	1	0	0	nonword	v	4
aoouaa	NA	0	0	0	0	0	0	nonword	v	6
aoueea	NA	0	0	0	0	0	0	nonword	v	6
aouiee	NA	0	0	0	0	0	0	nonword	v	6
auauee	NA	0	0	0	0	0	0	nonword	v	6
auea	NA	4	3	0	4	2	1	nonword	v	4
aueia	NA	0	0	0	0	0	0	nonword	v	5
auiao	NA	0	0	0	0	0	0	nonword	v	5
auiiei	NA	0	0	0	0	0	0	nonword	v	6
auoea	NA	0	0	0	1	0	0	nonword	v	5
bjnwt	NA	0	0	0	0	0	0	nonword	c	5
blpst	NA	0	0	0	3	2	1	nonword	c	5
bpcbxb	NA	0	0	0	0	0	0	nonword	c	6
btbvbm	NA	0	0	0	0	0	0	nonword	c	6
bysfq	NA	0	0	0	0	0	0	nonword	c	5
cdtrm	NA	0	0	0	0	0	0	nonword	c	5
cgwst	NA	0	0	0	0	0	0	nonword	c	5
cjnjlc	NA	0	0	0	0	0	0	nonword	c	6
cksvg	NA	0	0	0	0	0	0	nonword	c	5

cwxcxr	NA	0	0	0	0	0	0	nonword	c	6
dgwhx	NA	0	0	0	0	0	0	nonword	c	5
dlxtlw	NA	0	0	0	0	0	0	nonword	c	6
dtbtwd	NA	0	0	0	0	0	0	nonword	c	6
dxych	NA	0	0	0	0	0	0	nonword	c	5
eaeiia	NA	0	0	0	0	0	0	nonword	v	6
eaeuiu	NA	0	0	0	0	0	0	nonword	v	6
eaieia	NA	0	0	0	0	0	0	nonword	v	6
eaoio	NA	0	0	0	0	0	0	nonword	v	5
eaueou	NA	0	0	0	0	0	0	nonword	v	6
eiao	NA	1	1	0	8	4	0	nonword	v	4
eieaia	NA	0	0	0	0	0	0	nonword	v	6
eieuiu	NA	0	0	0	0	0	0	nonword	v	6
eiiaea	NA	0	0	0	0	0	0	nonword	v	6
eiiaeo	NA	0	0	0	0	0	0	nonword	v	6
eiuoeo	NA	0	0	0	0	0	0	nonword	v	6
eoiuae	NA	0	0	0	0	0	0	nonword	v	6
eoua	NA	0	0	0	2	0	0	nonword	v	4
euaee	NA	0	0	0	0	0	0	nonword	v	5
eueauo	NA	0	0	0	0	0	0	nonword	v	6
euieao	NA	0	0	0	0	0	0	nonword	v	6
euieii	NA	0	0	0	0	0	0	nonword	v	6
fbdsr	NA	0	0	0	0	0	0	nonword	c	5
fjmzk	NA	0	0	0	0	0	0	nonword	c	5

fpxwpk	NA	0	0	0	0	0	0	nonword	c	6
fsfpmz	NA	0	0	0	0	0	0	nonword	c	6
gczxcq	NA	0	0	0	0	0	0	nonword	c	6
ghrpc	NA	0	0	0	0	0	0	nonword	c	5
gmrys	NA	0	0	0	2	1	0	nonword	c	5
hfjcdc	NA	0	0	0	0	0	0	nonword	c	6
hjclk	NA	0	0	0	0	0	0	nonword	c	5
hlstf	NA	0	0	0	0	0	0	nonword	c	5
hrcjr	NA	0	0	0	0	0	0	nonword	c	5
hswcqc	NA	0	0	0	0	0	0	nonword	c	6
iuaeo	NA	0	0	0	0	0	0	nonword	v	5
jmzbk	NA	0	0	0	0	0	0	nonword	c	5
jqmtv	NA	0	0	0	0	0	0	nonword	c	5
jqtmxm	NA	0	0	0	0	0	0	nonword	c	6
jzkp	NA	0	0	0	0	0	0	nonword	c	4
lcwcbx	NA	0	0	0	0	0	0	nonword	c	6
llzpc	NA	0	0	0	0	0	0	nonword	c	5
lmcbr	NA	0	0	0	0	0	0	nonword	c	5
lsqsd	NA	0	0	0	0	0	0	nonword	c	5
mghqv	NA	0	0	0	0	0	0	nonword	c	5
mvbcrc	NA	0	0	0	0	0	0	nonword	c	6
mxscw	NA	0	0	0	0	0	0	nonword	c	5
mzrccs	NA	0	0	0	0	0	0	nonword	c	6
nchxdc	NA	0	0	0	0	0	0	nonword	c	6

ncqcnv	NA	0	0	0	0	0	0	nonword	c	6
ndjhj	NA	0	0	0	0	0	0	nonword	c	5
nxyjk	NA	0	0	0	0	0	0	nonword	c	5
oaaeei	NA	0	0	0	0	0	0	nonword	v	6
oaeei	NA	0	0	0	0	0	0	nonword	v	5
oaieae	NA	0	0	0	0	0	0	nonword	v	6
oeiee	NA	0	0	0	0	0	0	nonword	v	5
oeuaeu	NA	0	0	0	0	0	0	nonword	v	6
oieiei	NA	0	0	0	0	0	0	nonword	v	6
oueeai	NA	0	0	0	0	0	0	nonword	v	6
ouoiee	NA	0	0	0	0	0	0	nonword	v	6
pcfsh	NA	0	0	0	0	0	0	nonword	c	5
pqtmtt	NA	0	0	0	0	0	0	nonword	c	6
prkzvk	NA	0	0	0	0	0	0	nonword	c	6
pvgjy	NA	0	0	0	0	0	0	nonword	c	5
rbjbl	NA	0	0	0	0	0	0	nonword	c	5
rdkthh	NA	0	0	0	0	0	0	nonword	c	6
rvcfs	NA	0	0	0	0	0	0	nonword	c	5
sgjjss	NA	0	0	0	0	0	0	nonword	c	6
sgrgcr	NA	0	0	0	0	0	0	nonword	c	6
sjtdw	NA	0	0	0	0	0	0	nonword	c	5
smdfz	NA	0	0	0	0	0	0	nonword	c	5
tbvnkt	NA	0	0	0	0	0	0	nonword	c	6
tcxgkc	NA	0	0	0	0	0	0	nonword	c	6

tmfks	NA	0	0	0	0	0	0	nonword	c	5
tqrlc	NA	0	0	0	0	0	0	nonword	c	5
uaeaeu	NA	0	0	0	0	0	0	nonword	v	6
uaie	NA	0	0	0	6	0	0	nonword	v	4
uoueie	NA	0	0	0	0	0	0	nonword	v	6
vcxt	NA	0	0	0	0	0	0	nonword	c	4
vhsbp	NA	0	0	0	0	0	0	nonword	c	5
vwjlll	NA	0	0	0	0	0	0	nonword	c	6

Appendix II Spanish Pseudowords Experiment 1

Item Name	Neigbourhood Density Spanish LexStat	Neighbourhood Density English LexStat	Condition	Onset	Length
abasa	2	7	pseudoword	v	5
actigo	1	0	pseudoword	v	6
agude	5	0	pseudoword	v	5
ascena	1	3	pseudoword	v	6
atrede	3	0	pseudoword	v	6
blecha	2	0	pseudoword	c	6
crupe	3	7	pseudoword	c	5
detro	4	4	pseudoword	c	5
emplio	3	1	pseudoword	v	6
entea	2	3	pseudoword	v	5
erite	5	7	pseudoword	v	5
estavo	3	0	pseudoword	v	6
estera	7	1	pseudoword	v	6
fosma	1	3	pseudoword	c	5
gruese	2	1	pseudoword	c	6
hebio	1	2	pseudoword	c	5
jaura	4	4	pseudoword	c	5
luele	6	0	pseudoword	c	5
margo	8	3	pseudoword	c	5

nidra	3	3	pseudoword	c	5
oblito	1	0	pseudoword	v	6
onde	4	1	pseudoword	v	4
opesa	2	1	pseudoword	v	5
orano	4	4	pseudoword	v	5
orde	2	2	pseudoword	v	4
prunia	1	1	pseudoword	c	6
rimbre	2	1	pseudoword	c	6
santro	1	1	pseudoword	c	6
tople	1	5	pseudoword	c	5
vioso	2	0	pseudoword	c	5

Appendix III Spanish Pseudowords Experiment 2

Item Name	Neighbourhood Density with words of 4-6 letters N Within-Language	Neighbourhood Density with words with Zipf values above 2 Within-Language	Neighbourhood Density with high frequency words Within-Language	Neighbourhood Density with words of 4-6 letters N Between-Languages	Neighbourhood Density with words with Zipf values above 2 Between-Languages	Neighbourhood Density with high frequency words Between-Languages	Condition	Onset: vowel (v) or consonant (c)	Length
acrir	1	1	1	1	1	0	pseudoword	v	5
acupo	3	3	1	0	0	0	pseudoword	v	5
adeal	1	1	1	4	1	1	pseudoword	v	5
aditor	1	1	1	1	1	1	pseudoword	v	6
aerbo	1	1	0	1	0	0	pseudoword	v	5
aidrio	1	1	1	0	0	0	pseudoword	v	6
alco	6	6	3	11	6	1	pseudoword	v	4
alebo	5	5	0	0	0	0	pseudoword	v	5
algura	3	3	2	1	0	0	pseudoword	v	6
alidez	2	2	0	0	0	0	pseudoword	v	6
amba	1	1	0	10	3	0	pseudoword	v	4
amisa	6	6	1	9	6	0	pseudoword	v	5
ancos	2	2	0	2	0	0	pseudoword	v	5
arejas	4	4	2	2	1	0	pseudoword	v	6
arobio	1	1	0	0	0	0	pseudoword	v	6
arolir	1	1	0	0	0	0	pseudoword	v	6
arrazo	2	1	1	0	0	0	pseudoword	v	6
aspino	3	2	0	0	0	0	pseudoword	v	6
atajol	1	1	0	0	0	0	pseudoword	v	6

auga	5	5	1	11	4	0	pseudoword	v	4
auro	11	11	6	16	8	1	pseudoword	v	4
avad	6	4	0	13	3	0	pseudoword	v	4
azono	3	2	0	1	1	0	pseudoword	v	5
azte	2	2	2	4	2	0	pseudoword	v	4
azteja	1	1	0	1	0	0	pseudoword	v	6
becaz	1	1	0	1	0	0	pseudoword	c	5
bedazo	1	1	1	0	0	0	pseudoword	c	6
blacas	2	2	1	1	1	0	pseudoword	c	6
blamo	1	1	1	3	3	1	pseudoword	c	5
bolde	3	3	1	10	0	0	pseudoword	c	5
caciza	2	2	0	0	0	0	pseudoword	c	6
carza	7	7	3	4	2	0	pseudoword	c	5
cegias	1	0	0	0	0	0	pseudoword	c	6
chilo	9	9	2	11	5	2	pseudoword	c	5
clasa	4	4	2	7	4	2	pseudoword	c	5
delda	4	4	3	5	4	0	pseudoword	c	5
drofeo	1	1	0	0	0	0	pseudoword	c	6
dubida	2	2	0	0	0	0	pseudoword	c	6
dulpo	2	2	1	2	0	0	pseudoword	c	5
ecopio	1	1	0	0	0	0	pseudoword	v	6
edio	1	1	1	7	3	0	pseudoword	v	4
edulan	1	1	0	0	0	0	pseudoword	v	6
egota	1	1	0	0	0	0	pseudoword	v	5

elicaz	1	1	0	0	0	0	pseudoword	v	6
elovio	1	1	0	0	0	0	pseudoword	v	6
emagra	1	0	0	0	0	0	pseudoword	v	6
enfre	1	1	1	2	1	0	pseudoword	v	5
enidad	1	1	1	0	0	0	pseudoword	v	6
enirse	1	1	1	0	0	0	pseudoword	v	6
eribla	1	1	0	0	0	0	pseudoword	v	6
erufas	1	1	0	0	0	0	pseudoword	v	6
esados	3	3	0	0	0	0	pseudoword	v	6
esniso	1	0	0	0	0	0	pseudoword	v	6
esno	2	2	0	4	2	0	pseudoword	v	4
esocia	1	1	0	0	0	0	pseudoword	v	6
etalia	1	1	1	1	1	0	pseudoword	v	6
excaje	1	1	0	0	0	0	pseudoword	v	6
faices	1	1	0	4	2	0	pseudoword	c	6
floque	1	1	0	1	0	0	pseudoword	c	6
fugre	3	3	0	2	1	0	pseudoword	c	5
furte	1	1	0	3	1	0	pseudoword	c	5
gelope	1	1	0	0	0	0	pseudoword	c	6
gloja	2	2	0	0	0	0	pseudoword	c	5
gosca	3	3	0	3	1	0	pseudoword	c	5
gruzo	3	2	1	1	0	0	pseudoword	c	5
habaco	2	2	0	0	0	0	pseudoword	c	6
hirto	3	2	1	1	0	0	pseudoword	c	5

hobres	4	4	1	1	1	0	pseudoword	c	6
hotal	2	2	2	6	3	2	pseudoword	c	5
hurea	2	2	0	1	0	0	pseudoword	c	5
idiar	2	2	0	0	0	0	pseudoword	v	5
joca	11	11	6	11	6	0	pseudoword	c	4
juarzo	1	1	0	0	0	0	pseudoword	c	6
juevo	4	4	3	3	0	0	pseudoword	c	5
julco	2	2	1	1	1	0	pseudoword	c	5
larza	5	5	2	3	2	0	pseudoword	c	5
lerba	2	1	0	4	0	0	pseudoword	c	5
linilo	1	1	0	0	0	0	pseudoword	c	6
lirir	1	1	0	0	0	0	pseudoword	c	5
malte	6	6	0	6	4	0	pseudoword	c	5
matio	6	5	1	11	5	0	pseudoword	c	5
maznos	1	1	0	0	0	0	pseudoword	c	6
memplo	1	1	1	0	0	0	pseudoword	c	6
nandil	2	0	0	1	0	0	pseudoword	c	6
noedor	1	1	0	0	0	0	pseudoword	c	6
norta	8	8	5	9	5	1	pseudoword	c	5
nueca	6	6	1	4	0	0	pseudoword	c	5
obisa	1	1	0	3	0	0	pseudoword	v	5
obse	2	2	0	9	2	0	pseudoword	v	4
oche	3	3	1	8	2	0	pseudoword	v	4
ojaz	1	1	0	1	0	0	pseudoword	v	4

ollo	4	4	1	8	6	0	pseudoword	v	4
olva	2	2	0	9	2	0	pseudoword	v	4
omillo	1	1	0	0	0	0	pseudoword	v	6
onchos	1	1	0	1	0	0	pseudoword	v	6
opela	2	2	0	1	1	1	pseudoword	v	5
oranja	2	2	1	0	0	0	pseudoword	v	6
oriete	1	1	0	0	0	0	pseudoword	v	6
ostusa	1	1	0	0	0	0	pseudoword	v	6
otas	7	6	1	4	1	0	pseudoword	v	4
oximia	1	0	0	0	0	0	pseudoword	v	6
pezcla	1	1	1	0	0	0	pseudoword	c	6
pizos	7	6	1	2	0	0	pseudoword	c	5
pociva	1	0	0	0	0	0	pseudoword	c	6
potre	5	5	1	6	3	0	pseudoword	c	5
rasto	11	11	1	2	1	0	pseudoword	c	5
riegre	1	0	0	0	0	0	pseudoword	c	6
rueco	4	4	2	0	0	0	pseudoword	c	5
sarope	1	1	0	1	0	0	pseudoword	c	6
satia	3	3	1	9	3	0	pseudoword	c	5
semada	5	2	1	1	0	0	pseudoword	c	6
sonra	4	4	1	5	3	0	pseudoword	c	5
tedir	3	3	1	1	0	0	pseudoword	c	5
tefa	5	5	3	10	2	0	pseudoword	c	4
tigmeo	1	1	0	0	0	0	pseudoword	c	6

tirmo	2	2	0	2	0	0	pseudoword	c	5
unojo	1	1	1	0	0	0	pseudoword	v	5
unorme	2	2	1	1	0	0	pseudoword	v	6
vacto	6	6	1	2	1	0	pseudoword	c	5
voti	3	3	1	4	2	1	pseudoword	c	4

Appendix IV. Stimuli in English (L2) used in Experiment 1 and 2

Item	Zipf value	Neighbourhood Density with words of 4-6 letters N Within-Language	Neighbourhood Density with words with Zipf values above 2 Within-Language	Neighbourhood Density with high frequency words Within-Language	Neighbourhood Density with words of 4-6 letters N Between-Languages	Neighbourhood Density with words with Zipf values above 2 Between-Languages	Neighbourhood Density with high frequency words Between-Languages	Condition	Onset: vowel (v) or consonant (c)	Length	RT BLP	Acc BLP
abbey	4.3	1	1	0	0	0	0	HF	v	5	596	0.95
accent	4.2	2	2	1	0	0	0	HF	v	6	547	1.00
advice	4.8	1	1	1	0	0	0	HF	v	6	528	1.00
affair	4.3	0	0	0	0	0	0	HF	v	6	551	1.00
agency	4.5	1	0	0	0	0	0	HF	v	6		
amount	5.1	0	0	0	0	0	0	HF	v	6	524	1.00
anger	4.3	12	4	1	0	0	0	HF	v	5	532	1.00
angle	4.4	8	3	2	3	3	0	HF	v	5	522	1.00
ankle	3.9	4	3	1	1	1	0	HF	v	5	583	1.00
answer	5.6	1	0	0	0	0	0	HF	v	6	544	1.00
anyone	5.3	1	0	0	0	0	0	HF	v	6		
appeal	4.6	1	1	1	0	0	0	HF	v	6	581	0.97
apple	4.6	3	2	1	1	0	0	HF	v	5	492	1.00
army	4.9	11	4	1	3	3	1	HF	v	4	515	1.00
assets	4.1	1	1	1	0	0	0	HF	v	6	619	0.97
attack	4.9	2	1	0	0	0	0	HF	v	6	577	1.00
aunt	4.3	20	10	1	0	0	0	HF	v	4	553	0.97
autumn	4.4	0	0	0	0	0	0	HF	v	6	559	1.00
award	4.5	5	2	1	0	0	0	HF	v	5	624	0.90

banana	4.2	4	2	0	1	1	0	HF	c	6		
board	5.1	6	3	1	0	0	0	HF	c	5	529	1.00
breath	4.5	2	2	0	0	0	0	HF	c	6	597	1.00
bridge	4.7	4	3	1	0	0	0	HF	c	6	564	0.97
budget	5.2	3	2	0	0	0	0	HF	c	6	522	1.00
child	5.1	5	3	1	2	2	0	HF	c	5	497	1.00
choice	5.0	0	0	0	0	0	0	HF	c	6	524	1.00
cloud	4.8	3	2	0	0	0	0	HF	c	5	559	1.00
coast	4.9	4	3	2	0	0	0	HF	c	5	557	0.97
crowd	4.8	4	3	1	0	0	0	HF	c	5	555	1.00
daisy	4.6	4	3	2	0	0	0	HF	c	5	578	1.00
degree	4.5	1	1	0	0	0	0	HF	c	6	516	1.00
depth	4.2	1	1	1	0	0	0	HF	c	5	525	1.00
dream	5.0	5	3	1	0	0	0	HF	c	5	519	1.00
eagle	4.1	5	2	0	0	0	0	HF	v	5	527	1.00
earth	5.0	7	2	0	0	0	0	HF	v	5	490	0.95
ease	4.2	19	8	6	5	5	4	HF	v	4	508	0.95
east	5.2	21	11	7	0	0	0	HF	v	4	551	1.00
easter	4.1	15	6	3	0	0	0	HF	v	6	559	0.97
edge	4.8	8	2	0	0	0	0	HF	v	4	543	1.00
effect	4.8	2	1	1	0	0	0	HF	v	6	533	1.00
effort	4.8	1	0	0	0	0	0	HF	v	6	555	1.00
eggs	4.7	9	4	0	1	1	0	HF	v	4	507	0.98
empire	4.4	3	2	0	2	1	0	HF	v	6		

ending	4.3	2	0	0	0	0	0	HF	v	6	558	0.98
enemy	4.4	2	1	0	1	1	0	HF	v	5		
engine	4.5	0	0	0	0	0	0	HF	v	6	605	0.97
entry	4.1	4	1	0	3	3	3	HF	v	5	559	1.00
exam	4.1	7	1	0	0	0	0	HF	v	4	549	1.00
exit	4.0	7	2	0	0	0	0	HF	v	4	498	1.00
extent	4.4	4	2	1	0	0	0	HF	v	6	573	0.97
extent	4.4	4	2	1	0	0	0	HF	v	6	573	0.97
eyes	5.2	13	8	1	6	5	1	HF	v	4	506	0.97
field	4.9	5	3	0	0	0	0	HF	c	5	529	0.95
flight	4.6	5	5	1	0	0	0	HF	c	6	550	0.95
friend	5.3	1	0	0	0	0	0	HF	c	6	520	0.97
fruit	4.7	4	0	0	0	0	0	HF	c	5	523	0.98
ground	5.2	3	1	1	0	0	0	HF	c	6	482	1.00
growth	4.9	0	0	0	0	0	0	HF	c	6	547	0.97
guest	4.6	7	2	2	0	0	0	HF	c	5	518	0.98
half	5.6	12	8	3	4	4	1	HF	c	4	510	0.95
health	5.1	2	2	1	0	0	0	HF	c	6	543	0.98
heart	5.3	6	3	1	0	0	0	HF	c	5	518	0.98
heaven	4.6	5	1	0	0	0	0	HF	c	6	530	0.98
height	4.5	3	1	1	0	0	0	HF	c	6	532	1.00
helmet	4.1	4	3	0	0	0	0	HF	c	6	549	0.97
icing	4.0	11	2	0	0	0	0	HF	v	5	607	1.00
inches	4.2	3	2	0	0	0	0	HF	v	6	583	1.00

income	4.6	5	0	0	0	0	0	HF	v	6	554	1.00
injury	4.6	1	1	0	0	0	0	HF	v	6		
iron	4.5	15	4	1	1	1	0	HF	v	4	538	1.00
island	5.0	1	1	1	0	0	0	HF	v	6	529	0.95
issue	5.2	2	1	0	0	0	0	HF	v	5	519	1.00
item	4.7	7	1	0	0	0	0	HF	v	4	539	0.95
ivory	4.1	1	0	0	0	0	0	HF	v	5		
jacket	4.3	6	3	0	0	0	0	HF	c	6	532	1.00
judge	4.7	11	6	0	0	0	0	HF	c	5	557	1.00
juice	4.4	2	2	0	0	0	0	HF	c	5	547	1.00
laugh	4.8	4	3	0	0	0	0	HF	c	5	534	1.00
lawyer	4.2	2	2	0	0	0	0	HF	c	6	558	1.00
level	5.1	8	5	0	1	1	0	HF	c	5	525	1.00
lions	4.3	6	1	0	0	0	0	HF	c	5	523	0.98
market	5.2	7	2	1	0	0	0	HF	c	6	521	1.00
month	5.1	7	5	2	3	3	1	HF	c	5	570	1.00
mother	5.3	8	3	1	0	0	0	HF	c	6	507	0.98
movie	4.6	5	2	0	0	0	0	HF	c	5	535	1.00
needle	3.9	4	1	0	0	0	0	HF	c	6	536	1.00
noise	4.8	10	5	1	0	0	0	HF	c	5	504	1.00
number	5.6	6	6	0	0	0	0	HF	c	6	565	0.95
nurse	4.5	5	3	1	1	0	0	HF	c	5	533	1.00
odds	4.1	8	2	2	1	1	0	HF	v	4	541	0.98
offer	5.0	3	0	0	0	0	0	HF	v	5	522	0.95

office	5.1	0	0	0	0	0	0	HF	v	6	538	1.00
onion	4.3	4	2	1	0	0	0	HF	v	5	492	1.00
online	4.6	2	1	0	0	0	0	HF	v	6		
orange	4.6	2	1	0	0	0	0	HF	v	6	520	0.98
order	5.2	4	2	1	2	2	1	HF	v	5	511	1.00
others	5.1	2	1	0	0	0	0	HF	v	6	541	1.00
outfit	4.1	1	1	0	0	0	0	HF	v	6	549	1.00
oven	4.5	17	8	3	3	3	1	HF	v	4	501	1.00
owner	4.6	1	1	1	0	0	0	HF	v	5	531	1.00
pepper	4.4	5	2	0	0	0	0	HF	c	6	617	0.97
piece	5.3	3	2	0	0	0	0	HF	c	5	579	1.00
prize	4.8	5	5	3	1	1	0	HF	c	5	549	0.98
proof	4.3	5	0	0	0	0	0	HF	c	5	565	0.98
rabbit	4.4	6	3	0	0	0	0	HF	c	6	540	1.00
rhyme	4.0	2	1	0	0	0	0	HF	c	5	594	1.00
roast	4.2	6	4	2	0	0	0	HF	c	5	523	1.00
school	5.5	2	1	0	0	0	0	HF	c	6	509	1.00
screw	4.1	3	3	0	0	0	0	HF	c	5	526	1.00
smell	4.8	8	6	3	0	0	0	HF	c	5	489	1.00
steam	4.4	4	3	2	0	0	0	HF	c	5	554	0.95
target	4.8	2	1	0	0	0	0	HF	c	6	529	0.98
today	6.0	4	2	0	1	1	1	HF	c	5	546	1.00
tongue	4.4	1	1	0	0	0	0	HF	c	6	551	1.00
twist	4.4	5	1	0	0	0	0	HF	c	5	534	1.00

uncle	4.6	0	0	0	0	0	0	HF	v	5	558	1.00
unit	4.6	15	2	0	1	1	0	HF	v	4	564	0.97
value	5.0	5	2	0	1	1	1	HF	c	5	512	1.00
venue	4.2	4	1	0	4	4	1	HF	c	5	559	1.00
view	5.2	6	4	0	0	0	0	HF	c	4	514	0.98
ache	3.4	14	6	1	2	2	0	LF	v	4	524	1.00
aide	3.1	21	14	5	7	7	4	LF	v	4	702	0.80
airway	3.1	0	0	0	0	0	0	LF	v	6	627	0.97
alibi	3.3	0	0	0	0	0	0	LF	v	5		
alloy	3.1	7	4	1	0	0	0	LF	v	5	583	0.95
ally	3.8	18	10	0	0	0	0	LF	v	4	597	0.83
almond	3.4	1	0	0	0	0	0	LF	v	6	586	0.97
antler	2.7	2	2	0	0	0	0	LF	v	6	661	0.89
arch	3.9	15	5	1	3	3	1	LF	v	4	567	0.97
armour	3.9	2	2	0	0	0	0	LF	v	6	549	1.00
array	3.8	4	2	0	0	0	0	LF	v	5	618	0.95
arrow	3.8	6	1	0	1	1	1	LF	v	5	538	0.98
avenue	3.8	1	1	0	0	0	0	LF	v	6		
axis	3.3	10	5	0	0	0	0	LF	v	4	588	0.98
axle	2.9	6	2	1	0	0	0	LF	v	4	616	0.80
baboon	3.3	2	0	0	0	0	0	LF	c	6	675	0.95
bakery	3.7	2	2	0	0	0	0	LF	c	6		
belch	2.4	5	5	2	0	0	0	LF	c	5	706	0.79
blip	3.3	13	4	3	1	1	0	LF	c	4	680	0.71

bundle	3.4	5	1	0	0	0	0	LF	c	6	580	0.97
celery	3.7	1	0	0	0	0	0	LF	c	6		
chimp	3.4	9	6	0	0	0	0	LF	c	5	606	0.88
chord	3.6	8	2	0	0	0	0	LF	c	5	634	0.85
clover	3.2	9	6	2	1	1	0	LF	c	6	597	0.97
crumb	3.2	1	1	0	0	0	0	LF	c	5	632	0.95
denial	3.6	4	3	0	2	2	2	LF	c	6		
drape	2.6	6	2	0	1	1	0	LF	c	5	728	0.89
dryer	3.3	10	4	0	0	0	0	LF	c	5	609	0.97
duvet	3.7	0	0	0	0	0	0	LF	c	5	580	0.97
easel	3.0	7	4	0	0	0	0	LF	v	5	700	0.76
eater	3.3	20	11	4	1	1	0	LF	v	5	510	0.95
ebony	3.3	0	0	0	0	0	0	LF	v	5		
elbow	3.9	1	0	0	0	0	0	LF	v	5	598	1.00
elder	3.6	9	6	1	0	0	0	LF	v	5	615	0.89
enamel	3.8	0	0	0	0	0	0	LF	v	6		
encore	3.2	3	1	0	3	2	0	LF	v	6	646	0.89
entity	3.3	1	1	0	0	0	0	LF	v	6		
envoy	3.2	2	1	1	0	0	0	LF	v	5	655	0.83
envy	3.6	3	1	0	0	0	0	LF	v	4	507	1.00
eraser	2.1	3	2	1	0	0	0	LF	v	6		
eyelid	3.0	0	0	0	0	0	0	LF	v	6	568	0.95
fennel	3.8	7	3	0	0	0	0	LF	c	6	654	0.87
flake	3.2	8	5	1	0	0	0	LF	c	5	555	1.00

flea	3.5	11	5	1	0	0	0	LF	c	4	585	0.98
frown	3.2	5	5	4	0	0	0	LF	c	5	574	0.89
gambit	2.7	1	1	0	0	0	0	LF	c	6	648	0.58
gleam	2.8	3	1	0	0	0	0	LF	c	5	639	0.89
grill	3.7	7	5	1	1	1	0	LF	c	5	573	1.00
hawk	3.7	11	4	0	0	0	0	LF	c	4	564	0.95
heist	2.7	4	1	0	0	0	0	LF	c	5		
helix	2.7	5	1	1	1	1	0	LF	c	5		
heron	3.2	10	6	0	0	0	0	LF	c	5	634	0.90
hiccup	3.3	0	0	0	0	0	0	LF	c	6	613	1.00
idiocy	2.5	0	0	0	0	0	0	LF	v	6		
idyll	3.0	0	0	0	0	0	0	LF	v	5	702	0.39
index	3.7	2	0	0	0	0	0	LF	v	5	525	0.89
influx	3.3	0	0	0	0	0	0	LF	v	6	727	0.82
inlet	2.8	3	1	0	0	0	0	LF	v	5	651	0.85
inning	2.1	3	1	0	0	0	0	LF	v	6	730	0.60
input	3.7	2	0	0	0	0	0	LF	v	5	542	0.98
instep	2.0	0	0	0	0	0	0	LF	v	6	738	0.63
intake	3.5	1	0	0	0	0	0	LF	v	6	592	0.93
iodine	2.9	3	1	0	0	0	0	LF	v	6		
itch	3.3	4	2	1	0	0	0	LF	v	4	542	0.90
jaunt	2.7	7	5	0	0	0	0	LF	c	5	612	0.95
jigsaw	3.7	0	0	0	0	0	0	LF	c	6	610	0.97
joist	2.5	6	4	1	0	0	0	LF	c	5	684	0.63

joker	3.5	10	6	1	2	2	1	LF	c	5	531	0.98
lentil	2.8	2	1	0	1	1	1	LF	c	6	613	0.97
limb	3.7	9	6	2	3	3	0	LF	c	4	526	1.00
lizard	3.7	3	1	0	0	0	0	LF	c	6	548	1.00
lynx	3.2	4	2	1	0	0	0	LF	c	4	641	0.83
mauve	2.7	6	3	0	0	0	0	LF	c	5	719	0.73
merger	3.4	7	5	0	0	0	0	LF	c	6	645	0.98
moist	3.8	7	2	0	0	0	0	LF	c	5	550	0.95
mussel	3.3	8	2	0	0	0	0	LF	c	6	619	0.84
napkin	3.3	1	0	0	0	0	0	LF	c	6	555	0.95
nettle	3.1	7	6	2	0	0	0	LF	c	6	576	1.00
niece	3.7	6	1	1	1	1	1	LF	c	5	590	1.00
nuance	2.5	0	0	0	0	0	0	LF	c	6	657	0.60
oddity	2.8	0	0	0	0	0	0	LF	v	6		
omen	3.2	16	7	4	2	2	1	LF	v	4	605	1.00
onset	3.1	2	1	0	0	0	0	LF	v	5	660	0.92
opener	3.7	1	1	1	1	1	0	LF	v	6		
orchid	3.3	0	0	0	0	0	0	LF	v	6	610	0.92
osprey	3.1	1	1	0	0	0	0	LF	v	6	659	0.55
otter	3.8	7	3	2	0	0	0	LF	v	5	614	0.93
ounce	3.4	2	2	0	0	0	0	LF	v	5	557	0.95
outing	3.4	9	1	0	0	0	0	LF	v	6	581	0.98
outlaw	3.3	1	1	0	0	0	0	LF	v	6	563	1.00
oxen	2.9	13	6	3	2	2	1	LF	v	4	642	0.79

oyster	3.8	3	0	0	0	0	0	LF	v	6	560	1.00
peanut	3.6	0	0	0	0	0	0	LF	c	6	567	0.98
pickle	3.7	10	4	0	0	0	0	LF	c	6	547	1.00
poise	3.0	9	4	1	0	0	0	LF	c	5	668	0.73
prawn	3.7	3	2	1	0	0	0	LF	c	5	569	0.95
racoon	2.3	0	0	0	0	0	0	LF	c	6		
radish	3.2	3	1	0	0	0	0	LF	c	6	701	0.88
raisin	2.9	4	2	0	0	0	0	LF	c	6	687	1.00
sigh	3.7	14	6	2	2	2	2	LF	c	4	577	0.97
snail	3.7	5	1	0	0	0	0	LF	c	5	538	1.00
staple	3.5	1	1	1	0	0	0	LF	c	6	595	0.97
suede	3.1	4	1	0	5	5	3	LF	c	5	658	0.90
thigh	3.5	3	0	0	0	0	0	LF	c	5	623	1.00
thirst	3.3	2	1	0	0	0	0	LF	c	6	561	1.00
thorn	3.3	5	3	0	0	0	0	LF	c	5	542	0.98
tuner	2.4	8	4	0	1	1	1	LF	c	5	700	0.85
udder	2.7	3	3	1	0	0	0	LF	v	5	658	0.74
umpire	3.3	1	1	1	0	0	0	LF	v	6		
unease	3.1	1	1	0	0	0	0	LF	v	6	665	0.87
unity	3.8	6	5	1	0	0	0	LF	v	5		
unrest	3.6	0	0	0	0	0	0	LF	v	6	602	0.89
upkeep	3.0	0	0	0	0	0	0	LF	v	6	674	0.90
uproar	2.9	0	0	0	0	0	0	LF	v	6	666	0.95
uptake	2.9	1	0	0	0	0	0	LF	v	6	574	0.98

urchin	3.1	0	0	0	0	0	0	LF	v	6	686	0.88
usage	3.3	1	0	0	1	1	0	LF	v	5	631	0.93
velvet	3.6	1	0	0	0	0	0	LF	c	6	564	1.00
vixen	2.8	1	0	0	2	1	1	LF	c	5	655	0.90
void	2.6	21	7	1	0	0	0	LF	c	4	549	0.98
aaeiui	NA	0	0	0	0	0	0	nonword	v	6		
aeaioe	NA	0	0	0	0	0	0	nonword	v	6		
aeauoi	NA	0	0	0	0	0	0	nonword	v	6		
aeiuai	NA	0	0	0	0	0	0	nonword	v	6		
aeoau	NA	0	0	0	0	0	0	nonword	v	5		
aeoiei	NA	0	0	0	0	0	0	nonword	v	6		
aeoii	NA	0	0	0	0	0	0	nonword	v	5		
aieaio	NA	0	0	0	0	0	0	nonword	v	6		
aiee	NA	16	4	0	1	1	1	nonword	v	4		
aoeiu	NA	0	0	0	0	0	0	nonword	v	5		
aouie	NA	1	1	0	0	0	0	nonword	v	5		
aouiiu	NA	0	0	0	0	0	0	nonword	v	6		
auaio	NA	1	1	0	1	1	0	nonword	v	5		
auao	NA	1	1	0	1	1	1	nonword	v	4		
aueaiu	NA	0	0	0	0	0	0	nonword	v	6		
auee	NA	16	0	0	1	1	0	nonword	v	4		
auiu	NA	0	0	0	0	0	0	nonword	v	4		
blthht	NA	0	0	0	0	0	0	nonword	c	6		
bndccp	NA	0	0	0	0	0	0	nonword	c	6		

bpgsw	NA	0	0	0	0	0	0	nonword	c	5
bvbk	NA	0	0	0	0	0	0	nonword	c	4
bxbsyt	NA	0	0	0	0	0	0	nonword	c	6
cfgtnt	NA	0	0	0	0	0	0	nonword	c	6
cnphd	NA	0	0	0	0	0	0	nonword	c	5
cpcllz	NA	0	0	0	0	0	0	nonword	c	6
cvtgk	NA	0	0	0	0	0	0	nonword	c	5
czgnf	NA	0	0	0	0	0	0	nonword	c	5
dbtcg	NA	0	0	0	0	0	0	nonword	c	5
dfkjmj	NA	0	0	0	0	0	0	nonword	c	6
dlydj	NA	0	0	0	0	0	0	nonword	c	5
dyzsc	NA	0	0	0	0	0	0	nonword	c	5
eaaiei	NA	0	0	0	0	0	0	nonword	v	6
eaiu	NA	0	0	0	0	0	0	nonword	v	4
eaoiae	NA	0	0	0	0	0	0	nonword	v	6
eauiou	NA	0	0	0	0	0	0	nonword	v	6
eauoui	NA	0	0	0	0	0	0	nonword	v	6
eiea	NA	3	1	0	0	0	0	nonword	v	4
eieua	NA	1	0	0	0	0	0	nonword	v	5
eieui	NA	0	0	0	0	0	0	nonword	v	5
eiuai	NA	0	0	0	0	0	0	nonword	v	5
eiuoi	NA	0	0	0	0	0	0	nonword	v	5
eoae	NA	0	0	0	0	0	0	nonword	v	4
eoau	NA	1	1	0	0	0	0	nonword	v	4

eoiaou	NA	0	0	0	0	0	0	nonword	v	6
eouiae	NA	0	0	0	0	0	0	nonword	v	6
euioa	NA	0	0	0	0	0	0	nonword	v	5
fcztm	NA	0	0	0	0	0	0	nonword	c	5
fjxr	NA	0	0	0	0	0	0	nonword	c	4
fsfhpl	NA	0	0	0	0	0	0	nonword	c	6
fzdpz	NA	0	0	0	0	0	0	nonword	c	5
gdhgzh	NA	0	0	0	0	0	0	nonword	c	6
gsffd	NA	0	0	0	0	0	0	nonword	c	5
gsmkl	NA	0	0	0	0	0	0	nonword	c	5
hcqgr	NA	0	0	0	0	0	0	nonword	c	5
hfpddf	NA	0	0	0	0	0	0	nonword	c	6
hgxrd	NA	0	0	0	0	0	0	nonword	c	5
hvtn	NA	0	0	0	0	0	0	nonword	c	4
hwptsp	NA	0	0	0	0	0	0	nonword	c	6
iaeio	NA	0	0	0	0	0	0	nonword	v	5
iaeu	NA	1	1	0	0	0	0	nonword	v	4
iaeuei	NA	0	0	0	0	0	0	nonword	v	6
iauoa	NA	0	0	0	0	0	0	nonword	v	5
ieao	NA	1	0	0	0	0	0	nonword	v	4
ieoea	NA	0	0	0	0	0	0	nonword	v	5
ieoeui	NA	0	0	0	0	0	0	nonword	v	6
iiaeue	NA	0	0	0	0	0	0	nonword	v	6
iuaoia	NA	0	0	0	0	0	0	nonword	v	6

iueuae	NA	0	0	0	0	0	0	nonword	v	6
jbsmj	NA	0	0	0	0	0	0	nonword	c	5
jhxnp	NA	0	0	0	0	0	0	nonword	c	5
jncrb	NA	0	0	0	0	0	0	nonword	c	5
jvjdlk	NA	0	0	0	0	0	0	nonword	c	6
lhrhtq	NA	0	0	0	0	0	0	nonword	c	6
llzngf	NA	0	0	0	0	0	0	nonword	c	6
lrvgh	NA	0	0	0	0	0	0	nonword	c	5
ltjw	NA	0	0	0	0	0	0	nonword	c	4
mhyrv	NA	0	0	0	0	0	0	nonword	c	5
mkhbd	NA	0	0	0	0	0	0	nonword	c	5
mklzlk	NA	0	0	0	0	0	0	nonword	c	6
mvwfvm	NA	0	0	0	0	0	0	nonword	c	6
njzmtj	NA	0	0	0	0	0	0	nonword	c	6
nlrmss	NA	0	0	0	0	0	0	nonword	c	6
nrthv	NA	0	0	0	0	0	0	nonword	c	5
nsfrm	NA	0	0	0	0	0	0	nonword	c	5
oaeuia	NA	0	0	0	0	0	0	nonword	v	6
oaiaeo	NA	0	0	0	0	0	0	nonword	v	6
oaueia	NA	0	0	0	0	0	0	nonword	v	6
oeaii	NA	0	0	0	0	0	0	nonword	v	5
oeoiuu	NA	0	0	0	0	0	0	nonword	v	6
oeuai	NA	0	0	0	0	0	0	nonword	v	5
oiaouu	NA	0	0	0	0	0	0	nonword	v	6

oieuio	NA	0	0	0	0	0	0	nonword	v	6
oiua	NA	1	0	0	1	1	1	nonword	v	4
ooiau	NA	0	0	0	0	0	0	nonword	v	5
oueai	NA	0	0	0	0	0	0	nonword	v	5
ouei	NA	3	1	0	0	0	0	nonword	v	4
pgfpfd	NA	0	0	0	0	0	0	nonword	c	6
plxrk	NA	1	0	0	0	0	0	nonword	c	5
pstzs	NA	0	0	0	0	0	0	nonword	c	5
pydqlp	NA	0	0	0	0	0	0	nonword	c	6
rpfgr	NA	0	0	0	0	0	0	nonword	c	5
rpqpks	NA	0	0	0	0	0	0	nonword	c	6
rqrfcx	NA	0	0	0	0	0	0	nonword	c	6
sbrm	NA	3	0	0	0	0	0	nonword	c	4
sdxstp	NA	0	0	0	0	0	0	nonword	c	6
sjpdv	NA	0	0	0	0	0	0	nonword	c	5
svlcr	NA	0	0	0	0	0	0	nonword	c	5
tdnlt	NA	0	0	0	0	0	0	nonword	c	5
tgjzjg	NA	0	0	0	0	0	0	nonword	c	6
tjkykj	NA	0	0	0	0	0	0	nonword	c	6
tzsdv	NA	0	0	0	0	0	0	nonword	c	5
uaeii	NA	0	0	0	0	0	0	nonword	v	5
ueoaiu	NA	0	0	0	0	0	0	nonword	v	6
ueuiio	NA	0	0	0	0	0	0	nonword	v	6
uioei	NA	0	0	0	0	0	0	nonword	v	5

uoiaeo	NA	0	0	0	0	0	0	nonword	v	6
uoie	NA	6	2	0	1	1	0	nonword	v	4
vgpht	NA	0	0	0	0	0	0	nonword	c	5
vjsc	NA	0	0	0	0	0	0	nonword	c	4
vkhhss	NA	0	0	0	0	0	0	nonword	c	6

Appendix V English Pseudowords Experiment 1

Item Name	Neigbourhood Density Spanish LexStat	Neighbourhood Density English LexStat	Condition	Onset	Length
alame	3	5	pseudoword	v	5
albut	0	2	pseudoword	v	5
atter	1	11	pseudoword	v	5
badie	1	1	pseudoword	c	5
clazer	0	4	pseudoword	c	6
denit	0	9	pseudoword	c	5
eagar	3	1	pseudoword	v	5
engle	1	3	pseudoword	v	5
eurist	0	2	pseudoword	v	6
fattle	0	9	pseudoword	c	6
gowl	0	12	pseudoword	c	4
higar	3	5	pseudoword	c	5
imager	1	1	pseudoword	v	6
insere	0	5	pseudoword	v	6
islay	2	2	pseudoword	v	5
jeaset	0	2	pseudoword	c	6
lunce	2	7	pseudoword	c	5
midel	3	4	pseudoword	c	5
naitor	0	1	pseudoword	c	6

orgar	0	3	pseudoword	v	5
oridge	0	3	pseudoword	v	6
ority	0	1	pseudoword	v	5
pount	0	1	pseudoword	c	5
rangle	0	9	pseudoword	c	6
savil	1	5	pseudoword	c	5
tonger	0	9	pseudoword	c	6
uncley	0	1	pseudoword	v	6
urght	0	1	pseudoword	v	5
urist	0	9	pseudoword	v	5
velot	2	2	pseudoword	c	5

Appendix VI English Pseudowords Experiment 2

Item Name	Neighbourhood Density with words of 4-6 letters N Within-Language	Neighbourhood Density with words with Zipf values above 2 Within-Language	Neighbourhood Density with high frequency words Within-Language	Neighbourhood Density with words of 4-6 letters N Between-Languages	Neighbourhood Density with words with Zipf values above 2 Between-Languages	Neighbourhood Density with high frequency words Between-Languages	Condition	Onset: vowel (v) or consonant (c)	Length	RT BLP	Acc BLP
abow	2	1	0	0	0	0	pseudoword	v	4	699	0.89
abrast	0	0	0	0	0	0	pseudoword	v	6	678	0.93
abvid	0	0	0	1	1	0	pseudoword	v	5	605	1.00
acone	3	3	1	2	2	0	pseudoword	v	5	662	0.97
acters	4	4	1	0	0	0	pseudoword	v	6	788	0.60
adday	0	0	0	0	0	0	pseudoword	v	5	635	0.92
adle	4	6	1	0	0	0	pseudoword	v	4	711	0.70
ambent	0	0	0	0	0	0	pseudoword	v	6	731	0.88
ancing	1	2	0	0	0	0	pseudoword	v	6	645	0.92
antail	1	1	0	0	0	0	pseudoword	v	6	669	0.95
antox	0	1	0	0	0	0	pseudoword	v	5	594	0.98
anvy	1	3	1	0	0	0	pseudoword	v	4	669	0.98
aptile	0	0	0	0	0	0	pseudoword	v	6	687	0.98
aslaw	0	2	0	0	0	0	pseudoword	v	5	600	0.97
asocks	0	0	0	0	0	0	pseudoword	v	6	568	1.00
atread	0	0	0	0	0	0	pseudoword	v	6	617	0.97
ause	5	7	1	2	2	1	pseudoword	v	4	565	0.98
balves	4	3	0	2	2	0	pseudoword	c	6	613	0.93
biege	4	4	0	0	0	0	pseudoword	c	5	574	0.39

bimped	3	3	0	0	0	0	pseudoword	c	6	675	0.87
blift	0	1	0	0	0	0	pseudoword	c	5	567	0.97
buther	5	4	2	0	0	0	pseudoword	c	6	650	0.97
caffed	2	1	0	0	0	0	pseudoword	c	6	677	0.95
cheld	1	2	1	1	1	0	pseudoword	c	5	534	1.00
cilly	4	14	2	0	0	0	pseudoword	c	5	584	1.00
citre	3	2	0	2	2	0	pseudoword	c	5	652	0.95
cunsel	0	0	0	0	0	0	pseudoword	c	6	552	1.00
dasel	1	3	0	1	1	0	pseudoword	c	5	615	0.95
dauble	3	3	1	0	0	0	pseudoword	c	6	682	0.74
decise	3	4	2	1	1	1	pseudoword	c	6	864	0.39
dylly	3	3	0	0	0	0	pseudoword	c	5	562	1.00
echer	1	2	0	3	3	1	pseudoword	v	5	648	1.00
eding	0	1	0	0	0	0	pseudoword	v	5	662	1.00
elerts	3	3	0	0	0	0	pseudoword	v	6	595	0.93
elve	1	5	1	0	0	0	pseudoword	v	4	656	0.70
empter	0	1	0	0	0	0	pseudoword	v	6	831	0.84
ence	1	3	1	3	3	1	pseudoword	v	4	603	1.00
entol	2	2	0	0	0	0	pseudoword	v	5	648	0.89
epes	5	7	1	5	4	0	pseudoword	v	4	584	1.00
erbide	0	0	0	0	0	0	pseudoword	v	6	580	0.97
erves	2	2	0	1	0	0	pseudoword	v	5	581	0.95
esreed	0	0	0	0	0	0	pseudoword	v	6	594	0.97
etterd	0	0	0	0	0	0	pseudoword	v	6	646	1.00

etyl	0	0	0	0	0	0	pseudoword	v	4	560	1.00
evact	3	4	1	0	0	0	pseudoword	v	5	700	0.89
expain	0	0	0	0	0	0	pseudoword	v	6	830	0.45
fadish	2	1	0	0	0	0	pseudoword	c	6	670	0.76
favel	3	5	0	0	0	0	pseudoword	c	5	647	0.88
fesh	2	6	1	0	0	0	pseudoword	c	4	650	0.87
futty	4	7	0	0	0	0	pseudoword	c	5	642	1.00
gauce	3	5	1	2	2	0	pseudoword	c	5	610	0.88
gease	4	5	0	0	0	0	pseudoword	c	5	666	0.66
glears	3	3	0	0	0	0	pseudoword	c	6	689	0.82
hauted	2	4	0	0	0	0	pseudoword	c	6	694	0.88
healm	2	4	0	0	0	0	pseudoword	c	5	650	0.66
heeve	4	2	0	0	0	0	pseudoword	c	5	624	0.80
hirl	4	6	3	1	1	0	pseudoword	c	4	561	0.92
huthed	2	1	0	0	0	0	pseudoword	c	6	624	0.97
idgest	3	1	0	0	0	0	pseudoword	v	6	602	1.00
impall	2	1	0	1	1	0	pseudoword	v	6	647	1.00
impove	1	1	0	1	1	0	pseudoword	v	6	844	0.58
indint	2	0	0	0	0	0	pseudoword	v	6	660	0.98
inged	1	1	0	0	0	0	pseudoword	v	5	626	0.97
isews	0	0	0	0	0	0	pseudoword	v	5	514	1.00
istend	1	2	1	0	0	0	pseudoword	v	6	618	1.00
isyx	0	0	0	0	0	0	pseudoword	v	4	550	1.00
itle	2	2	1	1	1	0	pseudoword	v	4	644	0.95

jiaves	0	0	0	0	0	0	pseudoword	c	6	551	0.98
jigh	4	4	1	0	0	0	pseudoword	c	4	522	1.00
jompt	0	0	0	0	0	0	pseudoword	c	5	537	1.00
joult	3	3	0	0	0	0	pseudoword	c	5	786	0.55
laulm	1	0	0	0	0	0	pseudoword	c	5	591	0.97
lealms	1	1	0	1	1	0	pseudoword	c	6	597	1.00
lidg	3	4	0	0	0	0	pseudoword	c	4	519	1.00
lurn	5	6	2	0	0	0	pseudoword	c	4	661	0.98
maburb	0	0	0	0	0	0	pseudoword	c	6	572	1.00
manch	4	4	2	2	2	0	pseudoword	c	5	625	0.98
munced	1	1	0	0	0	0	pseudoword	c	6	703	1.00
muven	0	0	0	1	1	0	pseudoword	c	5	563	1.00
nalign	1	1	0	0	0	0	pseudoword	c	6	656	1.00
naugh	2	3	1	0	0	0	pseudoword	c	5	626	0.89
niew	1	1	1	0	0	0	pseudoword	c	4	555	0.98
nixel	2	2	1	1	1	1	pseudoword	c	5	652	0.80
nuffet	1	3	0	1	1	0	pseudoword	c	6	632	1.00
obone	1	2	0	1	1	0	pseudoword	v	5	670	0.93
occept	1	1	1	0	0	0	pseudoword	v	6	697	0.97
onging	0	0	0	0	0	0	pseudoword	v	6	819	0.75
onsue	1	1	0	0	0	0	pseudoword	v	5	685	0.78
oploge	0	0	0	0	0	0	pseudoword	v	6	587	1.00
orms	4	5	1	2	2	0	pseudoword	v	4	615	1.00
osaid	0	0	0	0	0	0	pseudoword	v	5	550	1.00

othect	0	0	0	0	0	0	pseudoword	v	6	592	1.00
ounge	3	3	0	0	0	0	pseudoword	v	5	659	0.93
outgel	0	0	0	0	0	0	pseudoword	v	6	679	1.00
outtit	2	2	1	0	0	0	pseudoword	v	6	737	0.84
owth	1	2	0	0	0	0	pseudoword	v	4	629	0.98
paber	6	9	1	4	4	2	pseudoword	c	5	599	1.00
peash	3	4	0	0	0	0	pseudoword	c	5	601	1.00
pesure	0	0	0	0	0	0	pseudoword	c	6	601	0.95
potace	0	0	0	0	0	0	pseudoword	c	6	618	1.00
rearth	2	2	0	0	0	0	pseudoword	c	6	640	0.88
rebow	0	0	0	0	0	0	pseudoword	c	5	648	0.80
rublet	1	0	0	0	0	0	pseudoword	c	6	592	0.93
scount	0	0	0	0	0	0	pseudoword	c	6	731	0.88
sewe	3	3	0	1	1	0	pseudoword	c	4	552	0.92
slile	5	5	3	0	0	0	pseudoword	c	5	593	0.99
suare	6	7	3	2	2	2	pseudoword	c	5	609	0.97
tadle	2	2	1	2	2	0	pseudoword	c	5	576	0.95
thitch	2	2	0	0	0	0	pseudoword	c	6	654	0.89
twack	1	2	1	0	0	0	pseudoword	c	5	661	0.85
ubip	0	1	0	0	0	0	pseudoword	v	4	513	1.00
unaste	0	0	0	2	2	1	pseudoword	v	6	683	0.97
unbock	2	1	0	0	0	0	pseudoword	v	6	702	0.87
unrend	1	1	0	0	0	0	pseudoword	v	6	695	0.88
urmer	0	1	0	0	0	0	pseudoword	v	5	563	1.00

uslard	0	0	0	0	0	0	pseudoword	v	6	624	1.00
usser	1	1	0	0	0	0	pseudoword	v	5	601	0.97
vangle	6	6	0	0	0	0	pseudoword	c	6	603	0.95
vetor	1	0	0	1	0	0	pseudoword	c	5	655	0.92
vish	5	12	3	1	1	0	pseudoword	c	4	635	1.00

Appendix VII. Stimuli included in Experiment 4

Item	Zipf value	Neighbourhood Density with words of 4-6 lettersN	Neighbourhood Density with words with Zipf values above 2	Neighbourhood Density with high frequency words	Condition	Onset: vowel (v) or consonant (c)	Length	RT BLP	Accuracy BLP
acloot	NA	0	0	0	pwfiller	v	4	535	0.97
afel	NA	9	3	0	pwfiller	v	4	538	0.97
asgent	NA	3	3	0	pwfiller	v	5	640	1.00
atch	NA	8	4	0	pwfiller	v	6	614	0.98
awant	NA	4	2	0	pwfiller	v	6	609	0.97
aybent	NA	0	0	0	pwfiller	v	6	550	1.00
eassee	NA	1	0	0	pwfiller	v	4	556	1.00
eints	NA	9	3	0	pwfiller	v	5	576	0.99
esax	NA	2	1	0	pwfiller	v	5	591	1.00
esite	NA	3	1	1	pwfiller	v	6	638	1.00
esking	NA	3	1	1	pwfiller	v	6	643	0.98
igns	NA	5	2	0	pwfiller	v	4	594	0.98
immunk	NA	2	1	0	pwfiller	v	6	581	1.00
innell	NA	1	0	0	pwfiller	v	6	583	1.00
ochish	NA	0	0	0	pwfiller	v	4	613	1.00
ocix	NA	0	0	0	pwfiller	v	5	553	1.00
oriets	NA	1	0	0	pwfiller	v	6	638	0.97
otiop	NA	0	0	0	pwfiller	v	6	542	1.00
unmick	NA	2	1	0	pwfiller	v	5	559	0.98

urled	NA	2	1	0	pwfiller	v	6	645	0.97
bawoor	NA	0	0	0	pwfiller	c	5	516	1.00
brasp	NA	5	3	1	pwfiller	c	6	603	0.97
chield	NA	4	1	0	pwfiller	c	5	650	0.95
clest	NA	12	5	1	pwfiller	c	6	625	1.00
drunts	NA	3	2	0	pwfiller	c	6	604	0.93
fawty	NA	3	2	0	pwfiller	c	5	615	0.98
gring	NA	17	9	1	pwfiller	c	5	612	0.97
hatbil	NA	0	0	0	pwfiller	c	4	573	1.00
houp	NA	12	4	2	pwfiller	c	6	540	1.00
jumit	NA	2	0	0	pwfiller	c	5	568	1.00
loff	NA	18	7	1	pwfiller	c	4	566	1.00
lonker	NA	8	4	1	pwfiller	c	6	615	1.00
marels	NA	1	1	0	pwfiller	c	6	655	0.98
nasib	NA	5	2	0	pwfiller	c	5	533	0.97
nifier	NA	0	0	0	pwfiller	c	6	600	1.00
peride	NA	2	0	0	pwfiller	c	6	624	0.93
rearls	NA	2	1	0	pwfiller	c	6	653	1.00
sempy	NA	0	0	0	pwfiller	c	5	568	1.00
thrim	NA	8	0	0	pwfiller	c	5	645	1.00
vicis	NA	4	2	0	pwfiller	c	5	579	0.98
adfler	NA	0	0	0	pwfiller	v	4	567	1.00
agfors	NA	0	0	0	pwfiller	v	5	540	1.00
agok	NA	7	4	0	pwfiller	v	5	574	0.97

alkoe	NA	1	1	0	pwfiller	v	6	548	1.00
atrorb	NA	0	0	0	pwfiller	v	6	573	1.00
auced	NA	4	0	0	pwfiller	v	6	620	0.98
ehus	NA	10	4	0	pwfiller	v	4	533	1.00
emrow	NA	0	0	0	pwfiller	v	5	591	0.97
etchly	NA	0	0	0	pwfiller	v	5	688	0.93
eweil	NA	1	1	0	pwfiller	v	6	532	1.00
extart	NA	2	2	0	pwfiller	v	6	652	0.97
ilming	NA	1	0	0	pwfiller	v	5	596	1.00
irches	NA	5	3	1	pwfiller	v	6	588	1.00
irtly	NA	0	0	0	pwfiller	v	6	577	1.00
omaved	NA	0	0	0	pwfiller	v	5	564	1.00
omile	NA	4	3	1	pwfiller	v	5	565	1.00
orspon	NA	1	0	0	pwfiller	v	6	585	0.95
oruls	NA	1	0	0	pwfiller	v	6	571	1.00
unnod	NA	1	0	0	pwfiller	v	5	582	1.00
upkips	NA	0	0	0	pwfiller	v	6	673	1.00
bogwin	NA	1	0	0	pwfiller	c	5	617	1.00
bumly	NA	5	3	0	pwfiller	c	6	623	0.97
coove	NA	10	4	0	pwfiller	c	5	581	1.00
deing	NA	15	4	3	pwfiller	c	5	667	1.00
dooken	NA	2	0	0	pwfiller	c	6	589	1.00
fusps	NA	2	1	0	pwfiller	c	5	559	0.98
gured	NA	5	3	0	pwfiller	c	5	591	1.00

heefs	NA	5	3	1	pwfiller	c	5	638	0.95
huscub	NA	0	0	0	pwfiller	c	6	587	1.00
jifto	NA	1	0	0	pwfiller	c	5	560	1.00
laun	NA	18	6	1	pwfiller	c	4	631	0.95
mertic	NA	0	0	0	pwfiller	c	5	638	0.95
mioch	NA	6	3	0	pwfiller	c	6	550	1.00
norus	NA	8	3	0	pwfiller	c	5	626	1.00
paxfy	NA	0	0	0	pwfiller	c	5	532	0.98
pitzed	NA	2	2	0	pwfiller	c	6	588	0.95
risnub	NA	0	0	0	pwfiller	c	6	538	1.00
shoss	NA	6	5	4	pwfiller	c	5	583	0.98
texbre	NA	0	0	0	pwfiller	c	6	604	1.00
vilils	NA	1	0	0	pwfiller	c	6	615	1.00
amlers	NA	2	0	0	pwfiller	v	4	626	1.00
argly	NA	3	0	0	pwfiller	v	5	700	0.95
atyps	NA	0	0	0	pwfiller	v	5	531	1.00
autoun	NA	1	0	0	pwfiller	v	6	637	0.97
awhe	NA	6	2	0	pwfiller	v	6	539	1.00
eddlem	NA	0	0	0	pwfiller	v	4	574	1.00
eltent	NA	3	1	1	pwfiller	v	4	573	1.00
ensah	NA	1	0	0	pwfiller	v	5	557	0.98
erdy	NA	6	1	0	pwfiller	v	6	545	1.00
ewts	NA	8	2	0	pwfiller	v	6	543	1.00
isser	NA	5	1	0	pwfiller	v	4	549	1.00

ites	NA	18	9	1	pwfiller	v	5	565	0.95
ixcurs	NA	1	0	0	pwfiller	v	6	537	1.00
oniate	NA	2	1	0	pwfiller	v	4	678	0.98
oocas	NA	3	1	0	pwfiller	v	5	541	1.00
orst	NA	11	2	0	pwfiller	v	6	617	1.00
oursed	NA	3	3	0	pwfiller	v	6	673	0.98
uelled	NA	8	5	0	pwfiller	v	4	588	1.00
ulls	NA	9	2	0	pwfiller	v	6	543	1.00
unpill	NA	1	0	0	pwfiller	v	6	697	0.95
bexer	NA	5	1	0	pwfiller	c	6	590	1.00
carch	NA	6	3	2	pwfiller	c	5	606	1.00
cucket	NA	1	1	1	pwfiller	c	6	663	0.95
doffy	NA	6	2	0	pwfiller	c	5	609	0.97
fimp	NA	10	5	0	pwfiller	c	4	596	0.99
flunch	NA	2	1	0	pwfiller	c	6	621	0.98
gorvan	NA	6	2	0	pwfiller	c	6	597	0.97
hulpy	NA	3	1	0	pwfiller	c	5	604	0.97
jarker	NA	11	6	0	pwfiller	c	4	593	0.97
jisa	NA	12	6	1	pwfiller	c	6	549	1.00
lealt	NA	4	4	2	pwfiller	c	5	604	0.99
mungs	NA	13	3	1	pwfiller	c	5	690	0.97
nauble	NA	2	1	0	pwfiller	c	4	650	0.97
ninx	NA	11	7	2	pwfiller	c	6	620	0.97
plawl	NA	1	0	0	pwfiller	c	5	583	0.97

rolis	NA	7	3	2	pwfiller	c	5	590	1.00
shie	NA	20	9	3	pwfiller	c	4	593	0.99
tiyrs	NA	1	1	0	pwfiller	c	5	593	1.00
vitter	NA	13	9	2	pwfiller	c	4	617	1.00
vufo	NA	1	0	0	pwfiller	c	6	507	1.00
floo	NA	NA	NA	NA	pwfiller	c	4	644	0.80
ajoin	NA	NA	NA	NA	pwfiller	v	5	752	0.48
buggle	NA	NA	NA	NA	pwfiller	c	6	791	0.64
ovel	NA	NA	NA	NA	pwfiller	v	4	739	0.73
elfen	NA	NA	NA	NA	pwfiller	v	5	599	0.74
unword	NA	NA	NA	NA	pwfiller	v	6	816	0.66