Co-activation in the bilingual lexicon: Evidence from Chinese-English bilinguals

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ABSTRACT

Investigation of the bilingual mental lexicon suggests that one of its defining characteristics is integration. Words across both languages are subject to parallel co-activation during language processing. An auditory stimulus typing task was used to assess connectivity on the basis of both morphology and phonology. English loanwords in Chinese and transparent English noun-noun compounds with Chinese translation equivalents with corresponding compound structure (corresponding compounds) were used as the critical stimuli. Accent was also manipulated to determine whether or not phonological cues may influence the degree of cross-linguistic co-activation. Results suggest cross-linguistic co-activation on the basis of phonological overlap in different script bilinguals but only weakly supported morphological integration in Chinese-English bilinguals. Accent led to greater co-activation of phonologically similar loanword pairs. Results are discussed in terms of inhibitory control, language acquisition, and the structure of the bilingual lexicon.

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INTRODUCTION

Bilinguals are like sporks. For the uninitiated, a spork is a brilliant utensil combining the curved concaveness of a spoon, with the prongs of a fork. It can used as a spoon in one moment and a fork in the next. However, in those moments, it never becomes a fork or a spoon. Functioning as a fork, it retains its spoon-like qualities. Functioning as a spoon, it retains its fork-like qualities. Thus, it cannot be understood as two separate utensils. It is a single system that serves two functions. The bilingual language system can be understood in the same way. Chinese-English bilinguals, for instance, are capable of speaking Chinese in one moment and English in the next. However, in those moments, their brain functions never mirror those of Chinese or English monolinguals (Grosjean, 1989) because Chinese becomes subtly involved in English processing and English becomes subtly involved in Chinese processing. Thus, bilingual language processing cannot be understood as two separate monolingual systems sharing a single brain. It is a single system that serves the processing needs for two languages. Much like a spork.

Anyone who has met a bilingual knows that they are in full control of their language production and comprehension. They can switch between languages with apparent ease and automatically comprehend speech spontaneously produced in either language. In other words, the two languages are functionally separate. However, at a subtler level, bilingual language systems are not as separate as they may seem. Some evidence of this integration is observable in everyday language use. For instance, foreign accent is defined as non-pathological speech that differs noticeably from the norms of native speakers (Munro & Derwing, 1995). Bilinguals often speak with a foreign accent that contains elements both their first (L1) and second (L2) language (Flege, 1991, Yeni-Komshian, Flege, & Liu, 2000). In other words, phonological variations foreign to the native ear are the product of intrusion of phonological rules from a bilingual's other language. This suggests an integration of the phonological and phonetic systems used to produce language. In creating new words, bilinguals will often produce neologisms that contain elements of meaning from both of their semantic systems (Edwards & Gardner-Chloros, 2007). In sentence production, bilinguals also tend towards grammatical structures that satisfy the syntactic constraints of both languages when possible (Gass, 1984). The two languages do not exist in a vacuum. They influence each other, and this influence is easily observable.

Most interlingual influences are not, however, so easily observable. They must be detected using precise measurement tools and experimental manipulation. Experimental psycholinguistic research into online language processing can play an important role in understanding the mental representations and processes that underlie bilingual processing. A rich source of data in this type of psycholinguistic research has been the analysis of millisecond-level processing time in language comprehension and production among bilinguals. It is this type of chronometric research that is at the core of this thesis.

Returning to the metaphor of bilinguals as sporks, if indeed the language system of a bilingual is, at least in part, a synthesis of individual language features, then that synthesis should have psycholinguistic consequences for the bilinguals, as well as for those with whom they communicate. By measuring patterns of lexical processing time in the target language (in this case, English), this thesis dives deeper into the bilingual lexicon and discover how the processing of both languages are subtly influenced by one another. The thesis has four key goals:

1. Methodological innovation

2. Understanding the role of interlingual lexical association

3. Understanding the role of interlingual morphological association

4. Understanding the role of accent

In the sections 1.1 to 1.4 below, I discuss each of these goals in detail. I contextualize the goal within relevant body of research literature, and I discuss its instantiation in my specific experimental investigation of English lexical processing in the context of Chinese-English bilingualism.

Thesis Goal 1: Methodological Innovation

This thesis focuses on lexical processing in a psycholinguistic experiment in which participants hear English words and then type them as quickly and as accurately as possible. The key dependent variables in the study all focus on that typing. They include:

(a) how much time participants take to begin typing a word after hearing it (as a measure of recognition ease) and

(b) how long participants take to type the subsequent letters in the word (as a measure of production ease).

(c) the extent to which typing patterns accord with structural linguistic patterns, such as morphological constituent boundaries, within the word (as a measure of linguistic development).

To the best of my knowledge, this is the first time that typing patterns have been used as psycholinguistic evidence in this type of investigation of lexical processing among bilinguals. An important component of the research, therefore, was to test the overall feasibility of the typing paradigm in the study of bilingual processing and the perception of second language speech.

In addition to testing the feasibility of this specific procedure, I have set out to be among the first to implement a psycholinguistic experiment of this type on a platform that enables the performance of participants to be tested with millisecond accuracy without requiring that they be tested in a psycholinguistic laboratory. The system that I have used is the newest implementation of PsychoPy (Peirce, 2007; Peirce et al. 2019). The knowledge that has been gained through this implementation and the associated lessons for subsequent research has been shared with the psycholinguistic community in Gallant and Libben (2019). As is noted in that paper, the use of web-based platforms for psycholinguistic investigation creates substantial new opportunities for the study of language processing among persons who are less easily recruited to a laboratory environment. It also enables the creation of experiments that have increased ecological validity in terms of setting, simply because they can be conducted under more natural language processing conditions (e.g., at home).

Thesis Goal 2: Understanding the Role of Interlingual Lexical Association: The Case of Loanwords

Lexical association within the mental lexicon. Linguistic information is stored in a cognitive system of lexical representation referred to as the mental lexicon (Jackendoff, 2002). This system is made up of interconnected constructs called lexical entries that contain information pertaining to the characteristics of that word, such as meaning (semantic), sound (phonological), appearance (orthographic), grammatical properties (syntactic constraints), and internal structure (morphology). Lexical entries within this representational network are highly interconnected with one another on the basis of these lexical characteristics. Association between lexical entries affects the way that words are processed. For instance, words associated at the level of phonology become co-activated during spoken word processing. This may be rather counter-intuitive, given our everyday experience of language. We never become conscious of multiple lexical entries becoming activated. The process of co-activation occurs during the mapping of linguistic input onto lexical entries stored in long-term memory (lexical access), prior to our conscious experience of hearing a word, which only occurs after a single word has been successfully selected (Marslen-Wilson, 1987). While imperceptible, this process of co-activation manifests behaviorally in millisecond differences in word recognition detectable with psycholinguistic measurement tools. For example, words are often associated with others that differ only by a single phoneme. By this logic, COOKIE, BOOKIE, and KHAKI would all be phonologically associated. Words with a high degree of phonological association are described as having ‘high phonological neighborhood density’. Processing of such words is often delayed by 10s of milliseconds due to competition from co-activated lexical entries (Vitevitch & Luce, 1998).

Loanword pairs. Words with etymological roots from another language are called loanwords. For example, the pronunciation of the Chinese word for ‘cookie’ is borrowed from English. It is pronounced ‘qǔqí’ (pinyin translation). I will refer to these two words; ‘cookie’ and ‘qǔqí’ as loanword pairs. Loanword pairs share similar phonological representations in the mental lexicon. However, differences will emerge due to the phonological system of the language they belong to. Unlike English, Chinese is a tonal language, meaning that there separate lexical items which differ only in tone. Referring the pinyin translation ‘qǔqí’, markers can be seen indicating the tone of each syllable. In the case of loanword pairs in Chinese and English, they do not share perfectly overlapping phonology. Moreover, they are do not share overlapping orthography either (‘曲奇’ in Chinese, versus ‘cookie’ in English). The question that this thesis is designed to answer is whether loanword pairs in Chinese and English are lexically associated within the Chinese-English bilingual lexicon, despite belonging to different languages and sharing only minimal structural similarity.

Cross-linguistic lexical association. Although association within the monolingual mental lexicon has been long established, there has been some doubt as to whether bilinguals exhibit lexical association across both languages. For instance, if two words share similar phonology, but belong to different languages, are they still associated? Early work on bilingualism posited a split lexicon, in which lexical entries were separated on the basis of language ownership (MacNamara & Kushner, 1971). However, work in the past two decades has provided convincing evidence to the contrary.

It has been well-established that during bilingual word recognition, phonological neighbors from across languages become co-activated. The majority of this research comes from studies utilizing the visual world eye-tracking paradigm. In these experiments, participants are presented with objects arranged in a matrix pattern and given verbal commands instructing them to point to or pick up a target item. During this task, participants eye movements are tracked. Due to the rapid integration of visual and linguistic processing, eye movements recorded during the unfolding of the speech signal reveal subconscious processes underlying word recognition (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

Using this paradigm, Marian and Spivey (1999) conducted a ground-breaking study, in which evidence of the co-activation of phonological neighbours across languages was observed. In the study, Russian-English bilingual participants were presented with different combinations of real-world objects; a target object (e.g. a SPEAKER), a within-language competitor (e.g. a SPEAR), a between-language competitor (e.g. a match, or SPICHKI in Russian) and an unrelated filler object (e.g. a NAPKIN). They were asked to place the target object into a nearby basket. Participants' eye movements were tracked and recorded during the verbal command using a head mounted ISCAN eye-tracker. Results indicated that participants fixated on between-language competitor objects (SPICHKI) significantly more often than filler objects (NAPKIN) when instructed to pick up the SPEAKER. This suggested that MATCH and SPEAKER were in some way lexically associated. However, this association could not be explained without considering the phonological representation of MATCH in Russian, providing strong evidence of lexical association and co-activation across languages on the basis of phonology. Given that use of Russian was not required in the task, it was hypothesized that entries from both languages are activated during language processing. This was termed non-selective access. The implication is that, structurally, there is an association across languages, and functionally, both are activated regardless of task relevance.

Subsequent studies utilizing similar methodologies have extended these findings to other bilingual populations, such as English-German and German-English (Blumenfeld & Marian, 2007), English-Spanish (Blumenfeld & Marian, 2013; Canseco-Gonzalez et al, 2010), Dutch-English (Weber & Cutler, 2004), and French-German (Weber & Paris, 2004). One issue with these findings is that most of the language pairs studied share similar writing systems, derived from Roman script. Thus, whether lexical entries are associated purely as a result of phonological similarity cannot be distinguished from a potential effect of overlapping orthography.

Lexical association in different script bilinguals. Chinese and English do not share the same script. While English uses an alphabetic script, Chinese uses a logographic script. This provides a useful avenue to study the association at the phonology level as distinct from orthography. Previous research has provided evidence of lexical association in different-script bilinguals; however, there is a paucity of research in this area. The only evidence comes from Japanese-English bilinguals. Japanese script is distinct from English, using both a logographic and syllabary system, as opposed to an alphabet. Japanese also contains many loanwords from English, which are adapted to the phonology of Japanese and represented by a distinct syllabary writing system. Using an English picture naming task, Hoshino and Kroll observed that Japanese-English bilinguals were faster to respond to pictures corresponding to loanwords than matched controls (2008). This suggests that the two lexical entries were associated at the level of phonology. Unlike during word recognition, where high phonological neighborhood density delays response time due to co-activation of lexical competitors, strong associations within a phonological neighborhood speed up oral production of words. This has been coined the cognate facilitation effect (Costa, Caramazza & Sebastian-Galles, 2000). Previous research of cognate facilitation looked exclusively at words sharing semantic, phonological, and orthographic similarity. Thus, Hoshino and Kroll's work extends these findings to loanwords, which only share semantic and phonological similarity. For the purposes of this study, these results merely suggest that lexical association is possible in the absence of orthographic similarity.

Although loanwords share phonological similarity, they often do not overlap perfectly due to differing phonological systems across languages. However, given research presented above, it seems likely that loanwords will show similar patterns of lexical association as phonological neighbors, despite differences in orthography. Thus, during spoken word processing, I predict that the representation of both words will become co-activated leading to interference during auditory word recognition.

Thesis Goal 3: Understanding the Role of Interlingual Morphological Association: The Case of Compound Words with and Without Correspondence Across Languages

Compound words and morphological structure in English. Morphologically complex words are those that are words that are not simple meaningful representations. Rather, they contain internal components that themselves can be said to carry meaning and/or function. These components are called morphemes. While there are many types of morphologically complex words, this thesis will focus solely on compound words.

Compounds are morphologically complex words formed from two, or more, unbound roots, called constituents. The compound's 'head' is the constituent which determines the syntactic category of the compound. English compounds are head-final, meaning that morphological head is always in the final position. For example, the compound 'moonlight' contains two constituents: a modifier; 'moon', and a head; 'light'. English compounds differ in their transparency. Transparency refers to the degree with which each constituent contributes to the semantic meaning of the whole-word compound. The semantic meaning of 'moonlight', i.e. light from the moon, is derived from the semantic meaning of both constituents and the relational structure of the compound. Thus, 'moonlight' is a transparent-transparent (T-T) compound.

Comparison of Chinese and English compound structure.

Morphological characteristics. In Chinese, morphological compounding is ubiquitous. It is estimated that between 74-80% of Chinese lexical items are disyllabic compound words (Zhou & Marslen-Wilson, 1995; Wang, Lin & Gao, 2010). This is because, unlike English, new lexical forms are not produced through morphological inflection or derivation. Chinese compound constituents can also vary in their boundedness. For example, a single word may have several different associated meanings, some of which may be bound morphemes and some that are not (Packard, 2000).

Semantic characteristics. Similar to English, compounds in Chinese are head-final and exhibit similar patterns of constituent transparency (Wang et al, 2010) and relational structure. For instance, ‘moonlight’ in Chinese is 月光. The first character means ‘moon’, and the second ‘light’. The meaning of each constituent contributes to the whole-word meaning of ‘light from the moon’.

Orthographic characteristics. Since Chinese uses a logographic script, each unit of meaning is represented orthographically using a single one-syllable character. Sentences are written in character strings without spaces, blurring the line between constituents and words (Packard, 2000). English makes more salient distinctions between the two through use of spacing. Thus, it is argued, that at conscious level, Chinese speakers do not make distinctions between constituents and whole-words. Colloquially, a catch-all term ‘zi’ can be used to refer to both constituents and whole-words. In other words, an English speaker may hesitate to refer to the MOON in MOONLIGHT as an individual word, as it perceived to be a part of a whole, whereas for a Chinese speaker, the MOON in MOONLIGHT may be considered just as much an individual word as MOON by itself.

The processing of compound words.

***Compound processing in English*.** According to theories of compound representation, the lexical entries for compound words are associated with the representations of their constituent morphemes (Libben, 2006). Constituent representations differ from their real-word counterparts in that they contain information regarding their position within the compound

(Libben, 2014). A constituent representation for 'moon' would contain the direction of connection, 'moon→'; its position, and its semantic relationship to the head, 'of the moon'. During the processing of compound words, representations of both whole-compound and constituents become activated and influence the way the word is processed (Libben, 2006). This is known as the dual-route theoryof compound processing (Sandra, 1990), and has received empirical support from studies in the field. For instance, visual word recognition experiments have shown that whole compounds prime their constituent morphemes (Zwitserlood, 1994; De Cat, Klepousniotou & Baayen, 2015; Zhang et al, 2012). The processing of monomorphemic roots is also linked to their morphological family size: the number of words that can be formed from a given stem via compounding and derivation (Schreuder and Baayen, 1997). This indicates that morphological information is encoded within lexical representations. Compounds that share constituents that vary in their position prime one another, while non-compounds that share only orthographic form overlap do not (Duñabeitia, Laka, Perea, & Carreiras, 2009). The findings of this study imply that 'moonlight' would prime 'lighthouse', but 'marinade' would not prime 'marital' despite having a chunk of orthographic form overlap. Finally, the relational structure between the two constituents in a compound also seems to play a role in processing. Compounds that share relational structure, such as 'snowfort' and 'snowball' (i.e. 'made of snow') show stronger priming effects than words that do not share the same structure (e.g. 'snowshovel', i.e. 'used for snow') (Gagné & Spalding, 2009). Thus, it can be said that compounds "are both greater than the sum of their parts and greater than the division of their wholes" (Libben, Gagné & Dressler, forthcoming, p. 11), meaning that compound representations contain information pertaining to both the whole-word compound and its individual constituents.

Compound processing in Chinese. Difference in Chinese compound structure may lead to important processing differences compared to English. Firstly, the fluidity of the word-morpheme boundary (Hoosain, 1992) may lead to differences in representation and processing of compounds between English and Chinese. Hoosain (1992) claims that "a greater proportion of multimorphemic words in Chinese (compared with English) is not necessarily listed in the lexicon but instead have meanings arrived at in the course of language use" (p. 126), implying that some compounds are processed by their constituents only. Thus, Hoosain casts doubt on the psychological existence of whole-word compound representations. This claim is refuted by several empirical studies suggesting that compounds are processed as gestalt units (Taft & Zhu, 1997; Zhou & Marslen-Wilson, 1995). Conflicting results also come from analyses on the role of morpheme frequency on compound recognition times. Some results indicate that morpheme frequency is not a factor in word recognition (Chen & Chen, 2006) or production (Janssen, Bi & Caramazza, 2008), implying that Chinese compounds may be processed as whole-word units, rather than morphologically decomposed into individual constituents during word processing. When there is no salient orthographic feature differentiating words from morphemes, the formation of constituent representations distinct from those of whole-words may not develop. In the absence of constituent representations, patterns of compound word typing latencies seen in English compound processing would not be observed.

Given the relative simplicity of Chinese morphology, it is possible that morphological processing is less involved in word processing, when compared to English. These findings are refuted by several studies in which manipulations of morpheme frequency yielded significant effects on lexical decision response latencies (Taft, Huang & 1994; Zhang & Peng, 1992) and response accuracy (Cheng, Wang & Perfetti, 2011), and the amplitude of electrochemical brain activity associated with lexical processing, measured using electroencephalography (Wang, Lu, He, Zhang & Zhang, 2017). Additionally, in auditory compound processing, it has been argued that Chinese morphemes are more distinct than English morphemes precisely because they are always monosyllabic, and that distinctiveness may facilitate access to Chinese constituents cross-linguistically (Cheng, Wang & Perfetti, 2011).

The rich interconnected network of compounds creates ample potential for cross-linguistic association to similar representations in other languages. Just as phonologically similar words are associated across languages, it is argued that morphologically similar ones are as well. This has been coined the 'morphological integration hypothesis' (Libben, Goral & Baayen, 2017). This implies that lexical entries across languages area associated at the level of morphology. Previous studies on bilingual morphological integration have been marred by differences in the morphological systems across the languages under study (Libben, Goral & Baayen, 2017). I will now outline the reasons why Chinese and English offer fertile ground for this topic of study.

Compound processing and morphological integration. Learning an L2 is facilitated the existing language system of the speaker's L1 (Kroll & Stewart 1994). Taking this developmental perspective, it is possible that during language acquisition, the existing L1 morphological system facilitates the development of the L2 system. This process will only be as successful as the two system are similar. Through this facilitatory process, it is possible that the two systems may become integrated.

Morphological rules and constituent representations are born in the mind. While phonological and orthographic whole-word representations are abstractions of sensory input signals, constituent representation must be extrapolated from existing representation of compounds and lexemes (morphologically simple words). This process has been called ‘morphological transcendence’ (Libben, 2014).

In an auditory lexical decision task, young (grade 2-3) Chinese-English bilingual children responded more accurately to English compounds that shared morphological structure with Chinese compounds (Cheng, Wang & Perfetti, 2011). It could be that morphological correspondence across languages facilitated their acquisition of the English compounds. Differences in accuracy scores across compound types were also telling. In compounds where the constituent morphemes were closely related semantically to the word as a whole (e.g. moonlight), accuracy scores were higher compared to compounds that were semantically opaque (e.g. jailbird). Higher morpheme frequency also led to higher accuracy scores. While accuracy data does not provide a clear window into word processing, there is some indication that the children’s lexical knowledge was facilitated by morphological know-how. This is most likely way by which morphologically corresponding compounds become associated across languages.

Considering the phenomenon of non-selective lexical access, it is also possible that morphological information is also subject to cross-linguistic activation regardless of its relevance for the task at hand. When compounds are broken down into their constituent parts during word processing, it is possible that the heuristics involved in recognizing morpheme boundaries extrapolate information regarding the composition, relational structure (Gagné & Spalding, 2009), and transparency of the internal word structure, which could in turn co-activate representations corresponding to that precise structure. Compare the word ‘moonlight’, with its translation equivalent in Chinese: 月光, pronounced, yuèguāng (月 yuè, meaning moon, and 光 guāng, meaning light). These two compounds do not show any form overlap other than morphological compositionality. They are head-final two-constituent compounds, with the same relational structure and constituent transparency. Given these similarities, if compounds with morphological overlap are interlingually associated, it is possible that the Chinese word for moonlight (月光) will be co-activated during the processing of the English compound 'moonlight' on the basis of morphological similarity.

Although research on this topic is in its earliest stages, there are several findings that support the above line of reasoning. In a lexical decision task, where the order of English compound constituents was reversed, advanced Spanish-English L2 learners made significantly more errors than German-English learners and monolingual speakers (De Cat, Klepousniotou & Baayen, 2015). This may be because in Spanish compound constituent order in the inverse of both English and German. When English compound were reversed, their compound structure became closer to that of Spanish compounds. Since this manipulation only slowed the reaction times for L1 Spanish speakers and not L1 German speakers, it can be concluded that L1 morphological structure rules were interfering with the acceptability judgements of L2 compounds. Taken a step further, the co-activation of Spanish constituent representations, which theoretically contain information regarding compositionality, needed to be inhibited before the correct lexical decision could be made. In the case of German-English bilinguals, the inhibition of co-activated constituent representations would not have been necessary as they correspond with the English representations in terms of morphological constraints.

L1 constituent representations have also been shown to affect the processing of L2 non-words in Hebrew-English bilinguals. When L2 non-word compounds were constructed from the translation equivalents of L1 compound constituents, responses were slower and less accurate than non-word compounds not exhibiting such correspondence (Libben, Goral & Baayen, 2017). Researchers also observed cross-linguistic constituent priming effects, whereby Hebrew constituents primed corresponding English compounds and vice versa (Libben, Goral & Baayen, 2017). This provides further evidence that constituents are subject to cross-linguistic co-activation. However, while L1 activation interfered with the processing of L2 non-words, contrary to the results discussed above, no effects were observed on real words. Priming patterns for compounds comprised of identical morphemes across languages were no different than compounds that were not. This result may be due to differences in morphology across the two languages. Hebrew compounds are head-initial and are written as two words separated by a space. English compounds are head-final and can be lexicalized, hyphenated, or presented with a space. Additionally, the number of compounds that share identical morphemes across the languages is minimal. As previously discussed, Chinese and English compounds are more similar in terms of their morphological structure and same more compounds with the identical morphemes. Taken together, observing morphological integration within the Chinese-English bilingual lexicon seems promising.

Compound Production in Typing. Morphological structure influences the typed production of compound words. Compound production is a cascade process, where the entire word is not planned before production begins. Prior to the onset of production, sub-lexical structural features encoded in the lexical entry are accessed and influence the motor planning process (Lambert et al, 2007). The length of a monomorphemic word's first syllable, rather than its length, predicts its production onset time, (Bertram, Tønnessen,Strömqvist, Hyönä & Niemi, 2015). Convincingly, this is true regardless of the number of syllables in the word (Lambert et al, 2007). Just as the production of monomorphemic words cascades from syllable to syllable, compound word production does so from constituent to constituent. This is indicated by an elevated latency at morpheme boundaries during compound word typing tasks (Libben & Weber, 2014; Bertram et al, 2015; Gagné & Spalding, 2015; 2016a; 2016b) that is not accounted for by bigram frequency and were not observed in other pseudo-compounds, suggesting that typing latencies reflect sub-lexical processes. The increased latency between keystrokes, or the inter-keystroke intervals (IKSIs), at morpheme boundaries indicates that participants "re-access the morphemic structure of the compound to obtain the structure corresponding to second constituent" (Gagné & Spalding, 2015, p.49). If the morpheme boundary effect was unrelated to constituent representation, similar effects would be expected in pseudo-compounds that exhibit the same surface structure as real-word compounds but are not represented in the mental lexicon.

While these findings indicate that constituent morphemes are accessed during typed compound production, there are mixed results regarding whether morpheme frequency affects compound production. Bertram et al. found that whole-word frequency (and not morpheme frequencies) predicted typing onset times. Similar results have been reported in other picture naming tasks with Mandarin Chinese (Janssen, Bi, & Caramazza, 2008) and English compounds (Janssen, Pajtas & Caramazza, 2014). Typing onset seems to be influenced by whole-word lexical characteristics, while typed production is influenced by sub-lexical morphological properties. Therefore, the difference in typing onset and inter-keystroke latencies of corresponding compound may be observed.

In sum, this thesis is designed to determine whether Chinese-English bilinguals show evidence of morphological integration, i.e. lexical association on the basis of sub-lexical morphological structure. I expect these associations to manifest in differences in word recognition time, but also the latency patterns of keystrokes during the typed production of these words. As discussed above, the second and third goals of this thesis concern the architecture of the bilingual lexicon, i.e., the lexical characteristics that govern lexical association across languages. I looked specifically at phonological similarity, as seen in loanword pairs, and morphological similarity, as seen in corresponding compounds. The following section considers the mechanisms which determine the levels of activation across the bilingual lexicon, focusing specifically on the role that accent may play in determining the degree of activation of lexically associated entries.

Thesis Goal 4: Understanding the Role of Accent

Bilingual Language Control. Theories of bilingual control have sought to determine the mechanisms by which bilinguals control language processing across both languages. Early theories posited a functional separation of both languages and a switch which could alternate between them (MacNamara & Kushir, 1971). As our conception of the bilingual lexicon evolved to accommodate evidence suggesting intricate interlingual connections across language entries, bilingual control models have changed accordingly. The inhibitory control model (Green, 1998) posits a mechanism in the central executive responsible for global inhibition across languages on the basis of 'language tags' during lexical processing. This is referred to as the supervisory attentional system (SAS), though the nature of 'language tags' or the basis for their development is not elaborated on. One way of identifying the language ownership of a single lexical entry is degree to which it conforms to the phonological schema of a particular language. At the level of the auditory input signal, languages differ in terms of their phonemic repertoire (the contrastive phonemes of that language), their sub-phonemic features, such as voice-onset time, and their suprasegmental features, such as intonation and tone. Thus, phonology may play a central role in the formation of putative ‘language tags’ as well as language control mechanisms. For instance, a spoken English word containing phonological features of the L1 and L2 may take longer to process because the lexical search cannot be constrained to one language. Additionally, if the English word has close phonological neighbors in the L1 of the listener, as in the case of loanwords, may the language control mechanism be tricked into allowing the L1-competitor to go inhibited for longer?

This thesis takes an exploratory angle on this question. I have not attempted to isolate particular phonemic qualities of language. Instead, I base my assumptions on the finding that the spoken production of a bilingual’s L2 will contain phonological features from their L1 (Flege, 1984). Thus, I treat accent as a categorical variable indicating whether or not L1 phonological features are present in the stimulus presentation. I will now review the relevant literature pertaining to the role of accent in determining cross-linguistic lexical processing.

Processing Foreign-Accented Speech. Non-native-accented speech contains phonological features of the L1 of the speaker. Deviations from the listeners’ stored phonological representation of the word can lead to processing difficulties. Additional cognitive resources must be harnessed to account for phonological variation during the process of mapping input onto stored representations. In most cases, foreign-accented speech is less intelligible (less likely to be successfully recognized) regardless of the language background of the speaker (Munro, Derwing & Morton, 2006). For a lexical access perspective, unintelligible speech is that in which the auditory input stream deviates so substantially from the phonological representation of the listener that the target word cannot be successfully accessed. Though many studies have looked at the processing of foreign-accented speech, few consider the role of response time as a measure of processing difficulty (Munro & Derwing, 1995; Wilson & Spaulding, 2010)

Since phonological representations are shaped by our sensory experiences of language, familiarity is a strong predictor of intelligibility. This has long been established in the literature on foreign-accented speech (Gass & Varonis, 1984). Given that familiarity helps shape our phonological representations to better map onto certain input patterns, it seems intuitive that L2 speakers will be most familiar with speech similar to their own, speech containing features of their L1. This has been coined the 'matched interlanguage speech intelligibility benefit' (Bent & Bradlow, 2003). Much of this research has primarily operationalized intelligibility in terms of accuracy scores. However, one mechanical problem arises due to phenomenon of non-selective access in bilinguals: if speech contains phonological features from both L1 and L2, how does the brain determine which lexical entry to activate? Another potentially complicating possibility is the emergence of a hybrid phonological system that does not mirror that of monolinguals at all.

Sub-Phonemic Variation and Lexical Access. Bilinguals are not always conscious of how fine-grained their ability to distinguish different phonemic contrasts is. In fact, bilingual language lexical access mechanisms have been shown to have moderate co-activation of entries on the basis of sub-perceptual acoustic-phonetic distinctions between interlingually associated entries (Elman, Diehl & Buchwald, 1977; Flege, 1984; Schulpen, Dijkstra, Schriefers, & Hasper, 2003).

At a structural level, phonological neighbors are associated within the mental lexicon. However, the degree of activation across phonological neighbors is partially determined by fine-grain distinctions in the acoustic input. In an eye-tracking study utilizing the same visual world eye-tracking methodology as Spivey and Marian (1999), Ju and Luce (2004) showed that subtle manipulations in the voice onset time (VOT) of auditory stimuli led to different patterns of cross-linguistic co-activation. VOT refers to the duration of time between the release of a stop consonant and the onset of voicing in the vowel that follows (the vibration of the vocal folds to create acoustic vibrations). Importantly, voiced stop consonants (e.g. [b] or [d]) in English and Spanish differ acoustically in terms of their VOT. By artificially manipulating the VOT to match either Spanish or English, Ju and Luce were able to investigate whether lexical access would be restricted to one language based on this acoustic cue, or whether entries from both studies would be activated as in Spivey and Marian's study (1999). Their results indicated that when the target Spanish word was presented with Spanish-appropriate VOT, proportion of fixations on the between-language distractor objects were no greater than control objects, indicating that the presence of English-inappropriate VOT restricted lexical access, preventing the activation of English phonological neighbors. Similarly, when the Spanish words were presented with English-appropriate VOT, the proportion of fixation to between-language distractors was significantly more than for controls. These results suggest that although at a structural level, the bilingual lexicon is interconnected, monitoring mechanisms sensitive to sub-phonemic acoustic-phonetic features of language govern the degree of activation during spoken language processing. In this case, Spanish-English bilinguals were able to successful restrict lexical access based acoustic-phonetic features of their dominant language. Extending these findings predicts that cross-linguistic co-activation will be attenuated by these putative control mechanisms during processing of the dominant language. However, this is not true of the non-dominant language.

Late bilinguals typically struggle making phonemic distinctions not present in their dominant language (Best & Strange, 1992). Consequently, bilinguals struggle to differentiate between a word and non-word when the only contrasting element is an L2-specific phonemic distinction (Broersma, 2002). Even bilinguals who are highly proficient in their L2 fail to make distinctions between contrastive phonemes not present in their L1 (Pallier et al, 2001). Catalan-

Spanish and Spanish-Catalan bilinguals' perception of contrastive phonemes specific to Catalan differ greatly. In a repetition priming lexical decision task, pairs of words containing Catalan specific phonemic contrasts (/e/-/ɛ/, /o/-/ɔ/, /s/-/z/, p. 447) were treated as homophones by Spanish-dominant bilinguals. Words pairs interspersed throughout trials failed to prime one another if the phonemic distinction between them was recognized. In the case of Spanish-dominant participants, minimal pairs exhibited repetition priming effects, meaning the bilingual control mechanism was not sensitive to these distinctions.

In cases when phonemic distinctions are not made, it is not necessarily true that these phonemes are not represented in the mind. It seems that the phonemic repertoire of the dominant language is a bit of a bully. It is suggested that even when non-dominant language distinctions exist, they can be superseded by those of the dominant language. This is evidenced in asymmetric distractor effect reported by Weber and Cutler (2004). Using an eye-tracking visual-world paradigm, Weber and Cutler investigated the effect of easily confusable vowel pairs on lexical access. Critical stimuli contained phonemic vowel distinctions not present in the phonemic repertoire of Dutch speakers (/ɛ/ and /æ/). The phonological realization of [æ] as [ɛ] in English words is a typical characteristic of the Dutch accent. Thus, [æ] is considered dominant. When, Dutch-English bilinguals were presented with a series of four objects and asked to point and click on a target, fixations to the distractor were greater when the target (PANDA) contained the dominant vowel phoneme and the distractor (PENCIL) contained the non-dominant vowel phoneme. Thus, the lack of phonemic distinction expanded the phonological neighborhood of the target, leading to greater activation of the distractor. However, this effect was not observed when the target (PENCIL) contained the non-dominant vowel phoneme and the distractor contained the dominant phoneme. This suggests that the phonological representation of the word PANDA does include the phoneme [æ], otherwise it would become activated by the input [pɛ]. However, since this is not the case, it seems that "native phoneme categories capture non-native phonemes" (Weber & Cutler, 2004, p. 13). Thus, the dominant repertoire seems to supersede the non-dominant during word processing.

A similar effect has also been observed on accent more broadly. In a gating experiment, Dutch-English bilinguals were quicker and more confident to identify inter-lingual homophones when those words were spoken with a Dutch accent than with a standard English accent (Schulpen et al, 2003). As participants were presented with increasingly longer segments of a Dutch-accented word, subtle phonological variations constrained the activation of potentially spurious entries. This was not the case for English-accent words. One potential interpretation is that the Dutch-English bilinguals lacked the sensitivity to these cues, or that they were superseded by Dutch phonological processing. This is consistent with previous research indicating that dominant language phonemic repertoires are more detailed and therefore the perceptual system is more sensitive to those sub-phonemic features in the input. In a follow-up cross-modal priming experiment, Schulpen et al. found that Dutch-accented and English accented inter-lingual homophones (LEAF-LIEF) showed asymmetric priming effects on related visual English targets (LEAF). Results indicated that English-accented primes showed a greater priming effect than Dutch-accented primes, when the target word was English. This finding implies that even though participants were less sensitive to the sub-phonemic cues of English phonology, they were sensitive enough to result in disproportionate activation of English interlingual homophone entries. It can then be inferred that the two phonological representations of LEAF and LIEF contain information regarding the typical phonological realization of these words, i.e. in different accents. This phonological information seems to coalesce from repeated exposure to particular accents that are associated with a particular language. In this case, Dutch-English bilinguals were assumed to have had greater exposure to English spoken with a British accent. Following this reasoning, if a bilingual's exposure to L2 is primarily L1-accented, they should show a processing advantage to L1-accented input.

Based on these findings, it seems that bilingual control mechanisms exists, which restrict lexical access to the L1 when L1-specific acoustic-phonetic features are presented in the input. Similarly, when L1 words are produced with a foreign accent, the dominant L1 phonemic repertoire also guides lexical access towards the desired L1 targets. However, bilinguals seem to run into trouble when processing L2 speech. Given that the control mechanism seems bias in favor of L1 distinctions and may not even encode all L2 acoustic-phonetic distinctions, spurious activations are more likely to occur. This is most likely to occur when the L2 speech contains L1-specific features.

Accent as a Sociolinguistic Cue. It is important to note that the structure and processing patterns of the bilingual lexicon depend largely the language experience of the individual (Grosjean, 1982; Paradis, 2004). Language doesn't typically occur in laboratory conditions. Rather than interacting with a computer screen, recordings, headphones, eye-trackers and the like, most language behavior is situated in environments full of rich extralinguistic information. Although the setting in which language occurs surely influences language behavior, it is currently assumed that non-linguistic information is not integrated into the system of speech processing. When discussing the modularity of language processing, Fodor (1983) cautions that our "notion of modularity ought to admit of degrees" (p. 37). Accents carry a depth of social information, including the language background of the speaker. Beyond the presence of sub-phonemic cues discussed above, it is possible that accent may act as a social cue that constrains on-line language processing.

Models of lexical access tend to be conservative in terms of the constraints that play a role in lexical activation. The logogen model (Morton, 1969) only includes semantic, phonological, and orthographic information as potential criteria for word selection. Subsequent models such as the autonomous search model (Forster, 1976), cohort model (Marslen-Wilson, 1987) and the shortlist model (Norris, 1994) include syntactic information as an additional constraint. The above-mentioned models, except the cohort model, treat the process of lexical access as completely autonomous, meaning that there is no interaction between bottom-up and top-down constraints. It is possible that other types of information, such as extralinguistic cues, and predictions play a role in the on-line constraining of lexical access that is not accounted for in these models. Recent findings provide evidence of such effects.

In a ground-breaking study on bilingual language production, Wu and Thierry (2017) provide evidence for proactive inhibitory control. In a bilingual picture naming task, Chinese-English bilinguals were asked to name pictures in either Chinese or English. Prior to the presentation of the picture, a simple visual cue appeared on the screen indicating the response language. ERP amplitudes were measured prior to the presentation of the picture but after the presentation of visual cue. The resulting ERP wave forms indicated greater negativity in amplitude prior to the production of English words. The results were interpreted in relation to the inhibitory control model (Green, 1998), which posits a control mechanism that inhibits the activation of non-target language representations. The model also predicts that this global inhibition is necessarily greater during L2 language processing, due to the relative strength of L1 representations. Based on this reasoning, it was concluded that the greater negative amplitude was evidence of the proactive inhibition of Chinese prior to English production. This suggests that extralinguistic, top-down cues may trigger inhibitory control systems even prior to language production.

Another intriguing finding from ERP research is the effect of perceived speaker identity on language processing. Van Berkum et al (2008) investigated whether anomalies between perceived speaker identity and message would result in an N400 effect. They used sentences such as ‘If only I looked more like <u>Britney Spears</u>’ spoken in a male voice, and ‘I have a big <u>tattoo</u> on my back’ spoken in a voice associated with high socioeconomic status among speakers of [British] English. ERP data were collected during the comprehension of the anomalous words (underlined above). They found that when the messages and voice pairing exhibited pragmatic violations, an N400 effect was observed in the latency between 300ms and 500ms after the critical stimulus. Since the sentences themselves were perfectly tenable, the N400 effect must have been causes by a difficulty integrating the message with the mental representation participants had constructed of the speaker. Speaker accent likely affects the type of representation we construct of a speaker. While such effects are less likely to be observed in experiments on single word processing, it is possible that repeated exposure to words spoken by the same speaker may affect behavioral responses. Since this thesis uses stimuli produced by only 5 speakers, trial effects may be observed as participants are repeated exposed to the same speakers and develop a mental representation of them based on the unique properties of their accent. Whether such representation affects lexical access remains to be seen. Whatever the significance that accent plays in lexical access, it seems that bilingual control mechanisms are sensitive to subtle, sub-phonemicacoustic-phonetic features.

Summary of Goals

The first goal of the thesis will be to contribute to methodological innovation in the field of psycholinguistics by utilizing the experiment design software PsychoPy3 and its associated online experiment platform Pavlovia to conduct my research. Additionally, I will extend research on typed word production to bilingual populations using an auditory stimulus typing task.

The second and third goals of this thesis look at the bilingual lexicon from a structural perspective, considering the lexical properties by which entries across languages may be associated. These goals are operationalized by selecting stimuli which exhibit cross-linguistic phonological similarity, in the case of loanwords, and morphological similarity, in the case of corresponding compounds. In both cases, it is hypothesized that the co-activation of interlingually associated entries will complicate, and therefore slow down, recognition and production processes. This leads to the following two hypotheses:

1) Interlingual association between morphologically similar English and Chinese corresponding compounds will lead to greater recognition and production latencies due to greater cross-linguistic lexical interference.
2) L1-specific acoustic-phonetic features present in the stimulus presentation will lead to greater recognition and production latencies for stimuli exhibiting interlingual association due to greater cross-linguistic lexical interference.

The fourth goal takes a processing perspective, looking at the features of the incoming speech signal that may influence bilingual control mechanisms. This goal is operationalized by presenting auditory stimuli recorded by speakers of different language backgrounds. Stimuli recorded by Chinese-English bilingual will contain phonological variations characteristic of their

L1 speech system. The goal is to determine whether these features play a role of bilingual control mechanisms. Thus, the third hypothesis of this thesis is the following:

> 3) Interlingual association between phonologically similar English and Chinese loanword pairs will lead to greater recognition and production latencies due to greater cross-linguistic lexical interference.

The following experiment was design and carried out with the purpose of confirming or falsifying the above hypotheses.

EXPERIMENT

To test the above hypotheses, an experiment including an auditory stimulus typing task was created and administered online. Auditory stimuli were used to facilitate the presentation of L1 phonological characteristics in the L2 lexical items. A typing task was chosen to obtain measurements of both word recognition via typing onset latency and on-line word production via inter-keystroke intervals.

Method

Participants. Several considerations were made in choosing the participant population. Firstly, a large enough local population of bilinguals from which to conveniently sample was needed. Additionally, the first language of the bilingual population needed to include a sufficient number of words with enough phonological and morphological overlap. The two populations that met these criteria were French-English and Mandarin Chinese-English bilinguals.

Ultimately, the Chinese-English bilingual population was selected because it offered several advantages over French-English bilinguals. 1) In terms of speaker identity, Chinese-English bilinguals are racially marked, whereas there are fewer salient visual cues that distinguish French-English bilinguals from English monolinguals. This factor is important for experiment 3. In terms of language background, Chinese-English bilinguals' language learning experience as well as language exposure is generally more homogenous than that of French-English bilinguals. As bilingual language processing is affected by language experience, choosing the population with less variance would likely produce stronger results. Another key consideration here is that Chinese-English bilinguals studying as international students at Brock University are more likely to have come from an EFL language learning environment. Thus, a large portion of their English language exposure will be Chinese accented. Exposure to accented input may lead to differing patterns of activation than in bilinguals with more varied exposure. This bilingual population was all unbalanced, late bilinguals. For brevity, I will use the word bilinguals when referring to these participants.

One drawback of investigating Chinese-English bilinguals over French-English bilinguals is that there are relatively few English-Chinese cognates whereas English-French cognates are abundant. Cognates are often defined in terms of common etymology. However, for the purposes of psycholinguistic inquiry, cognates can be alternatively defined as entries across language which exhibit orthographic, phonological, and semantic overlap. There are a considerable number of English loanwords used in Chinese that are similar enough semantically and phonologically to be operationally defined as cognates in this way. Since, Chinese and English do not share a common script, orthographic overlap is not possible. However, it should be noted that Chinese does have a Romanized script called Pin Yin, may have partial orthographic form overlap with English. Thus, choosing Chinese-English bilinguals limited the potential pool of critical stimuli, but within reasonable limits. However, conducting this research with Chinese-English bilingual provides an opportunity to extend findings reported in same-script bilinguals (e.g. English-Dutch), to different-script bilinguals. The control group selected for this experiment are English monolinguals of comparable age and educational achievement to the experimental group. Participants were recruited using flyers, verbal presentations in university lectures, social media, and MTurk. Participants recruited using MTurk were compensated in line with the norms of the platform.

In total, 94 people participated in the experiment. A breakdown of the participants is presented in table 1.0. Despite considerably effort dedicated to participant recruitment, data were only collected from 11 Chinese-English bilingual participants. The remaining bilingual participants were also late, unbalanced bilinguals with L1s other than Mandarin Chinese.

Table 1. Breakdown of participants by language background

Language Background	Number of Participants
Native English Monolinguals	64
Chinese-English Bilinguals	29
Mixed-L1-English-Speaking Bilinguals	24

Design.

Materials. Experimental stimuli can be broken down into four groups: 28 English-Chinese loanwords, 28 English-Chinese words with overlapping compound structure, and 28 filler words with characteristics matched with the loanwords and another 28 compound words matched to the compound words. A complete stimulus list is provided in Appendix A. In these four groups, half of the auditory stimuli were produced by English native speakers and half were produced by Chinese-English bilinguals. The breakdown of stimuli is presented in Table 2.0.

Table 2. Breakdown of experiment stimuli by lexical characteristics and accent condition for each experimental session.

Lexical Characteristics	Accent Condition	Example	N	Subtotal	Total
Compounds with Chinese-English compound correspondence	Chinese Accent	MOONLIGHT 月光 (MOON 月 + LIGHT 光)	14	28	112
Compounds with Chinese-English compound correspondence	Canadian accented		14		
Loanwords with Chinese-English phonological correspondence	Chinese Accent	COOKIE (曲奇, pinyin: qǔqí)	14	28	
Loanwords with Chinese-English phonological correspondence	Canadian accented		14		
Filler words (non-compounds)	Chinese Accent	GRIEF	14	28	
Filler words (non-compounds)	Canadian accented		14		
Filler words (compounds)	Chinese Accent	FIRSTHAND (FIRST + HAND)	14	28	
Filler words (compounds)	Canadian accented		14		

Loanword Pairs. An initial pool of Chinese loanwords was identified by the experimenter via internet searches for loanwords and with the help Chinese-English bilingual classmates. From this initial pool, loanwords that exhibited close phonological similarity were selected on the basis of subjective judgement by both the experimenter and a Chinese-English bilingual volunteer. The selection process aimed to eliminate loanwords that seemed to differ in more than one phoneme and where the initial phoneme differed across languages. After the stimulus list was constructed, a further analysis was carried out, comparing the phonetic transcriptions of loanwords in both English and Mandarin. Phonetic transcriptions were generated using an automatic transcription website and were verified by a Chinese-English volunteer.

Corresponding Compounds. Due to the lack of research into the role of morphology in interlanguage effects, there was no existing word lists from which to draw. Several methods were used to identify Mandarin words with the necessary overlapping compound structure. Firstly, Mandarin speaking colleagues were consulted, and several short lists of stimuli were generated. These stimuli were confirmed by searching the dictionary definitions of constituents to ensure overlapping compositionality. Amongst the initial list of words generated were many Chinese compounds the English equivalent of which included a space between constituents. Given that spacing and hyphenation can affect the mental representations of compounds as well as the motor planning and production of such words, these words were rejected. Only compounds with no space and overlapping compositional compound structure were selected. Additional stimuli were identified by the researcher who inputted lists of compounds in Google translate and checked the constituent meanings. This process was expediated by the researcher’s knowledge of Chinese characters acquired through learning Japanese. All compounds selected are transparent-transparent (TT) compounds wherein both constituents retain their meaning (Libben, Dressler & Gagné, forthcoming). Only compounds of this type were included because the transparency of individual constituents affects how compounds are processed (Libben, 2003) and there is considerable debate around how the opacity of constituent heads affects word processing. Once a final list of stimuli had been generated, the phonetic transcription of English compounds and Chinese translation equivalents were analyzed to ensure no significant phonological overlap. Words with one of more syllables showing phonological would have been rejected, however, none of stimuli showed any degree of overlap.

Matched Controls. Control words were generated using the English Lexicon Project resource available on the Words in the World website. Lists of loanwords and compounds were inputted separately and a list of word characteristics relevant to the current experiment was generated including length, word frequency, logged word frequency, bigram frequency, bigram sum, bigram mean, phonological neighborhood size, orthographic neighborhood size, number of syllables, number of phonemes, number of morphemes, mean lexical decision response time, and mean naming response time. Frequency measures were based on the Hyperspace Analogue of Language (HAL) corpus, containing 131 million words. After the characteristics of the experimental stimuli were generated, a list of words containing the same characteristic was generated and control words were randomly sampled from these master lists. Controls for compounds and controls for loanwords were both generated. Specifically, controls for compounds were all themselves compounds. This was done to accommodate analysis of morpheme boundary effects and constituent frequency. This allows for within-subjects analysis of word production and motor planning patterns. Using non-compounds would only allow for comparison between experimental and control groups. However, given idiosyncratic differences in typing ability across population, allowing for within-group analysis was deemed the most prudent approach.

Auditory Stimuli Recordings. Auditory stimuli were recorded using a Marantz Professional PMD handheld solid-state recording device. Recording was done in a WhisperRoom sound isolation booth to ensure that no environmental noise corrupted the recordings. When reading stimuli aloud for recording, speakers were instructed to read the words as part of part of the phrase “Now I say…” followed by the target word. This helped reduce unintended variations in stress, intonation, and other potential suprasegmental features. Recordings deemed unclear were repeated and re-recorded. In total, 2 native English speakers and 4 non-native English speakers were recorded on all stimuli. Two non-native speaker’s stimuli were not used because they contained too many critical pronunciation errors. These errors made the recording either unintelligible or phonologically ambiguous. This was judged by the experimenter and a Chinese-English bilingual volunteer. This issue could have been solved by training the non-native speakers on the pronunciation of the incorrectly pronounced words; however, training may have affected the way that speakers produced the words and would have drawn attention to the need for accuracy in production. This would have made the recordings less natural and perhaps influenced participants responses to the stimuli.

All stimuli from each speaker were recorded in one uninterrupted audio file, and target words were extracted manually using Praat. During the process of extracting individual words, care was taken to ensure that the beginning of the extracted audio file and the onset of the spoken word lined up precisely by using zero crossings. After all stimuli were extracted, all sound files were normalized, using Audacity, to prevent variation in loudness, which may lead certain stimuli to be more perceptually salient than others. Several recordings were removed due to poor recording quality or critical errors in the articulation of the word, which made the stimulus completely unintelligible.

Henceforth, the audio recordings will be referred to in terms of the accent condition of the stimuli. Chinese-accented stimuli were audio recordings of speech produced by Chinese-English bilinguals. Canadian-accented stimuli were audio recordings of speech produced by English monolingual Canadian university students from Southern Ontario.

Questionnaire Items. The demographic questionnaire items were developed to meet the needs of the experiment. Information regarding age, gender, educational achievement, language history, and typing experience were collected. Items targeting participants proficiency and degree of language contact was based on 'The Language Contact Profile' (Freed, Dewey, Segalowitz & Halter, 2004) which is adequately comprehensive while still time efficient.

Lexical Characteristics of Stimuli. Lexical characteristics of words were determined using the English Lexicon Project (Balota et al, 2007) and the CELEX word form database (Baayen, Piepenbrock & Gulikers, 1995). For each experimental stimulus, the number of phonemes, and bi-gram frequency was determined by using the 'Word Queries' tool on the English Lexicon Project website. Bi-gram frequency is a value given the word which indicates the frequency of each two-character combination within the word. This is an important characteristic to control for because higher overall bigram frequencies have been shown to decrease word production time (Kandel, Peereman, Grosjacques & Fayol, 2011). Word frequency was determined by searching experimental stimuli in the CELEX word form database. These frequencies are based on the CO-BUILD corpus containing over 17.9 tokens. The written, spoken, and combined CO-BUILD frequencies were collected. Experimental stimuli were translated into Chinese using Google Translate. Translations were then checked by a native Mandarin speaking graduate student at Brock University. The frequency of Chinese translation equivalents was determined using a word frequency list of the 100,000 most frequent words appearing in the Beijing Language and Culture University corpus of Chinese (https://www.plecoforums.com/threads/word-frequency-list-based-on-a-15-billion-character-corpus-bcc-blcu-chinese-corpus.5859/). This corpus contains over 15 billion characters and is compiled from news, literature (fiction and non-fiction), and blog entries. In addition to bigram frequency, trigram frequency of each three-letter combination within each word was also calculated. Microsoft Excel was used to extract each trigram. These were then matched against a database of trigram frequencies publicly available on the practical cryptography website (http://practicalcryptography.com).

PsychoPy3. An auditory stimulus typing task was created using the PsychoPy3 experiment design software (Peirce et al., 2019). PsychoPy3 provides a graphic-user-interface, where experiments can be constructed from preset components arranged along a timeline. Once the experiment is designed, the code for the experiment is generated automatically. This code is compiled in Javascript, meaning that it can be hosted on a webpage and executed by any web browser. PsychoPy3 offers a simple user interface, which is also highly customizable. Custom code lines can be created and inserted into the final code, and this expands the functionality of the program to the limits of the users coding ability. During the construction of this experiment, many lines of custom code were necessary to allow for recording and displaying of typed input. PsychoPy3 was designed for experiments in psychophysics (Peirce, 2007). Combined with the fact that the typing task is not yet a common methodology, creating the code for the experiment was challenging. The compiled code lines of the experiment were hosted on the Gitlab repository of Pavlovia.org, a platform providing unique URLs for experiments created in PsychoPy3.

Measures. The dependent variables recorded in this experiment were individual key presses and key press latency. Individual key presses provided information about the accuracy of participant responses and latency provided the relative timescale of word production. Typing onset was taken as an indicator of word recognition time (Bertram et al., 2014), while the latency between key presses, or inter-keystroke intervals (IKSIs) were taken as a measure of word production. Moreover, patterns in IKSI latency were taken to reflect on-line production processes.

Procedure.

Access. During the recruitment process, prospective participants were given the URL of the experiment and accessed to navigate to it if they wished to participate. Participants then accessed the experiment by navigating to the experiment URL using any computer with a web-browser, internet connection, and keyboard. Upon completing the experiment, recorded data were converted to an excel file and stored on the Gitlab repository, where it was available for download by the experimenter.

Trials. The experiment itself consisted of a consent form, instructions, 4 practice trials, 112 experimental trials, and a short 12-item demographic questionnaire. Upon navigating to the experiment URL, participants were presented with a consent form. Consent was indicated by button press and recorded in the final data file. All information was recorded in one data file. No information identifying the participant was gathered ensuring the anonymity of all participant data.

Experiment trial structure. Each trial consisted of a two-second fixation point followed by the presentation of an auditory stimulus. Each auditory stimulus was a single word spoken by either a native speaker of English or a Chinese-English bilingual. Participants were instructed to use headphones during the experiment, though this cannot be confirmed. The order of stimulus presentation was randomized, and the accent of each lexical stimuli was counter-balanced across trials, ensuring that the accent conditions of each stimulus was balanced across all sessions.

Immediately following the onset of the stimulus, participants were able to type the target word using the keyboard. This indicated by the appearance of a marker; “>>>”, indicating where the typed input would appear. Corrections to the typed input could be made using the BACKSPACE key. Every key press was recorded, including backspaces. The latency of each key press relative to the stimulus onset was also recorded. Once the participants finished typing, they pressed the ENTER key to proceed to the next trial. The next begin with the same two-second fixation point, allowing participants time to prepare for the next stimulus.

Upon completing all experiment trials, participants completed a short multiple-choice demographics and language background questionnaire. Once all questions were answered, participants were provided with a unique participant code. This code was used to collect their compensation and to request deletion of their data in the event that they decided to withdraw from the experiment. Finally, participants were instructed to exit from the experiment and ensure that data were properly saved.

RESULTS

Data Preparation

Data Trimming and Cleaning. Initial descriptive statistics for each dependent variable yielded some unusually high response latencies. Prior to trimming, all trials containing typing errors were removed. Trials containing typing onsets and inter-keystroke intervals (IKSI) of 0 or less were removed. These trials were likely the result of accidental button presses which occurred prior to the onset of the stimulus. Although, the Javascript code written by the experimenter did not allow for key press detection prior to the onset of the auditory stimulus, early versions of the experiment did not include this protocol. It is also possible that these latencies were the result of erroneous keystrokes being logged after the fact. However, any keystroke that occurred after stimulus onset would not be affected by this potential coding error. Trials containing typing onset latencies of under 300ms were removed as research has shown that the cognitive processes underlying spoken word recognition take at least this long to complete. Trials containing typing onsets of above 3 seconds, or inter-keystroke intervals of above 1.5 seconds were trimmed from the data set as such latencies were not taken to reflect on-line word processing.

After data were trimmed to remove extreme responses, response data were checked for outliers. To begin, the mean inter-keystroke intervals for each individual stimulus was calculated. A Shapiro-Wilk normality test was applied to the mean scores to determine whether they were normally distributed. A p-value of 0.81 indicated that they were indeed normally distributed. The mean response latencies were then visually plotted using a quartile-quartile plot, with the first data set being the observed means and the second being standard quartile values for a normal distribution curve. This aided in identifying outliers at either tail of the mean score distribution. IKSIs were converted to z-scores and, using a moderately conservative cut-off point (Levshina, 2015), z-scores of above 2.5 were identified. The stimuli BUYER and WRESTLER were identified as outliers based on this criterion. Inter-keystroke intervals for these stimuli were not included in future analyses.

The same process was then repeated for mean typing onset latencies; however, a Shapiro-Wilk test yielded a P-value of <0.001 indicating that the means were not normally distributed, despite quartile values aligning closely with a quartile-quartile line. Thus, outliers could not be identified on this basis.

The above procedure was repeated to identify participant outliers on the basis of each dependent variable. Mean typing onset and inter-keystroke intervals were not normally distributed across participants with the Shapiro-Wilk test indicated P-values of <0.001 and 0.012 respectively. Thus, outliers could not be identified using this criterion.

Lastly, participants' typing accuracy was considered. One Chinese-English bilingual participant was removed because their trial-level typing accuracy was below 10%. This reduced the total number of participants to 116 and the number of Chinese-English bilingual participants to 28.

Stimuli were also removed on the basis of lower accuracy scores. In total, 3 stimuli were found to have accuracy scores of less than 15%. Upon further analysis, it was identified that 1 stimulus: BASS (as in bass guitar), was a homophone of the word BASE. The existence of another target, which was collated as incorrect likely led to the low accuracy score for this stimulus. Similarly, COLOR and WHISKY were identified as having alternative spellings: COLOUR and WHISKEY. High error rates were likely the result of alternative spellings being collated as errors. All 3 stimuli were removed prior to further analysis.

Consideration of Typing Onset Time. The first limitation of operationalizing word recognition as typing onset time is that a number of other cognitive process likely occur between the moment of word recognition and the executing of the motor plan required to begin typing the word. For instance, using writing onset time as a dependent variable, Bertram et al. (2015) show that the first syllable of a word is fully prepared prior to production. This issue could have easily been remedied by having participants indicate word recognition with a button press prior to typing the word. This remains one of the limitations of this measure.

Secondly, typing onset was measured relative to stimulus onset, which fails to take into consideration the relative utterance length across words, speech rate, and uniqueness point (the point at which the word is phonemically distinct from all other words). To mitigate some of these shortcomings, the audio file length was added to all linear mixed effects regression (LMER) model of typing onset latency. Additionally, a second measure of typing onset was calculated relative to stimulus offset by subtracting audio file length from typing onset. However, when both typing onsets were modeled, as long as audio file length was included as a predictor, there was no difference across the two measures.

Lastly, during the recording of auditory stimuli, the potential for lexical characteristics of the stimuli to affect the oral production of targets (Costa, Caramazza, & Sebastián-Gallés, 2000), was not considered. While an analysis of the acoustic-phonetic quality of stimuli may have been revealing, it was outside the scope of this study and the capacity of the researcher. However, an analysis of speech rate by lexical characteristics (phonological or morphological similarity) was conducted. Speech rate was calculated by dividing the length of the audio file by the number of phonemes in the word. No significant differences were found across stimulus types. However, when speech rate was compared across different speakers, it was found that recordings of speech by Chinese-English bilinguals were consistently longer in duration than those of the monolingual English speakers. To account for any effects of speech rate, audio file length, rather than word length (in letters) was included as a predictor in relevant LMER modeling.

Descriptive statistics of typing onset and IKSI response data after cleaning and trimming is presented in Table 3.

Table 3. Descriptive statistics for typing onset and inter-keystroke intervals

	Min.	1st Qu.	Median	Mean	Std Dev	3rd Qu.	Max
Typing Onset (ms)	601	899	1050	1167	406	1317	2987
Inter-Keystroke Intervals (ms)	11	117	166	195	132	230	998

Validity of Psychopy3 as a Response Time Measurement Tool

This experiment utilized the newest version of the experimental software PsychoPy to collect response time data. PsychoPy3 allows for experiments designed in the PyschoPy to be run through an internet browser. Since this technology was only released in January 2019 and many technical issues were experienced during its use, it is prudent to ensure that experimental measures were indeed valid. To ensure the validity of experimental measures, data were analyzed to look for common processing patterns arising from lexical characteristics of stimuli: the effect of whole-word frequency of word recognition, and effect of morpheme boundary of word-internal production latencies. Both effects have robust empirical backing and have been replicated across many experiments with a variety of software programs and response measures. Observations consistent with these effects would provide support for the validity of the measurements recorded using PsychoPy3.

Frequency effect. Whole-word frequency affects the word recognition time such that more frequent words are recognized more quickly than lower frequency ones. Experimental stimuli were sorted into high frequency and low frequency bins based on the median frequency of all stimuli. Frequency measures were based on the COBUILD corpus. A linear mixed effect regression (LMER) model was created to estimate the effect of the categorical independent variable, word frequency, on the dependent variable, typing onset. Other variables hypothesized to have predicted typing onset were also included in the model: native language of the participant, word length, and accent condition of the stimuli. The data set used included only correct responses. The regression line indicating the estimated contribution of word frequency to typing onset latency is presented in Figure 1.

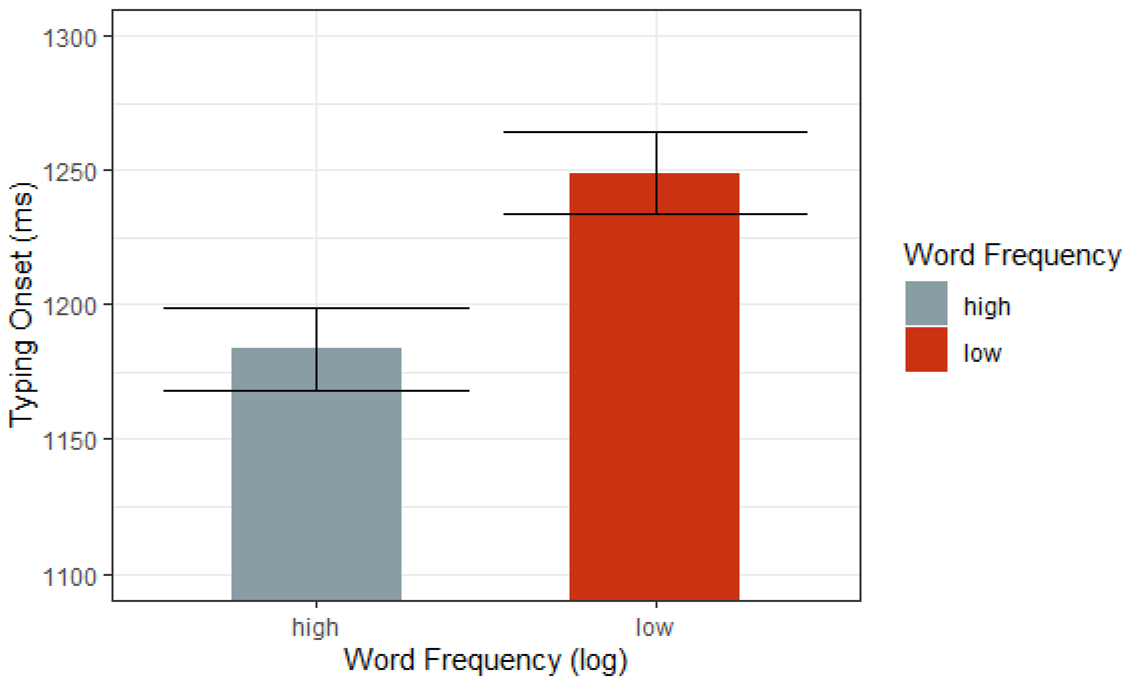

Figure 1. Effects of frequency, native language of participant, accent of stimuli, and word length on total word typing time

The LMER model estimated that the typing onset of low frequency words was 61 milliseconds slower than high frequency words. A p value of 0.02 indicated that these results were not likely due to chance.

Morpheme boundary effect. To ensure the millisecond accuracy of keystroke latency measurements, an analysis of IKSI latency of all compound word stimuli by typing position was conducted. To account for differences in word and morpheme length, IKSI were analyzed by typing position relative to the morpheme boundary. As discussed above, during the typed production of compounds, IKSI latencies tend to be higher at morpheme boundaries. Key presses within two letters of boundary of either side were included in the analysis. The contribution of typing position to IKSI latency was estimated using an LMER model and plotted in Figure 2. In this plot, as in others included in the results section, lines have been added to illustrate the relationship between independent variables. It should be stressed, however, that the points along these lines do not correspond to estimates produced by the models. They merely link the estimates produced by the model. Other predictors thought to have an effect of typed compound production latency were also included in the model.

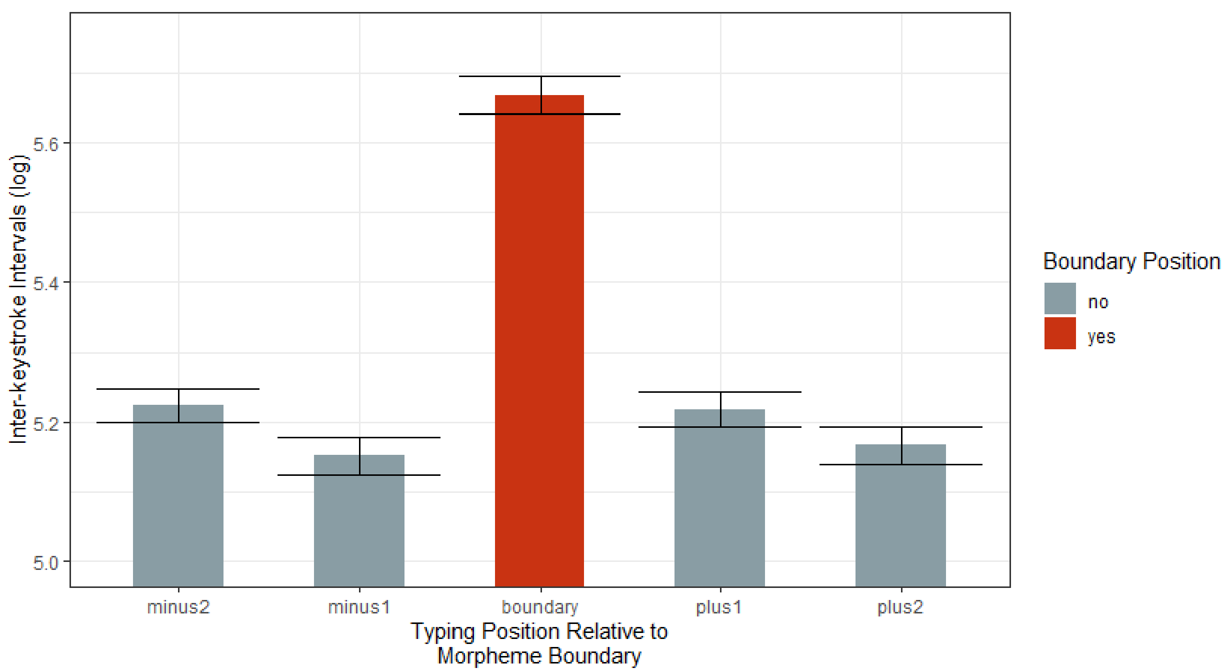

Figure 2. Plot of the estimated main effect of typing position (relative to morpheme boundary) on inter-keystroke intervals (IKSIs) for all compound words.

The model indicated a statistically significant (p= < 2e-16) effect of typing position. Further analysis comparing morpheme boundary IKSI latencies position to surrounding positions (minus2, minus1, plus1, and plus2) estimated that the boundary position accounted for 128 millisecond differences in IKSI. This model was also statistically significant ($p = < 2e-16$).

Findings from both the word frequency and morpheme boundary analysis align closely with previous studies. This provides support for the face validity of measures used, as well as the accuracy of the measurement tool: PsyhcoPy3.

Response Accuracy

Accent. Accuracy scores were analyzed using generalized linear mixed effect modeling, which allowed models to be constructed predicting the probabilistic outcome correct typing accuracy at the trial level. Other predictors added to the model were word frequency and word length. A summary of the fixed effects included in the model are presented in Table 4. There were significant differences in the likelihood of a correct response across participant groups. English monolinguals were more likely to produce correct typed responses than all bilingual participants. There was no significant difference across Chinese-English bilingual and Mixed-L1 bilingual participants overall ($p = 0.79$).

All participant groups were less likely to response correctly to Chinese accented stimuli, regardless of language background. However, there were significant relative differences in the negative effect of accent across participants. This interaction in plotted in Figure 3.1. English monolinguals showed significantly greater reduction in the likelihood of a correct response to Chinese-accent stimuli when compared to bilingual participants. Similarly, Chinese-English bilinguals showed a slightly reduced effect of Chinese accent when compared to mixed-L1 bilinguals, though the interaction was only near significant ($p = 0.08$). In other words, while all participants were more likely to make an error during Chinese accent trials, Chinese-English bilinguals were less likely to make an error than participants with non-Chinese language backgrounds. While Chinese-accented English was still less intelligible than non-accented English to Chinese-English bilinguals, there familiarity with Chinese phonology may have assisted in the recognition of Chinese accented stimuli. This provides some weak evidence in support of the interlanguage speech intelligibility benefit. However, it cannot be firmly established that this relative benefit compared to other bilinguals was not observed by chance.

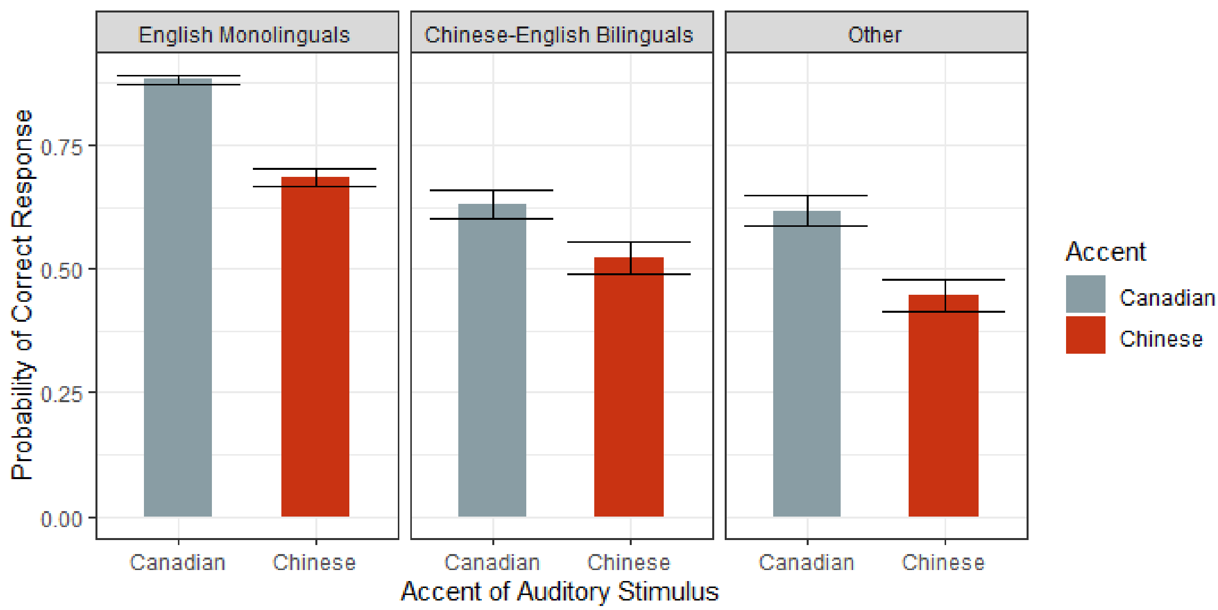

Figure 3. Plotted estimates of the probability of an accurate response by native language of the participant and the accent condition of the stimuli.

Phonological Correspondence. Comparing Chinese-English bilingual responses to those of monolingual English-speaking participants as a baseline, no significant difference in response accuracy for stimuli exhibiting phonological correspondence was observed. It may be that cognitive processes involved in typed production are encapsulated to a degree that prevents interference from spuriously activated entries. Alternatively, the difference in script may have reduced the possibility of interference. Additional analysis of the similarity between English spelling and the Pin Yin transcription of the Chinese loanwords may also reveal effects of formal overlap.

Table 4. Summary of generalized linear mixed effects regression model predicting the correct typing responses.

Fixed Effects	**Estimate**	**Std Err.**	**Z score**	**P value**	**Sig.**
(Intercept)	-0.05	0.47	-0.10	0.92	
Native Language: Other	-0.07	0.26	-0.26	0.80	
Native Language: English	1.52	0.21	7.12	<0.001	***
Accent: Chinese	-0.46	0.10	-4.72	<0.001	***
COBUILD Word Frequency: Low	-0.42	0.21	-2.04	0.04	*
Word Length	0.11	0.06	1.87	0.06	.
Native Language: Other * Accent: Chinese	-0.24	0.14	-1.74	0.08	.
Native Language: English * Accent: Chinese	-0.84	0.12	-6.76	<0.001	***

Compound Correspondence. No direct effect of compound correspondence was found across Chinese-English and monolingual English participants. However, a significant difference was found for high frequency corresponding compounds. Compared to monolingual English participants, Chinese-English bilinguals were more likely to type high frequency corresponding compounds than other high frequency matched controls. The estimate of the statistically significant ($p = 0.001820$) three-way interaction between word frequency, compound correspondence, and native language of participant on response accuracy is plotted in Figure 4. A summary of the model is presented in Table 5.

Table 5. Summary of generalized linear mixed effects regression model predicting the correct typing responses for compound stimuli.

Fixed Effects	Estimate	Std Err.	Z Value	P value	Sig.
(Intercept)	-0.04	0.49	-0.08	0.93	
Native Language: English	1.42	0.33	4.25	<0.001	***
Compound Correspondence: Yes	0.77	0.41	1.88	0.06	.
Co-Build Word Frequency: Low	-0.37	0.38	-0.97	0.33	
Accent: Chinese	-0.27	0.15	-1.86	0.06	.
Constituent 2 Co-Build Word Frequency (log)	0.41	0.17	2.47	0.01	*
Native Language: English * Compound Correspondence: Yes	-0.36	0.28	-1.26	0.21	
Native Language: English * Co-Build Word Frequency: Low	0.25	0.25	0.98	0.32	
Compound Correspondence: Yes * Co-Build Word Frequency: Low	-1.18	0.54	-2.19	0.03	*
Native Language: English * Accent: Chinese	-0.62	0.18	-3.40	<0.001	***
Native Language: English * Compound Correspondence: Yes * Co-Build Word Frequency: Low	1.16	0.37	3.12	0.002	**

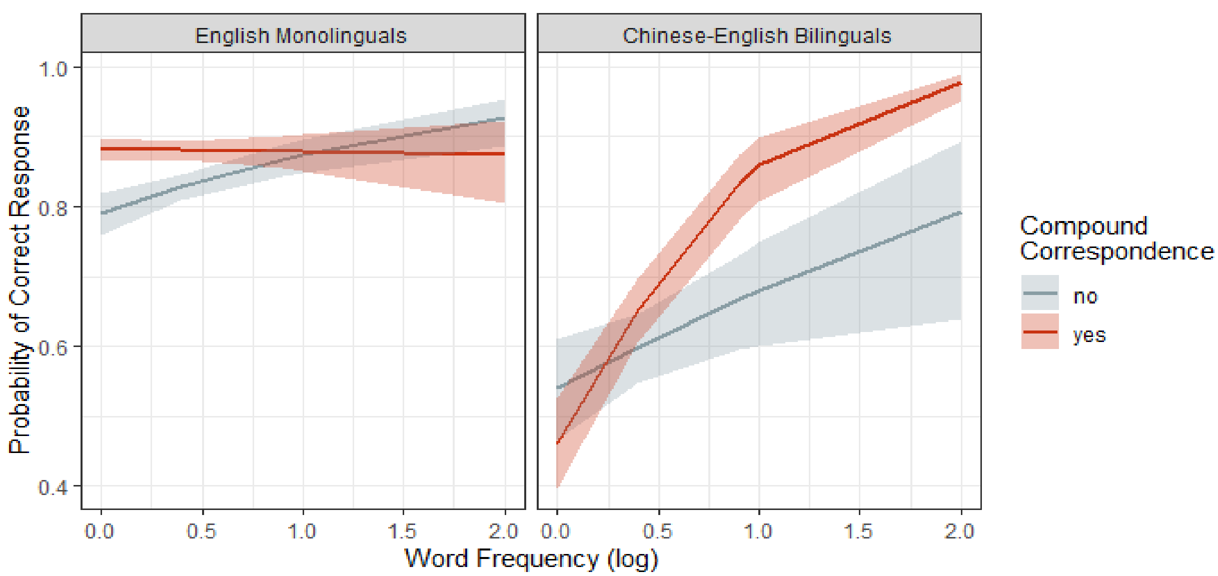

Figure 4. Plotted estimates of the probability of an accurate response by native language of the participant and the accent condition of the stimuli.

Corrected Errors. One limitation of the accuracy scores presented in this thesis is that they conflate two aspects of word processing: recognition and typed production. One way to probe whether an error trial was the result of an accidental production error or a failure to recognize the word is look at trials in which an error was made and subsequently corrected. Although this still fails to recognize trials in which trivial spelling errors were made, it does provide some insight into the production process across different trial conditions.

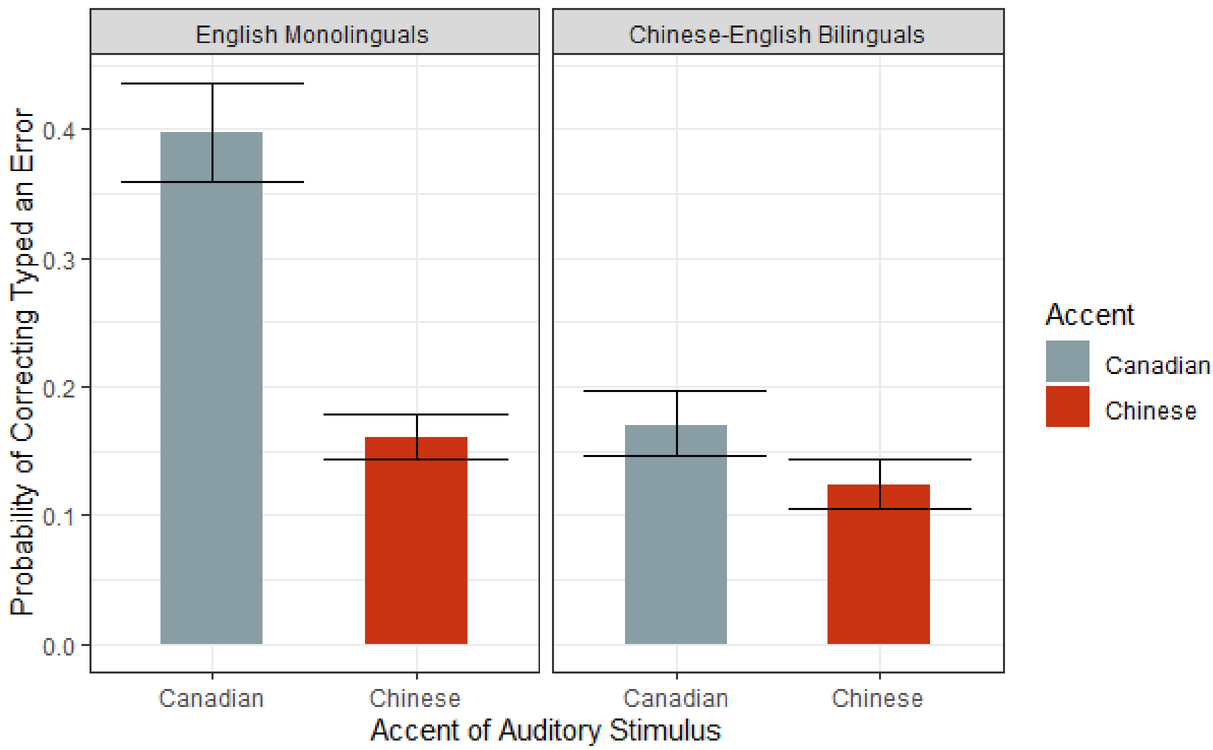

Figure 5. Plotted estimates of the probability of correcting a typed error by native language of the participant and the accent condition of the stimuli.

Table 6. Summary of generalized linear mixed effects regression model predicting the probability of correcting a typed error.

Fixed Effect	**Estimate**	**Std Err.**	**Z value**	**P value**	**Sig.**
(Intercept)	-3.72	0.53	-6.97	0.00	***
Accent: Chinese	-0.38	0.17	-2.28	0.02	*
Native Language: English	1.17	0.31	3.73	<0.001	***
COBUILD Word Frequency: Low	-0.44	0.22	-2.02	0.04	*
Word Length	0.32	0.06	5.15	<0.001	***
Accent: Chinese * Native Language: English	-0.87	0.21	-4.06	<0.001	***

Overall, monolingual English participants were more likely to correct typed production errors than Chinese-English bilinguals. When stimuli were presented in a Chinese accent, all participants were less likely to correct typing errors. As with overall typing accuracy, the reduction in the likelihood of a correct response was significantly greater for monolingual English participants. This seems to indicate that recognition errors were more common for Chinese accented stimuli across both participant groups. However, this is not definitive evidence because it does not take trivial spelling errors and unnoticed errors into account. Though it cannot be confirmed by this data, this finding may also be an indication of the attentional resources available during typed production. The above model estimates seem to indicate that monolingual English speakers are more likely to notice their own production errors when they are typing words presented in a familiar accent. However, this is only speculation and would need to be confirm by a more detailed collation of the data, which is outside the scope of this thesis.

Linear Mixed Effects Regressions Analysis

Method of model fitting. For the purposes of modeling the effects of key independent variables, response data from monolingual English participants served as a baseline against which Chinese-English bilingual responses were compared. In all mixed effects models, participant and stimulus were treated as random effects as this research project does not aim to provide insight into the effects of individual differences on language processing (Baayen, Davidson & Bates, 2008). Rather, it is primarily concerned with between-group differences in language background. Additionally, in analysis of IKSI latency the surrounding trigram, the three-letter combination formed by the typed letter, as well as letters immediately preceding and following it, was added into the model as a random factor. The rationale for its inclusion is that there a number of unknown characteristics of a trigram that will likely effect typing latency but are not of concern to this thesis. For instance, the position of the key on the keyboard relative to the preceding and upcoming letter will likely affect IKSI. However, this will not be a fixed effect because it depends greatly on the typing habits and hand position of the participant. The inclusion of trigram as a random effect should help to account for some of the idiosyncrasies of typed production.

The following analysis only included correct trials, i.e. trials containing no typing errors. Trials in which an error was made but subsequently corrected are also excluded, as were trials containing spelling errors or spaces between compound constituents. This thesis uses IKSI latency to determine the relationship between morphological structure and on-line typed production. Errors may cause irregular spikes in latency which may bias model predictions and added spaces or correction may affect word length or typing position. Trials with key presses deviating even slightly may confound results in unforeseen ways. Therefore, strict criteria for correctness were employed as a preventative measure, despite resulting in a smaller data set.

Phonological Correspondence

Analysis of phonological correspondence reported here included only responses from Chinese-English bilingual and monolingual English-speaking participants. This was done to reduce the complexity of models, which included complex interactions with native language and other independent variables. Preliminary analyses on responses from mixed-L1 bilinguals did not exhibit any significant differences on the basis on phonological correspondence between Chinese and English, as was expected.

Typing onset latency and phonological correspondence. Analysis of phonological correspondence involved only responses to loanwords with phonological correspondence and matched controls. An LMER model was created to estimate the contribution of phonological correspondence on typing onset latencies. It was hypothesized that responses by Chinese-English bilinguals would differ significantly from monolingual English speakers due to cross-linguistic co-activation on the basis of phonological similarity. Therefore, an interaction between the stimulus type (phonological correspondence vs. no phonological correspondence) and native language (Chinese and English) was included in the model. Accent of the stimulus was also included as a main effect. A summary of the model is presented in Table 4 and a plot of the regression lines for the interaction between phonological correspondence and native language of the participant is shown in Figure 4.

Table 7. Summary of linear mixed effects regression model predicting the effect of phonological correspondence on typing onset times.

Fixed effects	**Estimate**	**Std. Error**	**df**	**T value**	**Pr(>|t|)**	**Sig**
(Intercept)	0.65	0.03	236.70	19.55	<0.001	***
Native Language: English	-0.09	0.02	105.90	-4.27	<0.001	***
Phonological Correspondence: Yes	0.02	0.02	109.70	1.45	0.15	
Accent of Stimulus: Chinese	0.05	0.01	977.40	7.39	<0.001	***
COBUILD Word Frequency (log)	-0.02	0.01	41.71	-2.13	0.04	*
Audio File Length	0.34	0.04	241.60	8.28	<0.001	***
Trial Order	0.00	0.01	92303.00	-3.12	<0.001	**
Native Language: English * Phonological Correspondence: yes	-0.04	0.01	2285.00	-2.96	<0.001	**

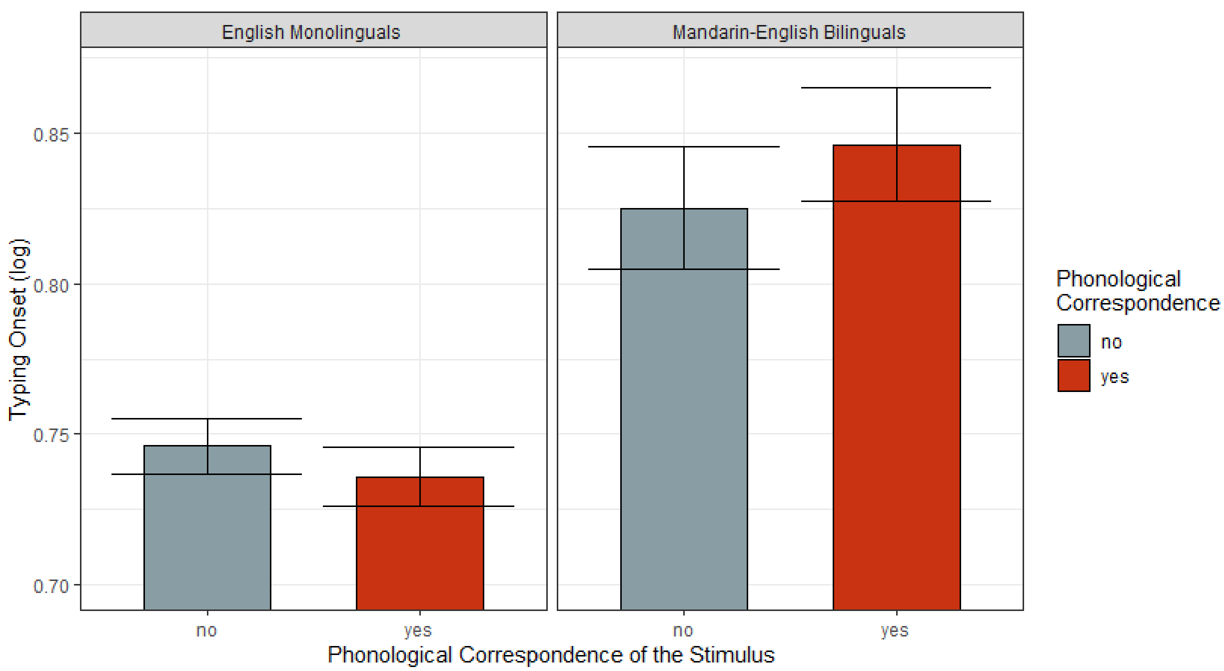

Figure 6. Bar plot for the fixed effects phonological correspondence and native language on typing onset.

According to the model, phonological correspondence led to greater typing onset latencies in the Chinese-English bilinguals when compared to monolingual English speakers. This interaction was statistically significant ($p = 0.00315$). Phonological correspondence did not, however, affect typing onset times for English monolinguals. Thus, no main effect of phonological correspondence was observed. A significant ($p = << .001$) main effect of accent was also observed across all participant groups. To test whether the degree of cross-linguistic co-activation was influenced by the accent of speaker, a three-way interaction between accent, phonological correspondence, and native language was added, but the interaction was not quite approaching significance ($p = 0.106$).

Inter-keystroke interval latency and phonological correspondence. No effect of phonological correspondence was found on IKSIs for words exhibiting phonological correspondence in Chinese-English bilinguals. This is consistent with the finding that phonological correspondence did not influence typing accuracy. Thus, the effect of phonological correspondence seems to be isolated to the process of lexical access and word recognition. Any interference caused spuriously activated lexical competitors seems to be resolved prior to the onset of typed production.

Morphological Correspondence

As with the analyses of phonological correspondence, analyses reported here included only responses from Chinese-English bilingual and monolingual English-speaking participants. Morphological correspondence did not have a significant effect on mixed-L1 participants' responses.

Typing onset latency and morphological correspondence. Just as with typing accuracy, compound correspondence was only found to be a significant predictor of Chinese-English bilingual typing onset latency when interacting with word frequency. High frequency corresponding compounds exhibited reduced typing onset latencies in Chinese-English bilingual participants. This is shown in Figure 7. A summary of the model presented in Table 8. No difference was seen in low frequency compounds compared with matched controls. Similarly, no effect of compound correspondence was observed in monolingual English participants. The same predictors of typing onset latency used in the model of phonological correspondence (audio file length, word frequency, and accent) were used here.

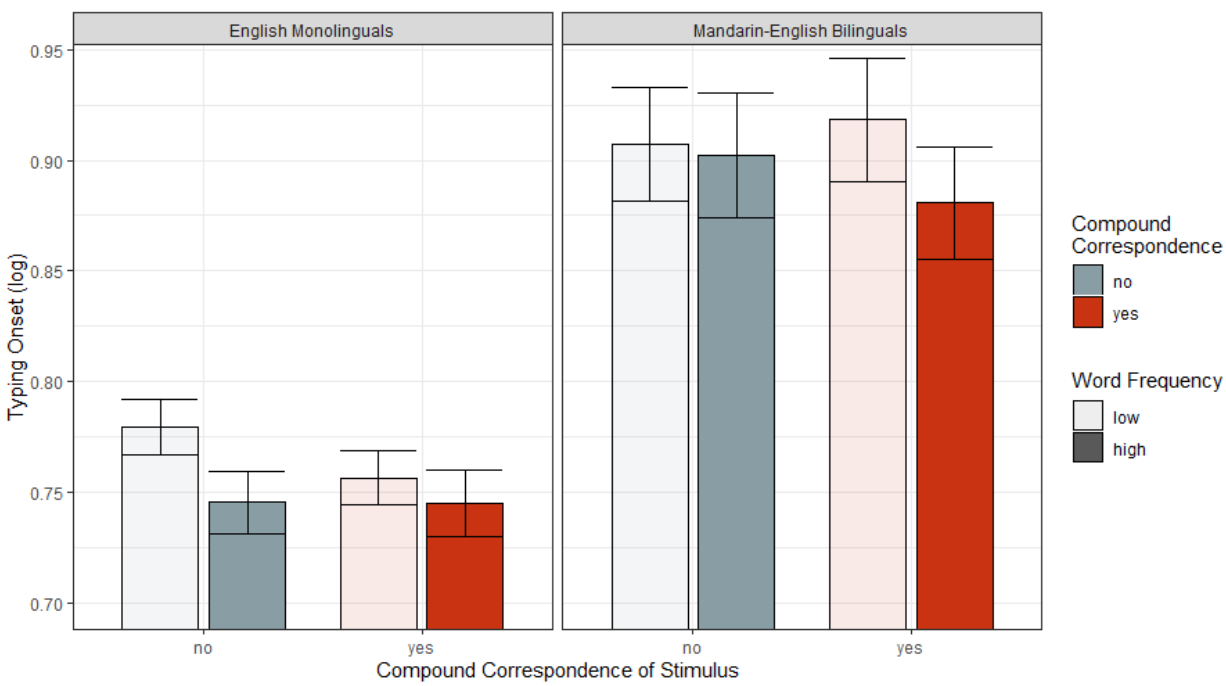

Figure 7. Bar plot of the fixed effects of morphological correspondence, word frequency, and native language on typing onset.

Table 8. Summary of linear mixed effects regression model predicting the effect of phonological correspondence on typing onset times.

Fixed Effects	Estimate	Std Err.	df	t value	P value	Sig.
(Intercept)	0.76	0.04	326.50	20.30	<0.001	***
Native Language: English	-0.14	0.02	168.00	-6.32	0.00	***
Compound Correspondence: Yes	-0.03	0.03	83.65	-1.11	0.27	
COBUILD Word Frequency: Low	0.00	0.03	100.40	0.18	0.86	
Accent: Chinese	0.09	0.01	1052.00	9.74	<0.001	**
Audio File Length	0.11	0.04	677.20	2.51	0.01	*
Native Language: English * Compound Correspondence: Yes * COBUILD Word Frequency: Low	-0.09	0.03	2676.00	-3.59	0.00	***

Inter-keystroke interval latency and morphological correspondence. Analysis of morphological correspondence looked only at responses to corresponding compounds and matched controls. It was hypothesized that an interaction between compound correspondence and native language would be observed, indicating the co-activation on the basis of similar compound structure. Initial model fitting did not indicate any significant effects of compound correspondence on typing onset latency. To further explore the data, various models were constructed using the ‘regsubsets’ function in the ‘leaps’ R package. This function takes a set of predictor variables and the model with the highest R-squared value, indicating goodness-of-fit. None of models returned by this function included compound correspondence as a significant predictor of IKSI latency for Chinese-English bilinguals.

While no effect of compound correspondence was found on overall IKSI latency, when considering the effect of compound correspondence at the morpheme boundary between compound constituents, a significant effect was observed.

To model the effect of morphological correspondence and native language on typed word production several independent variables were included to account for variability in word typing difficulty. Bigram mean, the average frequency of all two-letter bigrams in the word, was used as a measure of typing difficulty at the word level. The underlying assumption being that words containing more infrequent bigrams would be more difficult to type, leading to longer typed production times. Bigram mean values for each stimulus were retrieved from the English Lexicon Project database (Balota et al, 2007). Word length was added to account for word level typing difficulty. Word frequency (based on instances in the COBUILD Corpus, taken from Celex Database) was initially included in the model, but was removed as it was not a strong predictor.

Trigram frequency, the frequency of a given three-letter combination, was included as a control for individual letter typing difficulty. Given that typed word production proceeds in a cascade fashion, individual letter typing latency is closely related to the letters surrounding it. Letters in the middle position of infrequent trigrams were assumed to take longer to type because the articulatory motor patterns involved in producing that trigram are less common, and therefore, less automatized.

Finally, to account for variations in participant typing ability, the coefficient of variability (CV) was calculated for each participant by dividing the standard deviation by the mean of IKSIs of their responses. CV values are one way to operationalize production proficiency (Segalowitz & Segalowitz, 1993) as lower variability is an indication of higher automaticity, which is, in turn, associated with higher proficiency. Stated simply, participants with more consistent IKSI across all conditions were taken to be more proficient typists. Given the repetitive nature of the typing task, it was also hypothesized that participants typing times would improve over the course of the experiment. To account for habituation to the task, trial order was also included.

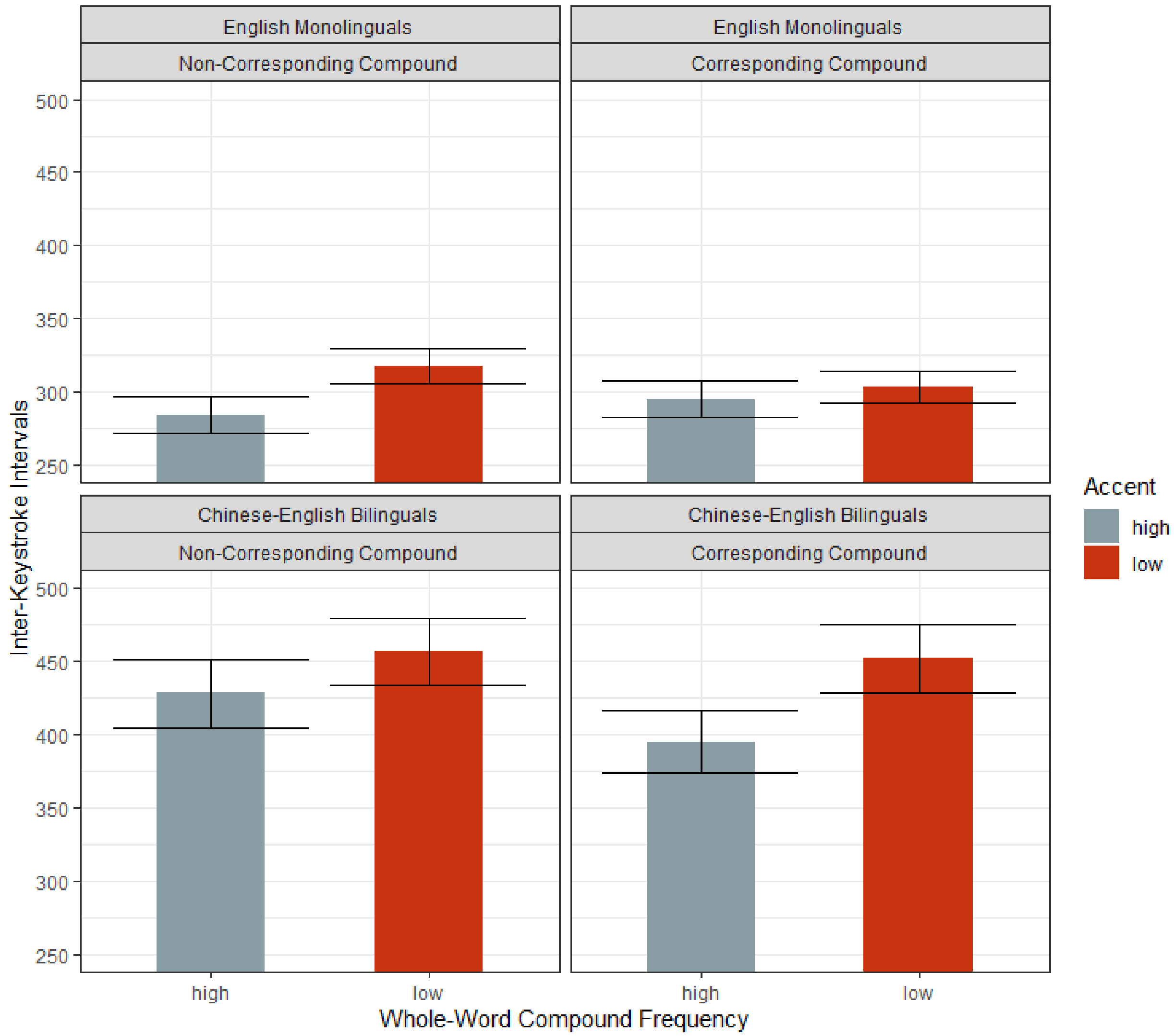

Figure 8. Regression lines for the fixed effect of the interaction between morphological correspondence, word frequency, native language, and typing position on inter-keystroke intervals.

This LMER model contained many predictor variables, including a four-way interaction. In accordance with the principle of parsimony, and to prevent over-fitting, the model was constructed hierarchically, adding one predictor at a time and comparing the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) across models. These criteria measure model-fit, taking number of predictors into account help ensure parsimony. The final AIC and BIC were lower than initial (428587 and 428638, compared to 230952, and 231140, respectively) and steadily decreased as new predictors were added, indicating that goodness-of-fit outweighed the penalty applied for additional variables. The addition of bigram mean resulted in a higher relative AIC and BIC. The p=value also indicated it was not a significant predictor. It was removed from the model. A summary of the LMER model including all remaining predictors is shown in Table 9. The regression lines for the interaction between phonological correspondence and native language are shown in Figure 8.

Effects of Foreign-Accent

Typing Onset and Accent. The following analyses were conducted on response data to all stimuli for all participants. Firstly, an LMER model was used to determine the contribution of accent condition to typing onset latencies. A highly significant ($p = << 0.001$) main effect of accent was observed. To further explore the relationship between accent and language background, an interaction between these two variables was added. The results of these interactions are plotted in Figure 6 and a summary on the LMER model is shown in Table 6. The model estimates indicate that foreign accent led to greater typing onset in English monolinguals compared to other bilingual participants. Unlike typing accuracy, no significant differences in overall typing onset latency ($p = 0.8$) was observed across bilingual populations, nor was the effect accent significantly different based on language background ($p = 0.17$). As with previous models of typing onset, audio file length, word frequency, and trial order were all significant predictors. A summary is provided in Table 10.

Table 9. Summary of linear mixed effects regression model predicting the effect of phonological correspondence on inter-keystroke intervals.

Fixed Effects	**Estimate**	**Std Err.**	**df**	**t value**	**P value**	**Sig.**
(Intercept)	521.77	47.55	110.20	10.97	<0.001	***
Morpheme Boundary: Yes	163.20	11.91	18391.68	13.70	0.00	***
Compound Correspondence: Yes	-2.80	8.45	148.39	-0.33	0.74	
Native Language: English	-83.33	14.02	100.58	-5.94	<0.001	***
Co-Build Word Frequency: Low	4.39	8.40	177.06	0.52	0.60	
Trigram Frequency (log)	-6.04	0.89	15864.18	-6.81	<0.001	***
Coefficient of Variance (IKSI)	-310.13	57.81	79.19	-5.36	<0.001	***
Forward Bigram Frequency (log)	521.77	47.55	110.20	10.97	<0.001	***
Constituent 2 Co-Build Word Frequency (log)	163.20	11.91	18391.68	13.70	0.00	**
Trial Order	-2.80	8.45	148.39	-0.33	0.74	**
Morpheme Boundary: Yes * Native Language: English	-83.33	14.02	100.58	-5.94	<0.001	***
Morpheme Boundary: Yes * Compound Correspondence: Yes * Native Language: English	4.39	8.40	177.06	0.52	0.60	*
Morpheme Boundary: Yes * Compound Correspondence: Yes * Native Language: English * Co-Build Word Frequency: Low	-6.04	0.89	15864.18	-6.81	0.007	*

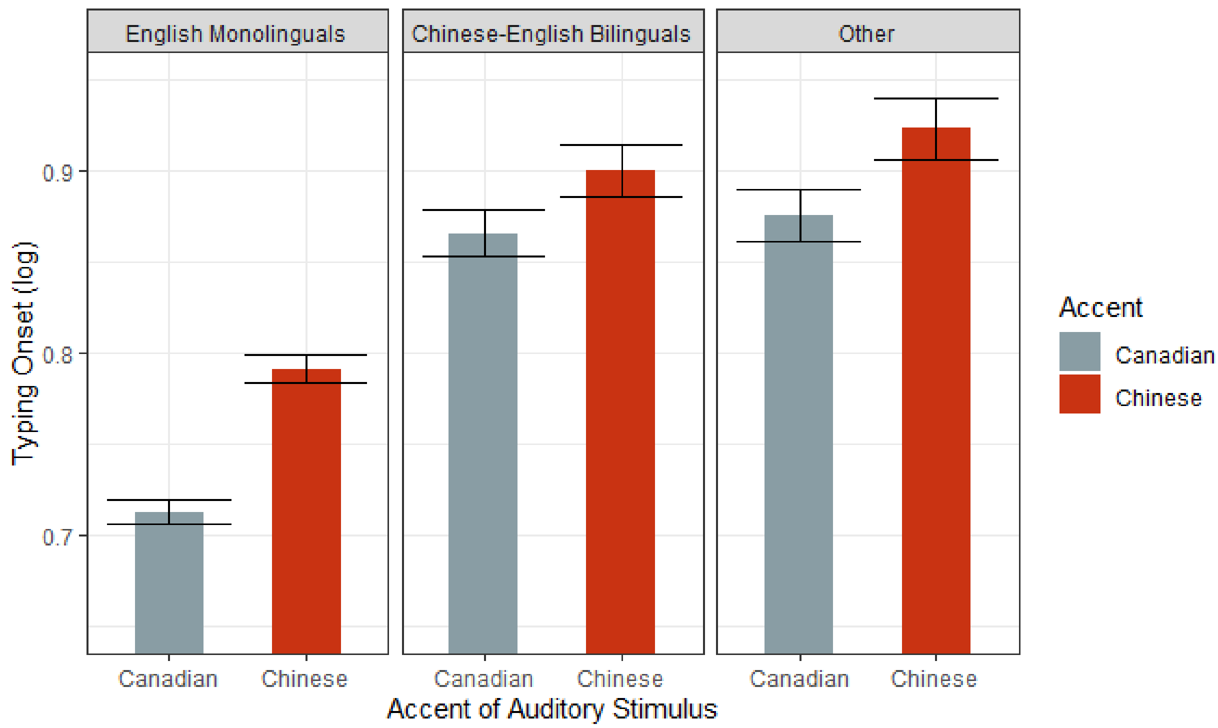

Figure 9. Regression lines showing estimated main effects of the native language of the participant and accent condition of the stimuli on typing onset latency.

Table 10. Summary of linear mixed effects regression model predicting the effect of native language of the participant and accent condition on typing onset for all stimuli.

Fixed effects	**Estimate**	**Std. Error**	**df**	**T value**	**Pr(>|t|)**	**Sig**
(Intercept)	0.73	0.02	403.00	29.39	<0.001	***
Native Language: English	-0.14	0.02	120.30	-6.97	0.00	***
Native Language: Other	0.01	0.03	122.20	0.26	0.80	
Accent: Chinese	0.03	0.01	5390.00	3.63	0.00	***
COBUILD Word Frequency (log)	-0.02	0.01	95.81	-2.13	0.04	*
Audio File Length	0.23	0.03	805.90	9.10	<0.001	***
Trial Order	0.00	0.00	6064.00	-3.17	0.00	**
Native Language: English * Accent: Chinese	0.05	0.01	6021.00	5.13	0.00	***
Native Language: Other * Accent: Chinese	0.02	0.01	5972.00	1.37	0.17	

Inter-keystroke interval latency and accent. To model the main effect of accent on inter-keystroke interval latency, predictors accounting for word-level typing difficulty (length, frequency, and overall bigram mean), letter-level typing difficulty (trigram frequency, bigram frequency, and morpheme boundary), and participant typing ability (CV, native language, and trial order) were included as predictors. Both forward and backward bigram frequencies were included in the model. Backward bigram frequency is the frequency of the two-letter combination formed by the current and subsequent letter, while backward bigram frequency is the frequency of two-letter combination formed by the current and preceding letter. AIC and BIC were considered to ensure parsimony. A significant difference in IKSI latency was observed between English monolinguals and Chinese-English bilingual participant groups with monolinguals typing faster overall. No significant difference was observed between bilingual populations. Chinese accented stimuli led to greater IKSIs and did not show any differences across participants groups. This effect is plotted in Figure 10. Further analysis revealed that accented stimuli exhibited greater IKSIs only during the early stages of typed production. A significant interaction ($p = 0.00325$) was observed between typing position and accent was observed when only the first 4 IKSIs were considered. IKSIs past position 4 did not show any differences across accent conditions. This is effect is plotted in Figure 11.

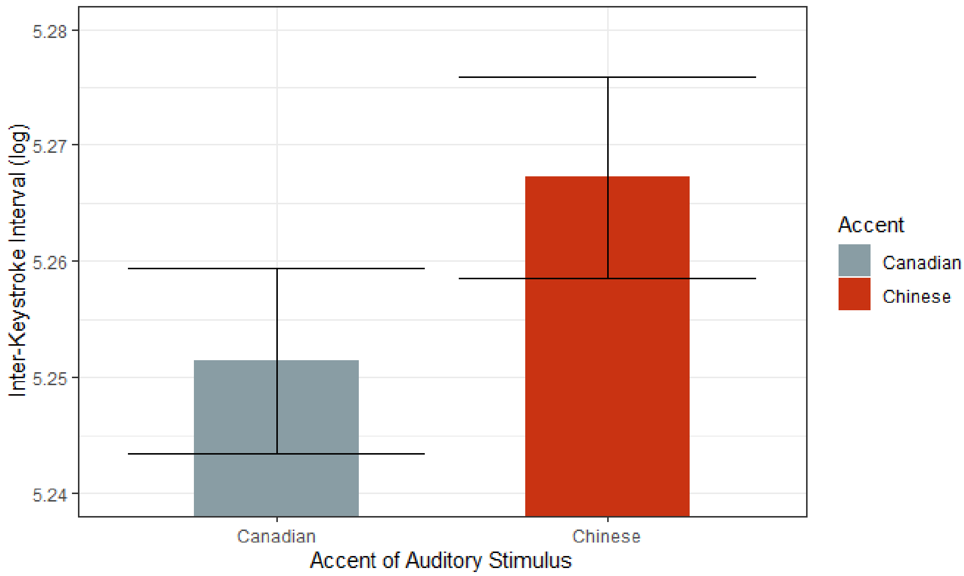

Figure 10. Regression lines showing estimated main effects of accent on inter-keystroke interval latency.

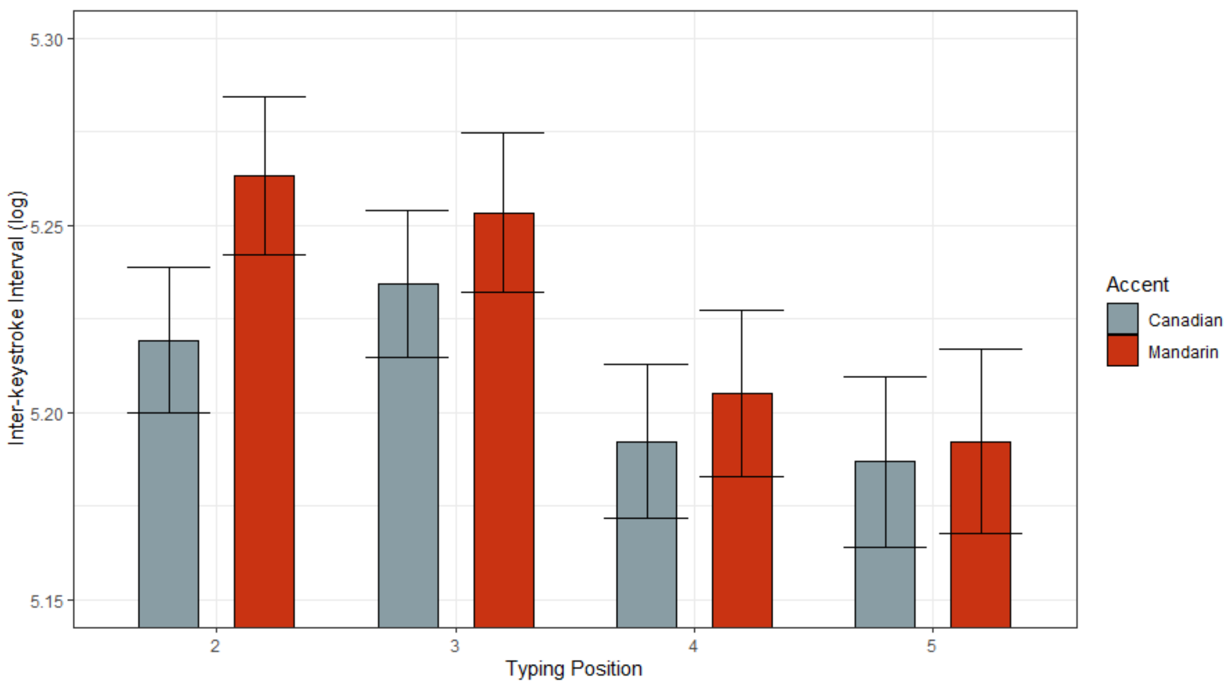

Figure 11. Regression lines showing estimated effects typing position and accent on inter-keystroke intervals.

Table 11. Summary of linear mixed effects regression model for inter-keystroke intervals for all stimuli and all participant groups.

Fixed Effects	Estimate	Std Err.	df	t value	P value	Sig.
(Intercept)	5.68	0.12	1125.00	48.13	<0.001	***
Native Language: English	-0.27	0.06	106.70	-4.45	0.00	***
Native Language: Other	0.01	0.07	107.90	0.14	0.89	
Accent: Chinese	0.08	0.02	23440.00	3.90	<0.001	***
Typing Order	-0.02	0.00	23420.00	-4.44	<0.001	***
Trigram Frequency (log)	-0.03	0.00	16870.00	-6.56	<0.001	***
Word Length	0.01	0.01	104.10	1.90	0.06	.
Morpheme Boundary: Yes	0.37	0.01	17480.00	25.37	<0.001	***
Co-Build Word Frequency (log)	-0.04	0.02	97.94	-2.20	0.03	*
Backward Bigram Frequency (log)	-0.02	0.00	20020.00	-5.66	<0.001	***
Forward Bigram Frequency (log)	0.03	0.00	20400.00	7.55	<0.001	***
Accent: Chinese * Typing Order	-0.02	0.01	23380.00	-2.94	0.003	**

DISCUSSION

This thesis was broken down in four goals: 1) methodological innovation, 2) interlingual association based on phonological and 3) morphological overlap, and 4) the role of accent in cross-linguistic co-activation. The discussion section will be sub-divided to address to extent to which these goals were achieved.

Goal 1: Methodological Innovation

This thesis made a methodological contribution to the field of psycholinguistics by conducting a chronometric behavioral experiment using the newest version of the PsychoPy experiment design software, PsychoPy3, which allows experiments to be created in Javascript code and run web-browsers. The beta-version of this technology was released in July 2018 and contained many bugs and glitches, which needed to be worked through with the development team. In most cases, obstacles and limitations were encountered that required a great degree of problem-solving to overcome. Additional complications arising from running the experiment online posed significant difficulty. Data were lost due to glitches and incompatibility with web-browsers, participants were confused by unclear instructions, and the experiment needed to be redesigned to be compatibility with software updates. However, throughout the process, considerations and best practices for PsychoPy3 and online experimentation in general emerged. These are outlined in a co-authored paper titled ‘No lab, no problem: Designing lexical comprehension and production experiments using PsychoPy3’ (Gallant & Libben, 2019) and in a series of tutorial videos outlining how to build psycholinguistic experiments in PsychoPy3. (https://youtu.be/lApinal-eUs).

Despite the many obstacles faced in running PsychoPy3 experiments online, the results reported above suggest that the experiment was able to replicate well established behavioural effects. Analysis of frequency and morpheme boundary effects support the validity of PsychoPy3 as a psycholinguistic measurement tool. Thus, in addition to contributing to our understanding of PyschoPy3 as a tool for online experiment, this thesis was also able to validate its developers’ claims of high temporal precision.

Goal 2: Interlingual Association and Phonological Overlap

This goal aimed to determine whether lexical entries in the Chinese-English bilingual lexicon were associated on the basis of phonological overlap responses to English target words with phonological similarity to Chinese loanword equivalents (e.g. cookie and qǔqí). Lexical association was investigated using behavior measures: typing accuracy, typing onset, and IKSIs.

Overall, significant differences in typing onset to loanwords, compared with controls, were observed only in the Chinese-English bilingual participant group. According to the non-selective lexical access hypothesis (Marian & Spivey, 1999), words from both languages exhibiting interlingual phonological association are activated during lexical access, regardless of task relevance. For Chinese-English bilinguals, greater typing onset latencies for words with phonological correspondence suggests that corresponding Chinese lexical entries were co-activated during the processing of English loanwords. Greater typing onset latencies reflect the additional time required to inhibit spurious activation and resolve the process of lexical selection. Although cognitive processes involved in the retrieval and execution of the motor plan for these words also occurred prior to the typing onset, the inclusion of predictors, such as the letter typed, as random factors in the model of typing onset hopefully accounted for some of the noise attributable to these unrelated cognitive processes.

These results are consistent with the well-established finding that during the unfolding of the auditory speech signal, entries corresponding from both languages are activated (Blumenfeld & Marian, 2007, 2011, 2013; Conseco-Gonzalez et al, 2010; Ju & Lace, 2004; Marian & Spivey, 1999, 2003a, 2003b; Spivey & Marian, 1999; Weber & Cutler, 2004; Weber & Paris; 2004). The results reported in this thesis further extend findings on non-selective lexical access to Chinese-English bilingual populations and supports results showing that cross-linguistic co-activation of phonologically similar lexical entries can occur in the absence of orthographic form overlap in different-script bilinguals (Hoshino & Kroll, 2008).

No effect of phonological correspondence was observed for typing accuracy or IKSIs. This leads to several possible interpretations. One possibility is that spuriously activated corresponding Chinese lexical entries were effectively inhibited prior to the onset of typed production. Thus, interference from the corresponding Chinese orthographic code is not observed. Alternatively, the interlingual association of lexical entries may be limited to connection on the basis of certain lexical information, such that the orthographic code of phonologically corresponding words is not activated during lexical access in different script bilinguals. Finally, since no difference in IKSIs were observed for stimuli exhibiting cross-linguistic form overlap, it is possible that typed production is sufficiently automatic and cognitively encapsulated that interference from spuriously activated lexical entries is not possible.

One unexpected finding was that English monolinguals exhibited reduced typing onsets latencies to stimuli exhibiting phonological correspondence between Chinese and English. Since none of the monolingual participants had any knowledge of Chinese, this was surprising. While this result may have been the result of an unidentified confounding variable in the stimulus list, there is a chance that phonological form overlap led to slight differences in the quality of recordings. Processing benefits for words with cross-linguistic correspondence have been observed in the oral production of cognates (Costa, Caramazza, & Sebastián-Gallés, 2000). It is possible that stimuli with phonological correspondence were produced more clearly by Chinese-English bilinguals during the recording of auditory stimuli. Greater typing latencies were observed in Chinese-English bilinguals despite this potential confound. However, more careful consideration of these effects may have led to greater effects of phonological correspondence being observed in Chinese-English populations.

Goal 3: Interlingual Association and Compound Overlap

It was predicted that cross-linguistic co-activation on the basis of compound correspondence would lead to lexical interference, and therefore, slower response times. However, the opposite effect was observed for both typing onset latencies and IKSIs at the morpheme boundary of corresponding compounds. Similarly, typing accuracy for corresponding compounds was significantly higher compared to matched controls.

Improved typing accuracy for corresponding compounds observed in Chinese-English bilingual participants supports previous results reported by Cheng, Wang and Perfetti (2011) in early Chinese-English bilingual children. The presence of a compound in the L1 with corresponding constituent structure seems to aid the acquisition and recall of corresponding compounds. Cheng, Wang and Perfetti reported higher accuracy scores during a lexical decision task, indicating that compound recognition was facilitated by compound correspondence. This thesis extends these findings to the typed production of compounds as well.

These findings are consistent with the pattern of L2 acquisition outlined in the Revised Hierarchal Model (RHM) (Kroll & Stewart, 1994). According to the RHM, the connection between an L2 lexical representations and the corresponding concept is mediated by the L1 representations. As L2 lexical representations develop, they become more and more independent of the L1 representation. The BIA-d model (Grainger, Midgley, & Holcomb, 2010) describes how co-activation patterns of L1 translation equivalents vary over the developmental span of L2 proficiency. As bilinguals become more proficient in their L2, the co-activation of L1 representations is lessened. In the case of corresponding compounds, the development of L2 lexical representations seems to be facilitated by the existence of a corresponding structure in the L1. Thus, the L1 structure acts as a kind of heuristic that can be immediately adopted by the L2 representation. Higher accuracy scores reported by Cheng, Wang, & Perfetti (2011) and in this thesis, seem to indicate a facilitation of L2 acquisition. Faster typing onsets and shorter IKSIs at the morpheme boundary for English corresponding compounds seem to indicate a stronger L2 lexical representation that is relatively independent from the L1 Chinese representation. Following the BIA-d, this would suggest that corresponding L1 constituent structure also aids in the continued development of L2 representations. Since only high frequency corresponding compounds exhibited a facilitation effect, it follows that this benefit only occurs through repeated use. This is consistent with the theory of morphological transcendence (Libben, 2014), which posits that compound constituent representations develop through repeated exposure. Thus, as L2 compound constituent representations form over the developmental span, the presence of corresponding constituent representations facilitate the formation of L2 constituent representations and the overall strengthening of the L2 lexical representation.

These results indicate that morphological integration does play a role in on-line processing and acquisition of corresponding compounds. Corresponding compound structure provides a schema by which new L2 constituent representations can be stored in mental lexicon. Corresponding compound structure does not seem to play a role in lexical access. Rather it seems to facilitate the development of independent L2 lexical representations, resulting in reduced co-activation of translation equivalents during L2 lexical processing, which is likely related to the developmental pattern of compound constituent representations.

Goal 4: Understanding the Role of Accent

The goal of this thesis was to determine whether accent influenced the degree of cross-linguistic co-activation. It was hypothesized that Chinese-English bilingual responses to stimuli exhibiting morphological and phonological correspondence would be more affected by accent relative to match controls. No interaction between stimulus type and accent was observed. Thus, the hypothesis was not confirmed, and the null hypothesis was not rejected. However, other effects of accent on typing accuracy, typing onset, and IKSIs were observed and are discussed below.

Accuracy scores for accented stimuli replicated previous findings that foreign-accented speech is less intelligible than non-accented speech regardless of language background (Munro, Derwing, & Morton, 2006). This does not mean that foreign accent in unintelligible. Rather, that foreign accent is simply less intelligible than native speech. While all participants had lower typing accuracy for foreign-accent stimuli, the effect was greatest for English monolingual speakers. This is likely due to higher overall proficiency and greater familiarity with native speech. There was no statistically significant difference between the typing accuracy of Chinese-English bilinguals and mixed-L1 bilinguals, though the p-value approached significance ($p = 0.0827$). This may have been due to greater familiarity with the phonological variation characteristic of Chinese-accented English (Adank, Evans, Stuart-Smith & Scott, 2009). Previous studies have reported evidence of a matched interlanguage speech intelligibility benefit (Smith & Bisazza, 1982; Munro, Derwing & Morton, 2006; Bradlow & Bent, 2008), suggesting bilinguals find speech consistent with their own interlanguage more intelligible than other types of speech, including native speech. This thesis provides only weak support of an interlanguage benefit in the form of a lessened disadvantage to L1-accented speech relative to other bilinguals and monolinguals. There are several differences in method between this thesis and previous studies on interlanguage intelligibility that may account for differing results. The use of sentence stimuli in previous studies may have disproportionately benefitted less intelligible L1-accented input by providing disambiguating contextual information. Similarly, the conservative collation of correct response used in this thesis may have conflated production errors with recognition errors. This potentially conflates a measure of comprehensibility with a measure of intelligibility. Comprehensibility refers the effort required to comprehend speech (Derwing & Munro, 1995). This has typically been operationalized using subjective ratings. However, typed production may provide a useful on-line measure of comprehensibility.

Typing onset latency for accented stimuli was also slower than for non-accented stimuli across all participant groups. As with typing accuracy, this difference was greatest for English monolinguals, likely due to their unfamiliarity with Chinese-accented speech. However, no difference in typing onset was observed between Chinese-English and mixed-L1 bilinguals. Longer typing onset latency is consistent with previous research reporting longer recognition times for foreign-accent stimuli (Munro & Derwing, 1995; Wilson & Spaulding, 2010). Foreign-accented word recognition involves greater processing difficulty arising from inconsistencies in stored phonological representations and incoming input signals. The resolution of unpredictable phonological variations results in longer recognition time, and therefore, longer typing onset latencies. Thus, foreign-accented speech in considered less comprehensible. This suggests that while an interlanguage intelligibility benefit may exist, there is no apparent comprehensibility benefit.

Accent does seem to play a role in lexical access and selection. Foreign-accent input typically does not map as accurately onto the phonological representations of lexical entries in the lexicon. The processes involved.

A main effect of accent on IKSIs during early typed production was also observed for all participant groups across all stimulus types. This effect suggests that foreign-accented words are not only more difficult to recognize, but are initially more difficult to type, even after they have been correctly recognized. It is possible that longer typing latencies are capturing a behavioral consequence of uncertainty. This may relate to the process of lexical selection. It is possible that the imperfect mapping of input onto lexical representations does not effectively inhibit lexical competitors. As a result, subsequent typed production is subject to interference from competing activated entries. Alternatively, longer IKSIs during early typed production may be due to relatively lower activation of target lexical representations, such that the orthographic code of the target receives relatively less excitatory stimulation during lexical activation. Before the word can be successfully typed, the orthographic code of the target must be further excited, leading to delayed production.

Our current understanding of lexical access, selection and subsequent production revolves around the notion of lexical representations: abstract entities containing the lexical information corresponding to a word. These representations are likely dynamic to allow for slight phonological variations and idiosyncrasies unique to different individuals and groups of speakers. The pathways and mechanisms leading to the activation and selection of lexical entries is poorly understood. Several possibilities may account for production difficulty stemming from phonological input variation. One possibility takes our finite supply of cognitive resources into account. As discussed, foreign-accented input requires some massaging to map onto phonological representations. Perhaps reallocation of cognitive resources to these processes leads to fewer resources available for production. This would account for slower typed production times.

Another possibility considers the co-activation of phonological neighbors. During the search process where multiple candidates matching the auditory input are becoming activated and competing with one-another for selection (Marslen-Wilson, 1985), it is possible that in cases of imperfect phonological mapping, co-activated entries remain more higher activated relative to the selected entry. During the subsequent production of that word, phonological neighbors may interfere with access to target articulatory motor code. Thus, during the process of typed production the competing articulatory codes of phonological neighbors must be inhibited to ensure correct typed production. This account would help explain longer IKSI latencies for phonologically corresponding loanwords in Chinese-English bilingual participants. Co-activation of interlingual competitors may have led to conflicts between articulatory codes, which would have to be resolved to successful type the word. However, IKSI of phonologically corresponding loanwords were not affected by accent.

Collectively, the relatively lower accuracy scores, increased typing onset latencies and IKSIs for stimuli in the Chinese-accent condition reported across all participant groups are consistent with previous findings that foreign-accented speech requires more cognitive resources to process regardless of language background. Put more generally, unpredictable phonological variations inconsistent with internal lexical representation in long-term memory necessitate greater involvement of cognitive resources to ensure successful word recognition. Furthermore, a connection between these processing difficulties and subsequent typed production was identified, a finding which warrants further investigation. Previous studies have shown an effect of phoneme-grapheme correspondence on the ease of typed production. Phonological variation in accented speech may interfere with the mapping of sounds to written language.

Limitations

The central limitation, but also one of the key contributions, of this thesis was the choice to use a largely un-tested, newly released experiment design software (PsychoPy3) and online platform (Pavlovia). This led to many technical difficulties which resulted in lost data and participants. During the running of this experiment, many unforeseen complications arose due to bugs in the PsychoPy3 software. While many of these issues were eventually mitigated with help from the PsychoPy3 development team, significant portions of data were lost due to crashes and incompatibilities with participants' web browsers. Additionally, early versions of the experiment showed unpredictable shifts in recorded response latency and stimulus presentation due to sub-optimal coding on the part of the experimenter. It is possible that many technical difficulties were not reported because the participants simply chose to withdraw from the experiment. Since data are only collected once the experiment is complete, there is no way to tell how many willing participants were lost in this way. One of the benefits of online experimentation is access to large participant pools via platforms such as MTurk. However, it was discovered that the countries with a large number of MTurk workers is currently limited. Consideration of MTurk worker demographics would have aided greatly in the recruiting of participants on this platform.

Another limitation of this thesis is the reliance of typing onset time to measure word recognition. As discussed, other processes, such as the retrieval and execution of an articulatory plan, must occur prior to first keystroke. Thus, this measure risks conflating processes that may have been differentially affect by the independent variables in the experiment. Moreover, the temporal resolution of auditory stimulus delivery in PsychoPy3 had not been guaranteed at the time of running the experiment. At the time, random fluctuations of between 10 and 30ms had been reported by developers. Thus, although systematic patterns in typing onset latencies were observed, it likely that random variation in stimulus onset times added noise into the final data set that cannot be identified or accounted for in regression models. The issue of variation in auditory stimulus delivery has been remedied in the newest 3.2.0 release of the software. Despite being a limitation of this research, future researchers wishing to use online methods of research should not be deterred as the precision, accessibility, and usability of available technologies seem to be steadily improving.

The final limitation was a lack systematicity in the selection of loanword stimuli and the manipulation of accent. Firstly, phonological similarity ratings should have been taken from several raters, instead of one, and the rating collected should have been stored for use during data analysis. Additionally, several phonological factors such as tone structure and Pin Yin transcription were not considered and may have acted as confounding variables. Similarly, the operationalization of foreign accent would have benefitted from being more systematic. Accent was treated as a categorical variable and Chinese-English bilingual recordings were not analyzed to identify the types of phonological variation that occurred in their production of the stimuli. Had the recordings been subjected to phonetic analysis, keystroke accuracy and inter-keystroke interval data could have analyzed on the basis of specific phonological variations. This would have added a great degree of depth to the analysis and potentially provide further insight into the connections between accent and typed word production.

Applications

The facilitation of cross-linguistic compound structure has important implications for vocabulary and reading instruction in instructed second language acquisition. Instruction directed at improving morphological awareness is typically given very little attention in second language learning curriculums and classrooms. What the findings of this thesis support is the notion that morphological structure aids in the recall and production of vocabulary items (Zhang & Koda, 2012; 2013). This is, in part, due to the way that our mental lexicon is organized, where the richer the connection between entries, the stronger those mental representations are, and in part to the fact that knowledge of morphemes leads to faster word recognition (Ramirez, Chen, Geva, & Luo, 2011). Thus, when a new word is encountered and stored, the more knowledge surrounding that word (in terms of meaning, related terms, and structure), the more effectively that word is retained. Increased morphological awareness also serves to strengthen connections between existing morphologically complex entries in the mental lexicon (Sandra, 1994). For example, a learner may retain the word HIGHWAY very early on, without any knowledge of its structure. However, once that learner has recognized a word's compound structure, their representation of that word will become stronger and more easily accessed. When a word has corresponding compound structure in the learner's L1, this process seems to occur naturally. Morphological knowledge has been shown to increase the memorability orthographic patterns (Carlisle, 2003). The role of morphological knowledge seems to benefit the development of vocabulary knowledge and for overall reading fluency. Moving forward, greater consideration should be given to facilitatory role that morphology can play in the development of second language vocabulary knowledge and reading fluency.

This thesis has provided a new way of measuring comprehensibility; the effort required to process accented speech, using typing latencies. This thesis reported greater overall typing latencies for Chinese-accented speech, across all participant groups. While the functional effect of accent on the typing of individual words was relatively small, on the order of milliseconds, the cumulative effect of in terms of increased comprehensibility is quite substantial. Considering that these effects were observed during the typing of known words, in the absence of any other working memory load, the increased processing load while listening to a university lecture in an unfamiliar language would be considerable, where the content is unfamiliar, speech continues for hours, and student must constantly take detailed notes. In such real-world conditions, it is easy to see how small effects at the single word level could quickly accumulate to the point where a functional effect could be observed. Although further research is required in this area, this thesis suggests that additional scaffolding should be provided to compensate for the additional effort that listeners of unfamiliar foreign accented speech must exert.

CONCLUSION AND FUTURE DIRECTIONS

This thesis accomplished two of its stated goals. It has driven methodological innovation by successfully conducting behavioral psycholinguistic research online using PsychoPy3. Furthermore, it is the first study to investigate spoken word recognition and typed production in bilinguals using an auditory stimulus typing task. Both innovations represent small steps in new directions for psycholinguistic research methodologies.

Well established findings regarding the interlingual association of phonological neighbors in different script bilinguals were extended to Chinese-English bilinguals, providing further support for the non-selective lexical access hypothesis. Interlingual association was found to affect processing in a variety of ways. Phonological and morphological correspondence seem to facilitate acquisition and recall of L2 words. However, conflicting orthographic codes between associated entries lead to lexical interference during typed production. Cross-linguistic co-activation of associated L1 entries also lead to slower recognition and typed production of L2 words. Thus, involvement of the L1 during L2 processing requires additional time and cognitive resources but increases the opportunity for successful word recognition. Metaphorically speaking, if words are like fish swimming down a stream, you are more likely to catch them if you have a bigger net. However, the bigger the net, the harder it is to manoeuvre.

Considerable progress was made towards achieving goals (3) and (4) of the thesis. The association of compounds with corresponding composition and constituents seemed to facilitate acquisition but did not seem to play a role in on-line processing. This extends previous research on corresponding compound recognition in elementary-school-aged early-bilinguals to university-aged late-bilinguals. Not enough data were gathered to explore the interactions between accent and cross-linguistic co-activation. However, the data collected were relevant to our understanding of the intelligibility of foreign-accent speech and its consequences on language processing. Specifically, an interaction between the accent of the stimulus and subsequent word production latency was discovered, creating interesting new directions for research into foreign-accent processing.

This largely exploratory thesis has paved the way for many potential future projects and methodologies. The success of this thesis in replicating previous behavioral psycholinguistic findings using PsychoPy3 shows that conducting research online is not only cost effective, and resource efficient, but it is also valid and reliable. Having online experimentation as an option opens the field of psycholinguistic experimentation to a broader array of researchers. It also offers a foil to the highly controlled nature of laboratory experimentation by which the differences between the two may become better understood. Having a viable alternative to the laboratory means that the two can be treated as independent variables. In this sense, the influence of laboratory conditions can be teased out. This will likely lead to a better understanding of how non-linguistic situational variables may impact language use.

The experiment conducted in this thesis is the first to look at bilingual language processing using typing data. Though the central question of morphological integration could not be adequately answered with the data set generated, interesting preliminary findings regarding bilingual typing patterns were found. Bilinguals reliably showed less automaticity is English word typing. Their typing latencies were generally longer, and they showed greater variability in typing across the experiment. Additionally, bilinguals were less likely to correct typing errors. This data set, or those generated by similar experiments, could be used to better understand the typing profiles of bilinguals in general, or to track development in English learners. Given the growing population of international students, who rely largely on typing to take lecture notes, completed online quizzes, and write term papers, the need to understand bilingual typing has never been greater. Typing tasks provide insight into the language processes occurring behind the scenes. Given that typing is such an integral part of student life, it should provide an ecologically valid why to better understand language processing as part of the international student experience. I believe that typing tasks are a powerful methodological tool that can potentially help universities to better understand and facilitate the learning of international students.

This thesis also provides promising developments for the field of foreign-accent processing. The typing task employed in this thesis mirrors that used in transcription tasks to measure intelligibility of foreign-accented speech. However, most transcription tasks are done with pen-and-paper, and therefore, do not have access to individual keystroke latency. Though outside the scope of this thesis, several differences in keystroke latency were observed in response to foreign-accented stimuli. This opens new doors to the possibility of examining the effect of foreign-accented speech on subsequent language processing.

Additionally, the finding that foreign accent significantly increased individual keystroke latencies is surprising. Considering that the words were successfully recognized and typed, it is counter-intuitive to think that they might be typed differently. This finding potentially points to strain of foreign-accent processing on finite cognitive resources available to perform linguistic tasks. The link between working memory and foreign-accent processing is already being researched, though not from a typed word production perspective. Research methodologies similar to that used in this thesis could be productively applied to this line of research.

The main contribution of this thesis has been methodological in nature. Due to its broad theoretical scope and utilization of unique research tools, it has generated findings that have the potential to drive future research in several different domains. Most importantly, the use of accessible, cost-effective, open-source online experimental methods, demonstrates that experimental research is available to anyone who has an empirical question to answer. I believe that this has the potential to usher in a host of new researchers with varied interests and backgrounds, who will inevitably alter the types of questions that we decide to ask about language processing.

I began this thesis by comparing the bilingual language system to a spork, an inseparably integrated system with two distinct functions. I think the findings of this thesis are largely captured by this metaphor. Imagine eating an ice cream sundae with a spork. You might use the spoon component to scoop up a bite of ice cream, but you cannot prevent the fork component from being involved. If the ice cream is melting, you might lose some drips through the tines. Similarly, when you go to skewer the maraschino cherry on the top of the sundae, the spoon comes along for the ride, and may prevent you from effectively piercing the cherry. The point isn’t to compare sporks to spoons and forks. The point is that sporks are an incredible feat of design, capable of integrating the functionality both a spoon and a fork in a single utensil, just as bilinguals are able to integrate two language functions in one brain.

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APPENDIX A - STIMULUS LIST

Corresponding Compounds	Matched Compound Controls	English-Chinese Loanwords	Loanword Matched Controls

basketball	airspace	amend	aspire
beehive	backdrop	angel	binding
birthplace	bedroom	aspirin	blaming
blackboard	boyfriend	bacon	breach
bookshop	checklist	ballet	buyer
bottleneck	crossword	bar	color
darkroom	dragonfly	bass	cougar
drugstore	driveway	bikini	curves
earphone	firepower	bowling	disapprove
eyeball	firsthand	buffet	downstream
goldfish	foolproof	chocolate	eagle
goldmine	giveaway	clone	feeling
graveyard	godfather	coffee	garden
hairstyle	hallmark	cool	grief
headache	homeland	disco	happens
heartbeat	loophole	hacker	income
honeymoon	motorcycle	honey	juggling
moonlight	outbound	loan	lowest
racehorse	overthrow	marathon	module
sandbag	peacock	marker	oath
seahorse	proofread	microphone	parent
steamboat	raspberry	motor	pasta
supermarket	saucepan	muffin	persons
tablecloth	spotlight	radar	rebound
teacup	textbook	saxophone	regret
wallpaper	witchcraft	shampoo	spanning
weekend	withdraw	tank	swings
wheelchair	workman	whisky	wrestler