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Finding the Means : The Bilingual Disparity in Semantic Context Use for Processing

Iyad Ghanim
Montclair State University

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Iyad Ghanim

Montclair State University

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of

Iyad Ghanim

Candidate for the Degree:

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Certified by:

[redacted]

Dr. Scott Herness
Vice Provost for Research and
Dean of the Graduate School

August 30, 2021
Date

Dissertation Committee:

[redacted]

Dr. Ilse Wambacq
Dissertation Chair

[redacted]

Dr. Mary Boyle

[redacted]

Dr. Lauren Covey

Abstract

Early and late bilinguals both differ in the speed with which they comprehend language or in their processing of sentences compared to monolinguals. This is possibly a result of cross-language interference, differential allocation of cognitive resources, or some other difference in language-dependent processes. This dissertation presents research and review focusing on one such language dependent process — the use of sentential context and lexical-associative semantic information — to process sentences. In a series of studies, 34 bilinguals and 28 monolinguals complete a retroactive masked priming task, which provides an isolated measure of the use of semantic information to backwards recognize degraded visual primes. Monolinguals demonstrated significantly faster reaction times as more semantic information became available in the conditions, whereas bilinguals did not. Compared to bilinguals, monolinguals also demonstrated faster reaction times in the condition of this task that had the most semantic information available to use for processing. These results suggest bilinguals use semantic information to activate word-level associates differently than monolinguals, and that their processing may even be inhibited by additional semantic context. Throughout this dissertation, these differential results are analyzed in the context of a differential processing mechanism in bilinguals and as the result of individual differences in cognition or their linguistic experiences.

Keywords: bilingualism, semantic processing, speech perception, speech perception in noise, cognition, psycholinguistics

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Chapter 1

Research into the psycholinguistics of bilingualism generally revealed that bilinguals appear to process sentences less-effectively than monolinguals. In this dissertation, I examine the role of word level semantics as a constituent process to sentence-level processing, since both word and sentence level processing are facilitated by the availability of semantic information. The goal of this dissertation is to examine differences in the use of semantic information for word-level processing and semantic spreading activation among bilinguals. To do so, the research investigates the use of semantic context for speech processing among bilinguals and examines whether bilinguals use this context as effectively as monolinguals. This research also explores other factors that may significantly contribute to processing differences that bilinguals exhibit. In doing so, I originate bilinguals' non-nativelike sentential processing to non-nativelike semantic use at the word level.

Chapter 2 reviews the psycholinguistic background of sentential processing and the use of various sources of information to facilitate comprehension. In this chapter, I consider the contrast between top-down and bottom-up sources of information and review research on how sentence-level semantic information is used to facilitate sentence processing. Next, the chapter explores the relevance of lexical-semantic information to sentence processing. I review literature on passive resonance among listeners, a processing mechanism that connects word-level processing to sentence processing. Chapter 2 continues with a discussion on bilingualism and the psycholinguistic effects of early acquisition on processing and ends with a review of studies showing semantic processing differences in bilinguals.

Subsequently, Chapter 3 presents word level processing experiments. The chapter begins with a discussion on semantic priming and the underlying mechanism of semantic spreading activation. I present the results of a retroactive masked priming experiment to describe the use of semantic information for word-level activation in bilinguals in comparison to monolinguals. With this study, I make the case that bilinguals apply semantic information for spreading activation in a different way than monolinguals and that this results in inefficiencies with sentence-level processing. This research is complemented by additional analyses that investigate the reason for these differences. I explore the possibility that bilinguals engage in different language-dependent processing strategies to facilitate word-level processing using a coefficient of variability and examine whether the differences are attributable to the bilingual experience.

Chapter 4 considers whether these differences are attributable to bilingual differences in language-independent cognitive and linguistic factors. I review and define the cognitive factors of working memory capacity and selective attention which demonstrable contributors to language processing. In a regression analyses, I determine if these cognitive measures, and linguistic variables such as language exposure length, frequency of use, and proficiency, impact word processing facilitation.

In Chapter 5, I present an analysis of the results that considers individual differences in the population. A critical look at the normed forward-strength associations used in this study and its applicability to bilinguals is provided at the end of the Chapter.

Finally, Chapter 6 provides an overview of the results and the impact of this dissertation to bilingual scholarship. Limitations to the studies in this dissertation are critically analyzed and directions for future studies are described.

Chapter 2

Overview

This chapter provides background on how listeners use various sources of information, including semantic and contextual clues, to process the meaning of a given sentence. In the chapter, I discuss how word-level information contributes to sentential processing through the mechanism of passive resonance. The revised hierarchical model and its predictions to first- and second-language processing by bilinguals are reviewed.

Bilingualism

It is frequent in bilingualism research to use monolingual behavior as a standard against which to compare bilinguals (e.g., Heredia & Cieślicka, 2015; Trofimovich & Isaacs, 2012). In this way, much of the research refers to bilingual production as "non-nativelike" deriving from the observed behavior of monolinguals. This custom stems from the fractional perspective on bilingualism which supposes that the bilingual language system is equivalent to two monolinguals' language systems in one (Grosjean, 1985, 1989). One criticism of this is Grosjean's perspective that it has the effect of reducing a bilinguals' ability to their degree of proficiency (1985). I review research to challenge the perspective of bilingualism as a monolith in alignment with this view.

Bilinguals are defined as individuals who "actively use" more than one language (Kroll et al., 2015, p. 378). Research in bilingualism characterizes the speakers by a global age of acquisition (AOA), which is often defined as the age at which the individual began regular and consistent exposure to that language (Montrul & Foote, 2014). As a note, research on language acquisition and word processing sometimes defines "age of acquisition" as the age at which a particular *word* is acquired, rather than the beginning of language exposure, during the lifespan of a bilingual (Alonso et al., 2015; Bird et al., 2001; Izura & Ellis, 2002). However, this dissertation uses the definition as a global language AOA.

Age of Acquisition

Speakers are considered "simultaneous bilinguals" if they began regular and consistent exposure to a second language (L2) in early childhood, which is set between a range of thresholds from birth (De Houwer, 2017; Yip, 2013) up to 3 years of age (McLaughlin, 1978) or even 5 (Grosjean, 2008). This work therefore defines simultaneous bilingualism as dual acquisition beginning from birth, with successive or "early" bilinguals beginning acquisition at some point after and up to 5 years of age (Grosjean, 2008; Yip, 2013). In these cases, the language terms "L1" and "L2" may be misleading, as there is no chronological difference in the acquisition which these terms may suggest. These terms also may misleadingly suggest a personal preference or linguistic dominance of one language or another, which may not be the case. Similarly, the terms "native speakers" and "non-native speakers" often are used respectively to refer to the monolinguals and late bilinguals processing the same language. I refrain from using the term "non-native" in this work, as it is accurate to consider early acquiring bilinguals as having two first, or two native, languages (Rothman & Treffers-Daller, 2014).

Acquisition that begins after early childhood (late bilingualism) may result in language differences compared to monolingual speakers and/or early bilinguals. Examples of this in semantic processing are well-researched: whereas monolinguals pre-activate the linguistic components of likely-upcoming words using cues in a text (Federmeier et al., 2007) and in previously-encountered words of a single sentence (Altmann & Kamide, 1999; Kamide et al., 2003), late bilinguals may not engage in prediction, or may not do so as effectively. As one example, in Martin et al. (2013a), late bilinguals read strongly biasing sentences that ended with an expected or unexpected noun phrase (see DeLong et al., 2005). Because late bilinguals did not demonstrate an N400 amplitude increase in response to the article preceding an unexpected noun like native listeners, Martin et al. (2013) concluded that late bilinguals do not predict final nouns to the same extent as monolingual listeners. Similar findings have been reported in the domain of morphosyntax, such as Mitsugi & MacWhinney (2016) who found that L2 speakers do not use the Japanese case-marking system to predict upcoming words. Hopp (2015) similarly found that while monolingual listeners use morphosyntactic cues like case-marking and word order to predict upcoming words, L2 learners only rely on word order and lexical-semantic cues embedded in verbs to predict what image represented the patient of a given sentence. Ito et al. (2018) found that bilinguals were slower than monolingual listeners at looking predictively at target objects, and that bilinguals did not look predictively at phonological competitors, unlike monolinguals. Grüter et al. (2017) investigated how Japanese-English and Korean-English L2 learners use contextual information to interpret the event structure of sentences and found that they have a reduced ability relative to English monolinguals to use higher-order contextual information in sentence interpretation. Finally, Dijkgraaf et al. (2019) found that L1 sentences resulted in greater visual fixations to semantic competitors than L2 sentences among the same late bilinguals, indicating that the ability to use semantic information to facilitate processing was slower and weaker in L2. Together, these studies suggest that there is a decline in the use of bilinguals' ability to use semantic information during processing with a later age of acquisition.

The decline of ultimate language proficiency with a later AOA is formalized in the development and subsequent revision of the critical period hypothesis (CPH) (Johnson & Newport, 1989; Lenneberg, 1967). Under the CPH, there is a decrease in potential language outcomes with acquisition that begins after early childhood (Johnson & Newport, 1989;

Lenneberg, 1967). However, the decrease in language ability is not a sharp decline, and it varies across different age ranges and linguistic contexts. While Johnson and Newport (1989) argued that there was a decrease in morphosyntactic language abilities that begins at around age 16, a replication of this study by Birdsong and Mollis did not find the same effect in Spanish-English bilinguals (2001), nor was an effect of AOA found in syntactic ability (Li, 2013).

Shi and Sánchez (2010) find differential results on a word recognition task with bilingual acquisition that begins after 8 years of age compared to bilingual acquisition before 8 years of age. Sabourin et al. (2014) tested simultaneous (AOA: birth), early (AOA: 3-5 years of age) and late bilinguals (AOA: 9-19 years of age) in a within-language and cross-linguistic semantic priming study, and found that only simultaneous and early bilinguals showed evidence of masked translation priming. Similar results were reported by Perea et al. (2008), which suggests that there is a significant effect of AOA before 5 years of age for developing the bilingual lexicon. However, the groups in this analysis did not involve participants with an AOA between 5-9 years of age. Cross-linguistic priming effects were also demonstrated in several other studies in bilinguals with an AOA prior to 7 (Chen & Ng, 1989) or 8 (Altarriba, 1992) years of age, or even up to adolescence with intensive exposure and training (Chen & Ng, 1989; Silverberg & Samuel, 2004). In a lexical decision priming task, Silverberg and Samuel (2004) demonstrated facilitative priming effects for early bilinguals with an AOA before 7 years of age. This suggests than the age of L2 acquisition has an influence on bilinguals' lexical representation and use of semantic information with significant differences emerging at an AOA past 7 - 8 years of age (Silverberg & Samuel, 2004). Further, Kousaie et al. (2019) posits that early bilinguals with an AOA past 6 years of age do not appear to be benefit from contextual information when processing speech. Kousaie et al. (2019) compared processing of high- and low-predictability sentences in simultaneous (AOA: birth) and early (AOA: 3-5 years) in noise and in quiet and found that simultaneous bilinguals can use contextual top-down information to repair impairments of a bottom-up signal better than early bilinguals

Top-Down and Bottom-Up Processing

Contextualizing this literature base, the terms “top-down” and “bottom-up” are used to refer to sources of information that a listener might use to decode an utterance. In top-down processing, a listener uses previous information, their experiences and memory, knowledge of the topic of conversation and other sources of contextual knowledge to facilitate comprehension of the message (Craik, 2007; Field, 2004; Goodman & Goodman, 2014). Field (2004) refers to this as a “directionality of processing” (p. 363), in that larger units of information influences the way smaller units are perceived rather than as “levels of processing.” In this way, a listener’s expectations of what is said drives and reshapes what is perceived in a top-down direction (Kuhlen & Brennan, 2010) before being integrated together (Bruner & Postman, 1949). Conversely, bottom-up processing includes the use of sensory input to extract meaning from utterances: in spoken languages, this would be auditory input from a perceived acoustic signal.

Two important points arising from the literature on top-down and bottom-up processing is first that these two processes are complementary and interact, and second, that these processes fluctuate and are flexible in their interaction. This ensures that the listener achieves comprehension effectively. Earlier theories about this interaction described the balance between “expectation vs. sensation” (Kintsch, 2005): a strategy of processing where listeners build expectations on what they are about to perceive, which is a form of top-down information like previous knowledge, before checking it against the input to re-strategize (Bruner & Postman, 1949). More recently, Kintsch’s construction-integration (CI) model explains how discourse comprehension can be so flexible: the input activates multiple inferences which are then facilitated or inhibited depending on how much support they receive from other sources of information. Field (2004) and Tsui and Fullilove (1998) also recognize the interplay between the two systems in their works.

This interplay is most evident in studies investigating the effects of age-related changes in cognition and hearing on language processing. Craik (2007) describes how audibility and cognition interact in older listeners, who rely on top-down knowledge of a speaker's voice and knowledge of the topic, among other top-down cues, more so than younger listeners. Adding more contextual support and "priming" (Craik, 2007, p. 544) older listeners with more top-down information will allow them to respond to processing tasks with the same speed and accuracy as younger listeners (Wingfield & Stine-Morrow, 2000).

Craik (2007) also discusses Rogers et al. (2006), a study which demonstrated a similar interplay of audibility and cognition in bilinguals. In Rogers et al. (2006), bilinguals and monolinguals were tasked with identifying monosyllabic English words in conditions of quiet, noise, and noise with reverberation. Although both groups had about the same word recognition performance in quiet, the bilinguals had poorer word recognition scores than monolinguals in noise and in noise with reverberation. This is a particularly striking outcome because the language skills of the bilinguals appeared to be equal to that of their monolingual peers: they had acquired L2 English prior to six years of age, spoke English with little or no foreign accent, and all bilingual participants reported using English 50% or 75% of the time (Rogers et al., 2006). They appeared to be perceptually equal to their monolingual peers, but when the processing system was strained under environments with background noise and reverberance, their word recognition abilities were more negatively affected than monolinguals (Rogers et al., 2006).

In addition to the clinical applications, Craik interprets these findings as suggesting that bilinguals require a stronger signal and a more favorable signal-to-noise ratio (SNR) to comprehend with the same performance as monolinguals (2007), similarly to the older listeners referenced in Craik (2007). The supposition is that top-down systems in bilinguals do not function as well as in other speakers, and so making the bottom-up cues more accessible to bilinguals and older listeners will help perception. The theory also suggests that the top-down system is overloaded in bilinguals and increasing bottom-up cues will relieve some of the overload of the top-down system. In total, these studies may suggest that a louder signal can compensate for a less efficient language representations in both older listeners and in bilinguals. This shows how audibility and cognition may interact: improving the bottom-up signal can result in better word recognition and compensate for some of the inabilities of the top-down system, a flexibility which ensures that the language and perceptual system maintains its effectiveness.

Other studies have shown the same compensatory effect in the opposite direction: that top-down cognitive factors are crucial for perception (Foo et al., 2007; Lunner & Sundewall-Thorén, 2007) and can compensate for the loss of acoustic signal in a suboptimal auditory conditions resulting from background noise (Humes, 2007) or presbycusis (Pichora-Fuller, 2008).

This compensation may work similarly among bilinguals, though there is some debate about a supposed “bottom-up dependency” among L2 listeners, including early bilinguals. In a review of non-native listening in noise, Cooke et al. (2008) describe bilinguals’ non-native-like perception performance that is apparent only in noise and not in quiet conditions. Mayo et al. (1997) found that while early bilingual performance on the Speech Perception in Noise (SPIN) test was equal to monolinguals in quiet, early bilinguals performed more poorly than monolinguals in noise. Here, the ability to repeat back a final word heard in noise was aided by a congruent sentential context; because bilinguals were not aided to the same extent as monolinguals, it is possible that their ability to use semantic information is more limited despite having acquired the language in infancy. Mattys et al. (2010) found that, under greater cognitive load, native speakers relied more on lexical-contextual information embedded in the words than acoustic cues for word segmentation, whereas early bilinguals did not. These studies suggest that a differential use of lexical semantic processing in bilinguals causes them to make lesser use of top-down processing to recover from impaired acoustic input. One view described in Field (2004) is that less proficient bilinguals occupy their cognitive resources on focusing on each word of the input, leaving less working memory and attentional resources available to assemble the words into a higher-level, sentence-scale meaning. Several other studies with monolingual listeners and readers confer on this conclusion: Hildyard and Olson (1982) write that skilled listeners use a knowledge-based schema to comprehend, whereas less-skilled listeners attend mostly to local details in a text. Shohamy and Inbar (1991) found that less-skilled listeners performed better on "local questions" that focused on details and facts, whereas skilled listeners performed better on "global questions" that required listeners to synthesize information, draw conclusions and make inferences (Tsui & Fullilove, 1998). The authors determined that whereas lower-level listeners processed the text in a data-driven manner (i.e., relying more bottom-up cues to process), higher-level listeners processed text in a knowledge-based manner (i.e., relying on top-down processing). This also coincides with Gernsbacher's structure building framework, a theory regarding L1 reading that describes listeners as building mental representations or structures and revising them when incoming information is incongruent with those representations. The suggestion is that less-skilled readers build small scale structures and do not integrate with larger structures or check it against their understanding; this monitoring is necessary for effective and successful comprehension (Field, 2004; Tyler & Warren, 1987).

This evidence suggests that listeners with lower language ability, such as early bilinguals and less-skilled monolingual listeners and readers, rely more on bottom-up information for processing sentences than top-down information. However, Field (2004) provides evidence that may counter the theories of bottom-up dependency during L2 processing. In Wolff (1987), participants were more inclined to use top-down strategies when the text was more difficult to understand. Koster (1987) finds that non-native subjects used top-down context to the same degree and sometimes to a greater degree when given enough time for processing (from Field, 2004). Despite these studies, all three studies of Field (2004) show that non-native listeners still rely on the onset of words to interpret sentences, and further, only provide evidence of top-down influence when the context was overwhelming and the sentence was highly predictable (Field, 2004).

In sum, the evidence presented overwhelmingly suggests that early bilinguals and less-proficient listeners are more likely to require more bottom-up information during sentence processing to achieve the same word recognition scores as monolinguals. This is evidenced in studies that show reliance on word forms in noise (Field, 2004) and poorer SPIN scores (Mayo et al., 1997; Rogers et al., 2006). There is also evidence that early bilinguals have a greater focus on details in a text than on big-picture ideas (Hildyard & Olson, 1982; Shohamy & Inbar, 1991). Therefore, bottom-up dependence may account for their attested difficulties processing in noise relative to monolinguals. It is possible for monolingual listeners to alternate and fluctuate the impact of each sources of information, which calls into question why this is not the case in early bilinguals: if they have access to any available top-down sources of information but are still reliant on bottom-up information, we may speculate that there is not any usable top-down information available or that there is an inability to rapidly integrate that top-down information with what they are perceiving to the same degree as native speakers. In their study, Bradlow and Alexander (2007) suggest that semantic and other top-down contextual information is available to non-native listeners but it is ineffective or underutilized at critical levels of acoustic impairments. The researchers sought to investigate if the processing difficulty non-native listeners experience in noise is offset by either semantic (top-down contextual) or acoustic (bottom-up) enhancements or both. In a final word recognition task, native listeners benefitted from each enhancement and in combination; however, non-native listeners only improved with both semantic and acoustic enhancements. This suggests that non-native speakers require a greater clarity in the signal in order for the top-down information to be used effectively, rather than an inability to use the top down information (Bradlow & Alexander, 2007).

One theory is that the over-dedication of resources to the perceptual system in bilinguals leaves very few resources available to integrate the top-down information; therefore, I dedicate upcoming chapters to exploring the impact of working memory capacity and attentional ability on L2 language processing. Another possibility is that bilinguals are less effective at generating and using semantic information, both top-down strategies, in order to comprehend acoustically impaired L2 utterances. To investigate these, upcoming chapters compare how monolinguals and bilinguals generate semantic information during priming tasks. Preceding this, it is necessary to focus on the utility of semantic information for sentence processing. Therefore, the next section of this chapter discusses how listeners use sentential semantic context and lexical semantic context to facilitate language processing.

Use of Sentential Semantic Context for Processing

Listeners use several different manifestations of top-down information to help in comprehension, including their expectations, memories and experiences, world knowledge, and semantic context. As discussed, this use of top-down information is relied upon more when the bottom-up acoustic information is compromised or not easily processed. This chapter will continue to focus on the semantic information embedded within in an immediate sentence and how that semantic representation is used to facilitate processing. Notably, several researchers define "semantic context" as the outside information, worldly knowledge or "scene-setting" that a listener might use to make sense of an utterance (Field, 2004); yet others define context as the information embedded in the preceding discourse (referred to as co-text; Brown & Yule, 1983). In this section, the term is used to describe the meaning-related representation that a listener builds during a sentence.

Studies have long demonstrated the facilitating effects of sentence contexts on congruent final words. In 1977, Schuberth and Eimas conducted a lexical decision task (LDT) in which participants classified presented words as real words or non-words while response time and accuracy measures in response to real word conditions were collected and compared (1977). In some conditions, the words were preceded by incomplete sentence stems that were either semantically congruent or incongruent with the word. As an example: *"The puppy chewed the [bone / hour]"* (Schuberth & Eimas, 1977). They found that congruent sentence contexts facilitated the recognition of real words and, somewhat surprisingly, the identification and rejection of non-words. Crucially, for incongruous real words, a sentence context had an inhibiting effect (Schuberth & Eimas, 1977). The authors suggest that the incomplete sentences act as "primes" on the processing system (Schuberth & Eimas, 1977, p. 34). Also using the LDT methodology, Kleiman (1980) found that the most common final word completions to sentence stems had the fastest lexical decision times. Kleiman also found faster reaction times for final words that were related to the most common completions than unrelated, and faster decisions for words that were congruent completions compared to incongruent completions. In a cross-modal priming experiment, Moss and Marslen-Wilson (1993) found that when a sentence was biased towards an object's particular semantic property, like the shape or color of a noun, the listeners demonstrated a greater priming effect for targets related to that semantic property than in neutral conditions. In sum, these studies and others (e.g., Fischler & Bloom, 1979) demonstrate the effect of a semantically biasing sentence context on the activation of upcoming final words.

Much of the research showing the facilitating effect of sentential semantic context on processing the sentence was demonstrated with Speech Perception in Noise (SPIN) sentences (Bilger et al., 1984). In these studies, participants heard sentences that were high or low in their final word predictability and which were presented in different levels of noise. A high-predictability sentence is one in which the final word is highly expected given the context of the sentence; as an example: "*My clock was wrong, so I got to school late"* (Bradlow & Alexander, 2007). In a low predictability sentence, the sentential context does not give a lot of information to predict a particular final word, such as: *"This is her favorite sport."* (Bradlow & Alexander, 2007). Bloom and Fischler (1980) generated a similar set of sentential stimuli by collecting completion responses to many sentences. Because the completions of these sentences were generated by participants, the authors provide several possible completions with their relative strength of completion. As an example, the sentence: *"When you go to bed, turn off the …"* was most frequently completed with *"lights"* (at a proportion of .89), but less-likely alternatives included *"radio"* (.03) and *"stereo"* (.02) (Bloom & Fischler, 1980). This allowed other researchers to group the sentences as *strongly biasing sentences* that have a strong sentential constraint bias or otherwise *weakly biasing sentences* as a measure of how strongly the sentential context leads to a particular final word. A strongly biasing sentence is: *"He mailed the letter without a [stamp]*"; a weakly biasing sentence is: *"They went to see the famous [actor, museum, man, statue, et al.]"* (Bloom & Fischler, 1980).

In these sentences, endings to highly expected sentences were generally faster to process than sentences that were less predictable (Bilger et al., 1984; Bloom & Fischler, 1980; Federmeier et al., 2005; Van Berkum et al., 2008). The purpose of these sentences was to demonstrate how semantic-contextual information may compensate when the signal is degraded. When the listener does not expect a particular final word, top-down contextual information is minimal, and the reaction time to judge the sentence as congruent or incongruent is delayed. This judgment reflects comprehension of the sentence. When the listener has an expectation for a final word, that expectation is incorporated as top-down contextual information compensates for a poor signal and aids the listener in understanding.

Use of Lexical-Semantic Context for Processing

In addition to building a sentence-level meaning representation and using that representation to anticipate likely upcoming words, listeners also use the information encoded in the words in a sentence to facilitate processing of upcoming words. This lexical prediction is the focus of the experiments in this dissertation. In this section, I review evidence regarding lexical prediction and describe the process of passive resonance. These two models both describe how lexical items of a sentence facilitate processing of the rest of the sentence.

Active Lexical Prediction

During active lexical prediction, listeners use linguistic and grammatical information encoded in a presented word to limit the activation to lexical items that fit those restrictions (Becker, 1980). This occurs with morphosyntactic information in which anticipatory effects were measured at grammatical gender marking cues (Lew-Williams & Fernald, 2007, 2010; Martin et al., 2013a) to predict plausible upcoming nouns. In DeLong et al., listeners exhibited effect of anticipation measured at the article that preceded a final noun to determine if the sentence was going to end in the way they expected given the meaning of the sentence (2005). Lew-Williams and Fernald demonstrated that Spanish-monolingual children (2007) and adults (2010) use gender-marked articles in Spanish as a cue during processing. In their eye-tracking studies, participants listened to sentences that ended in a final noun while looking at two images. The images depicted objects that were either of the same grammatical gender (i.e., both grammatically male or both grammatically female nouns) or of different grammatical gender (i.e., one of each). In the different gender conditions, both children and adults were faster to orient their looks to the correct picture in the different gender condition, where the gender-marked article could be used as an informative cue, compared to the same gender condition. This suggests participants were using the gender-marked article that preceded the noun as a predictive cue to constrain processing.

DeLong et al. (2005) showed a similar effect among monolingual adults in English using an ERP design. The study included highly biasing sentences ending with an expected noun phrase (NP) or an unexpected noun phrase including an article ("a/an") and its appropriate noun (beginning with a consonant or a vowel sound, respectively). The target noun phase was either the most expected ending to the sentence or a congruent but less expected ending. For example, the sentence: "*Since it is raining, it is better to go out with …*" would end with either the expected NP (*"an umbrella"*) or with the less expected but semantically plausible NP which ended with the opposing phonotactic article (*"a raincoat"*). Conditions were counterbalanced such that there were expected endings that began with a consonant and used the article "a" and less expected endings that began with "an" and a vowel. The participants showed a reduced N400 at the congruent noun and the preceding article. Similarly to the findings of Lew-Williams and Fernald (2010), these findings show effects of anticipation at the article preceding an expected final word (DeLong et al., 2005; cf. Nieuwland et al., 2020).

Listeners use semantic restrictions of nouns and verbs that are embedded in a sentence to limit pre-activation to words that fit that constraint (Altmann & Kamide, 1999; Contemori & Dussias, 2019; Kamide et al., 2003; Paczynski & Kuperberg, 2012). In one example from an eye-tracking study (Kamide et al., 2003), the verb in the sentence *"The boy will eat the…*" results in greater anticipatory looks towards edible referents, i.e., *cake*, more than the other inedible distractors. This demonstrates that listeners use the semantic features encoded in a lexical item (here, the verb "eat") to facilitate processing of objects that suit its restriction.

Passive Resonance

Passive resonance is a sentence processing strategy that is distinct from active lexical prediction (Collins & Loftus, 1975; Kaczer et al., 2015; Lau et al., 2013; Neely, 1977). Early studies did not disambiguate between active lexical prediction and passive resonance, and passive resonance was also considered to be an alternative theory to lexical prediction (Martin et al., 2013b). The current understanding of passive resonance is that, while a sentence unfolds, the listener activates encountered words and the activation in turn spreads outwards to other semantically related associate words (Gerrig & McKoon, 1998; Myers & O'Brien, 1998). Under theories of passive resonance, semantic content that is related to the words in a sentence becomes passively preactivated by association. This contrasts with theories of active lexical prediction in which the meaning representation of the sentence drives an active lexical search for the final word.

During sentence processing, passive resonance occurs on the word level and facilitates the processing of upcoming words that are related or co-occur with other words in the sentence. Therefore, by the time the end of the sentence is reached and the final word is encountered, it has a high likelihood of having been preactivated passively by its associates in the sentence (Lau et al., 2013; Neely, 1977). Notably, Myers and O'Brien (1998) point out that these resonance mechanisms between semantically associated words are distinct from facilitation from a congruent message-level meaning. Paczynski and Kuperberg (2012) indicate that sentential priming effects are larger than word priming effects but that there is an interaction between the contextual representation of the sentence and relatedness networks of the words. Any "resonance" leads to the facilitation of semantically related upcoming targets (Paczynski & Kuperberg, 2012). Beyond sentence processing, Gerrig and McKoon (1998) describe resonance-like mechanisms that facilitate comprehension in discourse. Neely (1977) describes a lexical decision task (LDT) in which targets were categorically associated or not to a preceding prime word. Neely's results support the theory posited by Posner and Snyder (2004) that there is an automatic component of attention, in which spreading-activation process is fast and automatic. This is the groundwork for spreading activation.

To demonstrate passive resonance, consider the sentence: *"She was afraid she would not catch her flight, so she hailed a taxi to get to the (airport)".* In this example, the listener theoretically builds a sentence-level meaning representation that evolves as the words in the sentence are encountered. In addition, the listener uses the grammatical constraints of the prior occurring words to constrain what words may come next. Here, "*catch*" may facilitate the processing of "*flight*", and "*hailed*" may facilitate "*taxi*". Under the semantic spreading activation account, processing the words "*catch, flight, taxi"* and others in the sentence increases the activation of semantically related associates in long-term memory Collins & Loftus, 1975; Meyer & Schvaneveldt, 1971). As a simplified example, the phrase *"hailed a taxi to get to…"* may result in activation of the word *"airport"* along with other related words and semantic features. Potentially related words are activated through passive resonance as a listener processes each incoming word.

Passive resonance suggests that the overlap of all the activations has the effect of priming the word "*plane*" as it is at least peripherally semantically related to many of the preceding words in the sentence. This facilitates its processing once the word *"plane"* is encountered. By way of comparison, active lexical prediction relies on extracting linguistic meaning out of preceding words in order to limit upcoming words to suitable candidates (Becker, 1980); "active" sentential prediction strategies rely on building an evolving meaning representation to predict upcoming words.

I review passive resonance to describe how words in a sentence may contribute contextual information that facilitates processing of an upcoming part of the sentence. For passive resonance to occur, a listener's relatedness networks of semantic information must be strong and intact (Paczynski & Kuperberg, 2012). In this way, the words encountered in the sentence can trigger the activation of related words and facilitate the processing of a related final word. This provides the theoretical groundwork for the experiments that follow: if listeners perform worse in speech perception tasks, speech in noise tasks, and using meaning-related information, then it is possible that there is a different semantic network that results in these impairments. I therefore investigate the word-level semantic network in bilinguals.

Framework of Bilingual Processing: The Revised Hierarchical Model

This literature demonstrates significant differences in the way bilinguals are processing words and sentences with an early versus a later AOA. Importantly, these results are linked to differences in the way bilingual speakers are using or facilitated by relevant semantic information. One possibility is that early acquirers might have better outcomes because the organization of the lexical items in bilinguals' mental lexicon is more efficient than later acquirers. This perspective will be assessed in an experiment described in the next chapter. Here, I discuss the differences in bilingual lexical organization with the framework of Kroll's revised hierarchical model (RHM) of bilingual processing (Kroll et al., 2010). Notably, the mechanism of the revised hierarchical model does not directly address the isolated effects of age of acquisition on bilingual proficiency, as differences in bilingual processing models are attributed to proficiency.

The RHM posits that lexical items in each language have differential access to a single, semantic domain depending on a bilingual's proficiency level (Kroll et al., 2010; Kroll & Stewart, 1994). Like other widely accepted models of the bilingual lexicon, the RHM identifies two language-specific lexicons containing word form information for each word as well as a single, shared repository of semantic and conceptual information. In the process of word identification, for example, a bilingual listener activates the perceived word at the lexical level of the spoken language and in turn activates the semantic information on the conceptual level for processing (Potter et al., 1984). Crucially, while the set of conceptual representations is shared between both languages, only the words of a more dominant and more proficient language have a direct pathway to the semantic and conceptual representations of each word. This is referred to as the “conceptual mediation pathway” (Potter et al., 1984). Conversely, the lexical representations of a weaker language access their conceptual representations only through links with translation equivalents in the first language. This is the “word association pathway” where weaker-language lexical items are primarily connected to the words of the stronger language, and not directly connected to their conceptual representations (Potter et al., 1984; Kroll & Stewart, 1994; Kroll et al., 2010).

According to this model, categorization to either the conceptual mediation or word association pathways hinges on a bilingual’s level of language proficiency. For late L2 learners and less-fluent bilinguals, the words of the L2 are associated to the concepts they denote only through their translation equivalents. In fully fluent bilinguals, words in both language lexicons have direct access to the concepts they denote. This model may explain why late bilinguals demonstrate differences in accessing semantic information compared to monolinguals. When several lexical competitors arise from suboptimal noise conditions in monolingual processing, conceptual information is triggered and top-down activation constrains the available lexical options in order to help select the appropriate word. For bilinguals who are less-fluent in that language than their native language, the increased distance caused by the indirect pathway between the conceptual space and the L2 lexicon may result in fewer, and thereby less-helpful, top-down constraints. Therefore, bilinguals would have difficulty associating the relevant semantic information to narrow down lexical competitors when too many are activated in noisy conditions.

In providing this framework for bilingual semantic organization, the RHM potentially explains the differences between early acquiring and late acquiring bilinguals’ use of context as originating at the level of the word-to-concept pathway. However, when compared to monolinguals, studies have suggested that even highly fluent, early acquiring bilinguals do not use semantic context to the same degree as monolinguals, and the RHM does not address any differences between monolingual and bilingual processing that may explain this. If the strength of the word-to-concept pathway were the only factor that controlled bilingual processing, then there would be no difference in the word processing of fully fluent or early bilinguals compared to monolinguals. Experimentally, Mayo et al. (1997) and Rogers et al. (2006) showed that there are differences between these groups when processing in noise. Therefore, there may be another factor that affects early bilinguals' processing in one of their two native languages. So, while the RHM accounts for differences in late bilingual performance, this work accepts the framework that the RHM attributes to early bilinguals and suggests a cognitive basis beyond lexical organization for their differential and non-native use of context.

This chapter presented literature that described two strategies for how listeners use semantic and contextual top-down information to aid in the processing of sentences. Both processes necessitate a semantic network in which words are linked to their semantically related associates. This chapter also discussed differences in monolingual and bilingual processing of meaning-related information and sentences, even among highly proficient and early-acquiring bilinguals who are otherwise considered to have monolingual-like language skills. Therefore, it stands to reason that differences in the word-to-concept pathways or the semantic network, which are responsible for the sentence processing strategies described, account for the non-nativelikeness in bilingual sentential processing. With the connection between word-to-concept pathways and a listener's ability to use semantic information established, the study presented in the next Chapter will investigate the use of context in bilinguals compared to the same use in monolinguals.

Chapter 3

Overview

Semantic context is used by listeners to aid in sentence processing. One way this is accomplished is through the activation of related words as words in a sentence are encountered, which increases the likelihood that a congruent final word is activated (Gerrig & McKoon, 1998; Kaczer et al., 2015; Lau et al., 2013; McKoon & Ratcliff, 1992; Neely, 1977). Therefore, strong semantic networks facilitate word-level processing and is a constituent process to sentence level processing.

With this framework, the purpose of this Chapter is to explore the impact of semantic information on word-level processing. If bilinguals differ in their ability to use semantic information to process words compared to monolinguals, then this may be a greater contributor to sentence processing then other factors that facilitate sentence processing.

This chapter begins with an introduction to semantic processing and priming tasks. To determine whether and how bilinguals use semantic information to process words, the methodology described herein is designed to isolate the effects of semantic information from other sources of context. I present the results of this priming experiment in comparison to monolinguals and two subsequent analyses to attribute the bilingual difference to cognitive factors or to fundamentally differential processing. The larger goal of this study is to attribute bilinguals' non-nativelikeness in sentence-level processing to differences with word-level processing. With these findings, I make the case that bilinguals apply semantic information during lexical retrieval slower than monolinguals and in not the same way. This difference in word level processing may result in the inefficiencies attested during bilingual sentence-level processing.

Semantic Priming Experiments

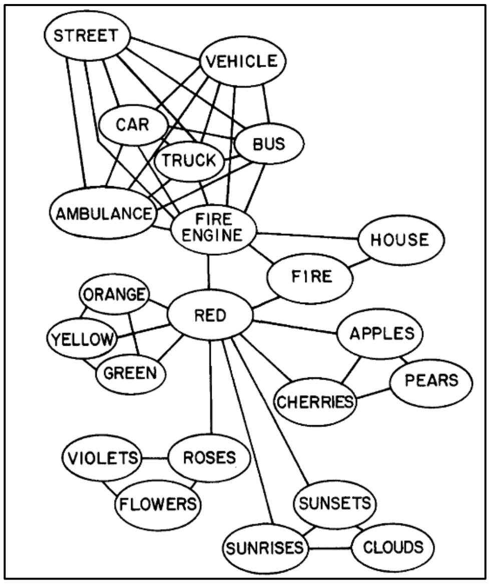
In this chapter, I present the results of an experiment designed to assess the impact of semantics on lexical access, specifically examining whether semantic information facilitates recognition for related word pairs. A retroactive masked priming task reveals to what degree participants will use semantic information to facilitate the recognition of a degraded visual prime. This priming method was designed strategically in order to look at the sole impact of semantic context on processing (Golestani et al., 2009). Because the pairs of words are linked only by their semantic association, the participant relies on just the semantic information encoded in a related target to help identify a degraded prime. If word pairs are related, this should aid in the backwards recognition of a not-immediately-identifiable degraded prime word. If word pairs are unrelated, there is expected to be no such facilitating effect of recognizing a degraded prime word. Before introducing the retroactive masked priming task, a brief overview of semantic priming tasks and their utility in informing psycholinguistic processing is warranted.

Previous studies addressed word-level processing using the semantic priming methodology. In a priming experiment, a researcher serially presents two stimuli, a "prime" and a "target," to participants (Meyer & Schvaneveldt, 1971). The linguistic relationship between the pairs is manipulated in the experiment such that they may be semantically, phonologically, or morphologically related or unrelated to each other. The participant then performs some task: in a lexical decision task, the participant makes a word/non-word judgment on the target item (Meyer & Schvaneveldt, 1971). In alternative designs, the participant may be asked to judge the relatedness of the prime and target words or classify the stimulus as belonging to one of two semantic categories such as "living" or "non-living" objects (e.g., Rips et al., 1973). In these designs and others, dependent measures such as reaction time (latency) and accuracy are measured and compared with that of the control condition in which the pairs of words are unrelated. The interpretation of the results of a priming paradigm rests on the assumption that, when a prime word is presented, activation spreads from the activated prime word automatically to nodes of semantically-related words (Basnight-Brown & Altarriba, 2007). As an example, the results of the lexical decision study in Meyer & Schvaneveldt (1971) showed that participants were faster at making judgments about real words if the words were semantically related to each other as compared to when the words were unrelated to each other. From this, the authors argue in support of a word retrieval in which there is a semantic relation and activation spreading between the prime and target (Meyer & Schvaneveldt, 1971). This explanation for the semantic priming effect is automatic spreading activation (Collins & Loftus, 1975; McNamara, 2005; Yap & Balota, 2015).

Under the framework of automatic spreading activation, linguistic features of a related target word have already been activated prior to its subsequent presentation during the priming experiment. This results in facilitated recognition, resulting in faster response times. Targets that are not semantically related to a given prime will not have been preactivated prior to their presentation, and so recognition (and therefore response times) will take longer. The keystone of automatic spreading activation is the assumption that words in the mental lexicon are linked together by semantic relatedness, such that two words that share many properties (e.g., *roses* and *poppies*, both being names of flowers) share more pathways than words that share few properties (e.g., *roses* and *firetruck*, both things that are red; Collins & Loftus, 1975). Activation from one word spreads along those pathways to the most-related and most-connected words, then diminishes in strength as it spreads across more pathways (Collins & Loftus, 1975; Kaczer et al., 2015). Figure 1 is a schematic of the semantic organization of lexical items, with lines representing the pathways connecting related words and line length representing greater degree of relatedness (from Collins & Loftus, 1975).

Figure 1

Schematic Representation of Lexical Organization (from Collins & Loftus, 1975, p. 412)



Semantic priming research with bilinguals more often focuses on priming effects across languages rather than within a single language (Dimitropoulou et al., 2011; Hartsuiker & Pickering, 2008; Holzen & Mani, 2014). These studies often use cross-language homophones and cognates with the goal of investigating whether lexical activation occurs across language boundaries (Jiang & Forster, 2001; Lauro & Schwartz, 2017; Phillips et al., 2004; Wu & Thierry, 2012). Studies that have investigated bilingual within-language priming using unilingual stimulus pairs have found a greater effect of priming in a first-acquired native language compared to a second language. In one such study, Phillips et al. (2004) measured the reaction time to primed and unprimed French and English words in blocks in L1 English speakers with varying degrees of proficiency in L2 French. The researchers also calculated an intra-individual variability in response time (coefficient of variation, or CV) which is said to be related to automaticity and an index of efficiency such that a lower CV value corresponds to greater efficiency (Segalowitz, 2008; Segalowitz & Segalowitz, 1993). The authors found that priming effects were greater, and processing was more efficient within a bilingual's first language than a second language, but that this effect was lessened with greater L2 proficiency. Here, the authors make the case for considering proficiency as an individual variable that impacts semantic processing.

Retroactive masked priming is a novel extension of the priming paradigm and will be employed in this study. In a typical masked priming paradigm, an obscured visual or auditory prime word affects the processing of a subsequent target word. Evidence from masked semantic priming studies suggest that imperceptible primes can produce semantic priming effects (Balota et al., 2006; Holender, 1986; Lucas, 2000; Yap & Balota, 2015). Bernstein et al. (1989) presented masked visual primes followed by semantically related or unrelated targets, or in which the primes were presented alone with no target words. They found that participants were more accurate in identifying briefly presented visual primes if they were followed by a related target compared to if the primes were presented alone, indicating that semantic context facilitates the retroactive recognition of an obscure word if the context arrives close in time. Golestani et al. (2009) used an auditory version of this paradigm specifically with the purpose of isolating the role of the semantic level of speech on bilingual processing. In the present study, I utilize Bernstein et al. (1989)'s visual methodology with the theoretical reasoning of Golestani et al. (2009).

In their study, Golestani et al. (2009) conducted this retroactive masked priming task with 9 native French-English bilinguals who acquired English between 11 and 18 years old, as well as a subsequent third language. At the time of testing, participants self-reported as "moderate" in their English fluency. In the experiment, primes consisted of a masked, imperceptible auditory word that was obscured by some level of background noise ranging from a speech-to-noise-ratio (SNR) of -7 dB (highest level of noise) to -4 dB (lowest noise level). Following this, a clearly audible target word was presented that was either related or unrelated to the prime word. Immediately after this, the participant viewed two visual words — one of which was the prime word shown without masking and the other was a semantically related word called a “foil” — and was asked to indicate which of the two words corresponded to the prime word. Their results indicated that a related target word helped facilitate the backwards recognition of the masked prime, but that this occurred in the native language (French) only. They concluded that the native language processing in bilinguals is facilitated by semantic context in a way that the non-native language is not. This, they report, accounts for the native language advantage bilinguals experience when processing native speech in noise that does not exist for a non-native language.

Surprisingly, they found an opposite effect in the non-native language: native French speakers hearing degraded words in L2 English had *better* performance on unrelated trials as compared to related trials. The researchers explain this as semantic interference, where the increased effort of non-native semantic processing leaves fewer cognitive resources to perform the task of recognizing acoustically degraded words. A similar result was found in a different study, where non-native speakers tasked with choosing the picture whose label rhymed with a target word tended to choose a word that was semantically related to the target rather than one that rhymed with the target (Moreira & Hamilton, 2006). Together these results point to key differences in how bilinguals process their two languages, with the processing of native language words being benefitted by access to semantic information, and the processing of non-native language words being inhibited by the addition of semantic information. These results may be attributed to native language lexical items having privileged access to semantic information that is not available to second language lexical items.

Methodology

In the present study, we employ a visual masked priming paradigm similarly to Bernstein, et al. (1989). Participants viewed prime-target pairs of visual words that varied in their semantic association to each other. Following this, participants were asked to select the prime word from a pair of words that followed. Reaction time was measured from the offset of the pair of words to the key press of the participant's response.

The methods described here are similar to that of Golestani et al. (2009) with several key differences. First, the masked priming paradigm was completed with visual masked prime words rather than auditory primes. Foil words were still visually presented. Previous studies showed that bilinguals were more disadvantaged by competing noise in speech perception tasks than monolinguals (Mayo et al., 1997; Rogers et al., 2006). In order to preserve the effect of semantic context on processing without the effect of auditory processing, the visual modality was used. Additionally, participants also completed measures of working memory capacity and attentional control for each participant. The impact of each of these cognitive variables is well-demonstrated in monolingual and bilingual processing, especially with complex tasks; therefore, an analysis that incorporates these individual differences is warranted (Craik, 2007; Kintsch, 2005; Posner et al., 2004; Shiffrin & Gardner, 1972; Zekveld et al., 2012). In addition, I present an analysis with the coefficient of variation (CV) as a dependent variable, which is a ratio of reaction time performance to variation that was conceived as a measure of processing efficiency (Phillips et al., 2004; Segalowitz & Hulstijn, 2005; Segalowitz & Segalowitz, 1993).

Another deviation from Golestani et al. (2009) involves the degree of semantic relatedness of word pairs used. The purpose of this study was to determine the effect of the availability of contextual information on processing. To best address this, the related-pairs stimuli in this study range in high and low associated conditions, whereas Golestani et al. (2009) used only associated or unassociated prime-target pairs. The three levels of the within-subjects factor in this study will result in a more robust analysis that addresses how increasing semantic information availability affects processing speed and efficiency.

Finally, the rationale of this study connects word-level processing to sentence-level processing compared across groups of bilinguals and monolinguals. Less relevant for this study are the differences in L1 and L2 processing, which was the main focus of Golestani et al. (2009). Since there are differences in bilingual processing of sentences throughout the range of the bilingual experience (Mayo et al., 1997; Rogers et al., 2006; Shi & Sánchez, 2010), data from various intersections of English-fluent bilinguals were included in this study, though the large majority of the bilingual participants were comprised of simultaneous and early-acquiring bilinguals.

Participants

Participants were individuals who were recruited to the study via word-of-mouth recruitment or who were enrolled in a Second Language Acquisition course in the Linguistics Department at Montclair State University. Students in this course who completed the study were compensated with course assignment credit, and students were offered the option of completing an alternative and equivalent assignment instead. The students had not met the investigator prior to data collection and were not briefed on the purpose of the experiment prior to data collection.

Of the total 68 participants who completed the study, data from 6 participants was removed after collection. Three of the 6 were removed because their rate of correct responses was at or below chance (defined as 50% accuracy) at 34%, 41%, and 46% accuracy each for each condition. One participant's data was removed because over 50% of their responses had "timed out" indicating that they had provided no responses to the presented stimuli. Two bilingual participants' data were removed because they reported using ASL and no other second language. The semantic differences of bimodal bilingualism is not well documented, including bimodal bilinguals may interfere with the homogeneity of the bilingual subjects in this experiment.

The data was analyzed with the results of the remaining 62 participants. Of this sample, 28 were monolingual and 34 were bilingual. Participants were between 18 and 38 years of age (*m* = 22.28 y), and 11 participants identified as male, 49 identified as female, 1 identified as non-binary, and 1 provided a null response.

All bilingual participants reported strong or high proficiency in English. On average, the bilinguals self-rated their proficiency in English as 6.7 on a scale of 7 (where 7 indicates "perfectly native-like" proficiency) with two individuals reporting a proficiency of 4 on the scale, and the rest as a 6 (*n* = 4) or 7 (*n* = 27) on the scale (one null response). Most participants were early bilinguals who reported English exposure that began at birth (*n* = 18) or before five years of age (*n* = 9). The remaining participants reported English exposure that began between 5 and 12 years of age (*n* = 4) or at or after 18 years of age (*n* = 2). All participants reported current and regular exposure to English that had not stopped since their time of exposure. The other, non-English language varied across participants: 23 bilinguals reported that their other language is Spanish, 3 bilinguals reported Arabic, 2 bilinguals reported French and Greek, and 1 bilingual reported Hebrew, Farsi, Japanese, and Portuguese.

Table 1 summarizes the criteria that describe the frequency of language use as self-reported by the bilingual participants.

Table 1

Self-reported Frequency of Language Use

Language criterion	English		Other language		Both languages	
	n	%	*n*	%	*n*	%
First to fully acquire	17	50.0	12	35.3	5	14.7
Speak more frequently	29	85.3	1	2.9	4	11.8
Exposed to more frequently	27	79.4	1	2.9	6	17.6
More dominant in	30	88.2	1	2.9	3	8.8
Prefer to speak in	22	64.7	1	2.9	11	32.4
Prefer to read in	29	85.3	2	5.9	3	8.8
Prefer to enjoy media in	17	50.0	4	11.8	13	38.2

Stimuli

The stimuli were 300 pairs of English words which included 100 pairs of words that had a high forward strength of association and 100 pairs of different words that had a low forward strength of association with each other. In addition, the stimuli included 100 pairs of words that were unassociated with each other. This set was comprised of half the primes from the strongly related word pair list and half of the primes from the weakly-related word pair list, each randomly selected and coupled with a completely unrelated target word. The unassociated set of words were screened to ensure they were truly unassociated with each other and randomly paired. Therefore, half the words in each "associated" condition also appeared in the unassociated condition. No words in the unassociated condition were unique to that condition. The total list of stimuli used are presented in the appendix in Table 48.

The word pairs were a selection of the word pairs in Golestani et al. (2009), which represent a selection from the University of South Florida Free Association Norms (Nelson et al., 2004). The strongly related context list represents the word pairs from Golestani et al. (2009), in turn from Nelson et al. (1998), for which the probability of free association (or forward strength, Nelson et al., 2004) is the top 100 strongest, or between a forward strength of 0.174 and 0.701. Weakly related pairs are those for which forward strength is the 100 weakest, or between 0.013 and 0.081. In their methods, Golestani et al. had ensured that the lists had consistent syllable length and word log frequency across each relatedness group (2009). Similarly, target words in this study were matched for lexical frequency and the number of syllables across each of the 3 context lists (strongly related, weakly related, unrelated lists). Foils also matched primes in the number of syllables.

Procedure

The study was implemented and distributed to participants online using the PsyToolkit experimental software (Stoet, 2010, 2017). All participants viewed all 300 stimuli in three counterbalanced blocks with stimuli randomized within blocks. Two blocks had 99 word pairs with 33 high, low, and unassociated prime-target pairs each. One block had 102 word pairs with 34 high, low, and unassociated prime-target pairs each. Among the foil words, the word that represented the prime was randomly assigned to the left or right position and this was counterbalanced for words across participants. Each prime word had appeared in the left and right positions equally across all participants.

During the study, a fixation cross (i.e., "+") was shown at the center of the screen at a randomly selected length of time between 150 and 200 ms. Then, a set of ten hashmarks (i.e., "##########") was presented for 600 ms and was immediately followed by a prime word for 54 ms, which was flanked by hashmarks in order to facilitate the obscuring (e.g., “#BIRD#”). This length of time is similar to other masked priming experiments which range between 50 and 55 ms (Balota et al., 2006; Chng et al., 2019). The prime word was shown in Arial font using all uppercase letters. Immediately following this, a set of ten hashmarks was again presented over 500 ms. Next, the target word was presented for 600 ms and then disappeared from the screen. After a 700 ms delay, two “foil” words were shown on either side of the display screen, one of which was the identical prime word in lower case Arial text (e.g., “bird”) and the other word was a word that was related to the prime (e.g., “feather”). Participants had 5000 ms to indicate via a button press on the keyboard which of the two foil words was the prime word (“A” key to indicate the left foil word; “L” key to indicate the right foil word). Reaction time and accuracy of response were recorded.

Prior to the first block, participants read a consent document and then completed a qualifying questionnaire and language history survey. After each of the first two stimuli blocks, participants were asked to take a break if needed. Following this, participants proceeded to either the memory task or the selective attention task, counterbalanced across participants. Participants completed the other task after their second break.

Questionnaires, Qualification and Assessments. Participants read a consent document and then completed a qualifying questionnaire to self-report as neurotypical and as having no language, hearing, or visual deficits and no cognitive deficits to participate in the study. This was important to ensure that language processing was not adversely affected by neurological or cognitive deficits and differences. Corrected vision was required to complete the task, since it was online and visual based. There were no other exclusionary or inclusionary criteria for the study.

Next, the self-report questionnaire presented participants with a list of conditions. Following these conditions, participants indicated if any of these conditions applied to them. If they indicate “yes,” then were redirected and participation in the experiment will end. The conditions asked:

(1) If you have ever had an MRI scan of the head and had results that required further or lasting medical attention;

(2) If you have ever been diagnosed with a learning disability, neurological disorder, developmental disorder, or central auditory processing disorder;

(3) If you have ever had any impairment with attention, memory, or decision making; or

(4) If you have ever had a diagnosis of attention deficit (hyperactivity) disorder (ADD or ADHD), autism spectrum disorders (ASD), or any disorder similar to those listed.

Then, in order to assess for language, hearing, and visual impairments, participants indicated whether they:

(5) have ever had a hearing test, and if so, if the results indicated you have some impairment to your hearing;

(6) have ever had a head injury;

(7) have ever had a vision test, and if so, if the results indicated you have some impairment to your vision that is currently not corrected; and if they

(8) currently or have ever had a diagnosed language disorder.

Participants then indicated their ages, gender, and provided an email address in order to be assigned course credit. Participants then indicated whether they were monolingual or bilingual and were redirected to language history questionnaires accordingly. The monolingual questionnaire asked participants to indicate which of the following statements applies to them with the option to select all that apply:

(1) I never studied any other language, or I studied another language but never used it or forgot it;

(2) I consider myself proficient in English; and

(3) I mostly use English in my daily life.

Monolinguals were then redirected to the beginning of the experiment. Participants who indicated they were bilinguals completed a survey that is an adapted version of the language experience and proficiency questionnaire (LEAP-Q) to quantify English language proficiency, age of acquisition, exposure, frequency of use, dominance, and what other languages they were exposed to or use (Marian et al., 2007). Bilingual participants were asked the following questions:

(1) Scale (min=1, “none”; max=7, “perfect”; start=4): What is your level of proficiency in English?

(2) Selection: At around what age did you begin regular exposure to/learning English? (birth / before age 5 years old / between 5 and 8 years old / between the ages of 8 and 12 years old / between the ages of 12 and 18 years old / at some point after 18 years old).

(3) Selection: Do you currently have regular exposure to English? (Yes / No)

a. If yes, when did your regular exposure to English stop?

(4) What other language do you speak?

(5) Scale (min=1, “none”; max=7, “perfect”; start=4): What is your level of proficiency in the other language (non-English) that you speak?

(6) About how many years and months have you spent living in a country where that other language (non-English) is spoken?

(7) About how many years and months have you spent with a family in which that other language (non-English) is spoken?

(8) About how many years and months have you spent in a school or working environment where that other language (non-English) is spoken?

(9) Scale (min=1, “no accent”; max=7, “very heavy accent”; start=4): In your perception, how much of a foreign accent do you have in that other language (non-English)?

(10) Selection: Do you have exposure or proficiency in another third language?

(11) Selection (English; Other (non-English) language; Both languages): In reference to English and your non-English language, please select which language most applies to each of the following:

a. The language I acquired first is...
b. The language I speak more frequently is...
c. - The language I am exposed to more, on average is...
d. - I am more dominant in ...
e. - When speaking to someone equally fluent in both my languages, I would prefer to speak in...
f. - I would prefer to read in...
g. - I would prefer to watch TV/enjoy media in...

The memory task was a Corsi block-tapping task administered through the same online software (Corsi, 1973; Kessels et al., 2000). The task presents participants with a series of randomly positioned squares that change color. Participants are asked to click on the sequence of squares that changed colors in the order of presentation. Clicking through the correct squares in the correct sequence will advance participants to replicate the trial with a longer sequence, up to 10 long. Three incorrect responses in the same trial (in which the wrong square is clicked or is clicked out of order) will end the task. Reaction time and accuracy are recorded and participants are assigned a “Corsi span” that corresponds to the longest sequence a participant can correctly repeat (Kessels et al., 2000; Stoet, 2010, 2017).

Selective attention was measured via a numerical Stroop task adapted for computer presentation (MacLeod, 1991). In the Stroop task, participants were asked to indicate the number of times a particular word was repeated on screen while reaction time and accuracy are recorded. In the baseline condition, participants viewed animal words (e.g., “panda, iguana”) repeated one to four times on screen. In the critical condition, participants viewed number words between one and five (e.g., “two two two”) repeated one to four times on screen. The number words shown and the number of times it was shown on screen were always in conflict (e.g., “two two” was never shown). The task requires greater attentional control to inhibit the incorrect response of the actual word and respond as to the number of times it appears. The reaction time for the baseline condition was subtracted from the interference condition, resulting in a “Stroop score” that measured participants’ attentional control ability.

Results

Trials that had reaction times less than 300 ms or longer than 5000 ms were removed from each participant’s data. This cutoff was chosen because we wanted to exclude participant responses in which a button was pressed without processing the stimuli and considering an answer. Typically, a cutoff value between 100 and 200 ms is chosen for single-word recognition tasks (Whelan, 2008); here, 300 ms cutoff was used because two words were presented on screen and the masked nature of the task made it more challenging. A response time shorter than 300 ms is likely too quick to have resulted from meaningful processing and was considered to be an unreliable response. Response times that were longer than 5000 ms were "timed out" by the presentation software. This is because any trials that take longer than 5 seconds have the possibility of reflecting other processing or responding strategies beyond semantic processing, and so omitting them preserves the validity of the experimental design. In total, 153 response times were removed for being less than or equal to 300 ms, and 181 response times were removed for being greater than or equal to 5000 ms. This represented 1.89% of the total number of trials. No participant had more than 42 trials removed from their total 300 trials.

I then averaged the reaction time data for each participant. These reaction time averages were then used for analysis using SPSS 27 Statistical Software (IBM Corporation, 2020). The average accuracy values were between 91.96% and 92.42% across all conditions for both groups. Descriptive results showed that both groups of participants were least accurate in the unassociated conditions. Mean accuracy values are reported in Table 2. Table 47 in the Appendix displays the distribution of reaction times for each word.

Table 2

Accuracy Scores

	High Association	Low Association	Unassociated	Group Total
Monolinguals	92.00%	91.96%	91.46%	91.81%
Bilinguals	92.42%	92.42%	90.90%	91.91%
Condition Total	92.21%	92.19%	91.18%	

Omnibus Differences in RT Data

A repeated measures two-way mixed analysis of variance (ANOVA) was conducted in order to determine whether responses to the conditions of forward strength of association (high association, low association, or no association) were different based on participant speaker status (bilingual group or monolingual group). Reaction time values for monolinguals were normally distributed as assessed by Shapiro-Wilk's test ($p > .05$). Reaction times were not normally distributed for bilinguals as assessed by Shapiro-Wilk's test (high association: p =.011; low association: p = .044; no association: p = .044). This is likely a result of the bilingual responses skewing leftward due to a higher frequency of high RT responses. In addition, a Normal Q-Q plot was inspected for normality and residuals did not appear to be significantly distorted from the diagonal line; these are shown in Figure 2. Figure 3 shows boxplots of the reaction times for each condition.

Figure 2

Normal Q-Q Plots for Bilinguals for Prime-Target Conditions (RTs)

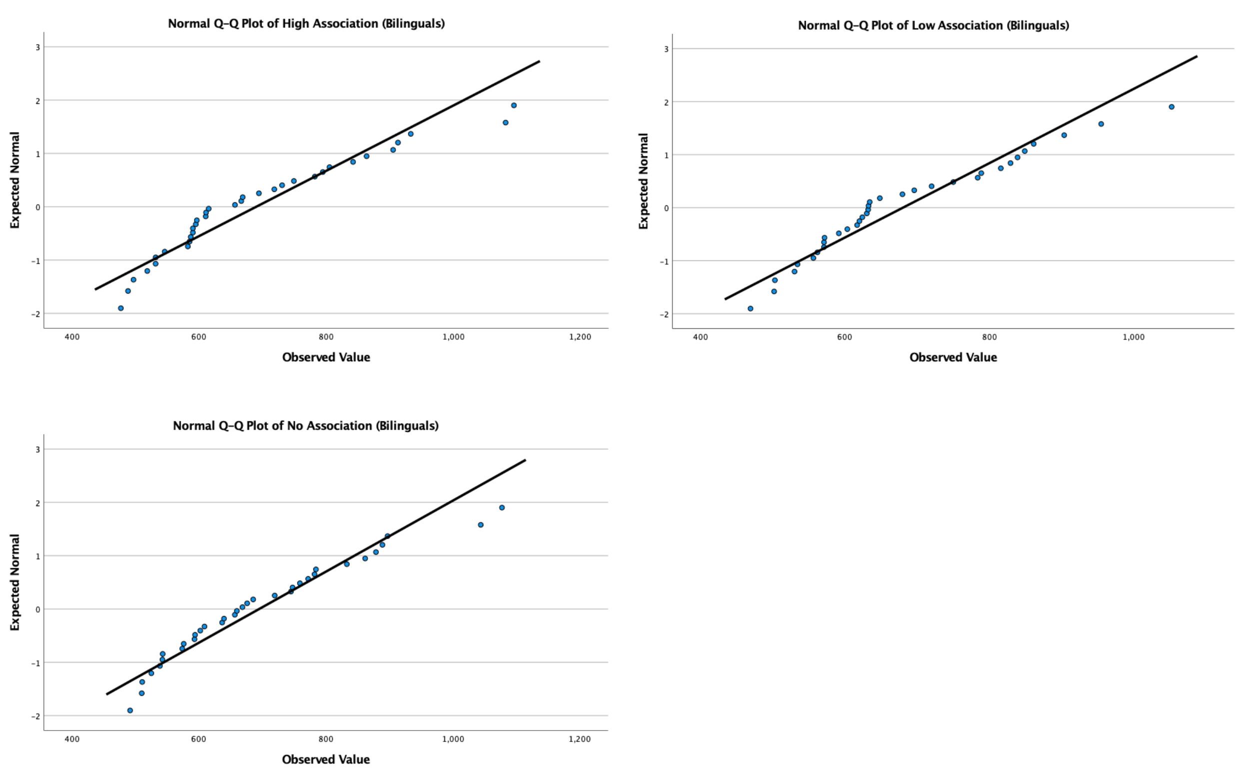
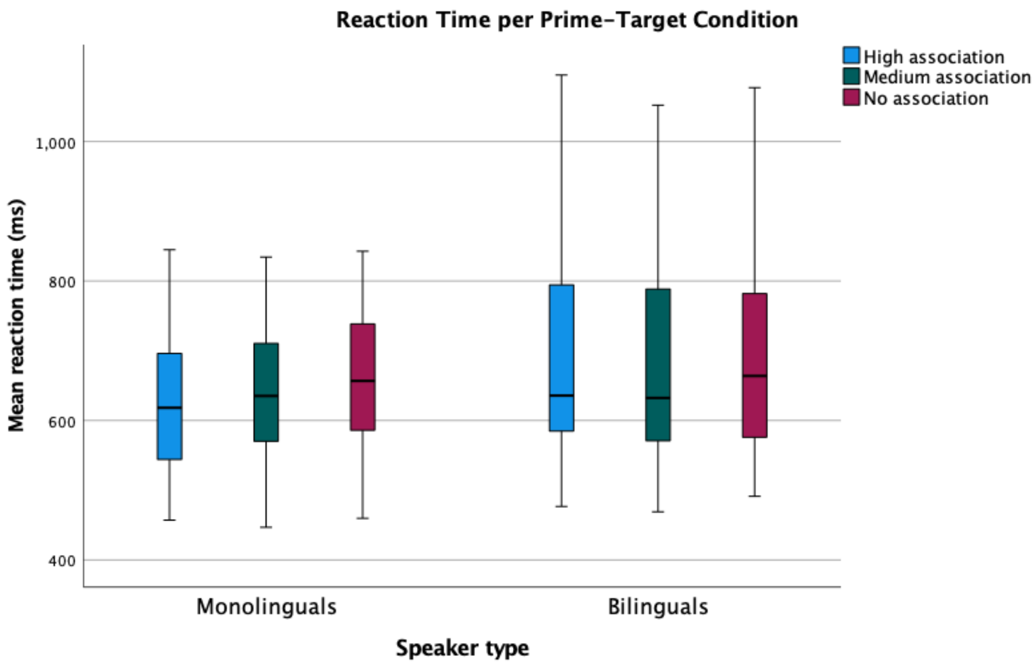


Figure 3

Boxplot of Reaction Time per Condition



The descriptive statistics of the reaction time data are shown in Table 3.

Table 3

Descriptive Statistics of Reaction Time Data

		Mean RT	Std. Deviation	N
High Association Pairs	Monolingual	623.75	96.08	28
	Bilingual	689.67	163.42	34
	Total	659.90	140.10	62
Low Association Pairs	Monolingual	637.76	95.10	28
	Bilingual	680.09	142.58	34
	Total	660.98	124.30	62
Unassociated Pairs	Monolingual	657.13	102.33	28
	Bilingual	694.63	150.17	34
	Total	677.69	131.10	62

Mauchly's test of sphericity indicated that the assumption of sphericity was met for the two-way interaction, $\chi^2 = 2.723$, $p = .256$. The omnibus ANOVA results are summarized in Table 4, and Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

Figure 4 shows a corresponding profile plot for the two-way ANOVA.

Table 4

Test of Within-subjects Effects for Omnibus ANOVA on RTs

	Type III Sum of Squares	df	Mean Square (RT)	F	Sig.	Partial Eta Squared	Observed Power
Association	13503.99	2	6752.00	8.56	**0.00****	0.12	0.96
Association * Speaker	7103.65	2	3551.83	4.50	**0.01***	0.07	0.76
Error (association)	94640.87	120	788.67				

Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

Figure 4

Profile Plot for Reaction Time (RT) Two-way ANOVA

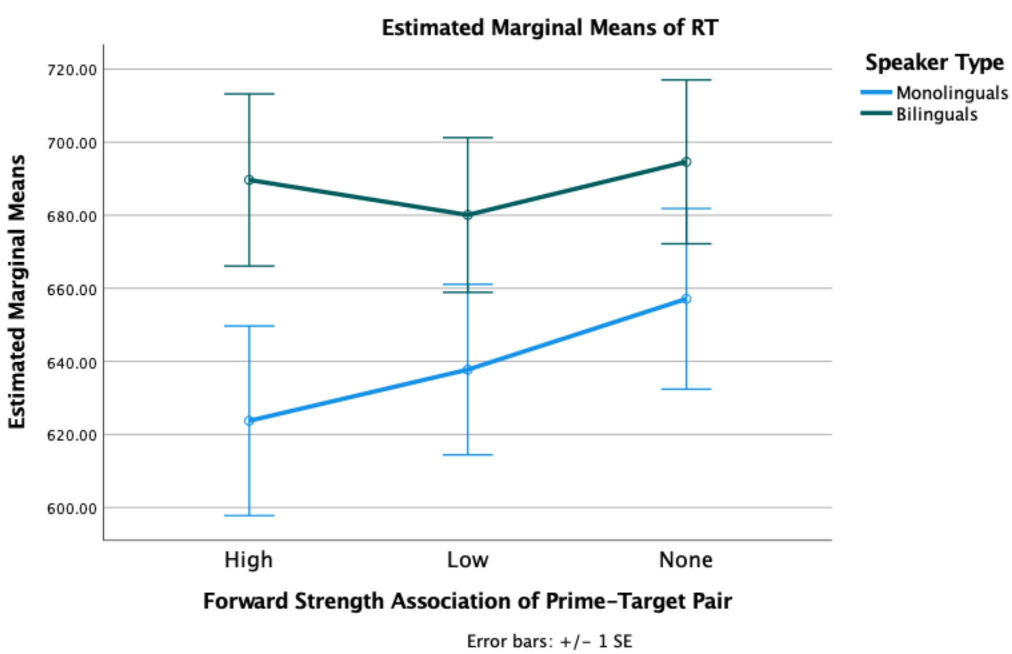


Table 4 shows that there was a statistically significant interaction between the forward strength of association and the speaker type, $F(2, 120) = 4.504$, $p = .013$, partial $\eta^2 = .070$.

Group Effects

Simple main effects of group were assessed post-hoc with independent samples *t*-tests comparing both groups for each reaction time measure. Results are shown in Table 5. Levene's test indicated unequal variances ($F = 7.69$, $p = .007$). A Bonferonni adjusted *p* value for multiple comparisons was set at .016.

Table 5

Results of Independent Samples t-tests Comparing Monolinguals and Bilinguals

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
High Assoc. Pairs	-1.97	54.73	0.05	-65.93	33.39	-132.86	1.01
Low Assoc. Pairs	-1.39	57.70	0.17	-42.33	30.35	-103.08	18.42
Unassociated Pairs	-1.16	58.12	0.25	-37.50	32.21	-101.97	26.96

Bilinguals had a numerically larger mean reaction time in all three conditions compared to that of the monolinguals. However, none of these differences was statistically significant.

Association Effects

Simple main effects of the associations for each group were assessed post-hoc with two repeated measures ANOVA with association strength (high, low, or unassociated) as the independent variable. Descriptive statistics for each group are shown in Table 6.

Table 6

Descriptive Statistics of Reaction Time Data by Group

Monolinguals	Mean	Std. Deviation	N
High association pairs	623.75	96.08	28

Low association pairs	637.76	95.10	28
Unassociated pairs	657.13	102.33	28
Bilinguals			
High association pairs	689.67	163.42	34
Low association pairs	680.09	142.58	34
Unassociated pairs	694.63	150.17	34

Table 7 shows the test of within-subjects effects for the post-hoc ANOVAs for each group.

Table 7

Test of Within-subjects Effects

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Monolinguals							
Association	15730.75	2.00	7865.38	14.12	**0.00****	0.34	1.00
Error(association)	30087.09	54.00	557.17				
Bilinguals							
Association	3713.98	2.00	1856.99	1.90	0.16	0.05	0.38
Error(association)	64553.77	66.00	978.09				

Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

There was a statistically significant main effect of Association in monolinguals, $F(2, 54) = 14.12$, $p < .001$, partial $\eta^2 = .34$. No significant differences in RT emerged between the three association conditions for bilinguals.

Pairwise Comparisons

A Bonferroni-corrected alpha level was set at .016 for the pairwise comparisons. These results are shown in Table 8.

Table 8

Pairwise Comparisons for Monolingual Group

Association (I)	Association (J)	Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference

		(I-J)			Lower Bound	Upper Bound
High	Low	-14.01	6.11	0.09	-29.61	1.58
	Unassociated	-33.38	6.16	**0.00****	-49.11	-17.65
Low	High	14.01	6.11	0.09	-1.58	29.61
	Unassociated	-19.36	6.64	0.02	-36.31	-2.42
Unassociated	High	33.38	6.16	**0.00****	17.65	49.11
	Low	19.36	6.64	0.02	2.42	36.31

Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

Pairwise comparisons for the monolingual group revealed that the source of the main effect of Association was the difference in reaction times between the high association condition and the unassociated condition: high association pairs had a significantly faster reaction time than unassociated pairs (*M* = -33.38, *SE* = 6.16 ms, $p < .001$). However, high association pairs and low association pairs were not significantly different from each other ($p = .09$) and low association pairs and unassociated pairs were not different from each other ($p = .02$).

Summary of Results

In this study, I aimed to determine whether bilinguals and monolinguals activate comparable semantic networks in response to incoming words in order to address whether bilinguals' sentence processing delays are related to inefficiencies at the word level. To do so, I used a retroactive masked priming task to determine the effects of how bilinguals utilize semantic information during word recognition. In this study, we found that the semantic relatedness of a target word helps resolve the identification of a previously presented and perceived (but not yet identified) degraded prime word to different degrees in bilinguals as in monolinguals.

The omnibus repeated measures two-way mixed ANOVA revealed a significant interaction between the Speaker Group and Association factors. This indicates that monolinguals and bilinguals do not have similar reaction times in response to changes in the association strength of pairs of words.

Post-hoc analyses within each condition revealed that monolinguals and bilinguals responded to high association, low association, and unassociated pairs with similar reaction times (shown in Table 5).

Post-hoc analyses within each group revealed that only monolinguals showed a significant effect of association strength, and that this effect was yielded by a significant difference between unassociated pairs and the high association pairs. This analysis found that monolinguals processed unassociated word pairs differently from highly associated word pairs, but that there were no reaction time differences between the high vs. low association pairs and the low vs. unassociated pairs. In contrast, bilinguals did not show a significant effect of association strength, indicating they processed high association, low association, and unassociated pairs not significantly different from each other.

Discussion

The results of this study showed several interesting findings. First, the presented data are largely in line with Golestani et al. (2009). In their study, Golestani et al. (2009) demonstrated a retroactive priming effect with auditorily-presented stimuli during native language processing. They take these results to suggest a specific contribution of semantics to native language processing and suggest that semantics aids the better use of context in a native language (p. 395). The present study shows largely the same effect in monolinguals: that a semantically related target word facilitated perception of a degraded prime word during processing of a language. These results extend Golestani et al.'s (2009) findings of a specific contribution of semantics to native language processing to the visual domain.

Second, the addition of a gradient between high, low, and unassociated pairs was done to examine whether the listener makes differential use of each level of a range of available semantic information. This study found significant differences between the reaction times of the high and unassociated pairs for monolinguals, but no difference between the high and low association pairs or the low association and unassociated pairs. These results suggest the use of higher-level linguistic context for processing is not correlative with the amount of semantic information that is available for use. In the frame of Golestani et al. (2009)'s interpretation, this particular finding demonstrates that the contribution of semantics to native language processing does not appear to function on a gradient based on the amount of contextual information available. However, it is possible that a stimuli design using finer gradations of association strength — e.g., four or more strength conditions ranging in their association strengths — would reveal an effect of association.

This study also found that bilinguals' reaction times in response to each condition appeared to be slower across the board compared to monolinguals. This suggests a difference in the way monolingual and bilingual individuals process semantic-rich information: while monolinguals appeared to be aided by strong semantic information, bilinguals were not. Notably, there was no significant group difference in the reaction times of any condition. Given the trend of the data, however, the bilinguals appeared to show the same degree of delay in low and unassociated conditions relative to monolinguals. This tentatively suggests a general delay with bilingual processing in these two conditions that could potentially be the result of a non-linguistic factor that affects processing, such as cognition, attentional control, or working memory differences resulting from simply knowing a second language. This possibility comports with the previous literature which regularly demonstrates delays in bilingual processing compared to monolingual processing (Dussias & Piñar, 2010; Lunner & Sundewall-Thorén, 2007). Kaan (2014) suggests that L2 processing in bilinguals operates on the same system, but appears to be slower because of frequency of language use, exposure length and quality, and other factors. These findings suggest that this slow-down in processing is persistent even for bilinguals' L1.

Comparing the groups, no significant differences were found for the high association, low association, or unassociated pairs. However, monolinguals had a significant effect of association. This suggests that bilinguals and monolinguals respond differently when presented with semantically relevant information. Monolinguals appear to make use of this semantic information to facilitate processing; bilinguals show no statistically significant difference in their responses to a semantically rich condition (high association condition) versus conditions with less semantic information available (low association and unassociated conditions). This suggests bilinguals do not make as effective use of semantic information for word-level processing compared to monolinguals.

Aligning with this view, the most significant finding of this data is that it shows that monolinguals had a significant effect of association between the unassociated and high association word pairs, whereas bilinguals did not. This finding suggests that monolinguals and bilinguals do not respond to pairs of words that were highly associated to each other in the same manner. I interpret this as an indication that monolinguals make additional use of semantic information as it becomes available to them, whereas bilinguals are not benefitted by the availability of more semantic information to the same degree. This outcome is similar to the results of previous studies that show bilinguals need more semantic information in addition to acoustic enhancements to match monolinguals' performance (Lecumberri et al., 2010), but this effect appears to occur in the native language in the present study.

Golestani et al. (2009)'s study clearly shows a benefit of additional context that exists only in native language processing in bilinguals, and which does not exist in non-native language processing. In their study, bilinguals were late learners who learned English after the age of 11 years old and in school; participants had acquired a third language and were considered "non-proficient" in English (Golestani et al., 2009, p. 386). In the present study, participants were highly proficient speakers of English, who acquired English in an immersive social setting mostly before 12 years of age (n = 31). The results of this study found no benefit of additional semantic context in one of bilinguals' two early acquired languages. Whereas Golestani et al. (2009) describes a native language benefit for using contextual information, these results suggest there does not appear to be a *bi*-native context benefit in early bilinguals: the native language context benefit that Golestani et al. (2009) found seems to disappear in languages acquired together in childhood. This finding has the implication that just early acquisition alone may not guarantee full nativelikeness in terms of a listener's proficiency with using contextual information during processing. While studies have found that early acquisition leads to more nativelike language outcomes (Shi & Sánchez, 2010), other studies have found that even early bilinguals do not reach true nativelikeness in certain linguistic elements upon deeper inspection. As an example, Bradlow and Alexander (2007) found non-nativelikeness for early bilinguals in phonetic production upon inspection of their speech using software. This present study shows this may also be the case for the use of semantics for word level processing.

Overall, while the graphs show a gradual increase in RT as a function of semantic association strength in monolinguals, the difference between high and low context is not significant. This could be due to a large variation in reaction time overall across subjects. Two strategies to neutralize the effects of variation across participants' processing RTs are described in the following section. First, I obtain difference scores by subtracting the unassociated pairs condition from the high and then the low association RTs. Second, I calculate the coefficient of variation, or CV, which is a measure used to account for the variation in the results and has been previously used as a measure of processing efficiency (Phillips et al., 2004; Segalowitz & Segalowitz, 1993).

Overview of Individual Variability Effects

The primary goal of this section is to account for the individual variation that participants demonstrate and reanalyze the outcomes. First, I present analyses with difference scores, which represent the value of the RT change in each of the two associated conditions from the unassociated conditions. This provides a measure of the effect of semantic association more directly by removing the impact of the lack of association for all participants.

Following this, I I present an analysis of the intra-individual variability in response time (coefficient of variation, or CV) values calculated for each subject. The CV for each subject is a ratio of the standard deviation to mean reaction time (SD/RT) of all a participant's correct responses and is used as a measure of the motoric efficiency of processing.

Analysis of CV Values

Introduction

In previous studies, CVs were used as an index of efficiency such that a lower CV value corresponds to greater efficiency (Segalowitz, 2008; Segalowitz & Segalowitz, 1993) and has been asserted as a measure that reflects the automaticity of processing (Phillips et al., 2004).

The rationale for the use of CV is that the calculation represents the variability in a participant's responses separated from the effects of individual differences. These individual differences might result in some participants completing a task faster than others, and these differences in reaction time speeds do not reflect a different or more efficient mechanism of language processing. To look at processing efficiency, a CV value represents the proportion of variability (SD) to mean reaction time for each participant. If the proportion of mean reaction time to variability are the same across groups despite absolute differences, that indicates that participants are completing the task with the same or similar language processes (Segalowitz, 2008). However, if the proportion of mean reaction time and variability are different across groups, that indicates that participants are completing the task using different processes (Segalowitz, 2008). A smaller CV proportion indicates that the processing is more efficient; it engages fewer of the slow and highly variable tasks that slow down processing, such as accessing L1 translation equivalents, processes involved in self-monitoring, error correction, and resolving problems associated with a poor bottom-up input (Phillips et al., 2004).

The goal of this analysis is to look at the mechanism of language processing to see if the measured differences are a result of automatic and more efficient processing. Differences in CV values would therefore directly indicate bilinguals' efficiency in word-processing tasks. It stands to reason that bilinguals, especially those with a younger AOA, may be disproportionately slowed down by language-dependent inhibitors such as processes related to self-monitoring and error correction. If bilinguals are engaging in less efficient processing than monolinguals during the presented word recognition task, this should be reflected in an analysis with this transformation.

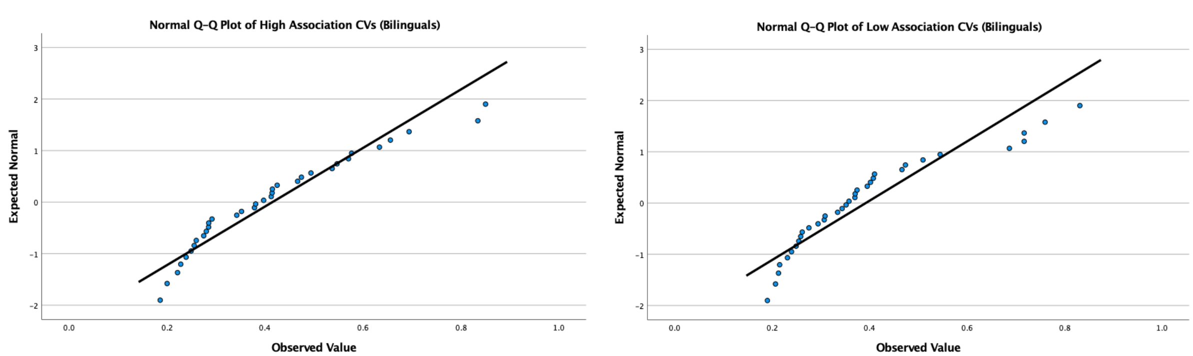
The analysis was done using SPSS 27 Statistical Software (IBM Corporation, 2020). Standard deviations of the reaction time values were calculated for each participant. These values were then divided over the average reaction time for each participant, and the resulting CV values for each participant were inputted into an ANOVA.

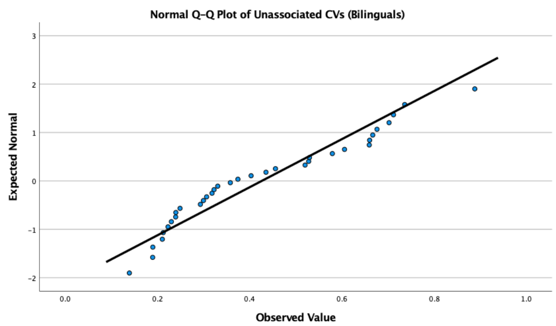
Results and Analysis

A repeated measures two-way mixed analysis of variance was conducted to determine if the CV of participants' reaction time responses to conditions of forward strength of association (high association, low association, or no association) were different based on participant speaker status (bilingual group or monolingual group). Reaction time values for monolinguals were normally distributed as assessed by Shapiro-Wilk's test ($p > .05$) but were not normally distributed for bilinguals as assessed by Shapiro-Wilk's test (high association: $p = .017$; low association: $p = .001$; no association: $p = .023$). Normal Q-Q plots were inspected for normality and residuals did not appear to be significantly distorted. These are shown in Figure 5. Because the ANOVA is considered resistant to mild violations of normality (Schmider et al., 2010), the ANOVA results are here presented.

Figure 5

Normal Q-Q Plots for Bilinguals for Prime-Target Conditions (CVs)

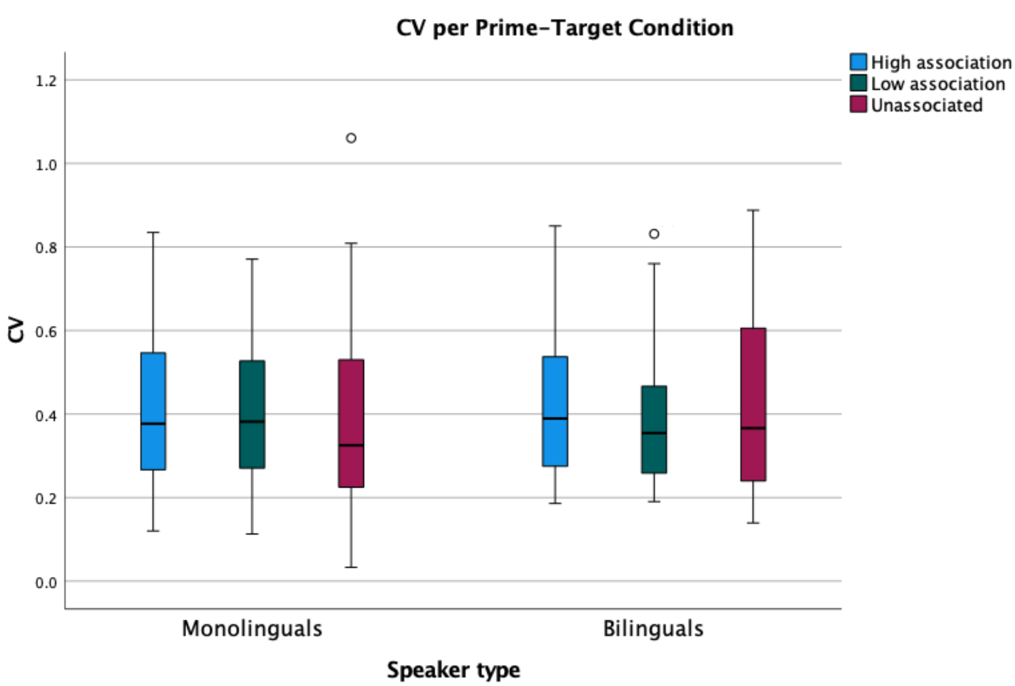




A boxplot indicated two outliers in the data: this shown in Figure 6 and the outlying participants are represented by a circle. This data was not removed from analysis in order to preserve a comparison with the reaction time analysis. Further, the outlying CV values represent valid data points which should be inputted into an analysis that compares the differences in group means.

Figure 6

Boxplot of CV per Condition



The descriptive statistics of the reaction time data are shown in Table 9.

Table 9

Descriptive Statistics of CV Data

		Mean CV	Std. Deviation	N
High Association Pairs	Monolingual	0.420	0.206	28
	Bilingual	0.415	0.176	34
	Total	0.418	0.189	62
Low Association Pairs	Monolingual	0.403	0.180	28
	Bilingual	0.392	0.173	34
	Total	0.397	0.175	62
Unassociated Pairs	Monolingual	0.396	0.241	28
	Bilingual	0.426	0.201	34
	Total	0.413	0.219	62

There was no statistically significant interaction in the CV values of the forward strength of association and the speaker type, $F(2, 120) = .362$, $p = .697$, partial $\eta^2 = .006$. The omnibus ANOVA results are summarized in Table 10, and Figure 7 shows a corresponding profile plot for the two-way ANOVA.

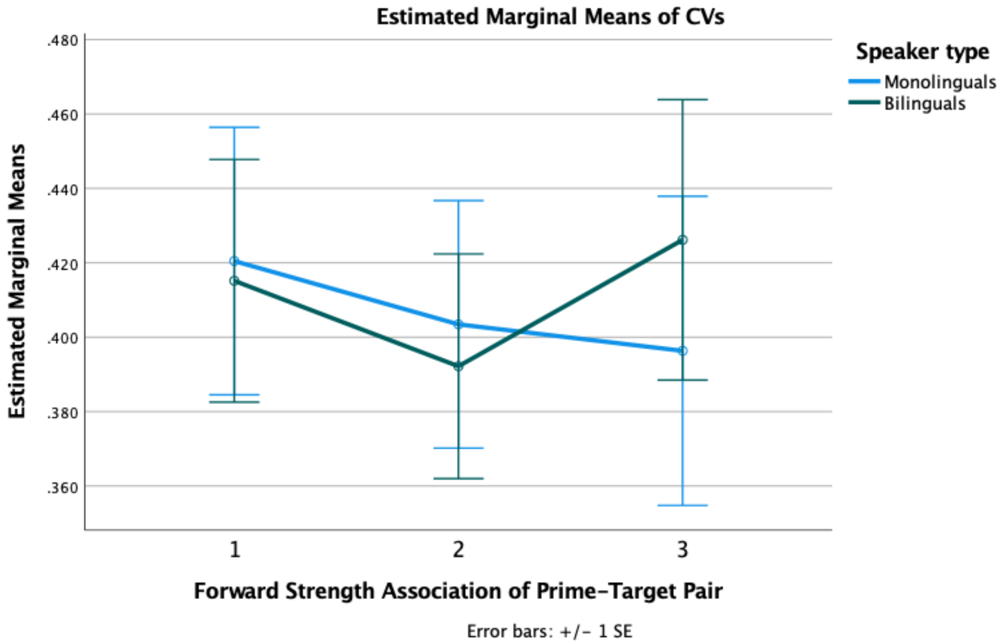
Table 10

Test of Within-subjects Effects for Omnibus ANOVA on CVs

	Type III Sum of Squares	df	Mean Square (CV)	F	Sig.	Partial Eta Squared	Observed Power
Association	.013	2	0.006	0.305	0.738	0.005	0.098
Association * Speaker	.015	2	0.008	0.362	0.697	0.006	0.107
Error (association)	2.510	120	0.021				

Figure 7

Profile Plot for the CV Two-way ANOVA



Discussion

The purpose of this reanalysis was to determine if the differences found in the monolingual and bilingual reaction time data was a result of different processing by each group or a result of the co-varying individual differences engaged in each of the group. The repeated measures two-way mixed ANOVA revealed no significant interaction effects between the speaker type and the association condition factors for the CV values. Accepting the interpretation of the CV value as indicating efficiency, this indicates that monolinguals and bilinguals are processing with the same processing efficiency or engaging in the same process to complete this task as each other.

Considering the significant differences in reaction times, it can be argued that the monolinguals have different reaction times in response to semantically associated vs. semantically unassociated pairs of words, and that this difference does not exist for bilinguals. In turn, this group difference is not a result of differential or less efficient processing, as the analysis of the CV values indicate that both groups are engaging in the same mechanisms to complete the task. As a result, we interpret these findings as suggesting that bilinguals, as a group, have concomitant individual differences that account for the differences in their reaction time outcomes.

The bilinguals in this study were English speakers who spoke a variety of non-English other languages. This may have an effect on the findings, as semantic categorization, which differs across languages, is shown to have transfer effects on the other language of a bilingual. I did not set exclusionary criteria based on language of use in order to be able to generalize potential findings to a wider bilingual community. The inconsequential effect of the other language is underscored by the fact that the present findings coincide with studies that *did* exclude all but speakers of a certain language. In addition, similar studies with tasks conducted exclusively in English did not restrict by languages spoken by the participants and still yielded findings (Ito et al., 2017).

Analysis of Age of Acquisition Effects

Another possibility that may account for the differences in the reaction time data is the large variability in the groups and particularly the bilingual participants. The bilinguals all reported strong proficiency in English, but two out of the 34 bilingual participants reported exposure to English that began after 18 years of age which may have affected the reliability of the data. The data from these participants were preserved because their responses were not outlying with respect to overall group means. In addition, these participants were both college students, reported an age that was not much greater than 18 years and self-reported high proficiency in English; therefore, it is possible that they misinterpreted the survey question and that their responses are not actually accurate. Still, while early age of acquisition is sometimes cited as an between 0 and 12 years of age (Segalowitz & Hulstijn, 2005), some other sources cite the cutoff for early bilingualism at 8 years of age (Shi & Sánchez, 2010). Therefore, to assess the possibility that the results of this study were due to large variability in AOA in the bilingual participants, an analyses with three groups is described below.

Results and Analysis

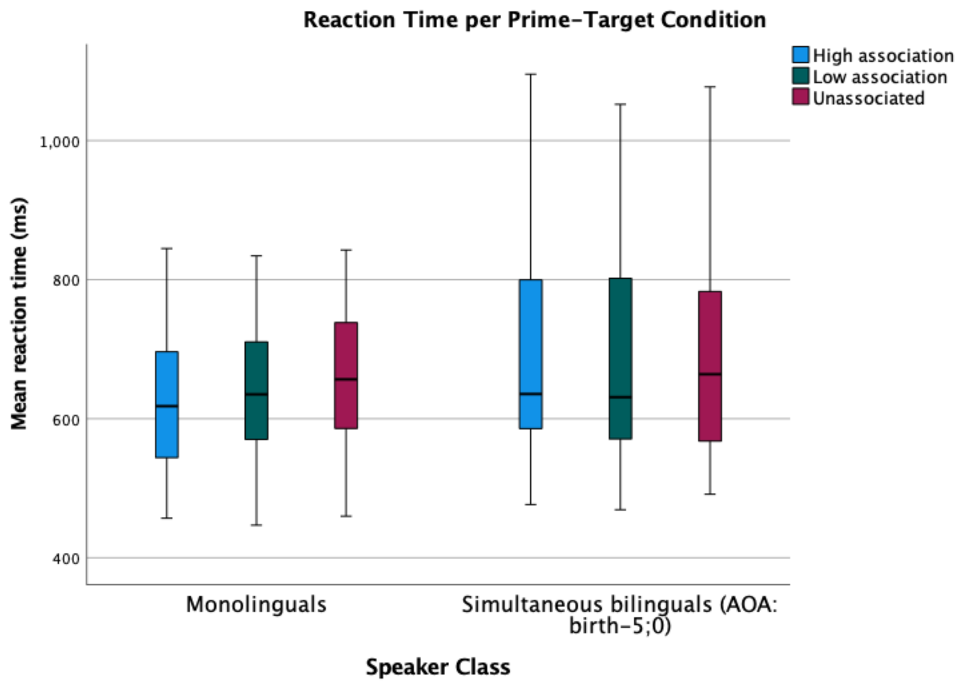
A repeated-measures two-way mixed ANOVA was conducted with speaker class as the between-subjects variable and association type as the within-subjects variable. The bilingual group of the previous analysis was restricted to only the simultaneous bilinguals who reported that their AOA was between birth and before 5 years of age. There were only four early bilinguals (AOA: between 5 and 8 years of age) and two late bilinguals (AOA: >18 years of age), so their results were excluded from the analysis. No participants reported an AOA between 8 and 12 years of age. The analysis also included the monolingual participants.

This particular subset of bilinguals was chosen to extract the results of individuals with an AOA in early childhood. Developmental research shows that ultimate language proficiency is non-nativelike with acquisition beginning at or around 3 years of age (McLaughlin, 1978; Yip, 2013) and up to 8 years of age (Shi & Sánchez, 2010). Grosjean (2008) defines the threshold of early childhood acquisition at 5 years old. This group delineation best fit the data, and so this is the threshold set for the analysis.

RT values were assessed for normally with Shapiro-Wilk's test and were found to be normally distributed among monolinguals ($p > .05$). RTs were not normally distributed for only the high association condition in bilinguals as assessed by Shapiro-Wilk's test ($p = .023$); in the low association and unassociated conditions, the RTs for bilinguals were normally distributed ($p > .05$). A boxplot showing the distribution of the data is represented in Figure 8.

Figure 8

Boxplot of Reaction Time per Speaker Class



The descriptive statistics of the RT data across these two groups are shown in Table 11.

Table 11

Descriptive Statistics of RT Data per Speaker Class

		Mean RT	Std. Deviation	*N*
High association pairs	Monolinguals	623.75	96.08	28
	Simultaneous bilinguals	692.02	169.42	28
	Total	657.89	140.74	56
Low association pairs	Monolinguals	637.76	95.10	28
	Simultaneous bilinguals	677.10	144.65	28
	Total	657.43	122.90	56
Unassociated pairs	Monolinguals	657.13	102.33	28
	Simultaneous bilinguals	695.83	158.12	28
	Total	676.48	133.40	56

The omnibus ANOVA results are shown in Table 12 and a profile plot illustrating the differences between groups is shown in Figure 9.

Table 12

Test of Within-subjects Effects for Omnibus ANOVA

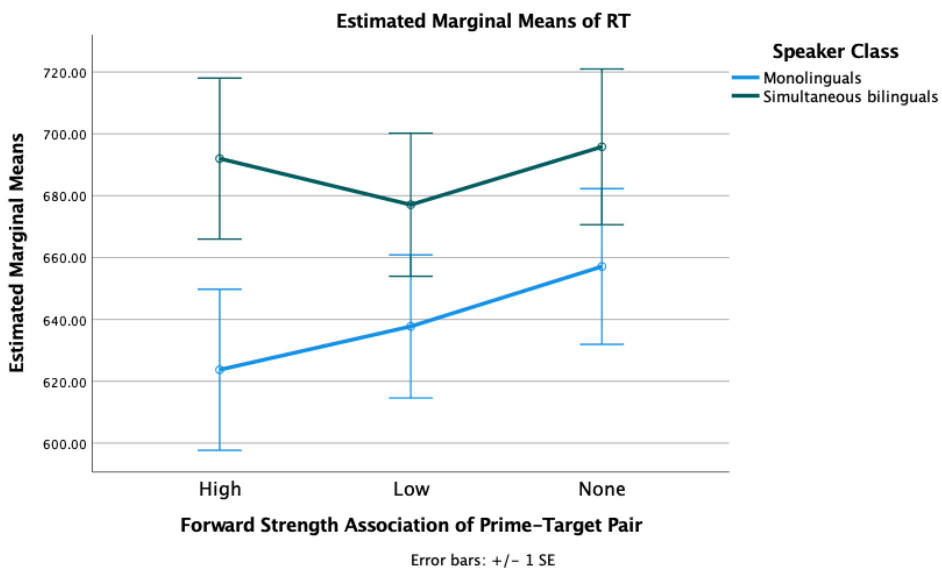
	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Association	13223.97	2	6611.99	8.35	**0.00****	0.13	16.70	0.96
Association * Speaker Class	7990.93	2	3995.47	5.04	**0.01***	0.09	10.09	0.81
Error(association)	85539.99	108	792.04					

Bold values indicate statistical significance.

$*p < .05$; $**p < .001$

Figure 9

Profile Plot for RT Two-way ANOVA



These results indicate a statistically significant interaction between the factors of association and speaker group, F(2, 108) = 5.04, $p = .01$, partial $\eta^2 = .09$. Simple main effects of group were assessed post-hoc with independent samples *t*-tests comparing both groups on their RT measures for each condition. Results are shown in Table 13.

Table 13

Results of Independent Samples t-Tests comparing Monolinguals and Simultaneous Bilinguals

	Mean Difference	Std. Error Difference	Sig. (2-tailed)	95% Confidence Interval of the Difference	
				Lower	Upper
High assoc. pairs	-68.28	36.81	0.07	-142.07	5.52
Low association pairs	-39.34	32.71	0.23	-104.93	26.25
Unassociated pairs	-38.70	35.59	0.28	-110.06	32.66

These results indicate no significance in any conditions between the groups. A Bonferonni adjustment was made for multiple comparisons and the adjusted values are represented.

Simple main effects of the associations within each group were assessed post-hoc with ANOVAs with association strength (high, low, or unassociated) as the independent variable. Descriptive statistics for each group are shown in Table 14.

Table 14

Descriptive Statistics of Reaction Time Data by Class

	Mean	Std. Deviation	*N*
Monolinguals			
High association pairs	623.75	96.08	28
Low association pairs	637.76	95.10	28
Unassociated pairs	657.13	102.33	28
Simultaneous bilinguals			
High association pairs	692.02	169.42	28
Low association pairs	677.10	144.65	28
Unassociated pairs	695.83	158.12	28

Table 15 shows the test of within-subjects effects for the post-hoc ANOVAs for each speaker class. This table represents Bonferonni-adjusted values for multiple comparisons.

Table 15

Test of Within-subjects Effects for each Speaker Class

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Monolinguals								
Association	15730.75	2	7865.38	14.12	**0.00****	0.34	28.23	1.00
Error (Assoc.)	30087.09	54	557.17					
Simultaneous bilinguals								
Association	5484.15	2	2742.08	2.67	0.08	0.09	5.34	0.51
Error (Assoc.)	55452.90	54	1026.91					

Bold values indicate statistical significance.

*$p < .05$; ** $p < .001$.

There was a significant difference in the association conditions in monolinguals, which was identical to the result demonstrated in the first analysis on RT values, $F(2, 54) = 14.12$, $p < .001$, partial $\eta^2 = .34$). In the simultaneous bilingual group, association appears to approach significance though it does not meet the threshold for statistical significance.

Analysis of Difference Scores: Effect of Semantic Context

A major goal of this study was to determine the additional contribution to processing that additional semantic information provides. To determine the effect of semantic association, the High Semantic Context effect was calculated by finding the differences between the mean RT for high association condition and the mean RT for the unassociated condition for each participant, and a Low Semantic Context effect was calculated by subtracting the mean RT for low association condition minus the mean RT for the unassociated condition for each participant. To process unassociated conditions, all participants should be using the same amount of contextual information — namely none, since no contextual information was available in those conditions.

They may still respond to these tasks at different base speeds. Therefore, the difference values represent the effect of making some level of semantic context available to the participant with the base speeds extracted.

These values represent the change in reaction time speed compared to the unassociated condition. Negative values represent a greater effect of semantic context in reducing the reaction time speed. Means and standard deviations of these values for all participants are shown in Table 16 below.

Table 16

Descriptive Statistics of Semantic Context Effects (RTs)

		Monolinguals (N=28)		Bilinguals (N=34)	
		Mean	SD	Mean	SD
Means	High context effect (m) (high association - unassociated)	-33.38	32.61	-4.96	37.27
	Low context effect (m) (low association - unassociated)	-19.36	35.13	-14.54	46.68
Std. Deviations	High context effect	2.78	133.89	-9.75	148.50
	Low context effect	-3.78	146.91	-27.54	159.01
Coeff. of Variation (CV)	High context effect	0.02	0.20	-0.01	0.21
	Low context effect	0.01	0.22	-0.03	0.21

The mean RTs of the high and low context effects were put into an ANOVA to determine group differences in whether significant differences in the high and low context effects emerged for each group. The results are shown in Table 17 and in the profile plot in Figure 10 below.

Table 17

Test of Within-subjects Effects for ANOVA on Context Effects (RTs)

Source	Type III Sum of Squares	df	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power
Context Effect	150.76	1	150.76	0.17	0.68	0.00	0.07

Context Effect * Speaker	4274.39	1	4274.40	4.93	**0.03***	0.08	0.59
Error(Context Effect)	52071.41	60	867.86				

Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

Figure 10

Profile Plot for Mean Context Effect Reaction Time (RT) ANOVA

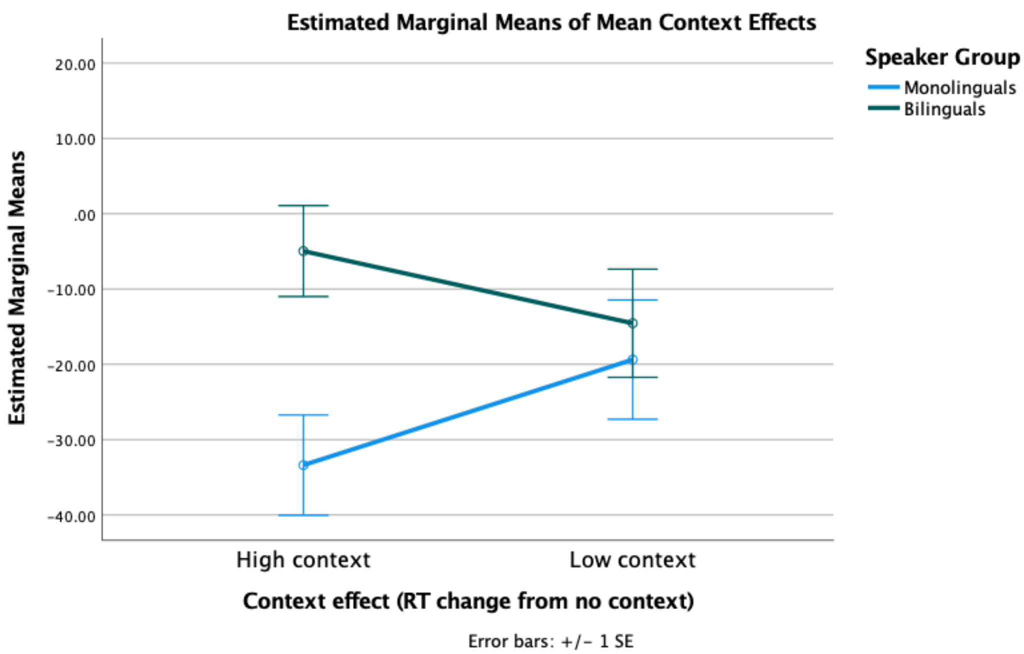


Table 17 demonstrates that there was a statistically significant interaction between the context effect and speaker group, F(1, 60) = 4.93, $p = .03$, partial $\eta^2 = .08$. This effect was investigated further within each group with post-hoc ANOVAs on the high and low context effects. This is shown in Table 18 below.

Table 18

Results of One-Way ANOVAs for Each Speaker Group (RTs)

Monolinguals	Type III Sum of Squares	df	Mean Square	*F*	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Context Effect	2749.26	1	2749.26	5.26	**0.03***	0.16	5.26	0.60
Error (Context Effect)	14112.95	27	522.70					
Bilinguals								
Context Effect	1560.89	1	1560.89	1.36	0.25	0.04	1.36	0.21
Error (Context Effect)	37958.46	33	1150.26					

The result of the one-way ANOVAs for each speaker group reveal an effect of context in monolinguals, $F(1, 27) = 5.26$, $p = .03$, partial $\eta^2 = .16$, but no effect for bilinguals. This indicates that there was a significant difference based on context in monolinguals only, with high context condition generating a significantly faster response effect compared to the effect in the low context condition. This indicates that the effect of high context conditions was significantly more helpful in reducing monolinguals' speed of processing compared to the low context conditions. The same effect was not found for bilinguals; in fact, while no significant effect emerged, the trend for bilinguals was that the high context conditions appeared to inhibit processing.

CV values

High and low semantic context effects were generated with the coefficient of variation (CV) values using the same difference calculation as described above. These values represent the change in processing efficiency compared to the unassociated condition. ANOVA results are shown in Table 19 below and the profile plots are shown in Figure 10. No significant effect emerged out of the CV value ANOVAs. This indicates that while there was a non-zero effect of semantic context on processing efficiency, the overall change in processing efficiency from their prior efficiencies was not different for the groups. The effect of semantic context did not cause a significant change to the processing mechanisms used by either speaker group.

Table 19

Test of Within-subjects Effects for ANOVA on Context Effects (CVs)

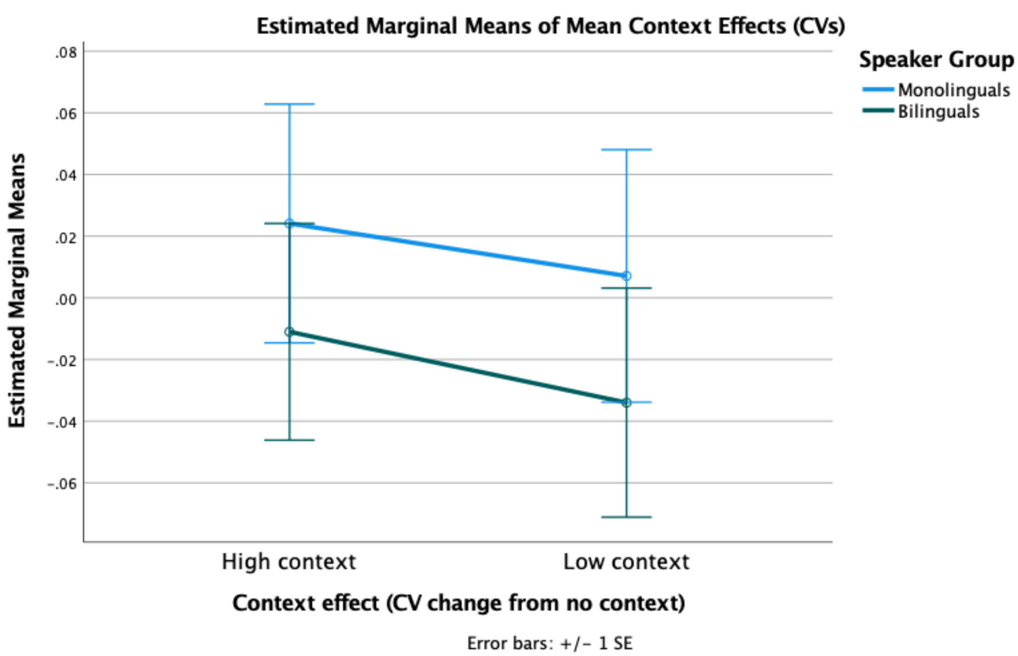
	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Context effect	0.01	1	0.01	0.67	0.42	0.01	0.67	0.13
Context effect * Speaker	0.00	1	0.00	0.02	0.90	0.00	0.02	0.05
Error(Context effect)	1.10	60	0.02					

Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

Figure 11

Profile Plot for Context Effect CVs ANOVA



Discussion

In monolinguals, there was a difference between the context effects with the high context effect being significantly lesser than the low context effect. This represents a that a high context condition contributed a significantly greater benefit to monolinguals' processing relative to low context conditions.

In bilinguals, based upon visual inspection, the high context resulted in a larger reaction time relative to the low context conditions. This does not represent a statistically significant difference, but it is notable to mention that the effect trends in the opposite direction of the monolinguals' significant difference. This appears to suggest that, while monolinguals experience a significantly greater benefit of more semantic context compared to conditions of low semantic context, bilinguals do not have a significantly greater benefit from more semantic context in the same way. In fact, this data appears to trend with the idea that greater context is more *inhibitory* for bilingual processing compared to low context conditions, though this effect was not statistically founded.

As for CV values, there were no significant effects that emerged from the ANOVAs. This indicates that the processing efficiency is not necessarily more benefitted by higher rather than lower context for both groups.

Semantic Interference

++ BY removing the eff of variation, we can see what the impact of semantics more cleanly.

The results of the present study appear to comport with Golestani et al. (2009)'s findings that top-down contextual information results in semantic interference in a second language. In the present study, bilingual responses to high and unassociated conditions were not significantly different. In monolinguals, these conditions were significantly different. The interpretation is that while monolinguals are significantly benefitted by more semantic information, bilinguals are not benefitted by this increase and may be inhibited. Like Golestani et al. (2009), the present findings suggest a disadvantage to word recognition resulting from too much semantic context, but in this study, is attested in highly proficient bilinguals rather than in less proficient late learners. Importantly, there was no difference in how bilinguals and monolinguals processed the high association pairs in this study.

Bloem and LaHeij (2003) find that context words induce semantic interference in a translation task, whereas context pictures induce facilitation (Bloem et al., 2004). This suggests an inhibitory effect of lexical activation which does not occur when activating the concept directly as in picture viewing. The authors account for this with the Conceptual Selection Model (CSM) which proposes that the activation of the target at the conceptual level activates related semantic cohorts at the lexical level in a process called "semantic cohort activation" (Bloem et al., 2004; pg. 309). Because the lexical representation of a semantically related word receives activation from this source, it becomes a lexical competitor to the target word.

Golestani et al. (2009) provides an explanation for semantic interference that accounts for the non-native language differences they found and attested in the present results. They suggest that semantic processing in bilinguals' non-native language uses up more resources due to a tendency to translate the words into the native language, and so semantic processing is less efficient and is a "more prominent" process (2009, p. 390). This accounts for the presence of semantic interference effects in a non-native language but its absence in a native language: with the addition of greater semantic information, more resources are used up and this affects the speed with which the task can be completed. A related study found evidence of semantic interference that was greater for non-native speakers. In Moreira and Hamilton (2006), non-native English speakers were slower at a rhyming task compared to native English speakers. The non-native speakers tended to select a semantically related word than the rhyming word. The authors suggest that because they are showing evidence of having engaged in the higher-level process of semantic processing, the non-native speakers were focusing too much on semantic processing in a non-native language (Moreira & Hamilton, 2006, p. 555). In the present study, this would mean that early acquiring bilinguals who are proficient in English are also demonstrating a greater prominence of semantic processing in that language which inhibits their task performance. While these studies suggest that semantic interference may be more prominent in a non-native language, the present study replicates such interference in one of two native languages in bilinguals. Therefore, the imbalance in the occurrence of semantic interference between the two languages may be accounted for by another factor beyond language nativity.

The results of a similar behavioral study propose yet another account that may explain bilinguals' response to conditions with high semantic context. The behavioral study by Schwanenfluegel and LaCount (1988), which investigated the effects of expected and unexpected sentence-endings on sentence processing. The researchers found facilitation for processing unexpected endings only in weak contexts and no facilitation for unexpected endings in strong contexts (Schwanenflugel & LaCount, 1988). The authors suggest that a strong context is selective and makes too many specifications for incoming words: the context has more restrictions to limit possible incoming words, and thus yields a narrower scope of activation than a weak context sentence. Therefore, facilitation is less likely in a strong context than in a weakly biasing context, which has a broader scope of activation (Federmeier et al., 2007). Under this perspective, the results of the present study may indicate that bilinguals are activating a too-narrow scope of activation in strong contexts.

However, I here describe an alternative proposal to account for what appears to be a lack of a facilitative effect for high associated words in bilinguals: the process of spreading activation may occur differently in monolinguals than it does in bilinguals. The mechanism of spreading activation, which describes the spread of the activation from a perceived word to linguistic components of related words, is that activation quickly spreads from one word to the highest associates first, and then after some time, spreads to more peripheral associates (Collins & Loftus, 1975). This is attested in sentential prediction studies, showing monolinguals show evidence of greater facilitation of activating the most expected upcoming final word compared to less likely upcoming words (Aydelott et al., 2012; Federmeier et al., 2007). In an ERP study, for example, Federmeier et al. (2007) shows N400 amplitudes correlated with the expectancy of an upcoming word. The bilingual results of the present study may be explained by a more uniform and wider spread that all occurs slightly slower than in monolinguals. Bilinguals therefore may activate higher and lower associations with similar speeds and may not prioritize the activation of a closer associate like monolinguals do. This fits in with the present findings, but also with the findings of previous studies in bilingual sentential prediction demonstrating that bilinguals are slower in using context for prediction (Grüter et al., 2017; Ito, Corley, et al., 2018; Martin et al., 2013a).

Determining what accounts for the non-nativelike bilingual response to high-contextual conditions is an important extension for future work and is possible to investigate with a finer gradient of word associations. More relevant to the implications of this work on the whole, however, is that the difference in the bilingual response to endings of high context sentences occurs also at the word level. Therefore, the presented findings meet the objective of associating the relationship between the bilingual difference in sentence processing in noise to differences in semantic spreading activation at the word level.

These findings demonstrate bilingual differences at the word level, but it is important to examine whether differences reflect individual differences that are coexistent with bilingual status that most bilinguals may experience (such as, e.g., a general slowdown related to a strained working memory capacity or expending greater effort to inhibit non-target responses). Alternatively, these results could reflect an underlying difference in the processing mechanisms or pathways that bilinguals engage in to process as a result of their dual language use (such as, e.g., activating translation equivalents before processing). One way to assess this is to analyze the degree to which participants of this study vary in the reaction time responses rather than their reaction time data. This reanalysis is presented in the following section.

General Discussion

In this study, word pairs of varying association strengths were processed with similar reaction times across groups. However, monolinguals responded to gradients of association strength with different speeds, but there was no difference in how bilinguals responded to gradients of association strength. An identical analysis using CV values as a measure of efficiency showed no effect of speaker or association, indicating that both groups processed the pairs through similar processing pathways.

In order to evaluate the effect of age of acquisition on semantic processing, I reconducted an analysis with the subgroup of the bilingual participants who reported an AOA before 5 years of age. This threshold is supported by previous research in simultaneous and successive language acquisition (Grosjean, 2008; Yip, 2013).

The interpretation of these results is similar to the outcomes of the initial analysis. This study demonstrates that bilinguals do not show the same sensitivity to differences in semantic information, and further that this effect maintains for simultaneous bilinguals with an age of acquisition before 5 years of age. The findings suggest that even early acquiring bilinguals are non-nativelike in their use of semantic information for processing. This result fits in with previous research on non-nativelike skills in early bilinguals, particularly in processing speech in noise and other difficult processing tasks (Mattys et al., 2012; Rogers et al., 2006). Key to this body of work as a whole is that an early age of acquisition does not necessarily guarantee native-like processing skills when the processing system is under a heavy task load.

Importantly, the difference scores support this in showing that monolinguals exhibited a significantly greater benefit in response to pairs with high associations in them relative to pairs with low associations in them. This was not the same effect in bilinguals, which in fact appeared to trend in the opposite direction, though not significant. A statistically significant outcome would indeed support the idea that bilinguals experience greater semantic interference than monolinguals do. Still, these results indicate a difference in the contribution of greater context in word pairs between monolinguals and bilinguals.

Summary

The aims of this study were to demonstrate differences in bilingual processing of pairs of words that differed in their degree of semantic association. Conclusively, these results show that bilinguals and monolinguals have differences in their retroactive recognition of a degraded word, with monolinguals being aided by highly associated pairs in a way that bilinguals are not. This result indicates that bilinguals and monolinguals are using semantic information in different ways during word processing.

The wider impact of this study is on sentence processing in bilinguals. Because bilinguals show a difference in their use of semantic information to process word pairs, it stands to reason that a larger-scale process such as processing sentences, which also relies on the same mechanisms of semantic spreading activation, would reflect this difference. This difference in sentence processing is attested in several studies on word prediction (Grüter et al., 2017; Ito et al., 2017; Martin et al., 2013a) and in bilingual sentence processing in noise (Cooke et al., 2008; Mattys et al., 2009; Rogers et al., 2006). The results of this study suggest that the slowdown bilinguals exhibit in sentence processing under cognitive load is fundamentally related to a slowdown at the word level. Specifically, bilinguals do not use semantic information for processes of word-level spreading activation to the same degree as monolinguals, which slows down mechanisms of sentence processing.

Notably, the follow-up analyses in this Chapter were informative in showing differences between monolinguals and bilinguals. First, the ANOVA on CV values suggested that participants were performing with much the same systems and that their processing pathways were similar. According to analyses of the CV values, it is likely the difference in response is therefore due to other cognitive factors and an overall slowdown of bilingual responses. This is corroborated by inspecting the average standard deviations per group: monolinguals had a smaller spread of their RT scores than the bilinguals, but the variability of reaction time was roughly consistent across conditions and bilingual participants. This indicates that there were no major outliers in bilinguals’ responses which may skew the results, and instead, that bilinguals were characterized by a consistently wider spread in their reaction time variability. Similarly, this outcome points to a difference of cognition and other factors that affect processing rather than a difference in the processes of word recognition. If the difference was on account of different processing mechanisms, then we would see a wider range of standard deviations in bilinguals and disproportionate CV ratios compared to monolinguals.

Some questions remain in this study: primarily, the effect of individual variables on attenuating this non-nativelikeness in semantic activation is an area for further investigation. In the next Chapter, I present analyses of the individual cognitive and linguistic variables measured and their impact on the reaction time measures.

Chapter 4

Overview

The RHM accurately predicts differences between early and late bilinguals' performance in word processing tasks and attributes these differences to the organization of the fluent and non-fluent speaker's lexicon and the associated semantic connotations. However, the differences between monolingual and simultaneous bilinguals' performance, which are demonstrated in the literature, are not explained by model of word-to-concept links that the RHM provides.

The findings that bilinguals do not use semantic information with the same speed as monolinguals could be because bilinguals operate with different pathways of language processing. Alternatively, it is possible that bilinguals do engage in the same mechanisms of processing but are slower in anticipatory processing and other top-down schemata as a result of other factors. I addressed this hypothesis by analyzing group differences in the variation of the reaction time responses (CV) and the results indicate no difference in the language-dependent mechanisms that contribute to semantic processing between monolinguals and bilinguals. Therefore, this Chapter is aimed at addressing other factors of the bilingual experience that may influence semantic processing among bilinguals.

I begin with a review of the impact of different linguistic and cognitive variables on bilingual processing in order to motivate an analysis of the reaction time data. This analysis is then provided and discussed.

Factors of Language History and Experience

The fact that bilinguals are slower in predicting the features of upcoming words might be confounded by other factors that coincidentally slow down processing. The impact of age of acquisition as a factor was addressed; other linguistic variables specific to the linguistic experience include frequency of exposure, quality of language input during acquisition, dominance, and other variables. Kaan (2014) summarizes this in her discussion on late bilingual sentence processing. She suggests that L1 and L2 comprehension processes are the same, but only differ in the same underlying factors that make L1 and L2 representations different. During comprehension, these factors make processing in each language — particularly anticipatory processing — appear to be different (Kaan, 2014).

Another factor that arises in the literature is the relatedness of participants' L1 and L2. In their replication of Martin et al. (2013) with different participants, Foucart et al. (2014) presents ERP results in which bilinguals demonstrate an effect of lexical context on sentence-ending words before they are presented (i.e., anticipatory processing) in both their L1 and L2. The authors conclude that bilinguals are able to predict similarly to monolinguals and explain that this is because the two languages of the bilinguals — French and Spanish or Spanish and Catalan — were closely related (Foucart et al., 2014). This also explains the results of Lew-Williams and Fernald (2010), which did not find an effect of prediction at the appropriate referent for incongruent final nouns likely because English does not use grammatical gender for nouns in the way Spanish does. Similarly, Molinaro et al. (2017) reports that L2 prediction is sensitive to the properties of the native language such that bilinguals reading in a second language rely on the properties of a first language to make predictions.

Further, proficiency has been demonstrated to influence the degree to which bilinguals engage in prediction during processing. Continuing with Foucart et al. (2014), the authors concluded that bilinguals can predict given a high enough proficiency level in the language. Participants in Foucart et al. (2014) were French-Spanish late bilinguals or Spanish-Catalan early bilinguals completing the task in Spanish. Though the late bilinguals were less proficient than the early bilinguals, as is expected given a later age of acquisition (Johnson & Newport, 1989; Shi & Sánchez, 2010), they still demonstrated proficiency in Spanish and their results were similar to the native comprehenders. Studies that have specifically addressed the impact of proficiency agree that high proficiency bilinguals do show evidence of prediction even if low proficiency bilinguals do not. In an eye-tracking study, Dussias et al. (2013) found differences in the way high and low proficiency Spanish learners respond to an unexpected grammatical gender marker to an unexpected final noun, with higher proficiency learners responding more like native Spanish monolinguals than low proficiency learners. A similar result was found in Hopp (2013) which investigated predictive processing of syntactic gender agreement and concluded that an effect of anticipation at the grammatical gender marker was measured in participants with advanced proficiency levels. Further, Peters et al. (2018) shows that participants with higher L2 vocabulary skill are able to adapt their linguistic predictions more efficiently than participants with low vocabulary skill, and in a way that is most similar to monolinguals. Vocabulary size and lexical skill has been found to correlate with grammatical skill and language proficiency (Bates et al., 2019; Polinsky, 2006).

Lending credence to the impact of proficiency on prediction, we can attribute the results of some of the previous studies that show bilinguals have weaker prediction than monolinguals to low proficiency and/or a late age of acquisition of the participants of those studies. In Martin et al. (2013), bilingual participants acquired L2 English after 8 years of age. Though the participants reported 2+ years of English immersion, they reported this use in a university setting and predominant use of Spanish at home. Notably, many stimuli in this study used vocabulary relating to furniture, groceries, and other “every-day” vocabulary items which are not likely to be encountered or used as frequently in a university setting (Polinsky, 2006). Likewise, participants in Hopp (2013) acquired L2 German after 11 years of age, and participants in Mitsugi & MacWhinney (2017) acquired L2 at a mean of 16.8 years of age. Notably, Grüter (2017) reports no impact of proficiency on predictive processing, and Molinaro et al. (2017) suggests L2 prediction is unlike L1 prediction even with high proficiency.

In an eye-tracking study, Chun and Kaan (2019) compare monolinguals' and proficient second-language learners' anticipatory looking in response to ambiguous relative clauses (Chun & Kaan, 2019). L2 listeners and L1 listeners made more anticipatory looks in the semantically biasing condition than a neutral baseline, though prediction was delayed by 180 ms for the L2 listeners. In line with bilingualism studies on prediction, the researchers suggest that there are no fundamental differences between the speakers' ability to predict although a delay was evident. Importantly, the researchers used a more complex syntactic construction to make the task more cognitively taxing for the participants. This allowed the researchers to submit that the availability of cognitive resources is important for language prediction to occur.

Working Memory and Language Selectivity

The availability of cognitive resources is shown to affect language processing, and one such cognitive resource is working memory capacity (WMC). Among monolinguals, WMC was found to have an effect on language processing such that a greater WMC was correlated with higher language performance and greater use of top-down contextual information. Huettig and Janse (2016), for example, found that working memory ability was a factor that contributed to anticipatory processing abilities in an eye-tracking study. Zekveld et al. (2012) found that greater WMC was associated with a greater benefit of related cues when processing sentences that followed. Similarly, Lev-Ari (2014) connects a greater working memory capacity to an individual's ability to use top-down contextual information to resolve acoustic ambiguities. In this study, listeners with higher working memory capacities were found to increase their reliance on context to anticipate the speaker's upcoming reference when following the complex instructions of a non-native speaker who was difficult to understand.

Working memory has also been shown to modulate bilingual processing in numerous studies. In Ito et al. (2018), L1 and L2 speakers listened to sentences with verbs that were predictive or not predictive to one of four objects they were viewing. Half of the participants performed a memory task concurrently with the listening task in order to strain their working memory capacity. The researchers found a predictability effect in comprehension among both L1 and L2 speakers, but a delayed effect in the participants who completed the memory task. This suggests that L1 and L2 speakers both engage in the same mechanisms to make predictions, in line with Kaan (2014), but also shows the impact of cognitive resources on predictive processing. These studies suggest a limited working memory may impact a listener's ability to use sources of context for comprehension.

In bilinguals, the need for working memory (WM) for language processing is exacerbated likely because of the differential lexical activation that bilinguals experience. Specifically, many studies have investigated whether bilingual lexical activation is non-selective, defined as spreading to related words and translation equivalents across language boundaries, or is restricted to related words within-language (Dijkstra & van Heuven, 2002; Lauro & Schwartz, 2017). It has been found that even in a monolingual setting, bilinguals activate lexical candidates in both languages in both auditory and visual word recognition tasks (Dijkstra & Kroll, 2005; Prior & Macwhinney, 2010; Spivey & Marian, 1999).

This cross-linguistic activation of words from a target language to a not-in-use language uses cognitive resources that monolinguals do not expend, because monolinguals do not have translation equivalents for lexical entries. Non-selective activation may be one source of the delay that less proficient that bilinguals exhibit during processing.

Bijeljak-Babic et al. (1997) demonstrated non-selective access by testing the effects of orthographically related primes in either the same or a different language as the target word. An example of a same-language pair is *real-HEAL* in which both are English words. An example of a different-language pair is *gens-GUNS* in which the prime is French and the target is English. These words are orthographic neighbors because the visual word differs in only one letter (Coltheart, 1977). When the prime and target were in the same language, the orthographic similarity resulted in an inhibitory effect compared to orthographically dissimilar primes (e.g., *roof-HEAL*). Critically, this effect only existed in different-language pairs among highly proficient bilinguals. This indicates simultaneous activation in both of a bilingual's languages (Bijeljac-Babic et al., 1997). Similarly, Van Heuven et al. (1998) found that word identification times took longer in English monolinguals if the word had more orthographical neighbors than words with fewer orthographical neighbors. However, even when completing the task in English, Dutch-English bilinguals were more influenced by the number of orthographical neighbors that L2 English word had in their L1 Dutch. In other words, they took longer to recognize a word with more neighbors in the language not in use. This suggests that bilinguals will activate L1 during L2 processing. However, this effect was also attested in the other direction: L1 Dutch word latency was influenced by the number of L2 English neighbors, suggesting that the opposing effect of L2 activation during L1 processing also occurs for bilinguals. In these latter experiments, this effect was found in less proficient bilinguals, and follow-up experiments did not determine an effect of proficiency. This suggests that for bilinguals, both languages compete for selection across a range of bilingual proficiencies (Assche et al., 2009; Brysbaert et al., 2000; Duyck et al., 2007).

During word recognition tasks, many studies have shown that bilinguals activate competitor words in both the target and non-target language. The activation of competitive targets exhausts working in a process referred to as lexical competition (Friesen et al., 2016; Lagrou et al., 2013; Weber & Cutler, 2004). Weber and Cutler (2004) demonstrated greater cross-language lexical competition resulting from phonological distractors for non-native than for native listener (see also Lagrou et al., 2013). Monolingual and bilingual participants in Friesen et al. (2016) viewed two semantically related, phonologically related, or unrelated pictures and simultaneously heard a word naming one of them. Both groups demonstrated effects of lexical competition in the form of longer processing times for semantically related distractors. However, in their ERP results, only monolinguals showed reduced N400 amplitudes in response to the semantically related distractors compared to the unrelated distractors. Bilinguals did not exhibit this N400 attenuation. The authors supposed that the two pictures shown do not exhaust the possibilities for naming for bilinguals, because they also have lexical alternatives from the other language that were activated. Therefore, this results in an unattenuated N400 amplitude, which reflects automatic semantic integration (Friesen et al., 2016; Kutas & Federmeier, 2011). In a follow-up experiment, when there was a time interval between picture and word onset, both monolinguals and bilinguals showed N400 attenuation for semantically related conditions. The authors suggest this is again the result of interference from the activation of the non-English language among bilinguals, which causes a delay in integrating the information shown and is resolved over time (Friesen et al., 2016). In this study, cross language selection added processing demands for bilinguals and limits within-language integration even when the task is in one language.

It stands to reason, then, that because bilingual processing taxes working memory (Hasegawa et al., 2002; Kroll et al., 2002), fewer cognitive resources remain available to engage in other language tasks, like anticipatory processing (Michael & Gollan, 2003). The implication of this is that more complex experimental tasks that require greater cognitive control to complete successfully would reveal greater differences between monolingual and bilingual processing. Dussias and Piñar (2010) investigated these task-related differences in native and second-language listeners of English. The authors investigated how WMC affected listeners' abilities to parse *wh*-questions and the use of semantic information in a sentence to do so. This is a complex task because interpreting *wh*-questions requires the parser to determine the origin of the phrase or clause that the *wh*-word replaces in the original declarative sentence representation (or "trace") before question movement occurred (Dussias & Piñar, 2010; Juffs & Harrington, 1995). The following sentences exemplify *wh*-question movement: sentence (a) shows the original declarative sentence that becomes question (b) following the movement operation. The letter "*t*" indicates the trace location of the noun phrase following movement.

(a) The children did read *[$_{NP}$ which book]* in class.

(b) [$_{NP}$Which book]$_i$ did the children read t_i in class?

In Dussias & Piñar (2010), the *wh*-words had an ambiguous but plausible trace location in the question and required listeners to use context to resolve its location and parse the question successfully. As an example (p 448):

(c) Who$_i$ did the police know the pedestrian killed t_i?

(d) Who$_i$ did the police know t_i killed the pedestrian?

In these sentences, speakers may first assign the filler to the object of the main clause (e.g., “Who did the police know?”). When the embedded clause is encountered, listeners reanalyze the sentence and reassign the filler. This experimental design allows the researchers to determine how listeners use sentence context to recover from and reinterpret an early misanalysis; in addition, the wh-word is far from its trace position, and so listeners must retain a lot of information from the sentence in working memory to parse it in the right way (Dussias & Piñar, 2010).

In this study, monolingual listeners and L2 listeners with higher working memory span scores (high-span group) took longer to interpret the sentence when the *wh*-word could plausibly fill a syntactic gap, even if it was an incorrect gap-filler; low-span L2 learners did not. These results indicate that the high-span group and the monolingual group both used the plausibility of the sentence semantics to re-interpret the sentence. Late learners with a high WMC were quicker to "give up" the interpretation as a monolingual reader would an implausible sentence (Traxler & Pickering, 1996), indicating that the plausibility of the sentence was not enough to cue low-span L2 learners to re-parse the sentence and that they did not make use of the semantic information to decode it. Overall, however, the researchers were able to distinguish the behaviors of two L2 learner groups based on low and high performance on working memory tasks (reading span and final word recall task). This study demonstrated that only L2 learners with increased WMC performed native-like on the task, suggesting an important role for working memory during bilingual sentence processing.

A task parsing *wh*-questions as used in Dussias and Piñar (2010) is ideal because of its difficulty; a task that taxes working memory is said to induce listeners to process the sentence using higher-level, top-down to facilitate the processing (Huettig & Janse, 2016; Williams, 2006). A similar conclusion in Wolff (1987) found that participants were more inclined to use top-down strategies to interpret a discourse when the text is harder to understand. In Lunner and Sundewall-Thorén (2007), cognitive test scores were associated with performance on a difficult speech-perception task in fluctuating noise conditions and less associated with performance under simple listening conditions. Participants with higher scores on a cognitive test also performed better with fast time constraints than participants with low scores (Lunner & Sundewall-Thorén, 2007), suggesting the benefit of WMC when the task is harder. Next, Ito and Corley et al. (2018) investigated whether L1 and L2 speakers used semantic features of verbs to predictively look at direct objects and if speed of fixation was modulated by cognitive load. The college-aged L2 learners were highly proficient in English with an average of 12.5 years of English exposure; further, L2 comprehenders' native languages varied. Results of this study showed that both L1 and L2 participants showed evidence of prediction, and both L1 and L2 participants who also completed the working memory task showed delay of about 800 ms. This shows the delaying effects of overloading WMC. In addition, this result was still found across different bilingual proficiency levels and different L1 languages, minimizing any potential effects of transfer or L1-L2 relatedness.

Attentional Control

Also critical to language processing is attentional control: when processing information, perceivers need to filter from a broad range of sensory information in their input to focus on relevant components (Kintsch, 2005; Shiffrin & Gardner, 1972). If both languages are activated during bilingual word recognition, then bilinguals need to suppress the activation of the unintended word in order to select the target word (Costa & Santesteban, 2004). This process requires more attentional control, and in turn expends more cognitive effort, to complete. Some studies have demonstrated a bilingual advantage (compared to monolinguals) in the Stroop task (Bialystok et al., 2008; Hernández et al., 2010), which is one measure of attentional control (MacLeod, 1991). In the Stroop task, participants view color words and are instructed to name the ink color of the text as quickly as possible. If the word *green* is written in green text, then there is no conflicting information in the stimulus presented and processing is easy. If the word *green* is written in red ink, however, there is an incongruence of different color-word information in the same stimulus, and the task is challenging. To accurately identify the ink color, participants need to suppress the production of the visual word (in this example, *green*) in order to produce the target word "red." The reaction time of the conflicting trials is compared against the non-conflicting trials and the resulting value represents the cost on reaction time of adding more processing requirements. Therefore, higher Stroop task scores indicates poorer attentional control. Better Stroop performance in bilinguals may lend credence to the idea that bilinguals engage in more attentional or inhibitory control during language processing compared to monolinguals; notably, however, other studies have not demonstrated this greater Stroop performance in bilinguals compared to monolinguals (Blumenfeld & Marian, 2014; Kousaie & Phillips, 2012).

Blumenfeld and Marian (2014) did find, however, that bilingual performance in a task that assessed Stimulus-Stimulus conflict (i.e., the Stroop task) was more efficient compared to another measure of cognitive control that assessed Stimulus-Response conflict. In monolinguals, the differences between the two tasks were minimal (Blumenfeld & Marian, 2014). The researchers therefore suggest that bilinguals engage in more Stroop-type cognitive control mechanisms because the Stimulus-Stimulus conflict that the Stroop task assesses matches with what the cross-linguistic activation that they experience during language processing (Blumenfeld

& Marian, 2014). Lev-Ari and Peperkamp (2013) demonstrate the effect of inhibitory skills on processing. They found that bilinguals with poorer inhibitory skill demonstrate greater activation of competitive targets from the non-target language, and that this activation leads to greater lexical competition (Lev-Ari & Peperkamp, 2013). In summary, while there may not be a bilingual advantage compared to monolinguals, this study demonstrates that bilinguals undergo processes that engage more cognitive control systems as a result of the cross-linguistic activation they experience.

In the analyses to follow, I make a case for the association of various individual linguistic factors and cognitive factors on the reaction times of a masked priming task. In the experiment, participants were presented with high association, low association, or unassociated targets following masked primes. Participants also completed a Stroop task and a Corsi block-clicking task, which are measures of attentional control and working memory capacity respectively. Bilingual participants also completed a language history and experience questionnaire to assess their proficiency and other language skills in both their languages.

I first analyze if WMC and attentional control measures differ between monolinguals and bilinguals. This would address whether bilinguals demonstrate greater cognitive control compared to monolinguals, for which there are mixed results in previous studies. Next, I determine whether WMC and attentional control are associated with monolingual RTs in the masked priming task using a Spearman's rank-order bivariate correlation. A second correlation analysis will determine if WMC, attentional control, and other linguistic variables are correlated with bilingual performance on the masked priming task. This will indicate if the use of semantic information for word processing correlates with greater working memory capacity or attentional control in bilinguals.

Finally, I analyze the impact of the individual cognitive measures as predictive factors for task performance in monolinguals with a hierarchical linear regression. Determining the factors that predict task RT speed informs a partial correlation that follows. I remove the effects of the contributing variable and determine if, controlling for those predictive factors, other variables are associated with RT performance scores. For bilinguals, this procedure is duplicated with the addition of the measured individual variables.

Preliminary Results and Analysis

The memory task was a Corsi block-tapping task in which participants were asked to click through a correct sequence of blocks in the order of their presentation. The resulting score indicates the longest sequence a participant can correctly remember and repeat, with higher scores (maximum of 10) indicating a greater capacity of working memory.

A numerical Stroop task was used to measure selective attention capabilities, with participants indicating the number of times a word (e.g., "panda" or "two") was repeated on screen. The reaction time for the non-conflicting baseline condition, in which the words were animal words, was subtracted from the interference condition in which the words were numerical words. This resulted in a "Stroop score" that indicates the increase in RT in the interference condition; therefore, higher values indicate poorer attentional abilities.

Group Comparison

Descriptive information is shown in Table 20 and includes the previously presented reaction time measures for convenience.

Table 20

Descriptive Statistics of RTs, Task Performance, and Assessments

	Monolinguals			Bilinguals		
	Mean	SD	*N*	Mean	SD	*N*

RT for High Association pairs	623.75	96.08	28	682.28	172.16	27
RT of Low Association pairs	637.76	95.10	28	676.04	150.28	27
RT of Unassociated pairs	657.13	102.33	28	686.82	160.84	27
Memory Task	4.96	2.01	28	5.15	1.43	27
Stroop Task	71.53	60.94	28	58.45	72.75	27
Proficiency self-rating (English)				6.74	0.66	27
AOA (English)				1.96	1.48	27
Proficiency (OL)				4.96	1.45	27
Years in OL country				4.33	7.10	27
Years with OL family				15.26	9.13	27
Years in OL school				5.93	7.22	27

An independent samples *t*-test was conducted to determine if there a difference between the means of bilinguals' and monolinguals' working memory scores; a second independent samples *t*-test compared the mean difference in the attention scores. There were 28 monolingual and 27 bilingual participants. The monolinguals had a slightly lower mean performance on the memory task and a mean higher value on the Stroop task which indicates poorer attentional control. The results of the independent samples *t*-test are shown in Table 21.

Table 21

Results of Independent Samples t-tests Comparing Monolinguals and Bilinguals

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Diff.	
								Lower	Upper
Memory Task	2.23	0.141	-0.89	60.00	0.38	-0.39	0.44	-1.26	0.48
Stroop Task	0.56	0.457	0.93	60.00	0.36	15.81	17.03	-18.25	49.88

There was no significant difference between the scores of bilinguals and monolinguals in either of the two tasks.

Monolingual Correlations

One Spearman's rank-order correlation was run for each participant group to assess the relationship between the cognitive measures, individual variables if measured, and the context effects on the masked priming task. This would show the effect of a high vs. a low context relative to the unassociated context condition. For monolinguals, the correlation included the following variables:

(1) Mean high context effect (high association RT – unassociated condition RT)

(2) Mean low context effect (low association RT – unassociated condition RT)

(3) Memory task performance

(4) Stroop task performance

(5) Age at time of testing

The correlation results for monolinguals are presented in Table 22.

Table 22

Monolingual Spearman's Correlation

	Variable	N	1	2	3	4	5
1	High context effect	28	--				
2	Low context effect	28	**0.566****	--			
3	Memory task	28	0.189	0.276	--		
4	Stroop task	28	-0.093	0.056	-0.105	--	
5	Age	28	0.277	**0.439***	0.293	**-.386***	--

Bold values indicate statistical significance.

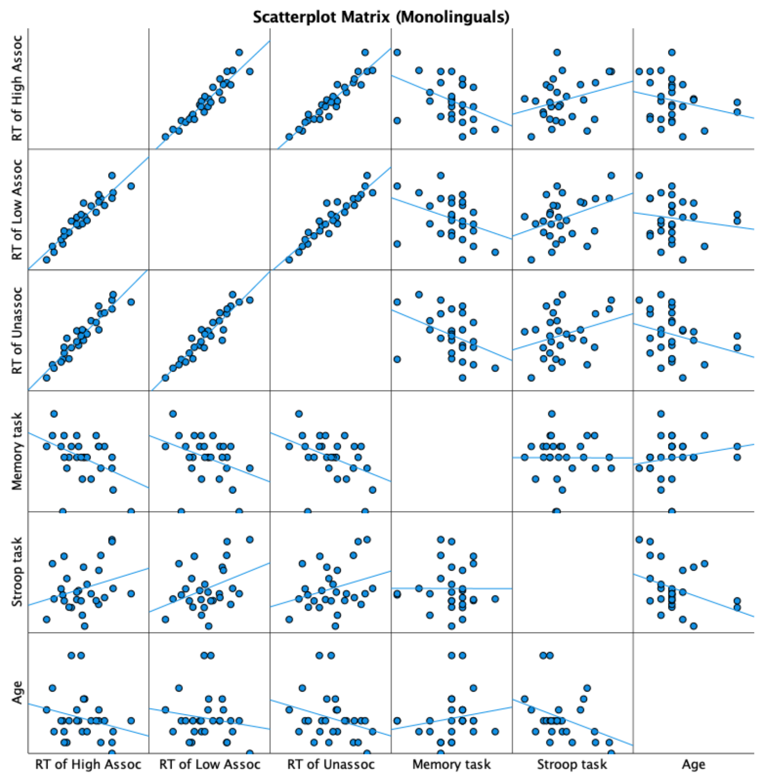
* $p < .05$; ** $p < .001$

Among monolinguals, the high and low context effects were positively associated with each other ($r = .566$, $p < .01$). The effect of low context was also positively correlated with age ($r =$

.439, $p < .05$). Performance on the Stroop task was negatively correlated with age ($r = -.386$, $p < .05$). A scatterplot of the associated variables is shown in the scatterplot matrix in Figure 12.

Figure 12

Scatterplot Matrix of Associated Variables for Monolinguals



Bilingual Correlations

Because bilinguals completed a language history questionnaire, the correlation additionally included the following variables:

(6) Proficiency (English)

(7) AOA (English)

(8) Proficiency (other language [OL])

(9) Years in OL-speaking country

(10) Years with OL-speaking family

(11) Years in OL-speaking school

(12) Foreign-Accent perception by others (OL)

The correlation results for bilinguals are presented in Table 23.

Table 23

Bilingual Spearman's Correlation

	Variable	1	2	3	4	5	6	7	8	9	10
1	High context effect	--									
2	Low context effect	**.395***	--								
3	Memory task	-0.100	0.053	--							
4	Stroop task	-0.047	-0.183	0.026	--						
5	Proficiency in English	-0.185	-0.073	0.129	0.083	--					
6	AOA in English	-0.041	-0.032	-0.256	**-.354***	-0.299	--				
7	Proficiency in OL	0.109	0.314	**-.475****	-0.099	-0.088	0.328	--			
8	Years in OL country	0.119	0.054	-0.198	0.189	-0.069	0.187	0.037	--		
9	Years with OL family	-0.033	0.062	**-.481****	-0.179	-0.119	0.111	**.523****	-0.034	--	
10	Years in OL school	0.284	-0.089	-0.065	**.392***	-0.128	-0.184	0.100	**.415***	-0.245	--
11	Foreign-accent perception by others in OL	0.215	-0.116	-0.031	0.184	0.034	-0.116	-0.255	-0.103	-0.098	0.126

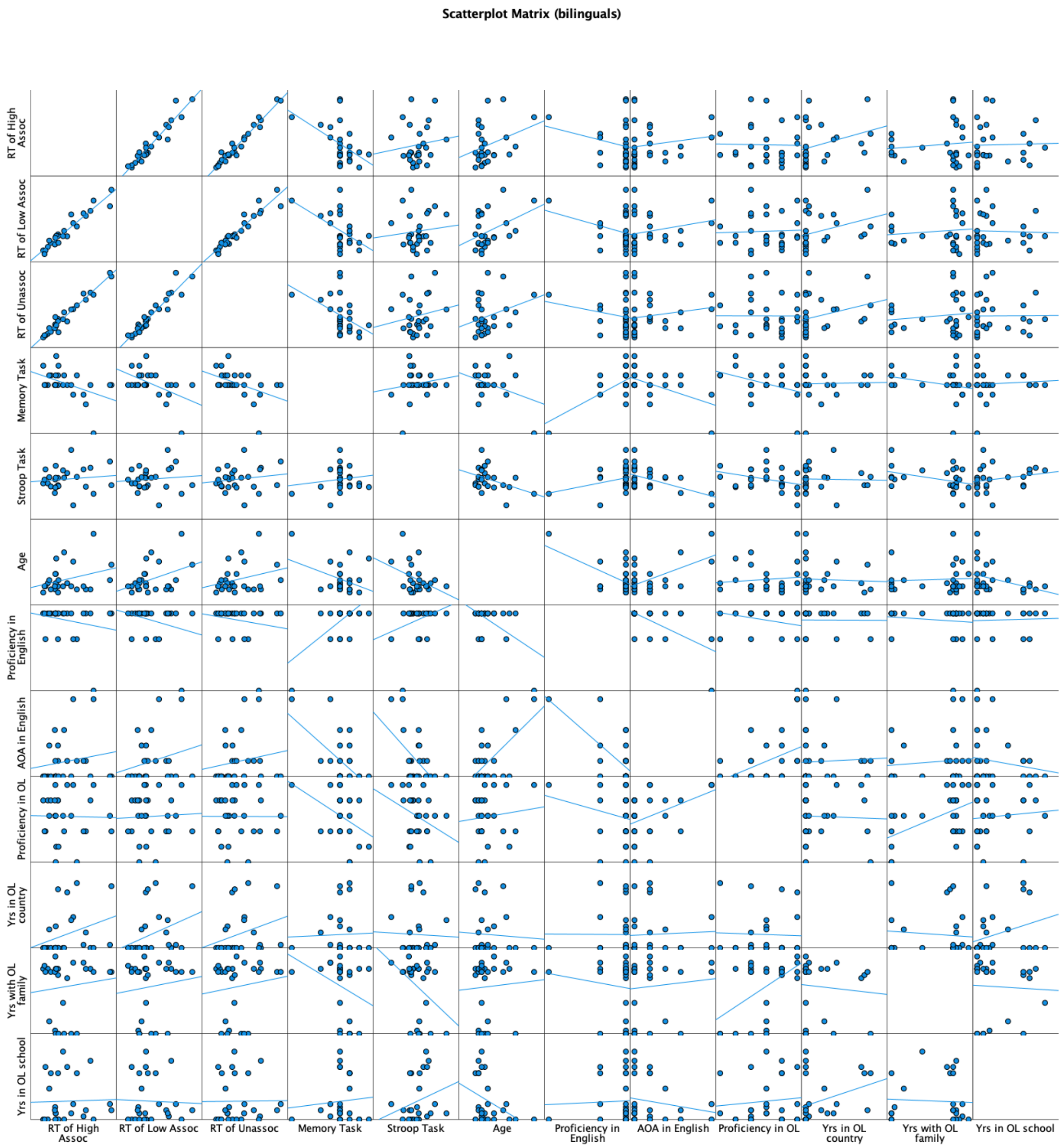
Bold values indicate statistical significance.

* $p < .05$; ** $p < .001$

A scatterplot of the associated variables for bilinguals is shown in Figure 13.

Figure 13

Scatterplot Matrix of Associated Variables for Bilinguals



Results and Analysis: Regression of Reaction Time

Impact of Independent Factors in Monolinguals

One hierarchical regression was conducted for each association condition to determine which of the following factors was a significant predictor for RT scores:

(1) Step 1: memory task

(2) Step 2: Stroop task

(3) Step 3: age

In monolinguals, the results for the regression with the dependent variable being RT to high association pairs are shown in Table 24. The regression for low association pairs is shown in Table 25 and the regression for unassociated pairs is shown in Table 26.

Table 24

Hierarchical Regression for Results of High Association Pairs in Monolinguals

Model	Unstandardized Coefficients		Std. Coeff.	R^2	Adj. R^2	ΔR^2	ΔF Sig.
	B	Std. Error	β				
Step 1				.192	0.16	.192	**.020***
(Constant)	727.89	45.03					
Memory Task	-20.98	8.43	-0.44				
Step 2				.276	0.22	.084	.101
(Constant)	695.06	47.57					
Memory Task	-20.94	8.14	-0.44				
Stroop Task	0.46	0.27	0.29				
Step 3				.28	0.19	.004	.707
(Constant)	764.55	189.08					
Memory Task	-20.33	8.43	-0.43				
Stroop Task	0.41	0.29	0.26				
Age	-3.28	8.62	-0.07				

Bold values indicate statistical significance.

* $p < .05$

As shown in Table 24, the regression model with Memory Task score as a predictive factor of RT of high association pairs in monolinguals (Model 1) was statistically significant, $R^2 = .19$, $F(1, 26) = 6.193$, $p = .02$. The addition of Stroop Task score to the prediction of reaction times (Model 2) did not result in a statistically significant increase in R^2 above and beyond the model with memory scores and adding age to the model (Model 3) did not lead to a significant increase in model fit. The full model of memory task scores, Stroop task scores, and age to predict RTs of high association pairs (Model 3) was statistically significant, $R^2 = 0.28$, $F(3, 24) = 3.12$, $p = .045$.

Table 25

Hierarchical Regression for Results of Low Association Pairs in Monolinguals

Model	Unstandardized Coefficients		Std. Coeff.	R^2	Adj. R^2	ΔR^2	ΔF Sig.
	B	Std. Error	β				
Step 1				.132	.098	.132	.058
(Constant)	723.07	46.21					
Memory Task	-17.18	8.65	-0.36				
Step 2				.276	.219	.145	**.035***
(Constant)	680.36	47.07					
Memory Task	-17.13	8.05	-0.36				
Stroop Task	0.59	0.27	0.38				
Step 3				.279	.189	.003	.754
(Constant)	622.99	187.27					
Memory Task	-17.63	8.35	-0.37				
Stroop Task	0.63	0.29	0.40				
Age	2.70	8.53	0.06				

Bold values indicate statistical significance.

* $p < .05$

Results for the low association pairs are shown in Table 25. The model with Memory Task score as a predictive factor of RT of low association pairs in monolinguals (Model 2) was not statistically significant, $R^2 = .13$, $F(1, 26) = 3.946$, $p = .058$. The addition of Stroop Task score to the model led to a statistically significant increase in R^2 of .145 and significantly improved the model fit, $R^2 = .276$, $F(2, 25) = 4.78$, $p < .05$. Adding age to the model did not significantly improve the model fit, and the full model (Model 3) was not significant.

Table 26

Hierarchical Regression for Results of Unassociated Pairs in Monolinguals

Model	Unstandardized Coefficients		Std. Coeff.	R^2	Adj. R^2	ΔR^2	ΔF Sig.
	B	Std. Error	β				

Step 1				.170	.138	.170	**.029***
(Constant)	761.43	48.61					
Memory Task	-21.01	9.10	-0.41				
Step 2				.259	.200	.089	.096
(Constant)	725.46	51.27					
Memory Task	-20.97	8.77	-0.41				
Stroop Task	0.50	0.29	0.30				
Step 3				.272	.182	.014	.508
(Constant)	857.01	202.48					
Memory Task	-19.82	9.03	-0.39				
Stroop Task	0.42	0.32	0.25				
Age	-6.20	9.23	-0.13				

Bold values indicate statistical significance.

* $p < .05$

Table 26 presents the results of the regression for the unassociated pairs in monolinguals. The model with Memory Task score as a predictive factor of RT of unassociated pairs in monolinguals (Model 2) was statistically significant, $R^2 = .17$, $F(1, 26) = 5.331$, $p = .029$. The addition of Stroop Task score did not lead to a statistically significant increase in R^2. Adding age to the model did not significantly increase the model fit, and the final model (Model 3) was not significant.

Interestingly, Stroop task performance emerged as a significant predictor only for low association pair conditions in monolinguals. This suggests an impact of selective attentional control to facilitate processing of more distantly associated prime words. It is logical that extending the reach of semantic activation to weaker associations would be associated with greater attentional control and focus, whereas such attentional control and focus may not be required to make judgments on more obvious pairs, such as highly associated or completely unassociated pairs.

Further, the results of the regression analysis indicated that performance in the memory task was a significant predictor in more than one condition of the reaction time measure. For that reason, it was inputted as a covariate into a partial correlation. Controlling for the effects of memory, monolinguals showed generally the same results. However, with the effects of memory accounted for, the performance on the Stroop task measure emerged as significantly and positively associated to performance on the low association pairs ($r = .93$). This connects with the results of the regression analysis above and indicates that the weaker association task required greater attention to succeed in, perhaps because it was more difficult due to a more distant connection between the pairs of words. These results are shown in Table 27.

Table 27

Spearman's Partial Correlation for Monolinguals

	Variable	1	2	3	4	5
	Controlled for: Memory task					
1	RT of High Association pairs					
2	RT of Low Association pairs	**0.94****				
3	RT of Unassociated pairs	**0.94****	**0.93****			
4	Stroop task	0.32	**0.41***	0.33		
5	Age	-0.19	-0.10	-0.24	**-0.37***	

Bold values indicate statistical significance.

* $p < .05$; ** $p < .001$

Impact of Independent Factors in Bilinguals

For bilinguals, one hierarchical regression was conducted for each association condition with the following factors:

(1) Step 1: memory task

(2) Step 2: Stroop task

(3) Step 3: Proficiency (English)

(4) Step 4: AOA (English)

(5) Step 5: Proficiency (OL)

(6) Step 6: Factors of bilingual immersion (years in country where OL is spoken; years with family that speaks OL; years in school where OL is used)

The results of the regressions with the dependent variable being RT to high association pairs are shown in Table 28. The regression for low association pairs is shown in Table 29, and the regression for unassociated pairs is shown in Table 30.

Table 28

Hierarchical Regression Results for RT of High Association Pairs in Bilinguals

Model	Unstandardized Coefficients		Std. Coeff.	R^2	Adj. R^2	ΔR^2	ΔF Sig.
	B	Std. Error	β				
Step 1				.222	.190	.222	**.013***
(Constant)	973.34	113.13					
Memory Task	-56.54	21.20	-0.47				
Step 2				.261	.200	.040	.268
(Constant)	964.55	112.75					
Memory Task	-60.24	21.33	-0.50				
Stroop Task	0.48	0.42	0.20				
Step 3				.265	.169	.004	.738
(Constant)	851.72	351.95					
Memory Task	-66.50	28.51	-0.55				
Stroop Task	0.44	0.44	0.18				
Proficiency (Eng)	21.86	64.45	0.08				
Step 4				.266	.132	.001	.873
(Constant)	801.95	474.01					
Memory Task	-65.18	30.25	-0.54				
Stroop Task	0.48	0.53	0.20				
Proficiency (Eng)	26.30	71.39	0.10				
AOA (Eng)	5.35	33.19	0.05				
Step 5				.307	.142	.041	.276
(Constant)	873.00	475.62					
Memory Task	-77.29	31.97	-0.64				
Stroop Task	0.37	0.54	0.16				
Proficiency (Eng)	44.60	72.85	0.17				
AOA (Eng)	12.72	33.65	0.11				
Proficiency (OL)	-28.27	25.30	-0.24				
Step 6				0.455	.212	0.148	.218
(Constant)	766.20	469.48					
Memory Task	-68.70	32.29	-0.57				
Stroop Task	0.69	0.59	0.29				
Proficiency (Eng)	40.06	71.06	0.15				

AOA (Eng)	22.75	36.04	0.20
Proficiency (OL)	-38.48	28.79	-0.32
Years in OL country	8.81	4.58	0.36
Years w. OL family	4.82	4.52	0.26
Years in OL school	-0.99	4.82	-0.04

The RT of high association pairs in bilinguals is shown in Table 28. Model 1 shows that memory score was a significant predictor, $R^2 = .22$, $F(1, 25) = 7.114$, $p = .013$. The addition of the Stroop task scores did not lead to a significant improvement in the model fit. Adding Proficiency in English, AOA in English, years in an OL-speaking country, years with an OL-speaking family, and years in an OL-speaking school into the models did not significantly improve the predictability of the models, and the resulting models were not significant (Models 3 – 6).

Table 29

Hierarchical Regression Results for RT of Low Association Pairs in Bilinguals

Model	Unstandardized Coefficients		Std. Coeff.	R^2	Adj. R^2	ΔR^2	ΔF Sig.
	B	Std. Error	β				
Step 1				.262	.232	.262	**.006***
(Constant)	952.15	96.17					
Memory Task	-53.63	18.02	-0.51				
Step 2				.295	.236	.034	.296
(Constant)	945.08	96.12					
Memory Task	-56.61	18.18	-0.54				
Stroop Task	0.38	0.36	0.19				
Step 3				.295	.204	.000	.924
(Constant)	917.71	300.72					
Memory Task	-58.13	24.36	-0.55				
Stroop Task	0.37	0.38	0.18				
Proficiency (Eng)	5.30	55.07	0.02				
Step 4				.302	.175	.006	.656
(Constant)	798.99	403.39					
Memory Task	-54.99	25.74	-0.52				
Stroop Task	0.48	0.45	0.23				
Proficiency (Eng)	15.89	60.75	0.07				
AOA (Eng)	12.76	28.24	0.13				
Step 5				.326	.166	.024	.394
(Constant)	846.63	409.29					
Memory Task	-63.11	27.51	-0.60				
Stroop Task	0.41	0.46	0.20				
Proficiency (Eng)	28.17	62.69	0.12				
AOA (Eng)	17.71	28.96	0.17				
Proficiency (OL)	-18.96	21.77	-0.18				
Step 6				.493	.267	.167	.155
(Constant)	785.69	395.22					
Memory Task	-54.67	27.18	-0.52				
Stroop Task	0.71	0.50	0.34				
Proficiency (Eng)	18.41	59.82	0.08				
AOA (Eng)	22.35	30.34	0.22				
Proficiency (OL)	-23.14	24.24	-0.22				
Years in OL country	8.74	3.85	0.41				
Years w. OL family	3.72	3.81	0.23				
Years in OL school	-2.94	4.06	-0.14				

For the RT of low association pairs in bilinguals, Model 1 shows that memory score was a significant predictor, R^2 = .262, $F(1, 25) = 8.859$, p = .006. The addition of the Stroop task scores did not result in a significant increase to the model fit. Adding in proficiency in English, AOA in English, years with an OL-speaking family, and years in an OL-speaking school into the models did not result in a significant increase to the model fit (Models 3 – 5).

Table 30

Hierarchical Regression Results for RT of Unassociated Pairs in Bilinguals

Model	Unstandardized Coefficients		Std. Coeff.	R^2	Adj. R^2	ΔR^2	ΔF Sig.
	B	Std. Error	β				
Step 1				.204	.172	.204	**.018***
(Constant)	947.63	106.88					
Memory Task	-50.66	20.03	-0.45				
Step 2				.261	.199	.057	.187
(Constant)	937.79	105.37					
Memory Task	-54.81	19.93	-0.49				
Stroop Task	0.53	0.39	0.24				
Step 3				.268	.173	.008	.626
(Constant)	784.77	327.99					
Memory Task	-63.29	26.57	-0.56				
Stroop Task	0.48	0.41	0.22				
Proficiency (Eng)	29.65	60.06	0.12				
Step 4				.278	.147	.010	.590
(Constant)	628.42	439.02					
Memory Task	-59.17	28.02	-0.53				
Stroop Task	0.62	0.49	0.28				
Proficiency (Eng)	43.59	66.12	0.18				
AOA (Eng)	16.81	30.74	0.15				
Step 5				.311	.147	.033	.330
(Constant)	687.45	443.06					
Memory Task	-69.23	29.78	-0.62				
Stroop Task	0.53	0.50	0.24				
Proficiency (Eng)	58.80	67.86	0.24				
AOA (Eng)	22.93	31.35	0.21				
Proficiency (OL)	-23.49	23.56	-0.21				
Step 6				.465	.227	.154	.197

(Constant)	568.67	434.40	
Memory Task	-58.13	29.87	-0.52
Stroop Task	0.91	0.55	0.41
Proficiency (Eng)	53.31	65.75	0.22
AOA (Eng)	35.90	33.35	0.33
Proficiency (OL)	-35.86	26.64	-0.32
Years in OL country	7.91	4.24	0.35
Years w. OL family	5.68	4.19	0.32
Years in OL school	-1.43	4.46	-0.06

For the RT of unassociated pairs in bilinguals, Model 1 shows that memory score was a significant predictor, $R^2 = .20$, $F(1, 25) = 6.399$, $p = .02$. The addition of the Stroop task scores did not significantly improve the fit of the model. Adding in proficiency in English, AOA in English, years with an OL-speaking family, years in an OL-speaking country, and years in an OL-speaking school into the models did not significantly improve the fit of the model, and Models 3–6 were also not significant.

Discussion

An independent samples *t*-test indicated no significant difference between the means of the monolingual and bilingual memory task scores or Stroop task scores, which measure selective attention. While not exhaustive, this analysis suggests that bilinguals and monolinguals can be characterized by the same attentional control and memory task abilities. In this section, I describe differences between the two groups which, in the context of this non-significant difference in ability overall, suggest differences in the way these cognitive abilities are applied to language processing.

Bilinguals showed a pattern of effects that suggested more strain in low association conditions. Similarly to monolinguals, the regression analyses showed that memory was a significant predictor of RT for high and unassociated conditions When years spent in OL-speaking country was introduced into the model, it emerged as a significant predictor only for the low association conditions. In other words, RTs for weaker associations are influenced by immersion in another language more significantly than highly associated primes or not associated primes. I interpret this as indicating that bilinguals who were immersed in another language have greater difficulty with making semantic associations to less associated pairs and can more easily determine pairs that are highly associated or not at all associated.

The results of the regression analysis indicated that performance in the memory task was a significant predictor in more than one condition of the reaction time measure. For that reason, it was inputted as a covariate into a partial correlation. Table 31 shows the results of a Spearman's partial correlation for bilinguals controlling for memory task performance.

Table 31

Spearman's Partial Correlation in Bilinguals

	Variable	1	2	3	4	5	6	7	8	9	10	11	12
	Controlled for: Memory task												
1	RT of High Association pairs												
2	RT of Low Association pairs	**0.94****											
3	RT of Unassociated pairs	**0.97****	**0.94****										
4	Stroop task	0.23	0.21	0.27									
5	Age	0.17	0.27	0.15	-0.37								
6	Proficiency (English)	0.13	0.07	0.17	0.26	**-0.44***							
7	AOA (English)	-0.12	-0.06	-0.10	**-0.56****	**0.52***	**-0.46***						
8	Proficiency (OL)	-0.26	-0.21	-0.23	-0.28	-0.05	0.08	0.25					
9	Years in OL country	0.38	**0.41***	0.35	-0.04	-0.05	-0.03	0.08	-0.03				
10	Years with OL family	-0.03	-0.04	0.00	-0.35	-0.06	0.12	-0.08	**0.47***	-0.08			
11	Years in OL school	0.07	0.01	0.05	0.23	-0.38	-0.02	-0.16	0.14	0.33	-0.03		

12	Foreign accent perception by others in OL	0.22	0.10	0.20	0.17	0.15	-0.16	-0.18	**-0.39***	-0.12	0.06	0.17

Bold values indicate statistical significance.

* $p < .05$; ** $p < .001$

Controlling for memory, proficiency in English emerges as a significant negative associate of age ($r = .44$). AOA of English emerges as a significantly negatively associated with Stroop performance ($r = -.56$) and proficiency ($r = -.46$). This indicates that high attentional control (indicated by a low Stroop task score) trends with high language proficiency. Age was also significantly positively correlated for AOA of English ($r = .52$). Finally, controlling for memory has the effect of liming the effects of years spent in an OL country to just the low association condition which were positively associated ($r = .41$). This indicates that participants who had spent longer time in an OL-immersive country had longer reaction times across the board, but that this effect is largely controlled by memory.

Working Memory

WMC was not correlated with the high or low context effects in monolinguals or in bilinguals. However, a separate analysis with the mean RT from the association condition showed a negative correlation with monolinguals. This may be because the difference values are smaller effects and may shrink any significant association, if any.

In the regression analyses on the RTs, WMC was the sole predictor that emerged in all conditions in both groups. When the effect of working memory capacity was extracted, the partial correlations indicated different results previously described. These two outcomes underscore the importance of working memory in language processing (Ito, Corley, et al., 2018).

Among bilinguals, WMC negatively correlated with two variables of interest: self-rated proficiency in the other language and years spent with a family that used the other language. As for the former, this indicates that a greater working memory capacity was associated with lower language proficiency in the other language. This result is congruent with the results of the previous literature, which suggests that bilinguals generally experience greater deficits of WMC and that this is exacerbated with higher proficiency in the other language (Dussias & Piñar, 2010). Individuals with high OL proficiency can be considered to be those who have balanced proficiency in both languages or who are more proficient in the other language than in English. Both of these populations have been shown in previous studies to do worse than monolinguals in an English task and also to have more limited WMC. I posit that more limited working memory availability is the result of activation of a language not-in-use, which would be more prevalent in individuals with higher proficiency in the OL. Conversely, greater proficiency and dominance in English makes it harder to activate non-English words if at all, and in turn, easier to suppress the ones that are activated. This would indicate that more WMC resources are available to complete an English task among individuals with less proficiency in language not-in-use. Of note, however, is that this analysis predicts an association between memory task performance and reaction time speeds in the English task: if it is true that people with less OL proficiency have higher WMC because of decreased distractors from the unintended language, then we expect to see this reflected in the English task with higher RT in individuals with higher English proficiency or with higher working memory capacities. This is not reflected in the correlations. English proficiency did not correlate with RT speeds, likely because of a skewed spread of higher proficiency among the speakers. WMC did not correlate with RT in bilinguals as expected, which may indicate that WMC is not a major or the sole contributor to RT performance in bilinguals.

WMC also negatively correlated with the number of years spent with a family that spoke that other language. The explanation of this outcome is similar to that of the correlation between working memory capacity and proficiency. As individuals spent more time with a family that used the other language regularly, we can expect that their proficiency also increased, and their working memory capacity became more strained in its use across two languages. This analysis is supported by a positive correlation between OL proficiency and years spent with family.

Attentional Control

A lower Stroop task performance indicates greater attentional control, as the Stroop task value represents the additional reaction time required to process a conflicting stimulus. In monolinguals, Stroop task values and age were negatively correlated, indicating that an older age is associated with greater attentional control among individuals in this study. Previous studies show that attentional control typically decreases with advanced age between 60 and 81 years (Kousaie & Phillips, 2012), and conversely, this present analysis showed increase of attentional control with age in monolingual individuals. However, it is important to note that the participants in this study were between the ages of 18 and 38 years of age and different from the prior studies on changes to attentional control in populations of advanced age.

Further, Stroop task performance positively correlated with RT on low association pairs in monolinguals when controlling for the effects of working memory capacity. As attentional control decreased, RT performance on low association pairs slowed. Similarly, the regression analyses revealed that attentional control was a significant contributor to the RTs in the low association condition for monolinguals. These results indicate that listeners with greater attentional control were better able to use semantics to retrieve a weakly associated word pair. This could point to the impact of selective attention on promoting the travel of activation from one word to a more distant associate in the semantic network. Attentional control was not useful for unassociated pairs since the travel of activation would never arrive to an unassociated word; in high association pairs, attentional performance was not used presumably because of how close the relatives were. This indicates that the semantic spreading activation to the boundaries of a network requires greater focus and attentional control in monolinguals.

This effect of attention was not found in bilinguals. Further, among bilinguals, Stroop task performance did not correlate with age as in monolinguals; however, Stroop task performance was negatively correlated with AOA in English for bilinguals. This indicates an association between greater attentional control (i.e., lower Stroop task performance) and a higher age of acquisition. This seems to suggest that a later acquisition is associated with or may lead to greater attentional control, but another non-causative explanation is proposed. This outcome may be the result of a selection bias: individuals in this study were highly proficient, some of whom who achieved this proficiency despite the challenges of a later age of acquisition (Shi & Sánchez, 2010). Therefore, it is possible that only the individuals with a high attentional control ability were able to overcome the challenges of a late AOA to proficiency and attend a predominantly English-speaking University in the United States.

Stroop task performance positively correlated with the number of years spent in an immersive school, indicating that greater attentional control was associated with a greater number of years spent in immersive schooling. Notably, immersive schooling did not correlate with OL proficiency, so this means that the association between Stroop task performance and immersive schooling is likely not attributable to increased language outcomes. It is likely some other additional variables covary with immersive schooling and lead to this outcome.

Immersion and Exposure

Among bilinguals, these results also suggest that a greater number of years spent in a country in which the OL is spoken correlated positively with the reaction time measures. Notably, other variables of OL immersion — years spent in a family or school — did not correlate with reaction time. When controlling for the impact of working memory capacity, the number of years in OL-speaking country still correlated with RT on low association pairs. The regression results similarly showed that years spent in an OL-speaking country was a contributor for the low association pairs, but neither of the two other conditions.

This result may be because living in a country provides more imbalanced language input than living in a house or family that uses the language, presumably in conjunction with a different societal language (Rothman, 2009). Therefore, listeners who received proportionally less English input demonstrated increased reaction time for low association pairs. In terms of language exposure and immersion, the difference between living in a country or spending time with a family or in a school is both in the quality of language exposure and the quantity of language exposure. A bilingual individual would be getting more balanced dual input from a family or school than from living in a country in which the OL is more dominant. Heritage language use, which is the use of a non-English languages specifically at home in a setting where the societal language is predominantly English, is shown to have differential language outcomes for listeners (Cabo & Rothman, 2012; Polinsky, 2006, 2018) because the quality of the language input is fundamentally different in heritage languages (Polinsky, 2006). This is concurrent with the present findings that years spent with an OL speaking family is not a significant contributor to OL outcomes when that family is living in a predominantly English society.

The impact of living in an OL-speaking country on the RT for low association pairs particularly interesting, because it maps onto the effect of attentional control in monolinguals:

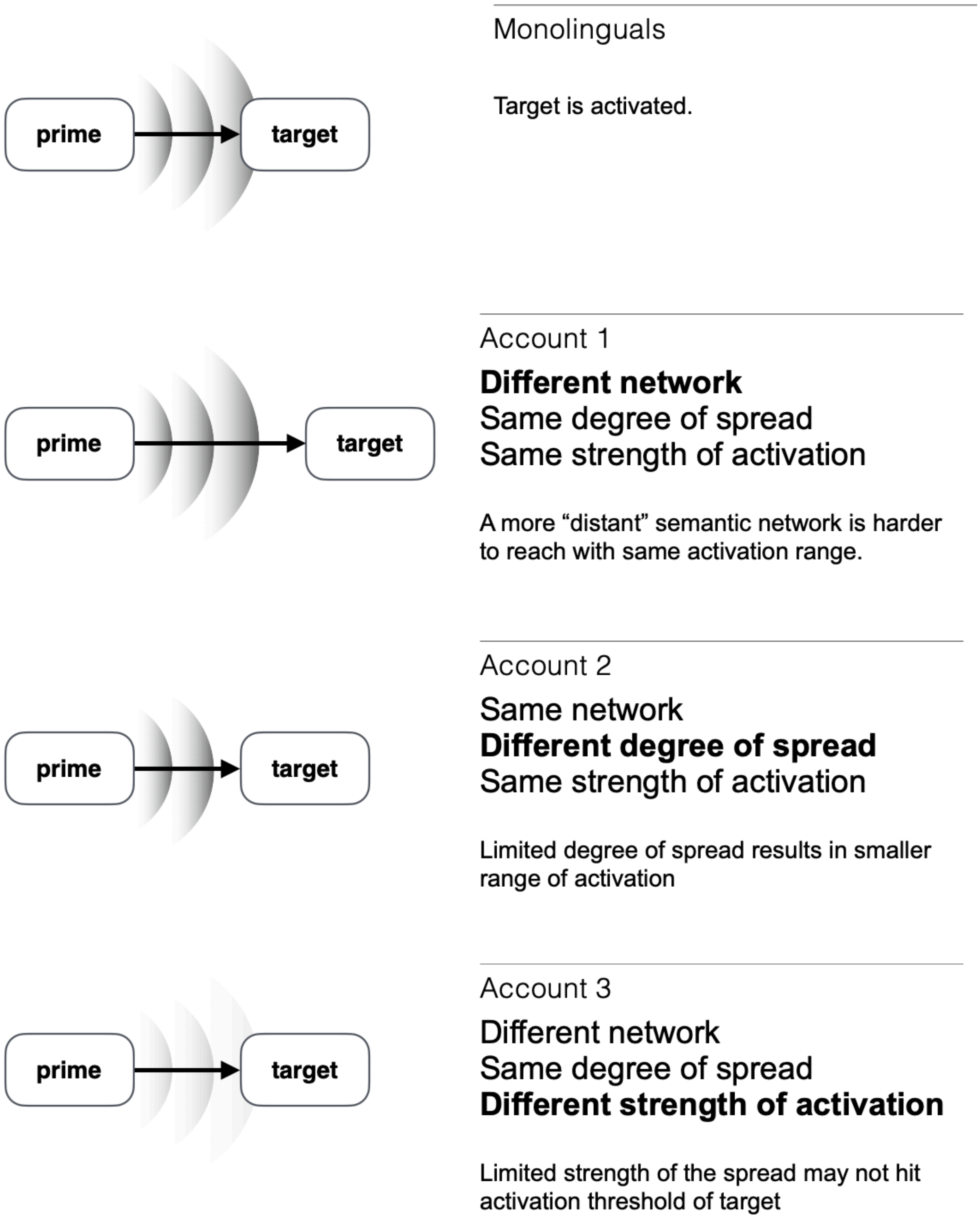
whereas monolinguals were aided by attentional control in retrieving more distant associates, bilinguals' retrieval of distant associates was negatively impacted by the years spent in an OL-speaking country. This is indicated by a positive correlation between Stroop task performance and low association RTs as well as its significant contribution in the regression in monolinguals. In bilinguals, this is indicated by a positive correlation between years in OL-speaking country and low association RTs as well as its emergence as a significant contributor in the regression analysis.

Conclusions

These findings suggest one of three theoretical accounts of bilingual semantic spreading activation and how it differs from the same process in monolinguals. These accounts are depicted visually in Figure 14, in which circles represent the lexical semantic network from a given prime word (center) to semantically related other words. The distance from the prime each of these other words is represented by the length of the spoke. In addition, semantic spread is represented by concentric circles that weaken as they move further from the prime. The models of bilingual spreading activation differ from that of monolinguals in the strength of the spread (powered by cognitive factors, such as attention), the size of the spread, or the distance of more unrelated words from the prime word, respectively.

Figure 14

Theoretical Accounts of Semantic Activation Differences in Bilinguals



First, bilinguals' semantic network might be characterized by distant associates that are proportionally *more* distant, and so while their selective attention capabilities and the degree of spread are the same as monolinguals, it is not as helpful in reaching the periphery of the network as it is in monolinguals. Conversely, bilinguals may be characterized by having the same network but activation spread that covers a more limited distance, and so while their selective attention abilities are the same as monolinguals, it is not as helpful in promoting the range of the spread as it is in monolinguals. Third, bilinguals may be characterized by the same semantic network and degree of spread as monolinguals but are not using selective attention capabilities to extend the "range" of activation to the same degree. This account could be explained by an exhaustion of selective attention resources on suppressing cross-linguistic activation, which was not directly tested in this experiment.

The analyses in this section make it clear that living in a non-English speaking country appears to have a more negative effect on processing in English, such that it results in a preoccupation of attentional resources, shortens the spread of activation, or extends the distance of distant associates. However, years spent in OL-speaking country and level of English proficiency did not correlate; thus, the effect of living in an OL-speaking country on the language system was not significant enough to overtly impact proficiency.

I discount the third account because it does not imply the results found. This account theorizes that selective attention and attentional control is preoccupied with the suppression and activation of the other language, and so less is available for activation in English. This would imply a high enough proficiency in the other language to be distracting to English processing and may also implicate a decrease in proficiency in English. Neither of these factors were accounted for in the correlation, and so this account is not likely. I compare the implications of the second and third accounts regarding differences in the bilingual semantic network in more detail in future chapters.

In sum, analyses of RT values indicated a general slowdown in bilingual performance and non-nativelike processing in bilinguals. Analyses of the CV values indicated that this difference was not the result of differential processing of the word pairs. A series of regression analyses and correlations tested the hypothesis that differences in cognitive impacted the slowdown in bilingual performance. Notably, the results refute the hypothesis that bilinguals have different levels of WMC or attentional control; instead, the bilinguals appear to employ cognitive strategies for processing to a different degree than monolinguals. Both groups showed working memory capacity was a significant contributor to all three association conditions. In the low association conditions, attentional control emerged as a factor contributing to monolinguals' performance and the number of years spend in an OL-speaking country emerged as a factor for bilinguals.

Results and Analysis: Regression of CV Values

Introduction

Bilinguals and monolinguals demonstrated a difference in reaction time measures, indicating a differential use of semantic information for processing. An analysis of the CV values, which is a measure of variation used as an index of processing efficiency in prior studies (Phillips et al., 2004; Segalowitz & Segalowitz, 1993), indicated an equality in efficiency and indicated that the difference was not a result of differences in the language processing mechanism. In the preceding section, this was underscored with regression analyses that showed how factors of cognition slowed down bilingual performance differentially from monolinguals.

In the section to follow, I input the CV values into a regression in order to determine if the predictive factors hold up in their contribution not to the speed of processing, but to the variation of processing (i.e., processing efficiency). The factors that emerge as predictors to variation would neutralize reaction time differences in subjects and indicate what facilitated processing in each group.

Results and Analysis

Monolinguals. The methodology replicated the previous regression analyses for monolinguals. The results for high association pairs are shown in Table 32, with results for low association pairs shown in Table 33 and unassociated pairs in Table 34.

Table 32

Hierarchical Regression Results for CV of High Association Pairs in Monolinguals

Model	Unstandardized Coefficients		Std. Coeff.	Sig.	R2	Adj. R2	R2 Change	Sig F Change
	B	Std. Error	Beta					
Step 1					0.04	0.01	0.04	0.28
(Constant)	0.53	0.11		0.00				
Memory Task	-0.02	0.02	-0.21	0.28				
Step 2					0.19	0.13	0.15	**0.04***
(Constant)	0.44	0.11		0.00				
Memory Task	-0.02	0.02	-0.21	0.25				
Stroop Task	0.00	0.00	0.38	0.04				
Step 3					0.21	0.11	0.02	0.42
(Constant)	0.78	0.42		0.08				
Memory Task	-0.02	0.02	-0.18	0.34				
Stroop Task	0.00	0.00	0.32	0.11				
Age	-0.02	0.02	-0.16	0.42				

Bold values indicate statistical significance.

* $p < .05$; **$p < .001$

None of the models were significant predictors for monolingual RT performance for high association pairs, although the addition of the Stroop task scores was shown to significantly improve the model fit and increase R^2 by .145, $F(2, 25) = 2.935$, $p = .04$.

Table 33

Hierarchical Regression Results for CV of Low Association Pairs in Monolinguals

Model	Unstandardized Coefficients		Std. Coeff.	Sig.	R2	Adj. R2	R2 Change	Sig F Change

	B	Std. Error	Beta					
Step 1					0.06	0.03	0.06	0.19
(Constant)	0.52	0.09		0.00				
Memory Task	-0.02	0.02	-0.25	0.19				
Step 2					0.15	0.09	0.09	0.11
(Constant)	0.45	0.10		0.00				
Memory Task	-0.02	0.02	-0.25	0.18				
Stroop Task	0.00	0.00	0.30	0.11				
Step 3					0.22	0.12	0.06	0.17
(Constant)	0.95	0.37		0.02				
Memory Task	-0.02	0.02	-0.20	0.28				
Stroop Task	0.00	0.00	0.20	0.32				
Age	-0.02	0.02	-0.28	0.17				

None of the models were significant predictors for monolingual RT performance for low association pairs. The full model with memory task, Stroop task, and age (Model 3) was not significant.

Table 34

Hierarchical Regression Results for CV of Unassociated Pairs in Monolinguals

Model	Unstandardized Coefficients		Std. Coeff.	Sig.	R2	Adj. R2	R2 Change	Sig F Change
	B	Std. Error	Beta					
Step 1					0.02	-0.02	0.02	0.53
(Constant)	0.47	0.12		0.00				
Memory Task	-0.01	0.02	-0.13	0.53				
Step 2					0.26	0.20	0.24	**0.01***
(Constant)	0.33	0.12		0.01				
Memory Task	-0.01	0.02	-0.12	0.48				
Stroop Task	0.00	0.00	0.49	0.01				
Step 3					0.27	0.18	0.02	0.46
(Constant)	0.68	0.48		0.17				
Memory Task	-0.01	0.02	-0.10	0.58				
Stroop Task	0.00	0.00	0.44	0.03				
Age	-0.02	0.02	-0.14	0.46				

Bold values indicate statistical significance.

* p < .05; **p < .001

For unassociated pairs, the model including Memory and the Stroop task (Model 2) was found to be significant, $R^2 = .26$, $F(2, 25) = 4.288$, $p = .025$. The inclusion of the Stroop task values was found to significantly increase the model fit, $p = .01$.

Bilinguals. The same factors were inputted in the same steps as in the previous bilingual regressions. The results for the high association pairs in bilinguals are shown in Table 35, for low association pairs in Table 36, and unassociated pairs in Table 37.

Table 35

Hierarchical Regression Results for CV of High Association Pairs in Bilinguals

Model	Unstandardized Coefficients		Std. Coeff.	Sig.	R2	Adj. R2	R2 Change	Sig F Change
	B	Std. Error	Beta					
Step 1					0.00	-0.04	0.00	0.93
(Constant)	0.43	0.13		0.00				
Memory Task	0.00	0.03	-0.02	0.93				
Step 2					0.14	0.07	0.14	**0.06***
(Constant)	0.41	0.13		0.00				
Memory Task	-0.01	0.02	-0.07	0.72				
Stroop Task	0.00	0.00	0.38	0.06				
Step 3					0.20	0.10	0.06	0.20
(Constant)	0.87	0.37		0.03				
Memory Task	0.02	0.03	0.12	0.61				
Stroop Task	0.00	0.00	0.45	0.03				
Proficiency (Eng)	-0.09	0.07	-0.32	0.20				
Step 4					0.20	0.06	0.00	0.90
(Constant)	0.90	0.47		0.07				
Memory Task	0.01	0.03	0.11	0.68				
Stroop Task	0.00	0.00	0.44	0.06				
Proficiency (Eng)	-0.09	0.07	-0.33	0.22				
AOA (Eng)	0.00	0.03	-0.03	0.90				
Step 5					0.37	0.22	0.17	**0.02***
(Constant)	0.98	0.43		0.03				
Memory Task	-0.01	0.03	-0.11	0.66				
Stroop Task	0.00	0.00	0.37	0.09				
Proficiency (Eng)	-0.04	0.07	-0.15	0.55				
AOA (Eng)	0.02	0.03	0.13	0.64				
Proficiency (OL)	-0.06	0.03	-0.49	0.02				
Step 6					0.38	0.12	0.02	0.92
(Constant)	1.00	0.46		0.04				

Memory Task	-0.01	0.04	-0.11	0.70
Stroop Task	0.00	0.00	0.38	0.14
Proficiency (Eng)	-0.04	0.07	-0.16	0.56
AOA (Eng)	0.01	0.04	0.09	0.76
Proficiency (OL)	-0.05	0.03	-0.43	0.11
Years in OL country	0.00	0.01	-0.04	0.86
Years w. OL family	0.00	0.00	-0.06	0.82
Years in OL school	0.00	0.01	-0.11	0.60

Bold values indicate statistical significance.

* $p < .05$; ** $p < .001$

For the CVs of high association pairs in bilinguals, the model with the variables of WMC, attentional performance, English proficiency, English age of acquisition, and other language proficiency (Model 5) was found to approach significance, $R^2 = .37$, $F(5, 22) = 2.539$, $p = .058$. The addition of the proficiency in the other language in Model 5 was found to significantly improve the model fit, $p = .02$. No other models were significant.

Table 36

Hierarchical Regression Results for CV of Low Association Pairs in Bilinguals

Model	Unstandardized Coefficients		Std. Coeff.	Sig.	R2	Adj. R2	R2 Change	Sig F Change
	B	Std. Error	Beta					
Step 1					0.10	0.06	0.10	0.10
(Constant)	0.59	0.13		0.00				
Memory Task	-0.04	0.02	-0.31	0.10				
Step 2					0.33	0.27	0.23	**0.01***
(Constant)	0.57	0.11		0.00				
Memory Task	-0.05	0.02	-0.38	0.03				
Stroop Task	0.00	0.00	0.48	0.01				
Step 3					0.34	0.26	0.01	0.55*
(Constant)	0.75	0.33		0.03				
Memory Task	-0.04	0.03	-0.30	0.17				
Stroop Task	0.00	0.00	0.52	0.01				
Proficiency (Eng)	-0.04	0.06	-0.13	0.55				
Step 4					0.34	0.22	0.00	0.90*
(Constant)	0.72	0.42		0.10				
Memory Task	-0.04	0.03	-0.29	0.22				
Stroop Task	0.00	0.00	0.53	0.02				
Proficiency (Eng)	-0.03	0.06	-0.13	0.60				

AOA (Eng)	0.00	0.03	0.03	0.90				
Step 5					0.38	0.23	0.04	0.27*
(Constant)	0.76	0.42		0.08				
Memory Task	-0.05	0.03	-0.39	0.13				
Stroop Task	0.00	0.00	0.49	0.02*				
Proficiency (Eng)	-0.01	0.07	-0.04	0.87				
AOA (Eng)	0.01	0.03	0.11	0.68				
Proficiency (OL)	-0.03	0.02	-0.23	0.27				
Step 6					0.48	0.27	0.11	0.29
(Constant)	0.83	0.41		0.06				
Memory Task	-0.04	0.03	-0.34	0.20				
Stroop Task	0.00	0.00	0.58	**0.02***				
Proficiency (Eng)	-0.03	0.07	-0.12	0.63				
AOA (Eng)	0.00	0.03	0.01	0.98				
Proficiency (OL)	-0.01	0.03	-0.09	0.70				
Years in OL country	0.01	0.00	0.25	0.19				
Years w. OL family	0.00	0.00	-0.03	0.90				
Years in OL school	-0.01	0.00	-0.36	0.08				

Bold values indicate a statistical change significance

[*] denotes significance of model fit (*p* < .05; ***p* < .001)

For the low association pairs, the model which included memory, attentional performance, proficiency in English, AOA in English, and proficiency in the other language (Model 5) was found to be significant, $R^2 = .38$, $F(5, 27) = 2.655$, $p = .05$. Model 2 was a significant model, and the addition of the attentional performance in Model 2 significantly increased the model fit, $R^2 = .33$, $F(2, 27) = 6.118$, $p = .007$. Models 3 – 4 were also significant models, but the addition of the variables in each of those models did not significantly increase the model fit. The full model, Model 6, was not significant.

Table 37

Hierarchical Regression Results for CV of Unassociated Pairs in Bilinguals

Model	Unstandardized Coefficients		Std. Coeff.	Sig.	R2	Adj. R2	R2 Change	Sig F Change
	B	Std. Error	Beta					
Step 1					0.03	0.00	0.03	0.36
(Constant)	0.57	0.15		0.00				
Memory Task	-0.03	0.03	-0.18	0.36				

Step 2					0.14	0.08	0.11	**0.08***
(Constant)	0.55	0.15		0.00				
Memory Task	-0.03	0.03	-0.23	0.24				
Stroop Task	0.00	0.00	0.34	0.08				
Step 3					0.21	0.12	0.07	0.15
(Constant)	1.14	0.43		0.01				
Memory Task	0.00	0.03	-0.02	0.93				
Stroop Task	0.00	0.00	0.42	0.04				
Proficiency (Eng)	-0.11	0.08	-0.35	0.15				
Step 4					0.25	0.12	0.04	0.30
(Constant)	0.80	0.53		0.14				
Memory Task	0.01	0.04	0.07	0.77				
Stroop Task	0.00	0.00	0.53	0.02				
Proficiency (Eng)	-0.09	0.08	-0.28	0.28				
AOA (Eng)	0.04	0.04	0.28	0.30				
Step 5					0.40	0.27	0.15	**0.03***
(Constant)	0.89	0.49		0.08				
Memory Task	-0.02	0.04	-0.13	0.58				
Stroop Task	0.00	0.00	0.46	0.03				
Proficiency (Eng)	-0.03	0.08	-0.11	0.66				
AOA (Eng)	0.06	0.04	0.43	0.10				
Proficiency (OL)	-0.07	0.03	-0.47	0.03				
Step 6					0.54	0.34	0.14	0.17
(Constant)	0.95	0.46		0.05				
Memory Task	-0.01	0.04	-0.09	0.70				
Stroop Task	0.00	0.00	0.54	0.02				
Proficiency (Eng)	-0.05	0.07	-0.15	0.53				
AOA (Eng)	0.05	0.04	0.37	0.17				
Proficiency (OL)	-0.05	0.03	-0.32	0.17				
Years in OL country	0.00	0.01	-0.09	0.59				
Years w. OL family	0.00	0.00	-0.08	0.70				
Years in OL school	-0.01	0.01	-0.35	0.07				

Bold values indicate statistical significance.

*$p < .05$; **$p < .001$

For the unassociated pairs, the model which included memory, attentional performance, English proficiency, English AOA, and proficiency in the other language (Model 5) was significant, $R^2 = .401$, $F(5, 27) = 2.950$, $p = .035$. The addition of the proficiency in the other language in Model 5 was found to significantly improve the model fit, $p = .028$.

The full model which included memory, attentional performance, proficiency in English, AOA in English, proficiency in the other language, and the immersion variables (Model 6) was also found to be significant, $R^2 = .539$, $F(8, 27) = 2.774$, $p = .032$; however, the addition of the immersion variables in this model did not significantly improve the model fit.

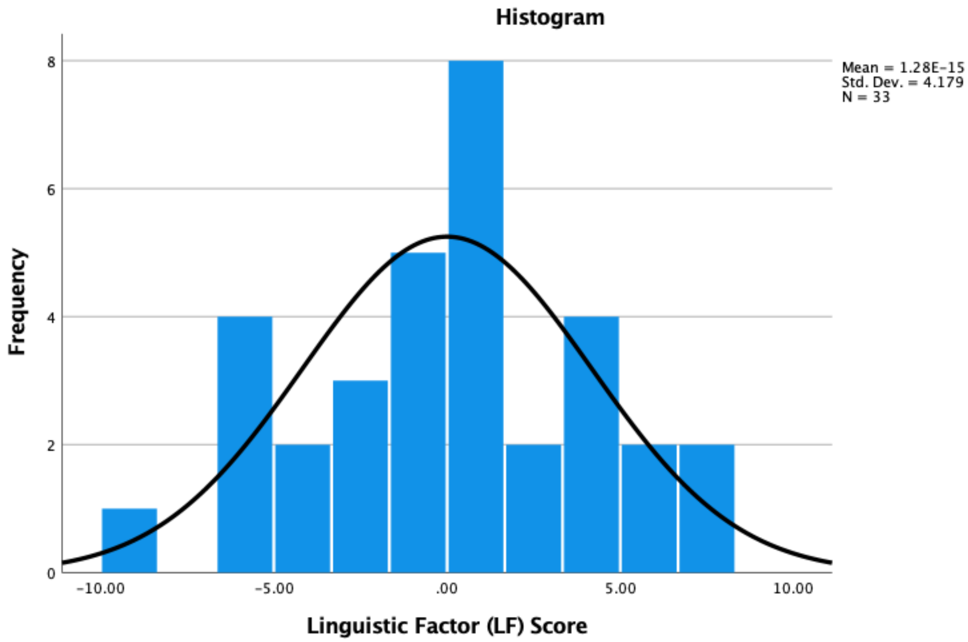
Results and Analysis: Linguistic Variables

The next goal was to study the impact of exposure length and frequency on the RT for the priming task. To assess the impact of these linguistic variables, I generated a single Linguistic Factor (LF) score for the bilingual participants that combines the following factors: (1) proficiency in OL, (2) years spent in an OL-speaking country, (3) years spent with an OL-speaking family, (4) years spent in an OL-speaking school, (5) self-perception of OL-accent by OL-native speaker, (6) language first acquired, and (7) self-ratings of language frequency, exposure, and dominance. AOA was not included in this selection because its impact was assessed in prior studies. Along with English proficiency, which was also not included, the impact of AOA on the RT values worked in the opposite direction (e.g., lower AOA had the opposite effect of lower proficiency effects). The LF score variable is used to quantify the bilingual experience and language use holistically. I assess the impact of these variables in combination on the RT values for each condition.

To do so, a standardized *z*-score was generated for each of the variables above and summed for each bilingual participant. The frequency of LF scores is shown in Figure 15.

Figure 15

Frequency of Linguistic Factor (LF) Scores in Bilinguals



These values were then associated with the reaction times of each of the association conditions as shown in Figure 16, Figure 17, and Figure 18. The vertical line indicates the LF mean (high association: m = 682.77 ms; low association: m = 670.24 ms; unassociated: m = 686.62 ms) and the horizontal line indicates the mean for the RT in that association condition.

Figure 16

Scatterplot of Linguistic Factors and High Association RT in Bilinguals

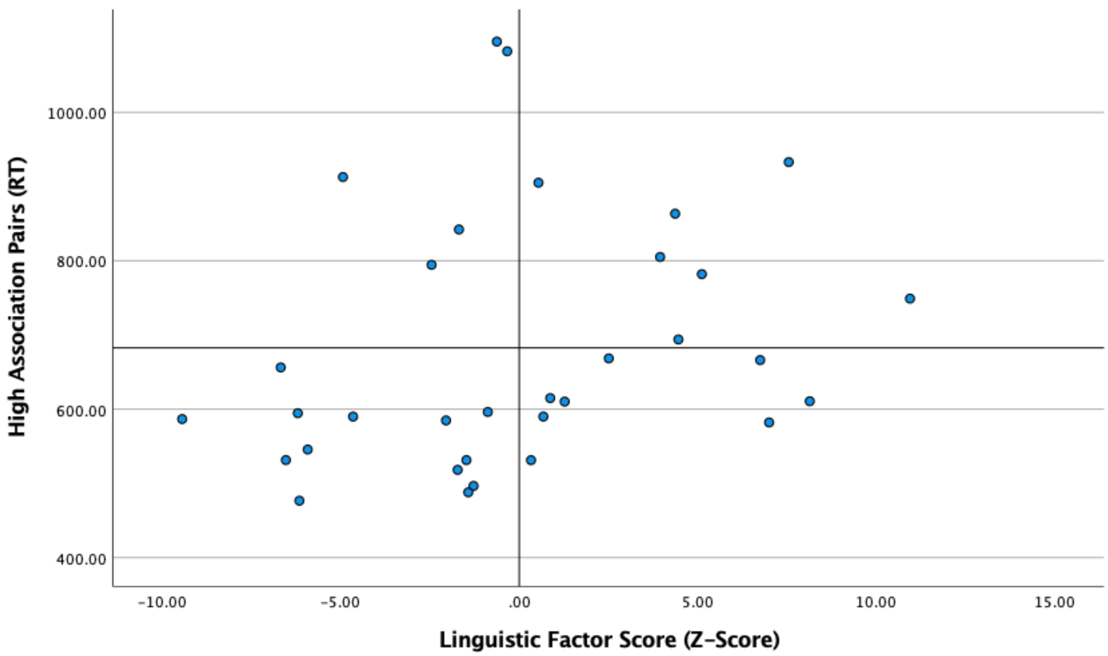


Figure 17

Scatterplot of Linguistic Factors and Low Association RT in Bilinguals

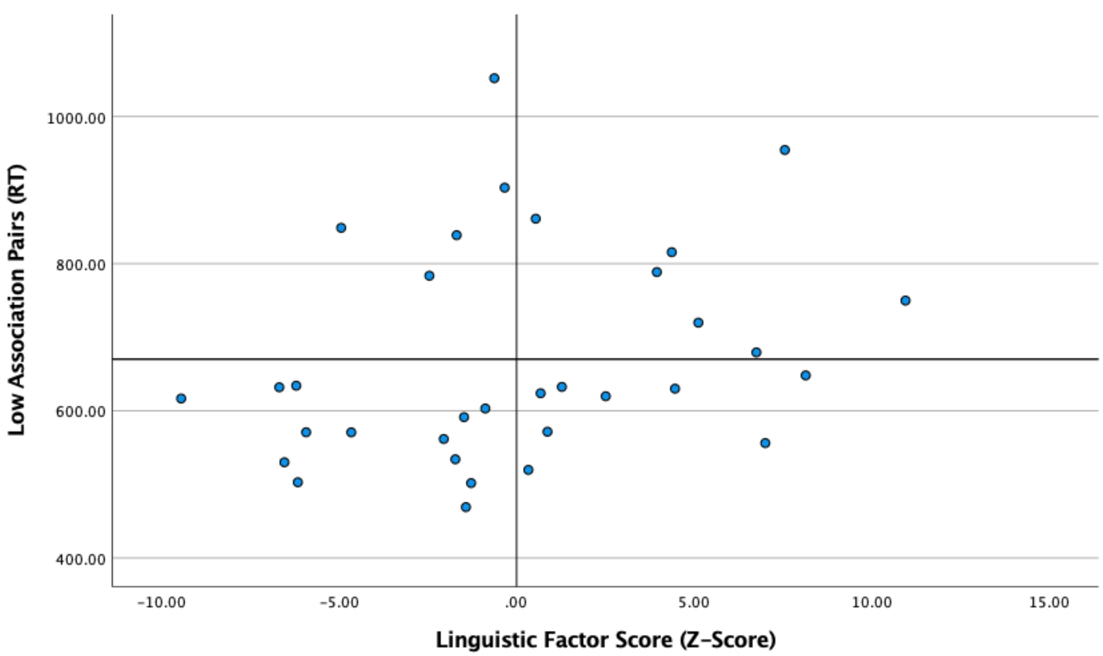
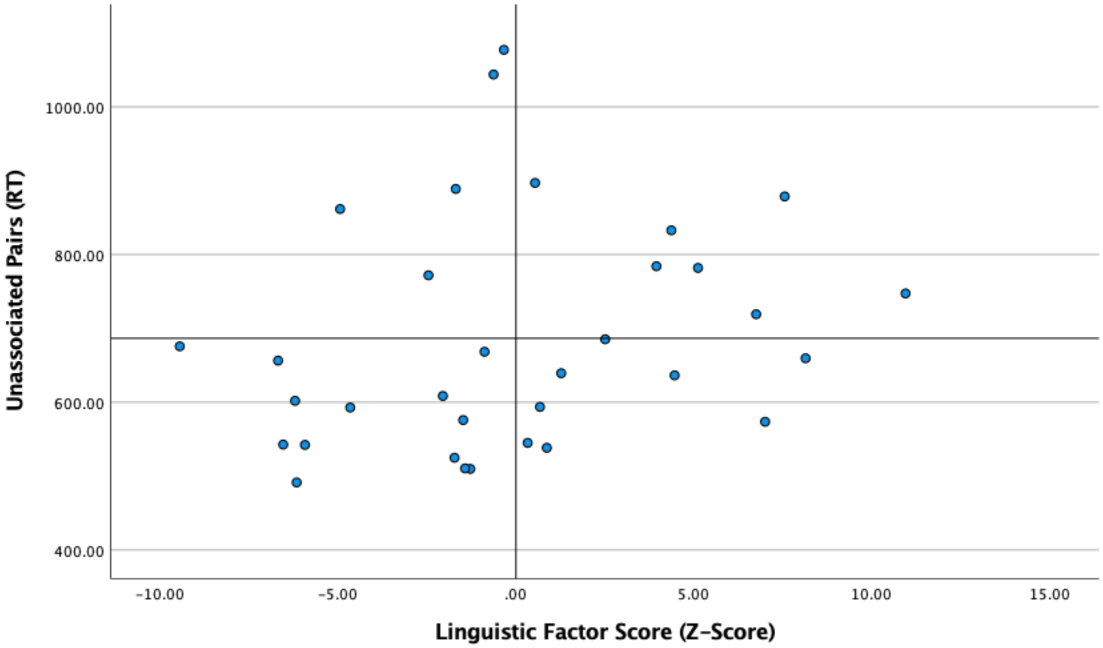


Figure 18

Scatterplot of Linguistic Factors and Unassociated Pairs RT in Bilinguals



This analysis indicates the incidence of a relatively high or low reaction time given a LF score. In order to statistically compare this, a chi-square on each quadrant of the values in each scatterplot. This would compare the incidences of having a high or low linguistic factor score paired with a high or low RT. Notably, there were the same number in each quadrant for each condition, which reaffirms the minimal differences that the degree of semantic information availability has on RT scores. Table 38 shows the count of the values in each quadrant.

Table 38

Count of Values in Each Quadrant

		Linguistic Factor Score (*n*)				
		Below Mean	% of Association Total (of LF total)	Above Mean	% of Association Total (of LF total)	Total
High Association Pairs RT	Below Mean	12	80 (57.1)	9	45 (42.9)	21
	Above Mean	3	20 (21.4)	11	55 (78.6)	14
Total		15		20		35
Low Association Pairs RT	Below Mean	12	80 (57.1)	9	45 (42.9)	21
	Above Mean	3	20 (21.4)	11	55 (78.6)	14
Total		15		20		35

Unassociated Pairs						
RT	Below Mean	12	80 (57.1)	9	45 (42.9)	21
	Above Mean	3	20 (21.4)	11	55 (78.6)	14
Total		15		20		35

The results of the chi-square test are shown in Table 39.

Table 39

Results of Chi-Square Test

		Value	Asymptotic Standard Error	Approximate *t*	Approximate Significance
Ordinal by Ordinal	Kendall's tau-b	0.354	0.152	2.291	0.022*
	Gamma	0.66	0.222	2.291	0.022*

The results indicate significant differences in the scatterplot quadrants that is identical for all three conditions (p = .022). Overwhelmingly, a low LF score was associated with the lower half of reaction time values (80% below the mean, 20% above the mean). A high LF score is associated with the upper half of RT values (45% below the mean, 55% above the mean).

Discussion

The first finding of this analysis is that a combination of linguistic factor scores was to some degree associated with performance on the upper or lower half of reaction time values. Individual measures were analyzed in additional tests not reported, but only the combination of these linguistic variables yielded significant results. This suggests an interaction of these different factors. Practically, this interaction reflects the bilingual experience: for example, the number of years spent in an OL-speaking country interacts with English proficiency and OL-proficiency levels, as well as language preference and dominance.

Specifically, participants with a high LF score placed in the higher RT quadrant with a slight bias (55% to 45%). This indicated that participants with a richer experience in the OL, including more dominance, proficiency, and exposure, were almost evenly distributed across the reaction time speeds but had a slight inclination to be slower. This is expected, because greater experience in another language might impact slow down performance on an English task.

Participants with a lower LF score, however, overwhelmingly placed with lower reaction time values (80% to 20%). This indicates that participants with less experience, exposure, and preference in another language were very likely to perform with a faster than average speed on this task. No effect of the linguistic experience on association strength was found, as the values were identical for all three association conditions.

In this way, these results seem to indicate an interactive effect of language experience. Having minimal OL language experience would make a bilingual use and access semantic information more quickly in English. Having greater OL language experience, however, may slow them down slightly but the effect is not as polarized as having no OL experience. This lends credence to the idea that bilinguals with greater language experience are capable of performing close to native-like levels.

General Discussion

To facilitate the discussion, a summary of the regression results for both speed and CV are presented in Table 40.

Table 40

Summary of Significantly Contributing Factors on Model Fit

	RT (speed)		CV (efficiency)	
	Monolinguals	Bilinguals	Monolinguals	Bilinguals
High association pairs	WMC	WMC	attentional control	attentional control OL proficiency
Low association pairs	WMC attentional control	WMC	--	attentional control
Unassociated pairs	WMC	WMC	attentional control	attentional control OL proficiency

These results show that monolingual efficiency in processing is aided by attentional control for the high association and unassociated pairs. In low association pairs for monolinguals, no factor emerged as predictive of efficiency. Compared to the regression on the RT performance, WMC vanishes as a predictive factor for all three association pairs, and attentional control vanishes for low association pairs.

This means that WMC likely influences the speed of semantic processing in monolinguals, but attentional control influences variability or efficiency of processing (but only for high association and unassociated pairs). I suggest that individuals with a greater attentional control have less variation and therefore more efficiency in their processing. For low association words, attentional control emerged as a contributor to RT performance; this may indicate that attentional control influences the speed of activation's travel to more distant associates. The lack of this same result for the CV values indicates that attentional control does not influence the efficiency of the process of activating more distant semantic associates.

Regarding speed, it appears that memory and attention contribute to RT performance with words that are weakly associated, but neither of these contribute to measures of variation or efficiency of processing weakly associated pairs. I conclude that with more distantly related words, working memory does not make the system more efficient, but only faster. For low association pairs, attentional control is additionally recruited to facilitate processing speed. This may be because distant associates are somewhat harder to recognize as related, compared to high association pairs which are so evidently related and unassociated pairs which are so evidently unrelated.

Among bilinguals, the results indicate that attentional control performance emerges as a predictive factor for processing efficiency in the high association, low association, and unassociated pairs conditions. This differs from the results of monolinguals in which efficiency of processing low association pairs was not influenced by attentional control. This result also differs from the predictive values of RT in bilinguals in which memory emerged as a predictive factor for all conditions.

In addition, proficiency in the OL emerges as a predictive factor of bilingual efficiency in the high association condition and the unassociated condition. It does not emerge as a factor for low association condition. Again, this highlights the difference in processing when encountering the low association pairs in all speakers. For one, attentional performance only influenced the speed of processing low association pairs in monolinguals, and the impact of attentional performance was absent from the efficiency of processing low association pairs in monolinguals. In bilinguals, OL proficiency did not influence the efficiency of processing low association pairs (though OL proficiency influenced efficiency in high association and unassociated pairs). I interpret this as indicating that listeners may be engaging in differential strategies to process the semantics of distantly related pairs of words. The efficiency with which listeners can extend the semantic activation to weakly related words is not influenced by memory or attention in monolinguals, unlike other pairs. In bilinguals, this efficiency with these pairs differentially depends, in part, on attentional control.

Interestingly, proficiency in the OL had no contribution for the processing speed but it did for efficiency. One theoretical assumption is that proficiency in the OL means that there is more lexical competition with English words; therefore, the emergence of this factor as a contributor could indicate that, while it doesn't necessarily influence speed of processing, cross-linguistic lexical competition may influence the processing efficiency of bilinguals. This is evidence that cross-linguistic competition may not account for the slowdown bilinguals experience though it may still otherwise affect the efficiency of their processing.

Notably, the ANOVA results showed that the bilinguals were not significantly different in their speed nor efficiency of processing of low association pairs compared to monolinguals. In other words, bilinguals are processing low association pairs in much the same way and just as fast as monolinguals, even though the regression results show that attentional control is a predictive factor. If lexical competition in bilinguals affects processing, but bilinguals still maintain a comparable processing efficiency relative to monolinguals, then it stands to reason that bilinguals had learned to compensate for processing using other strategies that might resolve these differences. I look to the finding that WMC emerged as a predictive factor for processing efficiency of weakly related pairs among bilinguals, and not so for the efficiency of monolinguals. It is possible, then, that bilinguals recruit WMC to facilitate the processing efficiency of weakly related words to overcome the influence of the effects of OL proficiency, namely cross-linguistic activation.

The subsequent chi-square analysis showed that individuals with lower linguistic factor scores had reliably fast reaction times, but individuals with higher linguistic factor scores were more evenly distributed across reaction time speeds. This indicates that having a richer experience with the OL does not slow down speakers across the board, which may have been expected. If speakers are indeed slowed down because of cross-linguistic activation, then this analysis indicates that having a richer experience in the OL does not correlate with greater cross-linguistic inference. This seems counter-intuitive, as speakers with greater dominance and use of another language might be considered to have to work through that language to operate in English (Kroll & Stewart, 1994; Potter et al., 1984). This would theoretically result in a slowdown in English performance compared to speakers who have a greater dominance and use of English. However, greater dominance and frequency of use in the OL language than in English does not preclude a speaker from English language mastery and use as is the case with more balanced bilinguals. These results indeed suggest an opposite effect: greater dominance and frequency of using the OL may slow down speakers in English, but it does not reliably render the speakers completely unlike participants with limited OL use. Instead, there is a wider spread in the RT performance of speakers with a richer OL experience. Considering the inhibitory effects of cross-linguistic activation, any potential cross-linguistic activation resulting from having more proficiency and exposure in an OL does not have a strong effect on slowing RT performance across all speakers. Another factor, likely an early AOA based on prior described analyses, allows those individuals with greater linguistic factor scores to have the opportunity to get faster reaction times.

Chapter 5

Overview

During the first study, participants viewed pairs of words that varied in their degree of association and made a decision while reaction times were measured. In this task, the stimuli included 100 prime words that highly associated to a target word and 100 prime words that had a relatively lower association to a target word. The degree of association was determined by forward strength of association, a probabilistic measure that provides a relative index of how sensitive the target word is to being activated by the target word (Gillund & Shiffrin, 1984; Nelson et al., 2005), as normed by Nelson et al. (2004) along with other similar variables. Nelson et al. (2004) summarizes the definition of forward strength as the probability of “relative accessibility of related words” in a person’s memory (p. 402). In this sense, prime-target pairs with a higher forward strength of association value indicates a greater probability of activating the target when prompted with the prime. This forward strength measure was used in several other studies, including by Golestani et al. (2009).

An important factor that may affect the applicability of these findings is how and when these forward strength measures were collected. To generate these norms, Nelson et al. (2004) provided participants with booklets containing all of the words systematically randomized and asked them to freely associate with a single related word. Over time, the researchers added additional words (Nelson et al., 2004). Several important factors present potential shortcomings for the present study.

The article reporting the norms, Nelson et al. (2004), was published in 2004 and has little information regarding how recent the norms were collected from the time of publication (Nelson et al., 2004). In the present study, using norms that were more recently generated may provide a different outcome due to the change of language over time and through different generations. In addition, little demographic information was provided about the participants in Nelson et al. (2004), and so their semantic associations for a given word may differ from that of college students in the present study. This effect may be exacerbated by the fact that the present study takes place at least 17 years after the norms were gathered.

Importantly, the participants in the present study included both bilinguals and monolinguals; bilinguals were not assessed in Nelson et al. (2004). Also important is that both groups in the present study used the same pairs of words defined as either of “high” or of “low association.” Because English monolinguals use only one language and that language representation is generally similar from one speaker to another, it can be assumed that each speaker has about the same semantic boundaries in their sole native language. However, speakers of different languages may categorize words in different ways. Word-to-referent mapping, defined as how a given lexical label is generalized to similar concepts or referents, differs cross linguistically (Ameel et al., 2008; Kronenfeld et al., 1985; Malt et al., 2003; Pavlenko & Malt, 2011). The degree of semantic association between pairs of words might differ between bilinguals and monolinguals due to these differential semantic boundaries between native languages and potential transfer effects from one language to another in bilinguals (Pavlenko & Malt, 2011). This was attested between Russian and English speakers in Pavlenko and Malt (2011), which found differences in how early (AOA: 1-6 years), childhood (AOA: 8-15 years), and late (AOA: 19-27 years) Russian-English bilinguals categorize common household objects.

Early bilinguals who were exposed to English in early childhood may still have different word-to-referent mapping due to transfer effects and interference effects. Pavlenko and Malt (2011) conclude describing an influence of L2 on L1 semantics. Speakers who acquired a second language had demonstrated differences in their categorization of L1 referents, even though the acquisition of the L2 followed that of the L1. An earlier L2 acquisition strengthened this effect, and the L2-L1 influence was also stronger in bilinguals who reported high L2 mastery and dominance. Still, effects were present in speakers across a range of ages of acquisition. Given this, bilinguals and monolinguals — and bilinguals within-group — will likely differ in their determination of what words relate to others. This ground-level difference could underlie the delay in sentential processing that bilinguals demonstrate relative to monolinguals and may not have been fully captured in this present study design.

In the present study, it was important to assess the possibility that monolinguals and bilinguals had differing semantic associations between pairs of words from that of Nelson et al. (2004). To test this, a free association task was replicated among the participants who completed the priming task. This data was used to inform differences from semantic change over time as well as between monolinguals and bilinguals. The descriptive results are presented in the first section of this chapter. Subsequently, I analyze the words for which both groups arrived the same target word (“matching responses condition”) separately from the words for which the groups’ responses were different (“non-matching responses condition”). Inputting this new variable into an ANOVA analysis would determine the degree to which differences in reaction time between the groups are the result of forward associations to different targets.

Methods

In this study, 61 participants completed provided a single-word free association to the same 200 words presented in the priming study. Participants were both monolinguals ($N = 36$) and bilinguals ($N = 25$) and were the same individuals who participated in the priming study. This free-association survey was distributed online with 10-15 words on the screen at a time. Only one word at a time was shown in black text and the others “greyed” out in order to reduce fatigue, reduce processing of a non-target word, and increase focus. Participants were asked to provide the “first related word” (target association) that comes to mind when prompted with the prime word. They were instructed to write only one word. Participants typed in their responses and were able to press the “enter” key to advance to the next word. Words were presented in three blocked pages with breaks in between and were randomized within blocks.

The responses were processed and tallied for each word. A percentage was calculated that represents the percent of participants in each group that arrived at that target association out of the total number of respondents for that prompt. A summary of these results showing the highest responses for each word presented alongside the Nelson et al. (2004) norms is presented in Appendix B.

Results and Analysis: Tests of Association

Responses that differed in plurality (e.g., “bird” vs. “birds,”) or inflection (e.g., “dance” vs. “dancing”) were consolidated to one version of the word. Responses that shared root morphemes were merged into one entry for analysis (e.g., “climb” and “climber” became “climb/climber”). This is based on the theoretical assumption that inflected words are generated from a single lexical entry (Clahsen, 1999). Invalid responses were mostly deleted from analysis and included proper names and nouns, titles from television shows or movies, or impulse reactions to a particular word that were evidently unrelated (e.g., “gross” in response to “broccoli”; “yum” in response to “dessert,” etc.). Due to a technical error with the survey, some words were not legibly presented to all participants and were removed from the analysis. One participant’s responses were removed because they were not in English; a second participant’s responses were removed because they were the identity of the presented word. The highest frequency response for each participant group is provided in the Appendix.

Subsequently, a new variable was added to the RT dataset of the priming task that indicated whether the word in the experimental trial evoked participant responses that matched with the Nelson et al. (2004) norms ("matching condition") or did not match with the Nelson et al. (2004) norms ("non-matching condition"). The list of high and low association words for which group responses matched and did not match is provided in Table 49 in the Appendix. This was used to analyze the reaction time differences with the additional factor of matching or not matching with the norms.

In addition, I counted the number of prime words for each of these conditions by speaker group. Analyzing the frequency of agreement or disagreement with the prior norms and differences across groups would indicate if bilinguals in this study drew semantic boundaries similarly to monolinguals. Group differences in the expected rate of agreement with prior norms would suggest a deviant way of interpreting the "high" and "low" association conditions that could affect the findings of the priming study. A summary of these counts for each association condition is provided in Table 41.

Table 41

Rate of Degree of Match and Group by Association

		Group	
		Bilingual	Monolingual
High Association			
Matching	Count	30	29
	% within Match condition	50.80	49.20
	% within Group condition	31.30	30.20
	% of Total	15.60	15.10
Non-matching	Count	66	67
	% within Match condition	49.60	50.40
	% within Group condition	68.80	69.80
	% of Total	34.40	34.90
Total	Count	96	96
	% within Match condition	50.00	50.00
	% within Group condition	100.00	100.00

	% of Total	50.00	50.00
Low Association			
Matching	Count	15	11
	% within Match condition	57.70	42.30
	% within Group condition	15.20	11.10
	% of Total	7.60	5.60
Non-matching	Count	84	88
	% within Match condition	48.80	51.20
	% within Group condition	84.80	88.90
	% of Total	42.40	44.40
Total	Count	99	99
	% within Match condition	50.00	50.00
	% within Group condition	100.00	100.00
	% of Total	50.00	50.00

This table presents the total number of primes in which both groups of participants converged on the same responses, or in other words, the primes for which the highest percentage responses were the same in each group.

Chi square tests for association were conducted to determine associations between the number of responses for each matching condition (matching and non-matching) and each speaker (monolingual and bilingual), and this was conducted for each association strength (high and low association). The number inputted into the analysis represents the number of speakers in that group that satisfied each condition (matching–high, matching–low, non-matching–high, or non-matching–low). All expected cell frequencies were greater than five. The results are summarized in the analysis table in Table 42.

Table 42

Frequencies and Chi-Square Results for Degree of Match in High and Low Association Pairs

		Group				χ^2
		Bilingual		Monolingual		
		n	%	*n*	%	
High Association	Matching	30	31.25%	29	30.21%	0.024
	Non-matching	66	68.75%	67	69.79%	
Total		96	1	96	1	

Low Association	Matching	20	18.00%	16	14.40%	0.708
	Non-matching	91	82.00%	95	85.60%	
Total		111	100.00%	111	100.00%	

There was no statistically significant correlation between association condition and group membership for neither the high association ($\varphi = 0.01$, $p = .88$) or low association ($\varphi = .06$, $p = .40$) conditions. This means that neither particular group was overrepresented in the counts of matching or non-matching conditions, indicating that the groups did not diverge in how their semantic associations related to that of previous work.

Results and Analysis: ANOVA on Degree of Match

Next, I sought to determine if there was a difference in RTs between the matching and non-matching words and for each participant group. To assess the differences in reaction time based on association (2) and on matching/non-matching responses condition (2) by speaker (2), a three-way repeated measures ANOVA was conducted. Reaction times for monolinguals were normally distributed as assessed by Shapiro-Wilk's test ($p > .05$). Reaction times for bilinguals were not normally distributed for the matching responses condition (high association: $p = .008$; low association: $p = .028$) or for the non-matching responses condition (high association: $p = .005$; low association: $p = .032$). A boxplot of the reaction times split by the degree of match condition (matching or non-matching) is presented in Figure 19.

Figure 19

Boxplot of Reaction Time per Condition

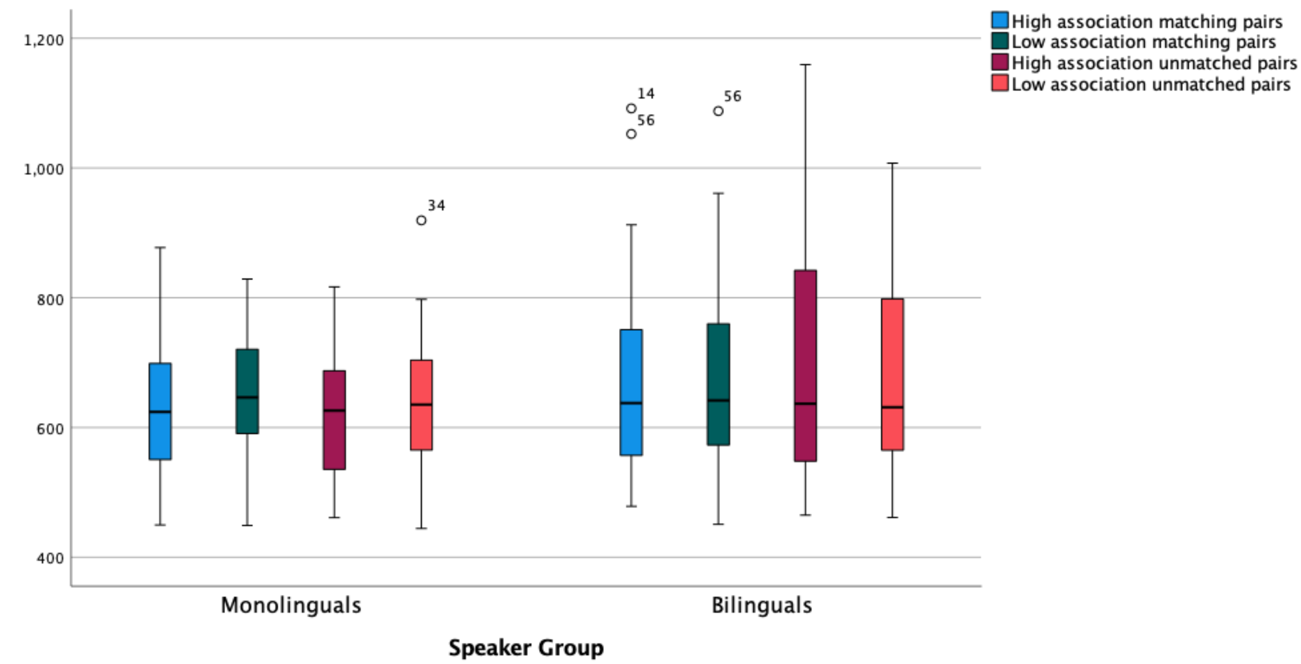


Table 43 provides the descriptive data for each group and for each of the conditions.

Table 43

Descriptive Results for Matching and Non-matching Responses per Group

	Monolinguals			Bilinguals		
	N	Mean	SD	N	Mean	SD
Matching responses						
High association	26	628.80	107.19	35	673.00	150.29
Low association	26	645.67	101.46	35	666.41	134.53
Non-matching responses						
High association	26	622.69	97.17	35	682.01	177.59
Low association	26	638.14	104.90	35	667.93	142.28

Omnibus ANOVA results are summarized in Table 44.

Table 44

Test of Within-subjects Effects for Omnibus ANOVA on RT

	Type III Sum of Squares	df	Mean Square	F	Sig.
Association	648.51	1	648.51	0.34	0.56
Association * Speaker	10023.40	1	10023.40	5.28	**0.03***
Error (Association)	113886.08	60	1898.10		
Match	25.18	1	25.18	0.02	0.90
Match * Speaker	2300.77	1	2300.77	1.47	0.23

Error (Match)	93735.46	60	1562.26		
Association * Match	471.18	1	471.18	0.20	0.66
Association * Match * Speaker	261.26	1	261.26	0.11	0.74
Error (Association * Match)	141646.68	60	2360.78		

Bold values indicate statistical significance.

*$p < .05$, **$p < .001$

The results of the three-way ANOVA indicated only a significant interaction between association and speaker, $F(1, 60) = 5.28$, $p = .03$. There were no other significant factors or interactions. Figure 20 shows the profile plot results on matching responses and Figure 21 shows non-matching responses, both of which were generated from a single three-way ANOVA.

Figure 20

Profile Plot for Reaction Time (RT) Three-way ANOVA for Matching Responses

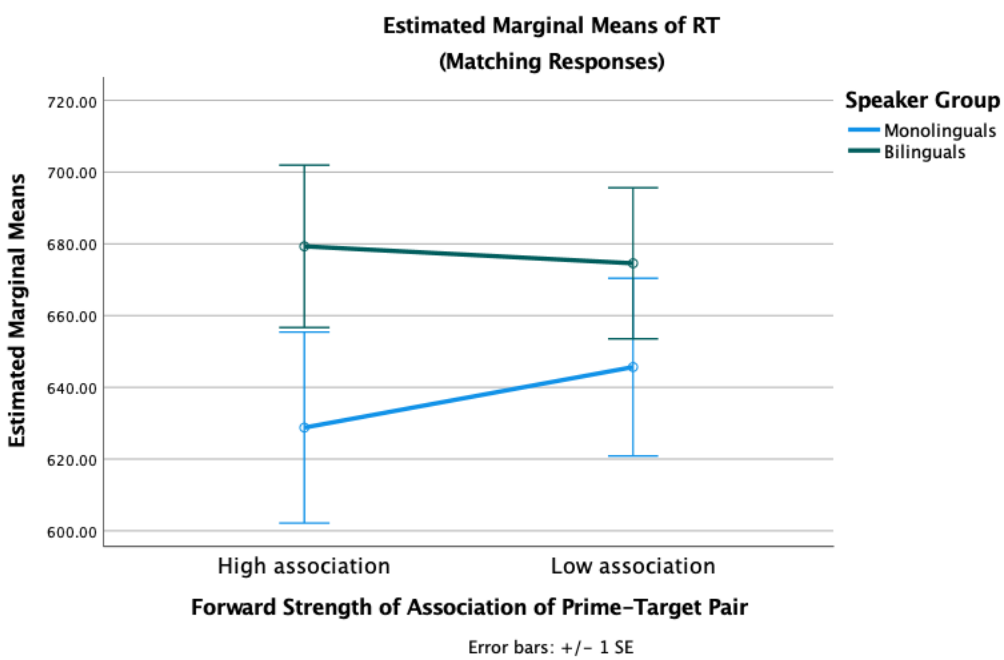
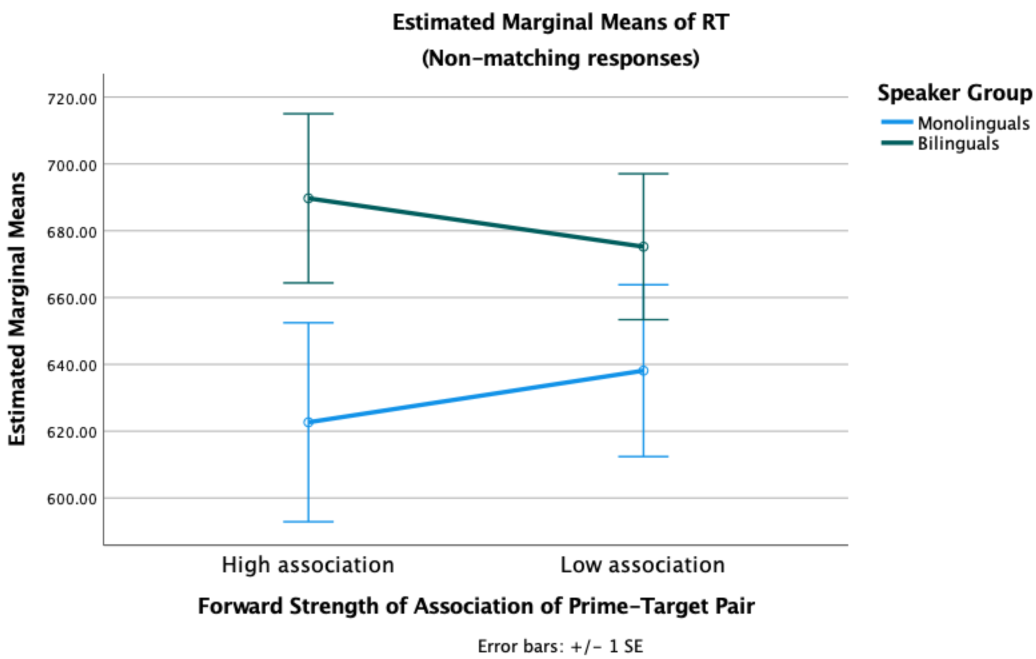


Figure 21

Profile Plot for Reaction Time (RT) Three-way ANOVA for Non-Matching Responses



Results and Analysis: ANOVAs by Forward Association Strength

The ANOVA revealed that monolinguals are faster in high association pairs than low association pairs and that this pattern holds for the matching and non-matching condition. This same pattern is absent in bilinguals. To further explore this interaction of speaker and association, two subsequent ANOVAs will determine the effects of the matching condition on the RT for high and low association pairs for each speaker group separately.

The results of the subsequent ANOVA for monolinguals' RT are provided in Table 45.

Table 45

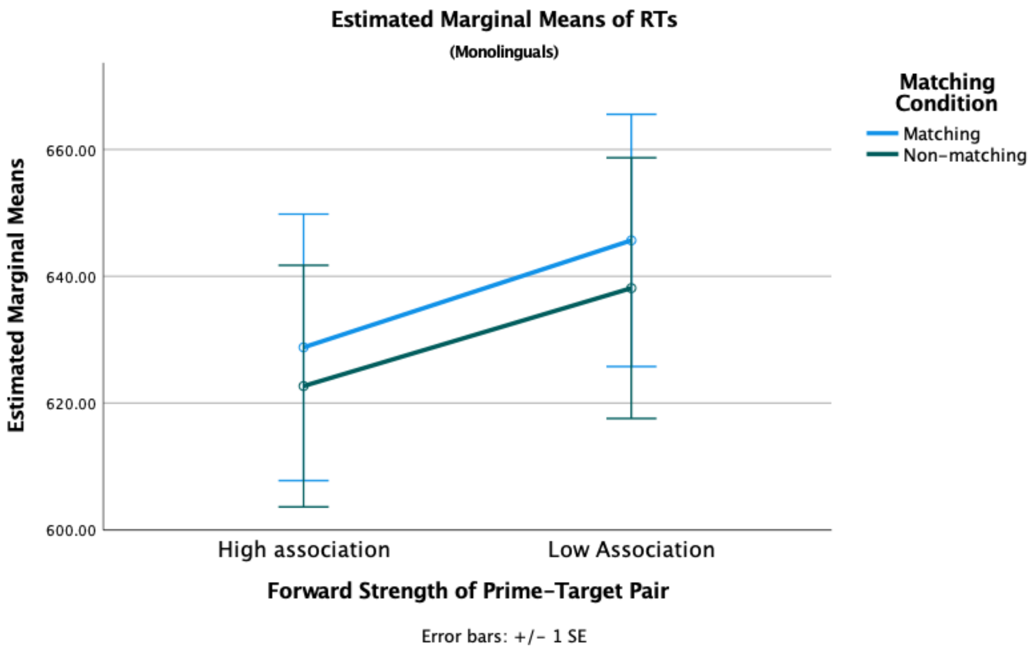
Test of Within-subjects Effect of Association and Match in RT of Monolinguals

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Association	6790.307	1	6790.307	5.027	0.034	0.167
Error (Association)	33770.884	25	1350.835			
Match	1208.711	1	1208.711	1.284	0.268	0.049
Error (Match)	23529.976	25	941.199			
Association * Match	13.229	1	13.229	0.004	0.949	0
Error (Association * Match)	80464.947	25	3218.598			

Similarly to the earlier ANOVAs, these results indicated an effect of association in the monolingual group, $F(1,25) = 5.027$, $p = .034$. The associated profile plot is shown in Figure 22.

Figure 22

Profile Plot for Effects of Association and Match in RT of Monolinguals



The results for the effect of association and match on bilinguals' RTs is shown in in Table 46.

Table 46

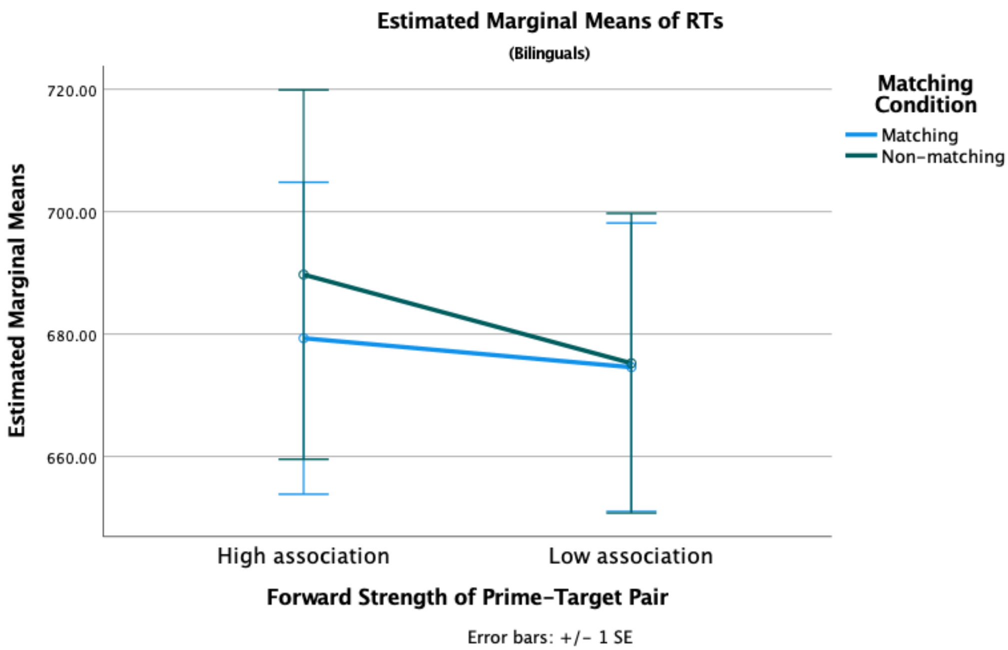
Test of Within-subjects Effects of Association and Match in RT of Bilinguals

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Association	3322.235	1	3322.235	1.451	0.236	0.04
Error (Association)	80115.197	35	2289.006			
Match	1099.645	1	1099.645	0.548	0.464	0.015
Error (Match)	70205.481	35	2005.871			
Association * Match	854.98	1	854.98	0.489	0.489	0.014
Error (Association * Match)	61181.735	35	1748.05			

No effect of association nor match was found for the bilinguals. The associated plot is shown in Figure 23.

Figure 23

Profile Plot for Effects of Association and Match in RT of Bilinguals



Discussion

The descriptive results indicate that word-to-word associations may differ across a generational time span and with a different population. The Nelson et al. (2004) were generated at least 17 years ago, with some forward-strength associations generated from earlier data (Nelson et al., 2004).

The bilingual participant responses in the current study matched those of the Nelson et al. (2004) norms in 31.3% (n = 30) of the high association words and 15.2% (n = 15) of the low association words for a total of 23.1% of the words (n = 45 of the total 195 words in both conditions). The monolinguals matched the previous norms in 30.2% of the high association words (n = 29) and 11.1% of the low association words (n = 11) for a total of 20.5% of all words

(n = 40). This suggests that both group responses showed some degree of diachronic change from the Nelson et al. (2004) norms. These results suggest that high association primes were slightly more resistant to change than the low association primes.

When mismatching from the Nelson et al. (2004) norms, the bilinguals diverged in 68.8% of their responses to high association pairs (n = 66) and in 84.8% of their responses to low association pairs (n = 84). The monolinguals diverged in 69.8% of their responses to high association pairs (n = 67) and in 88.9% of the low association pairs (n = 88). Neither group appeared to be disproportionately more different in their responses compared to the previous study. Therefore, both participant groups were affected to some degree by the different associations.

The ANOVA results tested for reaction time differences based on the condition of matching or not matching. The results of the ANOVA indicated there were no significant differences based on the match condition (p = .90). However, there was an interaction of speaker and association as found in the previous ANOVA results which was explored with subsequent ANOVAs separated by speaker group. These separate ANOVAs showed an effect of association for monolinguals but no effect for bilinguals. This outcome reaffirms that the differences from the prior norms or differences in semantic network does not significantly impact the results: dividing the stimuli based on whether or not the groups converged on their finding the same most-related target did not significantly affect the previously described findings. Importantly, these results indicate that the difference in bilingual processing — a lack of effect of association that exists in monolinguals — is likely not because of a difference in the degree to which they find pairs of words are related or unrelated. Therefore, the difference in our results and the trend of bilingual slowdown that our data preliminarily suggests is not a factor of a differential semantic network in bilinguals.

There is a notable trend in the results that is worth discussion. The RTs of monolinguals showed that low association word pairs were processed significantly slower (as measured by longer RTs) as compared to high association word pairs. The matching and non-matching words shared a nearly identical pattern, indicating an effect of degree of match that affected both high and low association pairs equally as indicated by a lack of significant association effect. This indicates that any time-related changes to the semantic categorization of the prime words in this study were consistent across association strengths in monolinguals. While not significantly different, there is a different trend in bilinguals that did not show an identical pattern in matching and non-matching pairs. The high association pairs were processed slower for non-matching pairs than matching pairs; in the low association pairs, match had no effect. This indicates that there is some time-related or speaker-related change to the semantic boundaries of words that has no effect on minimally related semantic associates in bilinguals but has the effect of slowing down RT for high association pairs. Overall, this trend highlights the differences in the semantic network between monolinguals and bilinguals and emphasizes the importance of standardizing norms across speaker type in future studies like this. However, this analysis warrants further investigation with a greater number of participants in the free response task before stronger conclusions can be made.

Chapter 6

Overview

In this final Chapter, the research question and rationale are restated and a summary of the analyses that were completed is provided. I address how this research addresses the points in the research question and the overall impact of this research on understanding the psycholinguistics of bilingualism. I discuss how the current research fits in with the literature base on this topic, address limitations to the research, and propose future directions to extend this work.

Research Summary

The research in this dissertation sought to address deviations in word-level processing that bilinguals might demonstrate relative to their monolingual counterparts in a series of studies. First, a retroactive masked priming study isolated how different degrees of semantic information were each used to elevate an unrecognized prime word into conscious recognition and identification. The results of this study showed that monolinguals relied on the semantic information available to identify words, whereas bilinguals were not similarly aided by the addition of more semantic context. Two follow-up analyses reaffirm the interpretation that this difference is not due to differential processing, but due to some factor that affects participants across a range of bilingual experiences. For one, restricting the bilingual subjects to an early age of acquisition showed no significant deviation from the prior analysis, indicating that early bilinguals, who should be the closest to monolinguals, also experience non-nativelike word processing. Second, an analysis of the CV values, a measure of processing efficiency, revealed no differences between the two groups' processing of each condition.

With these results, the research then focused on the individual differences in cognition that may affect the bilinguals' word processing. There was no difference in working memory or attentional control between the groups in this study, and a hierarchical regression revealed that bilinguals' and monolinguals' RT performance on the masked priming task were predicted by their working memory capacity for all conditions. Additional predictive factors emerged for both groups in the low association pair condition: Stroop task performance was a factor for monolinguals, and the number of years spent in a country in which the OL was spoken was a factor for bilinguals. This suggests that when the connection between the words is weak, an increase in attentional control affects their activation in monolinguals and OL immersion affected their activation in bilinguals. This was confirmed with a bivariate correlation showing that the years spent in an OL-speaking country positively correlated with an increase in reaction time performance across all three conditions. Controlling for the effects of WMC in bilinguals limited this correlation to the low association condition, suggesting a higher working memory can alleviate the effects of immersion in a non-English speaking country. This further underscores the impact of language immersion for proficiency outcomes.

In a follow-up regression on the CV values, attentional control emerges as a significant predictive factor for processing efficiency and the differences of low association condition are highlighted. For high and unassociated pairs, attentional control is a major factor for processing efficiency in both groups. For low association pairs, WMC and attentional control was a major factor on processing efficiency only for bilinguals, and for processing speed only in monolinguals. These results suggest that working memory and attention are major contributors to language processing but facilitate speed and efficiency differentially in monolinguals and bilinguals.

These studies point to two general conclusions: first, that bilinguals and monolinguals demonstrate differences in semantic spreading activation and word processing. Because a large part of sentence processing is semantic activation, I conclude that bilinguals' non-nativelike processing of sentences may be in part attributed to differences in word-level semantic activation. Prior studies demonstrated that bilinguals are slower in their processing of sentences (Martin et al., 2013a) and are more burdened by the presence of noise than monolinguals (Rogers et al., 2006). Two strategies for sentence processing include lexical-semantic activation in which semantic associates to the words in the sentence are activated and building a sentence-level representation of the meaning incrementally to predict final words. Of these two strategies, the present studies attribute the bilingual differences, at least in part, to processing differences at the word-level. This is because semantic information did not evoke associates the same for both groups in this study. Therefore, semantic information was not used the same for both monolingual and bilingual participants.

The second research question was determining what other factors contribute to processing differences. I addressed the possibility that bilinguals may engage in completely different language-dependent processing mechanisms with the analysis of the variability in the reaction time scores. That CV analysis suggests that both groups carry out processing in the same way with equal efficiency. I conclude that bilinguals are not engaging in different, more temporally-variable and slower processes because the variability in their response times were slower but still proportional to that of monolinguals (Phillips et al., 2004). Therefore, bilinguals engage in the same process, but are slowed down potentially due to other factors. Some of these factors include cognitive factors like working memory and attention. This was addressed in regression analysis and found variability in the recruitment of cognitive resources, especially for low association tasks. Other differences between monolingual and bilingual semantic processing could be associated with a difference with the size and shape of the lexical-semantic network, the range of spreading semantic activation, or the strength or degree of spreading activation. Each of these differences alone may account for the variation in bilingual word processing attested in this study and are compared below.

General Discussion

Bilingual Use of Semantics for Processing

Semantic organization in bilinguals is an understudied area of research, and the conclusions presented in these results impact current research of bilingual lexical-semantic organization and models of bilingual processing.

This study primarily demonstrates that bilinguals differentially use semantic information for language processing compared to monolinguals. Differently from prior studies discussed, the present study notably did not compare between L1 and L2 processing, but dual-native language processing in proficient English bilinguals. Coulter et al. (2020) finds that simultaneous bilinguals benefitted from semantic context both L1 and L2 processing to a degree that was similar to monolinguals. Golestani et al. (2009) also finds that L1 processing is facilitated by the addition of semantic context (Golestani et al., 2009, 2013; Hervais-Adelman et al., 2014); however, for L2 processing in late learners, the addition of semantic context provided no benefit (Kousaie et al., 2019) or otherwise conferred an inhibitory effect on processing (Golestani et al., 2009). Ito, Pickering, and Corley (2018) also used longer and more naturalistic sentences and found slower anticipatory eye movements during L2 processing in bilinguals than in native listeners. In the present study, the results indicate that bilingual processing in one of the two native languages may not be facilitated by the addition of semantic context in the same way as in monolingual speakers.

In this way, this work addresses prior work on the bilingual differences in sentential processing and bilingual reliance on bottom-up information. Because there was a differential effect of semantic context in bilinguals, this study suggests that bilinguals may not be using semantic information for processing when the bottom-up input is degraded. Conversely, the study shows that monolinguals are recruiting top-down semantic information to aid in processing a degraded input. This confers with the findings of Mattys et al. (Mattys et al., 2009) which find that early bilinguals do not compensate for bottom-up degradation with top-down cues as effectively as native listeners. The analyses of this work attributes the difficulties bilinguals experience during sentence processing to non-nativelike use of semantic information during word processing.

Other studies in bilingual use of semantic information have been mixed in addressing whether bilinguals use top-down context to aid in processing like monolinguals, but the difference may lie in the difficulty of the experimental task. This is addressed in an upcoming section. In short, the results of the present study showed that bilinguals were not recruiting semantic information in a native-like way during L1 processing and revealed differences with increased task difficulty.

The studies and analyses presented in this dissertation sought to determine the reason why bilinguals may use semantic information differently. I conclude that differences may exist in the size of bilinguals' semantic network, use of that semantic network and semantic information to aid in processing, the range of activation spread throughout the network, and the implication of cognitive differences to affect any of these factors.

Bilingual Semantic Network

The semantic network relates to differences in the connectivity and interconnectivity of words in bilinguals. As proposed, bilinguals' insensitivity to increasing semantic context relative to monolinguals could be a result of a different setup of the semantic network. A semantic network where interrelated lexical items require more activation to reach an activation threshold would have less likelihood of activation with the same strength and range of activation as in monolinguals.

This account is compelling because of the evidence from the Word Association Study. In this study, monolinguals and bilinguals provided free associations to high and low association primes used in the priming study. The results indicated that monolinguals and bilinguals had arrived at different "most-related" words with at least 20% of the targets across both conditions. Therefore, this could provide evidence that primes are linked up with different associates in monolinguals and bilinguals. Results of previous studies find that bilinguals have different semantic categories than monolinguals, which concurs with this theoretical account (Pavlenko & Malt, 2011).

Conversely, it is important to note that the results of the association task are from a small population size and so conclusions on the organization of words in bilingual listeners may not be reliably drawn solely from this dataset. In addition, the ANOVA results show that there were no significant differences in the reaction times of the priming task. If bilinguals and monolinguals truly had different semantic associates and drew different semantic categories, we may expect to see this in significantly lower reaction times in the priming task for bilinguals since the stimuli were not optimized for their population. This was not attested in this study. Therefore, there may not be differences in the sizes of the network or organization of the lexical items, or otherwise, this effect is undetected in this priming task due to the sample size of this study.

The most compelling evidence disputing the possibility of an overall different semantic network comes from the CV values regression analysis of individual cognitive variables. Low association pairs of words would be the most sensitive to changes in semantic organization because of their low degree of connectivity. The monolinguals and bilinguals, however, had different responses to low association pairs of words compared to their respective responses to high association and unassociated words. Because low association pairs were responded to differently from the other conditions in both groups, we expect that the network and organization of semantic associates is similar in both groups. If there were differences in the semantic network between monolinguals and bilinguals, we would not see a special treatment of low association pairs of words within each group. The different factors that contributed to speed and efficiency are best described with cognitive accounts, suggesting a cognitive difference in bilinguals compared to monolinguals. This is addressed in an upcoming section.

Cognition and Language Selectivity

If the semantic network is the same, then one possibility to explain the differences in semantic usage is that the activation strength is weaker in bilinguals than in monolinguals. Because activation wanes over time and with distance from the prime (Heyman et al., 2016), then the size and scope of reach of activation would decrease as a result of the weaker strength.

Research shows that functioning in a non-native language depletes cognitive resources at a faster rate than a native language (Kousaie et al., 2019; Volk et al., 2014), and Kousaie et al. (2019) suggests this may be due to less automatic language processing. The present study finds evidence that cognitive resources are used in a different way among a population of high-proficiency speakers who were mostly early acquiring bilinguals. The non-difference in the CV ratios across the groups suggests that it is not due to a difference in processing efficiency, or less-automatic processing (Segalowitz & Segalowitz, 1993). As a result, there must be another language-related factor outside of automaticity that depletes cognitive resources and manifests in bilingual processing differences. Working memory capacity and selective attention emerged as significant contributors to processing in the regression analyses. In monolinguals, only the speed of accessing words was aided by working memory, and only distantly related words recruited attentional control in addition. In bilinguals, working memory similarly aided in the speed of access, but distantly related words *also* recruited working memory abilities in bilinguals, and this improved the efficiency, not speed, of processing. Therefore, this differential use of working memory and attentional capacity appears to have impacted the ability of bilinguals to use semantic information for processing like monolinguals do.

This evidence converges on the point that bilinguals, even early acquiring bilinguals, are unilaterally responding differently to gradients in semantic information. One leading factor that could affect all bilinguals is the impact of cross-linguistic activation of an unintended language. In the present study, the impact of cross-linguistic activation is affirmed by a negative correlation between proficiency in the other language and working memory capacity (i.e., as OL proficiency decreases, working memory increases and becomes more available for English processing). It appears that linguistic variables, including the years in an OL-speaking country and level of OL proficiency, add challenges to the processing system with which bilinguals must cope. More evidence comes from the demonstration that bilinguals were not significantly different from monolinguals in the cognition factors I measured and also used the same mechanisms for processing. Therefore, the most likely possibility is that cognition is used differently which slows down the bilingual speakers.

Investigating the impact of cross-linguistic activation and suppression of unintended targets can directly address these questions. Literature in the field acknowledges cross-linguistic activation effects of translation equivalents (Dimitropoulou et al., 2011) and rhyming pairs (Wu & Thierry, 2011): however, the activation in early bilinguals, its slowing effect on sentence processing, and the effect being mitigated by a higher working memory capacity are areas of research that are not directly or thoroughly investigated in the literature base. The research presented here promotes the possibility that cross-linguistic activation may impact bilingual processing — not just in late bilingual processing, but for native language processing in early bilinguals as well.

The results of this study do not address integration of the lexical systems, but largely fit in with the account put forth by the RHM about non-selective language access. Notably, the RHM was not designed for word recognition, but Kroll et al. suggests that translation tasks require some level of word recognition and activation (Kroll et al., 2010). The RHM posits a connection between the lexical domains of languages and the present study, in demonstrating a slowdown in bilinguals, fits in with this account. However, the RHM suggests that simultaneous cross-linguistic activation depends partly on whether the subject is naming in their proficient language (Jared & Kroll, 2001; Kroll et al., 2010). The idea is that word to concept links are strengthened with increased use and higher proficiency. In this study, we find that there is an impact of working memory that should be integrated into this framework to explain these findings.

Linguistic Differences: Age of Acquisition Effects

One major consideration in this work is the less-than-expected impact of age of acquisition on processing efficiency. While work in bilingual language development and simultaneous language acquisition promote the efficiency of language learning at that early age, this work suggests that there are still non-nativelike differences in language processing with early acquisition. This complements research that finds non-nativelikeness in simultaneous bilingual processing when under difficult conditions (Rogers et al., 2006).

The present study focused mostly on early-acquiring bilinguals in order to determine the effects of a second language on processing; therefore, effects of AOA cannot be properly determined here. However, Sunderman and Kroll (2006) show the semantics of L2 words were accessible even to less proficient L2 learners. This promotes the idea that another factor contributes to word and sentence processing beyond an early age of acquisition.

Silverberg and Samuel's (2004) study assessed the impacts of age of acquisition and proficiency in a lexical decision priming paradigm using word form, mediated form, and semantic primes. Semantic primes were facilitatory for early-acquirers (AOA: < 7 y/o), but not for the late group (AOA: >7 y/o). This pattern of results suggests an integration of the shared semantic architecture in early acquirers. The results of the present study match the findings of Silverberg and Samuel (2004) in suggesting that an early age of acquisition in bilingualism is better for language proficiency relative to later acquisition. A key point added in the present study is that early acquisition still does not render an individual completely monolingual-like as early theories of bilingualism put forth; Grosjean (1989) agrees that the bilingual does not have two isolable monolingual-like competencies.

Linguistic Differences: Attention and Task Effects

Generally, under a cognitive load, bilinguals do not appear to process L2 words with the speed and accuracy of native speakers (Mattys et al., 2010). Whether or not a bilingual is recruiting top-down context to aid in processing like monolinguals may lie in the level of difficulty of the experimental task. In the present study, there is evidence that all speakers engage in differential processing when the task is more difficult, but it might not result in greater use of semantics.

Many prior studies investigated task effects in L2 bilingual processing and revealed a differential effect with increased task difficulty. Dijkgraaf (2019) highlights the importance of testing semantic usage with a task that can appropriately tax the language system. Bilinguals' processing differences emerge with more difficult processing tasks like perceiving speech in noise (Rogers et al., 2006) or with understanding a text that is difficult to comprehend (Wolff, 1987). Coulter et al. (2020) found that late bilinguals used semantic context to the same degree in both L1 and L2 processing. However, the researchers mention this difference is the result of their using a higher signal-to-noise ratio (SNR) compared to Kousaie et al. (2019), and suggest that bilinguals may not benefit from semantic context as much with more difficult listening conditions than used in their study. Therefore, it is possible that the tasks used in Coulter et al. (2020) did not require the recruitment of semantic context to the same degree as in other studies. Similarly, Dijkgraaf et al. (2019) finds that bilinguals use sentence-embedded information to predict referents in the L2 with a slower and weaker spread than in the L1; this contrasts directly with the results of a previous study by the same authors, in which bilinguals were found to use semantics to predict referents in L1 equally as in the L2 and equally to monolinguals (Dijkgraaf et al., 2017). In a discussion, the authors cite that this difference in outcome is the result of task-based differences: in Dijkgraaf et al. (2017), the bilingual participants used lower-level lexical associations in the sentence to predict final words. With the longer and more syntactically complex sentences used in Dijkgraaf et al. (2019), low-level lexical associations played less of a role and the bilinguals needed to rely on using higher-level information for processing (Dijkgraaf et al., 2019). Only when the task required the recruitment of higher-up processes and thereby more cognitive resources did the early bilinguals demonstrate non-nativelikeness (i.e., slower and weaker spread of activation) in processing. In total, this evidence suggests that both early- and late-acquiring bilinguals may not benefit from additional semantic information in stimuli with high language processing demands in the same way as monolinguals.

In the present study, the masked priming task and the low association condition required the recruitment of semantic context and higher-up levels of processing. Determining the relatedness of pairs that are minimally associated with each other is a more difficult task than highly associated or completely unassociated pairs. It is likely that a more "distant" semantic associate is more challenging to recognize because the strength or range of the semantic activation spread is diminished by the time it reaches the distant associate. Therefore, it is harder for a minimally related word to reach the threshold for selection.

The present results suggested a differential processing with increased task difficulty in both speaker groups, with all recruiting different cognitive resources for the low association pairs in the priming study than to the other association conditions. Importantly, the results indicate that speakers recruit additional cognitive resources to complete a difficult task, but do not indicate that speakers use more top-down resources to facilitate this task as predicted in prior studies. This is because regression results show that both the speed and the processing of low association pairs are predicted by different factors than high association and unassociated pairs in both speakers. However, it is likely that this increased cognitive recruitment for harder tasks affects bilinguals differently, who are already expending more cognitive effort as a result of background processing of another language.

Specifically, the results of the regressions indicate that speed of processing in monolinguals is predicted by attentional control in the low association condition only. The difficulty of “reaching” distant associates is attenuated by attention; minimizing the impact of other distracting factors helps the activation of distant associates. The results of bilinguals also showed a difference in their handling of the low association pairs which implicates the difficulty of processing in this condition. Their speed of processing is predicted by the years spent in an OL-country, which, as discussed, imparts an experience of immersion in the OL that may detract from English proficiency or exacerbate the effects of cross-linguistic interference. These effects are only evident in the more difficult task. Unlike monolinguals, the bilinguals demonstrated an effect of attentional control on the efficiency of processing these pairs. Also unique to bilinguals is the use of WMC for efficiency. I interpret this as recruitment of other cognitive resources to counter the effects of cross-linguistic interference.

Limitations

One limitation of this study has already been addressed: that the degree of association between the prime-target pairs is not generalizable to the demographic of speakers in this study. In a replicated norming pilot study, however, current-day bilinguals’ and monolinguals’ responses were about-equally different from those of the norming study (Nelson et al., 2004). This suggests that using stimuli that were normed for current speakers would not yield distinct findings, but this is an avenue for future research to explore in detail.

In addition, bilinguals in this study were varied in the other language that they used in an effort to accurately reflect the variety of the bilingual experience. This may lead to differences in the development of semantic categories and would influence the degree to which bilinguals find that the high association pairs are truly of high association. Another issue is the differential impact of transfer from the other languages on English processing. However, Ito et al. (2018) also used bilinguals of different first languages with a minimal effect on the results. A finding in the present study was still found and can be generalized to bilinguals with a range of other languages. This also may indicate a more limited effect of the L1 differences in highly proficient English speakers.

Another limitation to the study involves the mode through which the experiment was shared with participants. This experiment relied on fast (54 ms) display times to ensure that a prime word was not immediately identifiable. The experimental software is able to produce this and can work with modern computers to reliably show the primes (Stoet, 2010, 2017); however, there was still no guarantee that participants were viewing the primes at the intended 54 ms time frame, nor that the environmental conditions were the same across participants. This study discusses the importance of working memory capacity on processing. If participants completed the study in a non-standard experimental environment, there is no assurance that no outside factors may have distracted them while completing this task and in turn affected the WMC they can dedicate towards the task completion.

A second issue with the nature of the visual task is whether or not the degraded prime word leaves a "visual imprint" for the viewer, which the viewer can then use to identify the degraded prime word as one of the two foils rather than using semantic information. Because the task is visual in nature, there is the question of whether participants were actually able to rely on visual word-shape similarities between one of the foil words to identify the degraded prime rather than the intended semantic effects. The methods attempted to account for visual effects in three ways: first, the number of hashmarks used (10) were selected to be able to mask word shapes and diffuse visual focus. This would reduce some of the greater visual effects found in longer words (Balota et al., 2006). Second, hashmarks flanked either side of the degraded prime word to make it more difficult to visually perceive the word. Third, the prime was presented in uppercase letters and the foil words were all lowercase to have a decreased effect on visual recognition. However, other studied used different masking characters (i.e., #$%#$%# instead of #######) which may have more successfully inhibited visual identification of the prime word.

Future Directions

This research identifies several key areas of research in the psycholinguistics of bilingualism and bilingual semantic processing. In this section, I discuss potential areas into researching the impact of the age of acquisition, investigating task-related differences and cognition, semantic interference, and relatedly, cross-linguistic interference.

Much of the bilingual research focuses on investigating the L2 of second language learners, the L2 of non-proficient early learners, or the L2 of balanced bilinguals. The L1, or one of the first-acquired languages of simultaneous bilinguals, is often overlooked in research. It is likely it is taken as a theoretical assumption that an early-acquired language is often not different from that of monolinguals because of the trajectory of high proficiency with an early acquisition (Johnson & Newport, 1989; Shi & Sánchez, 2010). This is a problem due to the demonstrated bilingual differences in first language processing. Even if bilingual language representation is underlyingly identical to that of monolinguals, it may surface as different due to the influential factors of cross-linguistic interference and cognitive differences (Chun & Kaan, 2019; Kaan, 2014). The present study highlights these effects for early acquiring bilinguals and for the L1.

Replicating these studies with both languages of simultaneously bilinguals is crucial, as well as conducting the research with the L1 of early acquiring and late acquiring speakers. Another strategy may be to more finely assess the ages of acquisition beyond a range of age of exposure. Other variables, such as the quality and length of exposure, have been revealed in this study to impact word processing skills. Therefore, any measure of age of acquisition should take into account the quality and length of time that an individual was exposed to language rather than just the age at which it began.

The review of relevant research has brought up the importance of task-related differences on bilingual processing. In this task, the use of semantic information to recognize words was investigated. This study and others have indicated that with greater cognitive strain, the use of top-down context for processing becomes limited (Field, 2004; Wolff, 1987). The present study found this in a correlation between working memory capacity and task performance in bilinguals. However, additional research on the impact of task complexity would complement this work. One such task may be to provide listeners with a more complex memory task during the study in order to demonstrate lasting cognitive strain. The results of this present study would suggest that an increase in task difficulty would further limit the ability of bilinguals to use semantic information to complete the task.

Beyond the cognitive effects on processing, other factors that differentially affect all bilinguals include transfer of L1 and L2 interference and cross-linguistic impact. Other studies have explored co-activation of cognates across the language boundary (Wu & Thierry, 2010) and translation equivalents (Dimitropoulou et al., 2011) and even words that rhyme with words in the other language (Moreira & Hamilton, 2006; Wu & Thierry, 2011). The results of the present study pointed to an impact of cross-linguistic activation even in early-acquiring bilinguals who are proficient in English. To test the account of the impact of cross-linguistic activation in early bilinguals, a similar study may use prime-target pairs that are from the same language or from different languages. Alternatively, using just one language, word pairs should not just be semantically related or unrelated, but also be sound-related (phonologically) to the unused language. If there was cross-linguistic impact from the unused language, it would contribute a "distracting" effect on word pairs for the phonologically related pairs. This condition would not have an effect if there was no cross-linguistic impact.

Underexplored in this work is the presence and cause of semantic interference. In this study, I found evidence of semantic interference with bilinguals not aided by the high association conditions. Bilinguals also seemed to trend towards worse reaction times with high association conditions than low association conditions, though this difference was not statistically significant. Additional research needs to explore this area of bilingual processing more closely. Schwanenflugel and LaCount (1988) suggest semantic interference arises if a prompt is too selective; Moreira and Hamilton (2006) and Golestani et al. (2009) suggest semantic processing is more prominent in the non-native language than the native language. Together, these accounts explain that a non-native language is more affected by the limiting effects of semantic relatedness than native language processing. An alternative view proposed in this dissertation regards the speed and spread of semantic activation: among bilinguals the semantic spread does not prioritize activation to the most related associates, whereas it does in monolinguals. Further research would improve our understanding of semantic interference in bilinguals. In particular, ERP studies have found hemispheric differences in the processing of sentences that map to the prediction of a congruent final word and to the integration of the sentence on the whole.

Investigating how these hemispheric differences manifest in bilinguals can be key in identifying the shape and strength of the spreading activation.

Conclusion

The results of this collection of studies reaffirm a general consensus that research on the psycholinguistics of bilingualism is complex. The impact of individual variables, both cognitive and linguistic, are major contributors to assessing the language proficiency of bilinguals.

There is a habit often found in bilingual research of comparing bilingual performance to monolingual performance. On the surface, it may be apt to relate the language skills of bilinguals relative to the most well-researched and most homogenous group of language users whose skills deviate very little from person to person. Second, observing the effects of developmental differences in timing, length, and quality of exposure on language proficiency is only morally possible with bilinguals. This is the motivation behind using the same comparisons in the present study. However, it is worthwhile to consider that the bilingual experience is fundamentally different from that of monolinguals. Grosjean (1978) aptly reaffirms that the bilingual is not just two monolinguals in one body; therefore, comparing bilinguals to the “native-like” baseline may not be accurate. Language exposure later in life more than likely affects language outcomes; however, this is concomitant with a huge set of other differences that bilinguals experience, not the least being an entire second system of language that influences the psycholinguistic process of both languages. This study, most importantly, serves to underscore this distinction between monolinguals and bilinguals at the root level of psycholinguistics and cognition and calls for a recognition of these incompatibilities. Above all, future work in bilingualism can recognize these distinctions in language processing in appreciation of the bilingual experience.

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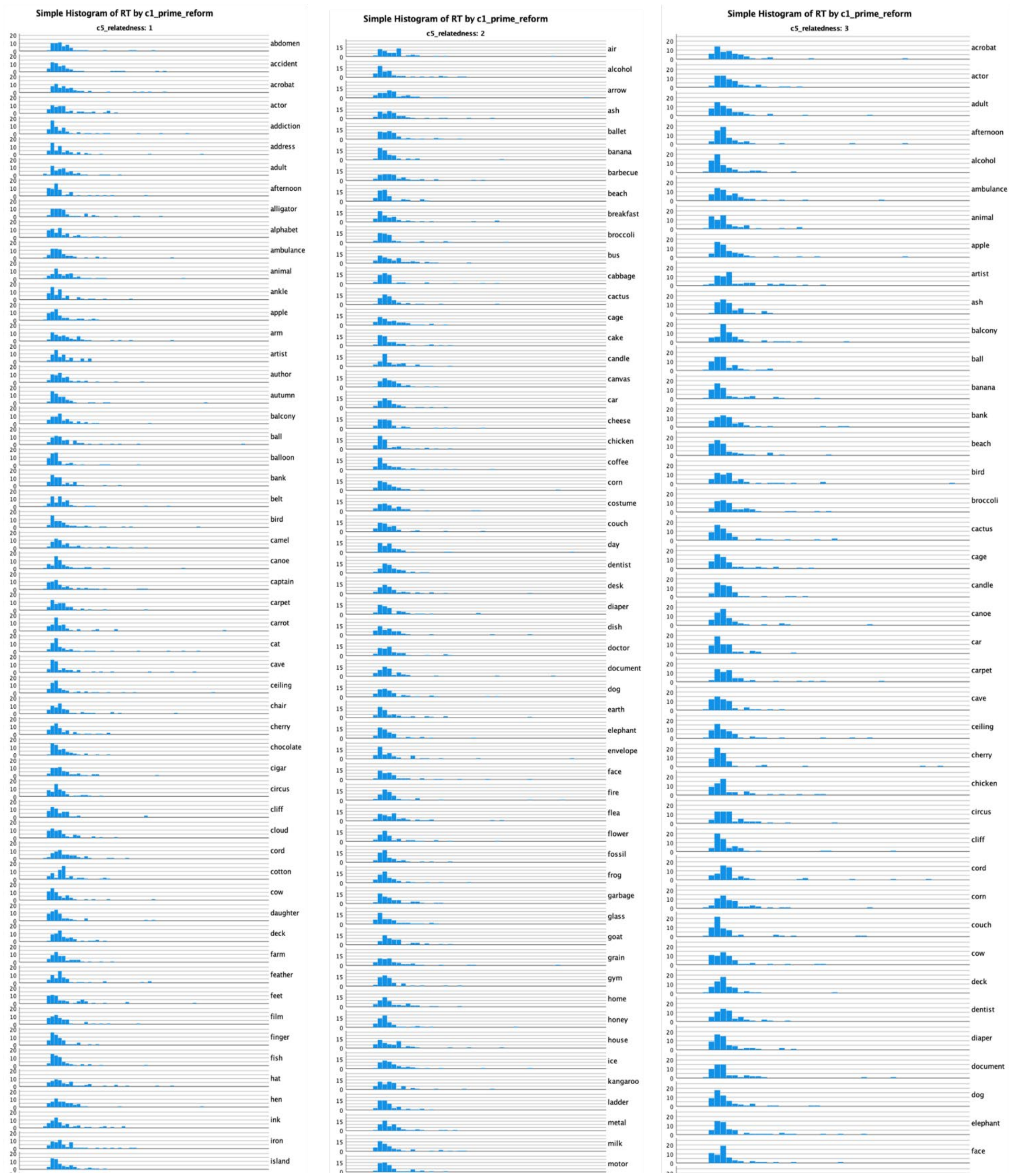
Appendix

Table 47

Distribution of Reaction Time for Each Word Grouped By Relatedness



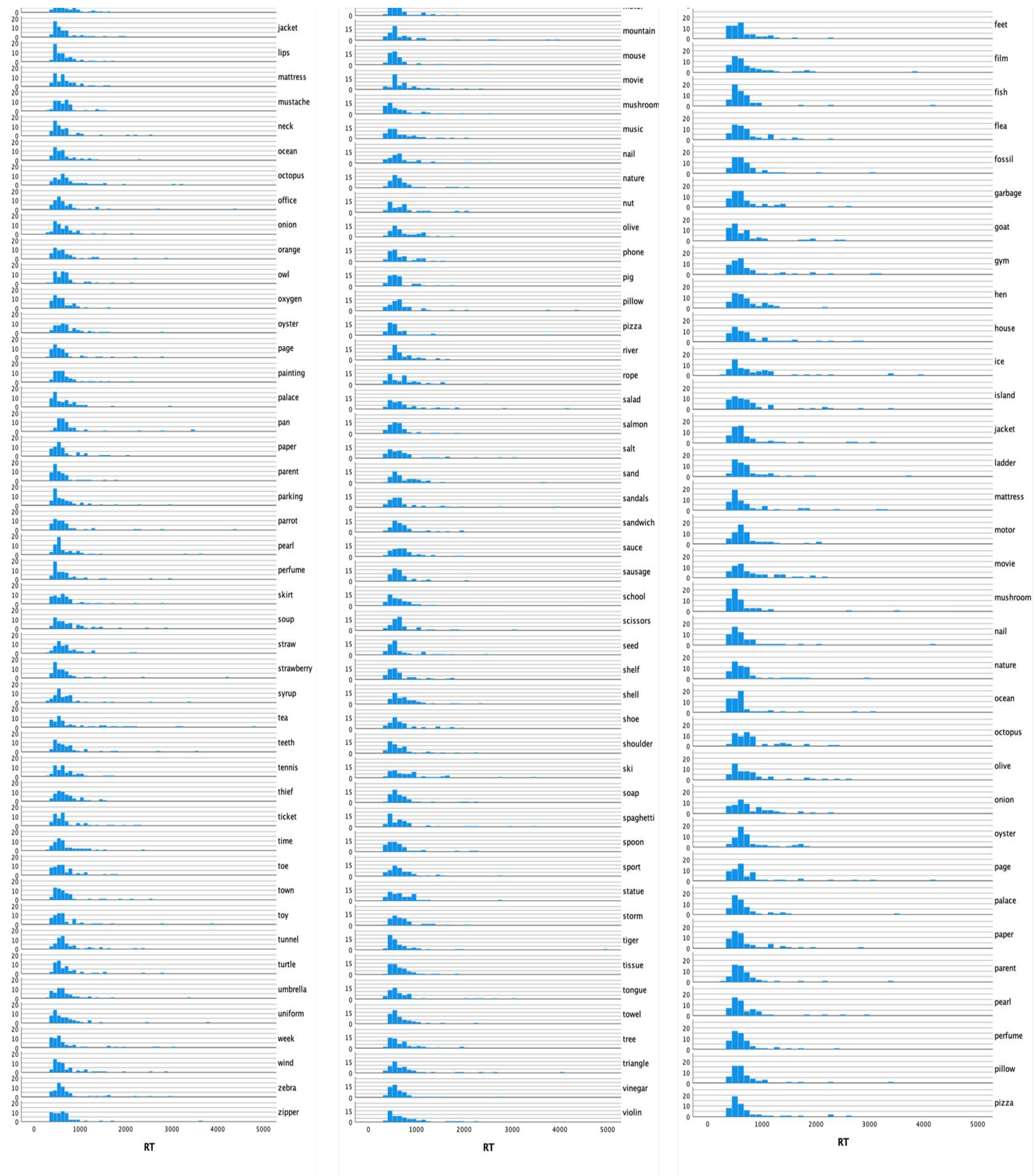

jacket
lips
mattress
mustache
neck
ocean
octopus
office
onion
orange
owl
oxygen
oyster
page
painting
palace
pan
paper
parent
parking
parrot
pearl
perfume
skirt
soup
straw
strawberry
syrup
tea
teeth
tennis
thief
ticket
time
toe
town
toy
tunnel
turtle
umbrella
uniform
week
wind
zebra
zipper
0 1000 2000 3000 4000 5000
RT
mountain
mouse
movie
mushroom
music
nail
nature
nut
olive
phone
pig
pillow
pizza
river
rope
salad
salmon
salt
sand
sandals
sandwich
sauce
sausage
school
scissors
seed
shelf
shell
shoe
shoulder
ski
soap
spaghetti
spoon
sport
statue
storm
tiger
tissue
tongue
towel
tree
triangle
vinegar
violin
0 1000 2000 3000 4000 5000
RT
feet
film
fish
flea
fossil
garbage
goat
gym
hen
house
ice
island
jacket
ladder
mattress
motor
movie
mushroom
nail
nature
ocean
octopus
olive
onion
oyster
page
palace
paper
parent
pearl
perfume
pillow
pizza
0 1000 2000 3000 4000 5000
RT

Table 48

Stimuli List of High and Low Association Pairs Used and Means

High Association Pairs							
	Prime	Target	Fwd. Strength	Foil	Mean Reaction Time (ms)		
					All	Monolings.	Bilinguals
1	umbrella	rain	0.701	Tornado	617.23	643.70	606.14
2	uniform	soldier	0.701	Warrior	574.41	596.55	633.57
3	ink	pen	0.695	Write	700.92	652.67	636.17
4	island	beach	0.695	Ocean	625.96	769.36	631.50
5	arm	leg	0.673	Hand	710.69	648.74	604.42
6	artist	painter	0.673	Canvas	680.54	660.25	637.38
7	addiction	drug	0.664	Alcohol	668.69	739.48	597.24
8	adult	mature	0.664	Woman	679.64	588.57	692.76
9	parrot	bird	0.628	Eagle	617.29	679.43	671.89
10	perfume	woman	0.628	Pretty	597.88	554.35	660.89
11	abdomen	stomach	0.566	intestine	656.32	511.92	596.36
12	acrobat	circus	0.566	elephant	809.65	643.59	572.44
13	town	city	0.529	Crowd	597.83	675.64	621.00
14	toy	child	0.529	Boy	583.57	607.45	672.74
15	cigar	smoke	0.507	Habit	669.16	519.52	541.89
16	cliff	mountain	0.507	Hill	579.53	573.83	600.82
17	author	book	0.493	Paper	675.45	598.04	638.10
18	balcony	apartment	0.493	building	654.80	568.04	610.15
19	alligator	crocodile	0.460	Animal	725.93	616.05	692.86
20	ambulance	hospital	0.460	Clinic	614.06	571.23	598.96
21	oxygen	air	0.455	pollution	565.17	542.96	632.46
22	zebra	stripe	0.455	Tiger	618.98	735.70	565.56
23	palace	queen	0.455	Royal	607.27	592.45	586.89
24	zipper	pocket	0.455	Jacket	589.10	697.05	661.93
25	mustache	beard	0.446	whiskers	619.60	626.08	875.32
26	ocean	wave	0.446	Water	625.42	674.35	634.67
27	daughter	son	0.444	Mother	554.76	577.68	646.11
28	deck	boat	0.444	Sail	641.29	636.14	594.96
29	alphabet	letters	0.412	envelope	612.15	496.57	644.33
30	animal	dog	0.412	Puppy	662.87	732.25	732.04
31	captain	ship	0.392	Water	628.29	578.14	649.79

32	carpet	floor	0.392	Ceiling	612.77	626.08	722.46
33	time	clock	0.372	Watch	613.06	621.68	631.78
34	toe	foot	0.372	Shoe	626.52	553.70	618.48
35	ankle	foot	0.364	Leg	594.67	584.85	569.54
36	apple	orange	0.364	Lemon	555.06	557.59	665.70
37	hat	head	0.359	Hair	796.26	721.30	694.17
38	hen	egg	0.359	Yolk	645.95	605.68	689.07
39	accident	car	0.358	Bicycle	646.12	544.09	554.74
40	actor	movie	0.358	Popcorn	660.67	575.38	634.07
41	pan	pot	0.351	Tea	737.96	607.74	629.22
42	parent	child	0.351	Adult	544.40	682.27	567.71
43	cloud	sky	0.346	Rain	609.49	663.71	722.32
44	cord	phone	0.346	Call	698.87	594.00	620.83
45	neck	head	0.333	Back	628.06	588.52	591.03
46	octopus	legs	0.333	chocolate	765.23	598.00	566.13
47	chair	table	0.314	Couch	653.95	623.67	603.07
48	cherry	tree	0.314	Flower	626.40	808.25	606.07
49	owl	night	0.311	Day	651.66	642.30	572.93
50	page	book	0.311	School	551.92	616.71	775.10
51	belt	pants	0.307	Legs	604.84	578.48	704.66
52	bird	feather	0.307	Light	708.58	581.62	530.41
53	skirt	dress	0.295	Long	612.58	568.00	725.58
54	soup	sandwich	0.295	Food	699.38	649.18	608.50
55	painting	art	0.279	Color	589.92	591.74	655.90
56	paper	white	0.279	Color	579.62	648.00	864.42
57	camel	desert	0.277	Cactus	697.20	612.08	607.34
58	canoe	river	0.277	Water	609.25	708.67	690.96
59	address	home	0.273	Parent	619.34	622.96	833.14
60	afternoon	evening	0.273	morning	618.12	488.91	585.10
61	finger	hand	0.268	Glove	549.96	685.43	613.82
62	fish	sea	0.268	Boat	606.98	599.71	708.07
63	iron	steel	0.258	Silver	706.17	740.44	836.44
64	jacket	sweater	0.258	Winter	653.10	682.06	618.88
65	cat	mouse	0.256	Rat	576.20	564.25	620.75
66	ceiling	floor	0.256	Carpet	617.16	496.27	602.96
67	straw	hat	0.243	Head	627.24	577.14	642.33
68	syrup	sugar	0.243	Honey	588.68	621.62	630.33

69	orange	juice	0.235	Apple	618.88	532.36	701.07
70	oyster	pearl	0.235	Earring	676.20	590.95	630.38
71	strawberry	fruit	0.217	Banana	580.21	623.05	604.07
72	tea	coffee	0.217	Cream	732.14	604.67	711.76
73	week	month	0.216	Year	616.00	509.70	591.79
74	wind	storm	0.216	Cloud	613.83	650.87	633.43
75	autumn	leaves	0.208	Flower	589.34	613.48	624.45
76	teeth	mouth	0.208	Tongue	760.29	603.83	643.28
77	ball	round	0.208	Flat	677.38	584.08	549.52
78	thief	criminal	0.208	Jail	652.92	643.63	576.11
79	feather	light	0.205	Pillow	660.60	632.52	608.24
80	parking	car	0.205	Travel	592.10	541.88	629.57
81	film	video	0.205	Show	586.76	705.00	746.87
82	pearl	sea	0.205	Blue	643.82	611.71	616.07
83	chocolate	candy	0.196	fattening	619.96	613.00	722.83
84	circus	clown	0.196	Funny	590.78	606.59	691.38
85	balloon	air	0.189	Water	531.80	604.65	724.11
86	bank	money	0.189	Rich	588.37	567.68	588.52
87	tennis	racket	0.186	Wooden	645.04	595.29	599.81
88	ticket	concert	0.186	Singer	643.43	580.90	585.73
89	cotton	ball	0.185	Soccer	675.12	682.00	632.62
90	lips	mouth	0.185	Face	557.38	763.90	844.85
91	cow	milk	0.185	White	611.88	572.96	653.71
92	mattress	bed	0.185	Pillow	604.39	646.48	561.43
93	carrot	orange	0.180	Apple	660.15	630.86	699.52
94	cave	rock	0.180	Stone	646.67	653.41	702.72
95	turtle	shell	0.179	Ocean	648.36	723.42	701.38
96	tunnel	train	0.179	Engine	625.22	618.96	733.00
97	farm	cow	0.176	Mild	643.64	663.52	730.00
98	feet	shoes	0.176	Socks	694.69	562.43	671.97
99	office	desk	0.174	Table	618.15	606.43	625.79
100	onion	garlic	0.174	Odor	623.08	520.40	619.42

Low Association Pairs

	Prime	Target	Fwd. Strength	Foil	Mean Reaction Time (ms)		
					All	Monolings.	Bilinguals
1	coffee	cream	0.081	White	653.92	737.96	584.38
2	grain	rice	0.081	Corn	664.27	675.74	654.86

3	towel	shower	0.081	Water	611.96	633.96	593.89
4	corn	field	0.081	Grass	652.10	574.91	715.00
5	gym	exercise	0.081	Run	600.57	562.42	631.10
6	tongue	mouth	0.081	Breath	631.22	573.75	686.40
7	bus	school	0.079	Book	738.60	759.27	720.40
8	flower	petals	0.079	Garden	648.06	642.76	652.04
9	cactus	sharp	0.079	Needle	631.96	583.83	671.79
10	fossil	dinosaur	0.079	Ancient	591.69	588.81	593.70
11	ballet	dancer	0.076	Music	669.08	705.87	639.90
12	banana	yellow	0.076	pineapple	617.86	546.95	671.66
13	music	song	0.074	Record	609.02	612.59	606.21
14	nature	green	0.074	Apple	637.92	639.42	636.64
15	barbecue	steak	0.073	hamburger	706.25	664.61	740.46
16	dish	food	0.073	Lunch	567.87	557.95	576.60
17	beach	summer	0.073	Green	568.66	577.58	561.28
18	document	official	0.073	important	674.76	576.71	745.76
19	breakfast	morning	0.068	Evening	637.13	629.04	644.07
20	broccoli	green	0.068	vegetable	626.36	576.81	662.24
21	sandwich	bread	0.067	Butter	673.69	623.09	715.25
22	sausage	ham	0.067	sandwich	646.16	650.79	642.77
23	home	family	0.061	Child	648.12	661.50	637.97
24	sandals	summer	0.061	Water	723.78	712.23	733.19
25	house	building	0.061	Home	687.59	719.74	667.23
26	sauce	tomato	0.061	Soup	730.16	724.52	734.39
27	pig	farm	0.056	Cow	576.40	575.43	577.17
28	pizza	cheese	0.056	Cheddar	631.88	672.27	600.14
29	earth	sky	0.055	Air	601.46	588.05	612.81
30	river	boat	0.055	Water	663.10	657.50	667.85
31	elephant	giraffe	0.055	Animal	558.45	541.39	572.46
32	rope	ladder	0.055	Roof	635.83	628.70	642.96
33	metal	silver	0.054	Money	659.69	649.58	668.36
34	motor	car	0.054	Engine	667.12	715.04	626.30
35	doctor	sick	0.051	Surgeon	615.62	569.77	655.96
36	mouse	hole	0.051	Golf	629.92	559.04	684.27
37	shoe	boot	0.051	Foot	647.37	624.82	668.04
38	dog	cat	0.051	Mouse	612.40	649.15	586.14
39	nail	finger	0.051	Toe	683.00	741.40	639.74

40	ski	slope	0.051	Snow	695.00	645.50	732.13
41	costume	mask	0.048	Disguise	640.51	679.79	605.59
42	phone	number	0.048	Math	608.08	578.45	629.80
43	couch	chair	0.048	Seat	574.61	550.30	594.57
44	pillow	bed	0.048	Tired	682.77	826.77	577.17
45	air	sky	0.047	Cloud	655.14	631.62	676.61
46	alcohol	drunk	0.047	Liquor	607.32	619.05	597.85
47	school	student	0.041	Book	600.78	612.78	590.93
48	seed	plant	0.041	Soil	603.92	575.61	628.04
49	canvas	art	0.039	Painting	633.94	605.09	657.64
50	salad	tomato	0.039	Lettuce	697.38	645.91	744.72
51	car	bus	0.039	Stop	606.35	670.68	553.93
52	salt	pepper	0.039	Spice	687.54	777.74	610.70
53	arrow	target	0.038	Practice	697.51	699.48	695.92
54	ash	fire	0.038	Hot	654.00	684.95	631.89
55	desk	lamp	0.034	Light	682.26	676.59	686.71
56	diaper	baby	0.034	Infant	615.45	639.68	595.70
57	kangaroo	pocket	0.032	Camera	641.78	603.81	668.37
58	ladder	roof	0.032	Ceiling	603.57	616.75	593.03
59	cheese	bread	0.03	Dough	593.83	577.58	607.75
60	chicken	egg	0.03	Yellow	543.69	555.14	535.00
61	cabbage	leaf	0.029	Lettuce	555.58	560.91	551.39
62	cage	animal	0.029	Cat	663.24	681.83	646.70
63	envelope	paper	0.028	Pencil	603.78	614.64	595.25
64	face	eyes	0.028	Nose	672.02	591.48	738.18
65	cake	sweet	0.027	Pie	624.47	637.55	614.55
66	frog	pond	0.027	Duck	593.04	630.25	561.14
67	nut	almond	0.027	Bar	733.02	775.96	696.44
68	candle	wax	0.027	Paper	687.69	685.33	689.78
69	garbage	dirty	0.027	Rotten	643.63	583.55	692.59
70	olive	oil	0.027	Petrol	647.64	628.52	663.08
71	honey	sugar	0.026	Cookie	629.76	629.27	630.14
72	ice	cold	0.026	Snow	674.83	666.71	681.38
73	sport	game	0.025	Card	635.04	648.70	624.21
74	storm	thunder	0.025	Loud	660.12	690.32	637.21
75	milk	butter	0.024	Knife	631.25	601.27	654.00
76	salmon	tuna	0.024	Salad	584.60	581.14	587.13

77	scissors	knife	0.024	Butter	608.90	582.67	627.27
78	spoon	cereal	0.024	Milk	548.92	533.45	561.07
79	movie	theatre	0.024	Music	766.82	731.89	793.36
80	sand	castle	0.024	King	697.24	720.33	680.52
81	shelf	closet	0.024	Room	613.52	583.74	637.14
82	statue	monument	0.024	Tower	671.40	611.43	722.48
83	day	light	0.022	Sun	604.90	579.64	624.07
84	soap	shower	0.022	Bath	667.06	686.30	651.25
85	dentist	teeth	0.022	Doctor	638.53	609.91	660.24
86	spaghetti	noodle	0.022	Italy	657.94	560.54	735.87
87	shell	snail	0.021	Slow	718.90	723.78	714.74
88	tiger	jungle	0.021	Forest	615.67	594.61	632.38
89	shoulder	arm	0.021	Finger	613.19	533.96	676.03
90	tissue	nose	0.021	Nostril	606.07	646.00	574.12
91	mountain	valley	0.02	Canyon	659.40	763.76	578.22
92	mushroom	salad	0.02	Lettuce	607.45	605.26	609.25
93	fire	smoke	0.018	Flame	677.10	581.85	745.14
94	flea	dog	0.018	Cat	746.98	692.36	788.41
95	glass	sharp	0.015	Pain	589.18	572.55	601.79
96	goat	milk	0.015	Cold	708.41	701.61	714.42
97	tree	pine	0.014	Cone	611.39	623.57	602.25
98	triangle	square	0.014	Circle	676.84	638.71	705.43
99	violin	orchestra	0.013	Music	678.47	620.17	730.04
100	vinegar	sour	0.013	pineapple	579.94	573.13	585.79

Table 49

Stimuli by Matching or Non-matching Conditions

High association		Weak Association	
Matched	Unmatched	Matched	Unmatched
abdomen	actor	air	Ash
accident	adult	alcohol	Breakfast
acrobat	afternoon	arrow	Bus
addiction	alligator	ballet	Cabbage
address	alphabet	banana	Cactus
animal	ambulance	barbecue	Cake
arm	ankle	beach	Candle
artist	apple	broccoli	cheese

author
autumn
bank
belt
bird
captain
carpet
carrot
cat
cave
chair
cherry
chocolate
cigar
circus
cloud
cow
farm
feet
film
finger
hat
hen
ink
iron
mattress
ocean
office
onion
orange
owl
oxygen
page
painting
palace
parrot
perfume
straw
strawberry
tennis

balcony
ball
balloon
camel
canoe
ceiling
cliff
coffee
cord
cotton
daughter
deck
feather
fish
flower
fossil
island
jacket
lips
neck
octopus
pan
paper
parent
parking
skirt
soup
syrup
tea
teeth
ticket
toe
turtle
zebra

cage
canvas
car
chicken
coffee
costume
day
dentist
diaper
doctor
document
dog
flea
frog
garbage
grain
gym
home
house
ice
ladder
milk
motor
mouse
nut
olive
pizza
river
salmon
salt
sand
sandals
sausage
scissors
seed
shelf
shoe
shoulder
ski
soap

corn
couch
desk
dish
earth
elephant
envelope
face
fire
glass
goat
honey
kangaroo
metal
mountain
movie
mushroom
music
nail
nature
phone
pig
pillow
rope
salad
sandwich
sauce
school
shell
tiger
tongue
tree
triangle
vinegar
violin

thief	spaghetti
time	spoon
town	sport
toy	statue
tunnel	storm
umbrella	tissue
uniform	towel
week	
wind	
zipper	