Examining the Electrophysiology of Long-term Priming: Repetition And Talker Specificity Effects on Spoken Word Recognition

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EXAMINING THE ELECTROPHYSIOLOGY OF LONG-TERM PRIMING: REPETITION AND TALKER SPECIFICITY EFFECTS ON SPOKEN WORD RECOGNITION

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ABSTRACT

Our knowledge of how spoken words are represented in the brain is currently limited. In this study, we aimed to probe the representation of spoken words to determine if details related to an episode of exposure to a spoken word are included in those representations. We hypothesized that episodic details of a spoken word are included in mental representations of spoken words, but that these details are not accessed until a relatively late stage of processing. Participants were presented with disyllabic high and low frequency real words in American English, as well as nonwords. Participants were initially exposed to stimuli in block 1, completed a distractor math test, and then were re-exposed to the same stimuli in block 2 (long-term repetition priming), in the context of a lexical decision task. Half of the re-exposed stimuli were spoken by the same talkers in blocks 1 and 2, while half were spoken by different talkers. Block 2 also included a control condition with new, unprimed words. Reaction times, accuracy, and event-related potentials were measured during block 2. The results were as follows: There was no evidence for repetition effects (advantages for words repeated by the same talker, compared to unprimed words) or talker effects (advantages for words repeated by the same talker compared to words repeated by different talkers) in accuracy for either high or low frequency words. Significant repetition effects in RT were found for both high and low frequency words, such that participants were quicker to respond to words repeated by

the same speaker compared to unprimed words. A trend toward talker effects in high frequency words was observed, but not in low frequency words, as we had predicted[1].

[1]Due to the COVID-19 pandemic, we were unable to complete data collection or access much of our ERP data. Consequently, the behavioral analyses are tentative, until we are able to complete data collection and analyze the complete dataset. Moreover, we plan to complete the ERP analyses as soon as possible.

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CHAPTER I

INTRODUCTION

Human language, or a system of informational sounds and written symbols (Colman, 2001), allows for complex and nuanced communication. Language, and its resultant communicative abilities, has allowed humans to create lasting works of literature, build cities, and form governing bodies. To understand the complexities of human language, however, it is necessary to understand the nuances of how language is represented in the brain. The concept of representations of words in the brain, or the *mental lexicon*, has attracted significant attention. Comprised of various elements including word meaning, syntax, (Sanches, Routier, Colliot, & Teichmann, 2018), morphemes, and phonemes (Marslen-Wilson, Komisarjevksy, Waksler, & Older, 1994), the mental lexicon is a testament to the complexities of language. While applicable to various modalities of language, such as visual and auditory, one issue of the mental lexicon of particular interest is in regard to the mental representations of spoken words. Research into this question has led to two major theoretical approaches regarding the representation of spoken words in the mental lexicon: abstractionist and episodic.

Abstractionist Representational Theories

Abstractionist theories posit that representations of spoken words in the mental lexicon contain information about word forms (e.g., phonemes) and meaning, which allows listeners to distinguish each word from all other words in the mental lexicon, and exclude any information specific to the incident of exposure (McQueen, Culter, Norris, 2006; Mullennix & Pisoni, 1990). These representations are postulated to include phonological and form-based properties and are comprised of the least amount of details necessary to access a spoken word upon exposure. Abstract representations are thought to be formed through a process of normalization, which filters out extraneous details, such as those associated with a specific talker or from a given event (Mullennix & Pisoni, 1990).

Ellis (1982) found evidence for facilitative *repetition priming effects*, or facilitated processing of a stimulus during subsequent exposures, on spoken-word recognition. Specifically, participants either received visual, auditory, or no priming of a word. After initial exposure, participants then listened to words spoken in background noise and were tasked with repeating the word aloud. Participants' accuracy of identifying the word was measured and compared between groups. There was a significant facilitation effect of word repetitions when the words were auditorily primed (Ellis, 1982), thus indicating that auditory word representations are stored and accessed upon subsequent auditory exposure to the word.

Jackson and Morton (1984) sought to further examine priming of spoken words. Participants either received an auditory prime by the same female voice used during test, by a different, male voice, by a mix of the male and female voice, a visual prime, or one of two control groups. Participants in the study were first exposed to the experimental words during the priming phase, where they were instructed to indicate if the presented word was of a living or nonliving noun. During test, participants listened to the experimental words presented in background noise, and accuracy of writing down the word as quickly as possible was measured.

Jackson and Morton (1984) found significant repetition priming effects, where word identifications were more accurate when the word had been repeated. However, there was an absence of voice context effects, or *talker-specific priming effects*, in the recognition of spoken words after priming where repetitions of a word by the same speaker did not lead to more accurate word repetitions (Jackson & Morton, 1984). The absence of voice-specific priming effects provides support for theoretical positions in which the mental lexicon consists of abstract representations.

Mullennix and Pisoni (1990) examined the extent to which variation in stimuli affected the perception of speech, measured by the accuracy of classification of presented stimuli. To test the effect of stimulus variations on the perception of spoken words, the researchers manipulated the number of different speakers and the number of different words presented. Participants were then instructed to classify stimuli either by word or by voice. In addition to manipulating the variability of stimuli, these researchers also manipulated participants' attention by instructing the participants either to attend to the speaker's voice or to the word. Mullennix and Pisoni (1990) found that when participants were instructed to attend to the word, and the number of words within a set increased, classification performance decreased linearly. However, when participants were instructed to attend to the voice, and the number of speakers increased, word classification performance initially decreased but then leveled off. These researchers suggest that neither voice information nor phonetic information can be ignored selectively when listening to spoken words. Therefore, when listeners attempt to attend selectively to phonetic information, there is apparent interference by variation in speaker voice. Nevertheless, Mullennix and Pisoni (1990) found that after an initial decrease in classification accuracy, when the number of voices increased, the effect leveled off, suggesting that talker variation eventually did not affect spoken word processing. These researchers suggest that evidence from the study provide insight into normalization processes of spoken word processing. Specifically, these results appear to demonstrate a process of normalization, where details associated with talker variability ultimately do not interfere with spoken word recognition, but details associated with phonetic information lead to interference. The study conducted by Mullennix and Pisoni (1990) appears to support abstractionist models of word representation, where basic elements such as phonetic information compose the mental lexicon, but extraneous elements, such as speaker voice, do not.

The studies conducted by Ellis (1982) and Jackson and Morton (1984) provided evidence that information of a spoken word are stored and later accessed in the mind, allowing individuals to recognize different spoken words. Furthermore, Jackson and Morton (1984) demonstrated that various voice contexts do not seem to influence the accuracy of spoken word recognition when a word has been primed. Relatedly, Mullennix and Pisoni (1990) found evidence for the process of normalization, where talker variability does not ultimately negatively influence accurate classifications of spoken words. These studies provide evidence for abstractionist theories of spoken word representations, where the mental lexicon is composed of information that allows for the recognition of a spoken word while discarding various information that is irrelevant for distinguishing between words. However, abstract representational theories are challenged by evidence suggesting that differences in talkers do, in fact, have consequences for spoken word processing. Episodic representational theories posit that event-specific instances in the presentation of a spoken word influence the representation, and subsequent processing, of spoken words.

Episodic Representational Theories

Episodic representational theories suggest that the details of each exposure to a spoken word are encoded alongside the form of words in the lexicon (Goldinger, 1996, 1998; Goh, 2005; Kouider & Dupoux, 2008; Luce & Lyons, 1998; McLennan & Luce, 2005). This position stands in direct contrast to abstractionist theories, which state that such episode-specific details are actively stripped when making contact with the lexicon.

Goldinger (1996) used repetition priming and talker-specific priming, where the word is primed and tested in the same or different voice, to test responses to spoken words. Participants listened to words spoken by 10 different speakers during a study phase, then listened to the words again during test either by a different speaker or the same speaker. Participants were tested by indicating during the testing phase if the word had been spoken twice. Participants' reaction times (RT) were measured. In a supplemental study, the researcher additionally examined the length of delay between priming and test, which included a 5-minute, one day, or one-week delay. Participants' hit, false alarm, and miss rates of recognizing a word as being repeated were measured. Results indicated that talker-specific repetition led to faster RTs, as well as more accurate recognition of repeated words, compared to repetition priming. Furthermore, Goldinger (1996) found that episodic traces, such as specific voice recognition, influenced recognition of words for up to a week. The evidence of the influence of specific talkers on spoken word recognition is critical, since according to Goldinger (1996), these results suggest that episodic details not only affect memory but may also influence subsequent perceptions of spoken words.

In another study, Palmeri and colleagues (1993) examined the recognition of words presented by varying *lag* (the number of intervening words) and speakers in a short- and long-term priming paradigm. Participants were primed with spoken words during the study phase, then heard the word again by either the same speaker or a different speaker during a subsequent test phase. Additionally, words were repeated after varying lags, which spanned from one to 64 intervening words. Participants' accuracy in button selections of choosing "old" or "new" upon hearing the word, as well as RT, were recorded. These researchers demonstrated that same-voice repetitions led to more accurate button presses and faster reaction times in recognition, compared to different voice repetitions. Importantly, the results of the study further suggest that aspects of voice are encoded into memory and affect later performance of spoken word recognition.

Similarly, Takayanagi and colleagues (2002) examined talker-specific priming effects on word recognition when individuals were either native listeners, non-native listeners, non-native listeners with impaired hearing, or native listeners with impaired hearing. The researchers also added the manipulation of word difficulty in addition to varied talkers in order to determine the extent to which talker effects play a role in word recognition. Participants listened to both easy and hard words presented by the same speaker and by multiple speakers. Participants' familiarity ratings of target words were recorded. According to Takayangi and colleagues (2002), results indicated that generally, word recognition was better in conditions of single talkers compared to conditions of multiple talkers. Additionally, easy words generally had more accurate recognition compared to difficult words. According to the researchers, these results indicate substantial influences of talker variability on word recognition in both native and non-native English listeners.

Despite the evidence for episodic encoding and representation of spoken words in the mental lexicon, many researchers argue that it would be incorrect to assume that the existence and use of abstract representations should be rejected completely. Rather, hybrid approaches, which postulate that the mental lexicon is composed of both abstract and episodic representations, offer an alternative (Goh, 2005; Kouider & Dupoux, 2008; McLennan & Luce, 2005).

Hybrid Approach

As support for a mental lexicon of episodic details began to grow, the position that the mental lexicon is neither composed entirely of abstract representations nor of episodic representations similarly gained traction; rather, an alternative approach is that the mental lexicon includes both abstract and episodic representations (e.g. Goh, 2005; McLennan & Luce, 2005; Kouider & Dupoux, 2008). This approach suggests that both abstract and episodic representations exist in the mental lexicon (Goh, 2005; McLennan & Luce, 2005; Kouider & Dupoux, 2008); however, the access to these representations may depend on a variety of factors, including the nature of the task (Goh, 2005), or processing demands (McLennan & Luce, 2005).

Goh (2005) sought to examine the use of mental representation in speech perception and spoken-word recognition. Specifically, the researcher examined whether the encoding of voice-specific information assisted or impaired the subsequent recovery and discrimination of words presented for study. If, as abstractionists believe, contextual details are undesirable for the processing of speech, then voice information may impair recovery; however, if episodic representations are used in speech processing, like episodic representational theorists believe, then voice information may aid in the recognition of studied spoken words.

Goh (2005) measured spoken word recognition accuracy, where responses to whether or not a participant recognized a word as having already been heard or not were recorded. The researcher found that recognition accuracy was worse when studied words were spoken by a new voice, meaning that participants often failed to recognize a studied word when it was repeated by a new voice during the testing phase. The differences in recognition accuracy are important, as the results suggest that recognition of words was better when the words were presented in the same voice (Goh, 2005), as previous research had also found (e.g., Goldinger, 1996; Palmeri et al. 1993; Takayangi and Moshfegh, 2002). In addition, participants incorrectly identified unprimed words as having been studied when the unprimed words were presented by studied voices. These false identifications are similarly important, as the misidentifications suggest that voices were also recognized during test independently from the words themselves. According to Goh (2005), the misidentification of unprimed words as having been previously heard when they were presented by familiar voices suggests that specific voice details are stored in memory during speech processing and accessed in lexical retrieval.

Nevertheless, although talker differences appear to be important in speech perception, the use of episode-specific details in word recognition may be situation-dependent, so a complete rejection of abstract representations might be incorrect.

Kouider and Dupoux (2008) proposed that exact representations of the mental lexicon are affected both by episodic and abstract features, where episodic features are impactful only when the episodes of exposure are easily accessible. The researchers manipulated both lag between study and exposure, talker changes, and priming type. The investigators included manipulations in which words were either repeated exactly, words were similar in sound, words were similar in meaning but not sound or spelling, or the repeated word was a nonword and thus not similar at all to the studied word.

Kouider and Dupoux (2008) measured RT during the testing phase where participants determined if they had heard the word during the study phase. The researchers found that in the absence of semantic and morphological priming, RTs were faster when the speaker was the same between prime and test. Nevertheless, results also indicated that when there was more time between study and test of a primed word, the influence of episodic details seemed to have degraded so that RTs were comparatively faster in the morphological priming condition. Kouider and Dupoux (2008) thus posited that increasing the lag between priming and testing leads recognition of the word to reflect activation of a more abstract representation. Additionally, the researchers argue that priming in which the word and source were the same, compared to when the source was different, indicate the additive contributions of both episodic and abstract priming, since these conditions led to the best results in terms of faster and more accurate participant responses.

Furthermore, Kouider and Dupoux (2008) contend that the results may indicate that the balance of repetition priming, and talker-specific priming effects, is dependent upon the accessibility of the prime. For example, the researchers report that shorter lag between study and test with the same word and talker allowed for greater access to episodic features, and thus faster RTs. Conversely, longer lag intervals between study and test, along with changes in talkers, limited episodic influences and reduced the priming to a more morphological, and therefore more abstract, prime. When these results are combined, they represent a hybrid approach of lexical representations of spoken-word processing, where both abstract and representational elements affect word recognition in different situations.

Similarly, McLennan and Luce (2005) hypothesized that both abstract and episodic representations compose the mental lexicon; however, the researchers developed the *time-course hypothesis* (Luce & Lyons, 1998; McLennan & Luce, 2005), in which access to these representations are not only situation-dependent, but that they occur at different times during the processing of a spoken word.

Time-Course Hypothesis

According to McLennan and Luce (2005), the mental lexicon includes both abstract representations and episodic representations. In addition, the abstract features of words are easier to process, as abstract features are more commonly experienced, while episodic features are relatively more difficult to process, as particular episodic features are unique to each exposure, and thus less commonly experienced. Due to the varying commonality of abstract and episodic features, McLennan and Luce (2005) postulated that during the processing of a spoken word, abstract representations may be accessed initially, while episodic representations are accessed after a delay.

In order to test the time-course hypothesis, McLennan and Luce (2005) manipulated the ease of word discrimination with different indexical variables (speaker rate or talker identity), and then measured behavioral responses in a lexical decision task and a shadowing task. Easy-discrimination lexical decision conditions included words and nonwords that did not sound particularly word-like, while difficult-discrimination lexical decision conditions used words and word-like nonwords. Specifically, the researchers hypothesized that talker effects take more time to develop and influence the processing of spoken words, so when processing is easier and faster (e.g., in easy-discrimination & speeded shadowing conditions), talker effects would be less identifiable; conversely, when processing is more difficult (e.g., in hard-discrimination & delayed shadowing conditions), talker effects would be evident. Results indicated that in more difficult conditions, talker effects produced facilitative effects in word recognition, where words were recognized more quickly and accurately when presented by the same talker during study and testing. In addition, when processing was easier, there were no significant differences in the effectiveness of same- and different-talker primes. According to McLennan and Luce (2005), talker information in speech typically takes more time to influence the processing of spoken words, compared to more abstract information.

Measuring Spoken-Word Processing

Previously, *endpoint measurements*, such as reaction times, have been used as the primary measurement of spoken word recognition (e.g., Goh, 2005; Goldinger, 1996;

Kouider & Dupoux, 2008; Luce & Lyons, 1998; McLennan & Luce, 2005). While important, endpoint measurements provide only one measure, and at the completion of a process. However, cognition, such as spoken language processing, is not a sudden cognitive transition, as endpoint measurements might suggest, but rather the culmination of various processes that occur continuously over time (Osterhout, McLaughling, & Bersick, 1997; Spivey & Dale, 2006). *Continuous measurements,* therefore, are necessary to provide a more complete understanding of temporally sensitive cognitive process. Analysis of event-related potentials (ERP) is one such measurement, which provides insight into the temporal development of neurocognitive processes. ERPs are computed as the time-locked and subsequently averaged electroencephalographic (EEG) response to a class of stimuli (Osterhout et al., 1997).

Campeanu and colleagues (2013) sought to extend the understanding of same-talker facilitation on word recognition by examining the effect of two voice parameters (pitch & accent) on word recognition in a short-term priming paradigm. Using both endpoint and continuous measurements, the researchers found that when words were repeated by the same talker, response to the target word was more accurate. In addition, ERPs indicated that words, when presented a second time by the same speaker, resulted in a significantly more positive modulation. Furthermore, as the speaking voice of a word at test became less similar to the voice of a word at study, the ERP modulation became weaker. Campeanu and colleagues (2013) suggest that the ERP modulations found in this study support and supplement the endpoint evidence for episodic representations of spoken words by providing corresponding neural evidence.

Measuring the Time-Course Hypothesis: ERPs

Continuous measurements, such as ERPs, have provided insight into the neural mechanisms underlying spoken word recognition (Campeanu et al., 2013). Critically, ERPs are sensitive to the temporal unfolding of cognitive processes. Since the time-course hypothesis involves temporally specific predictions, ERPs are an ideal technique for testing those predictions.

Similarly, Dufour and colleagues (2017) were interested in determining the exact moment in which talker effects influence spoken-word processing in words that are easier to process (i.e., high frequency words), compared to words that are more difficult to process (i.e., low frequency words) in conditions of same- and different-talker priming. Using ERP measurements in a short-term priming paradigm, the researchers found that talker-specific details do not affect the earliest stages of spoken-word processing. Critically, however, talker-specific priming effects were found between 450 and 600 milliseconds (ms) from word onset, indicating that talker-specific details were accessed, but not until relatively later in spoken-word processing. Additionally, this modulation of priming effects as a function of talker change only occurred in lower frequency words. These physiological findings are thus consistent with the time-course hypothesis, since later access of talker-specific features were found in lower frequency words on a neural level. However, since the researchers used a short-term priming paradigm, the study does not necessarily reflect processing of stored representations, which would instead require application of a long-term priming paradigm (by necessitating all information has had time to be cleared from sensory buffers and working memory).

Long-lag repetitions are thought to allow for the examination of the activation of established representations (Becker, Moscovitch, Behrmann, & Joordens, 1997) rather than the activation of brief word traces within the perceptual subsystems of stimulus recognition in short-term priming paradigms (McKone & Dennis, 2007). Therefore, there remains a significant gap in the literature, which is relevant for spoken word processing and the time-course hypothesis; there is a lack of studies examining talker ERP effects in the context of long-term priming.

Following the study conducted by Dufour and colleagues (2017), Hurley, Bell, Farrell, and M^{c}Lennan (2019) sought to examine the time-course of spoken word processing using a long-term priming paradigm. Hurley and colleagues (2019) employed monosyllabic words and examined the effects of repetition priming and talker-specific priming. The researchers measured RTs, accuracy, and ERPs during a lexical decision task where participants indicated on each trial whether the stimulus was a real word or a nonword. The researchers found significant repetition priming effects, where repeated words led to faster RTs and higher accuracy, compared to unprimed words. Talker-specific priming effects, however, were not observed in accuracy or RTs when same-talker repetitions were compared to words repeated by different talkers. The lack of a talker-specific priming effect is in contrast to previous studies (e.g., Dufour, 2017; Goldinger, 1996; Goh, 2005; Kouider & Dupoux, 2008; Luce & Lyons, 1998; M^{c}Lennan & Luce, 2005), which found that same-speaker repetitions led to faster RTs and greater accuracy compared to different-speaker repetitions.

Aligning with the endpoint behavioral RT and accuracy measurements, Hurley and colleagues (2019) also found significant ERP effects (Figure 1). Critically,

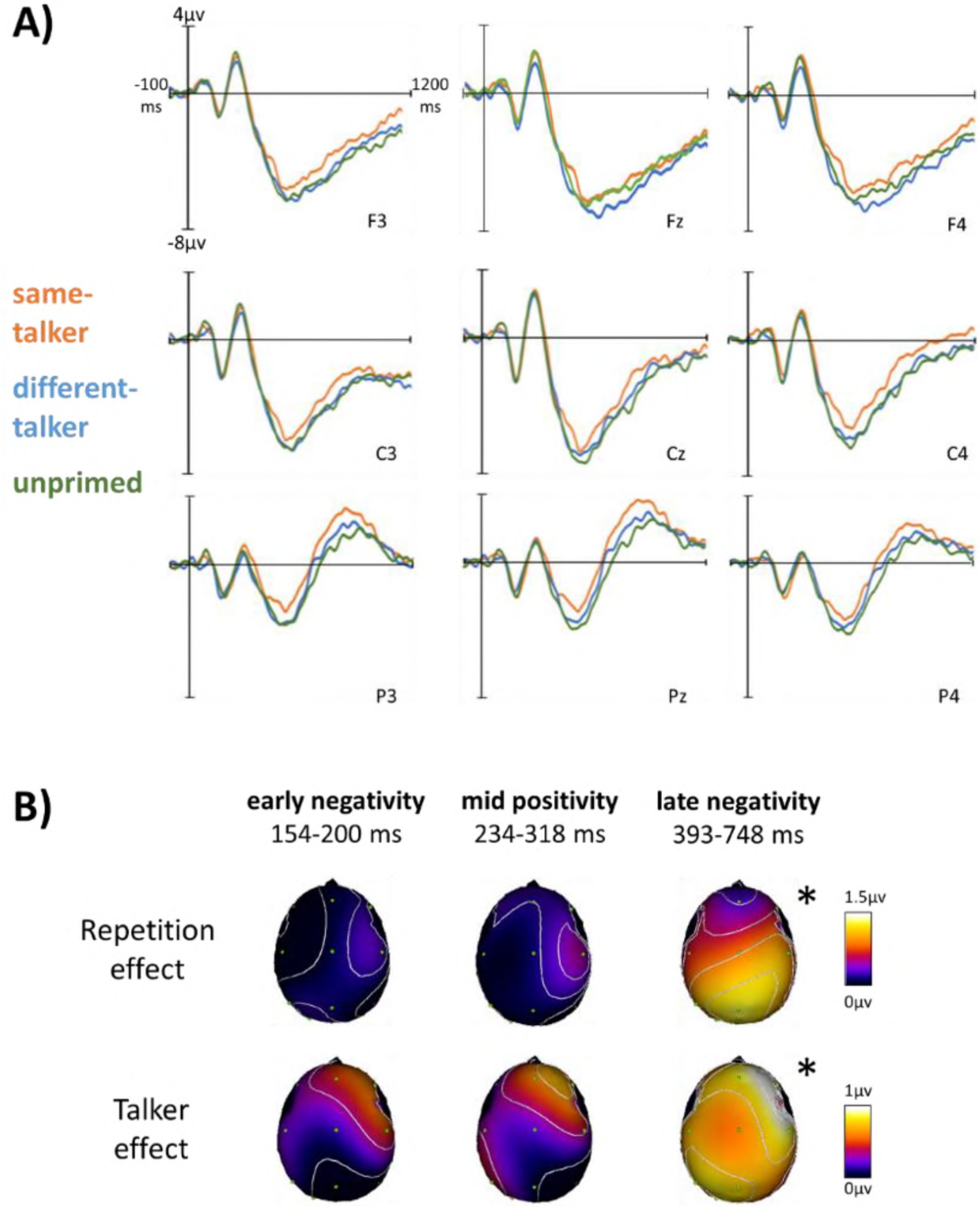

Figure 1. ERP results in response to monosyllabic American English words. Time-amplitude (A) and topographic plots (B) demonstrate significant repetition and talker effects in late time windows (393-748 ms). Note: * p < .05. Adapted from "Electrophysiology of long-term priming for spoken words: Effects of repetition and talker specificity" by Hurley, Bell, Farrell and McLennan (2019).

significant talker-specific priming effects were found in later time-windows (Figure 1A), though they were of small amplitude and inconsistent across electrode sites (Figure 1B).

Although Hurley and colleagues (2019) found significant talker-specific priming ERP effects in a long-term priming paradigm (Figure 1), aspects critical to the time-course hypothesis were not evident. Specifically, although the researchers examined word frequency as a manipulation of the ease of spoken word processing, the study was not explicitly designed for an ease of processing manipulation. For example, since there are a limited number of monosyllabic words, monosyllabic words are constrained in terms of frequency, which makes the words generally more common (e.g., Shi, 2015). To assess the time-course of spoken-word processing with consideration to the abstract and episodic representations of words in a long-term priming paradigm, explicit manipulations of the ease of processing may facilitate the assessment of the time-course of spoken-word recognition.

Current Study

In the current study, we aimed to more definitively evaluate the time-course hypothesis and spoken-word processing by examining the reaction times, accuracy, and ERPs of responses to two-syllable words in a long-term priming paradigm. Critically, previous research has found ERP evidence of the time-course hypothesis in a short-term priming paradigm (Dufour et al., 2017). However, unlike Dufour and colleagues (2017), we implemented a long-term priming paradigm to the study in order to examine the activation of established representations. Additionally, unlike Hurley and colleagues (2019), we explicitly included in the design of the study the manipulation of high and low frequency disyllabic words in order to more tightly control and manipulate ease of processing. The word frequency manipulation is critical, since according to the time-course hypothesis, the processing of more difficult words takes longer, and thus makes it possible for the access to episodic features of a word to be discernable (McLennan & Luce, 2005).

Hypotheses

Operationalization of repetition and talker effects

Repetition effects are operationalized here as higher accuracy, quicker reaction times, and/or attenuated ERP waveform amplitudes in responses to words repeated by the same talker compared to responses to unprimed words. *Talker effects* are operationalized here as higher accuracy, quicker reaction times, and/or attenuated ERP waveform amplitudes in responses to same-talker repetitions of words compared to different-talker repetitions.

Behavioral predictions

Repetition effects were predicted in reaction times, accuracy, or both. Additionally, consistent with previous research (e.g., Goldinger, 1996; Palmeri et al., 1993), talker-specific priming effects were expected in reaction times, accuracy, or both, in all word types. Regarding the manipulation of word frequency, both high and low frequency words were expected to show repetition effects. However, in accordance with the time-course hypothesis, only low frequency words were expected to display talker effects.

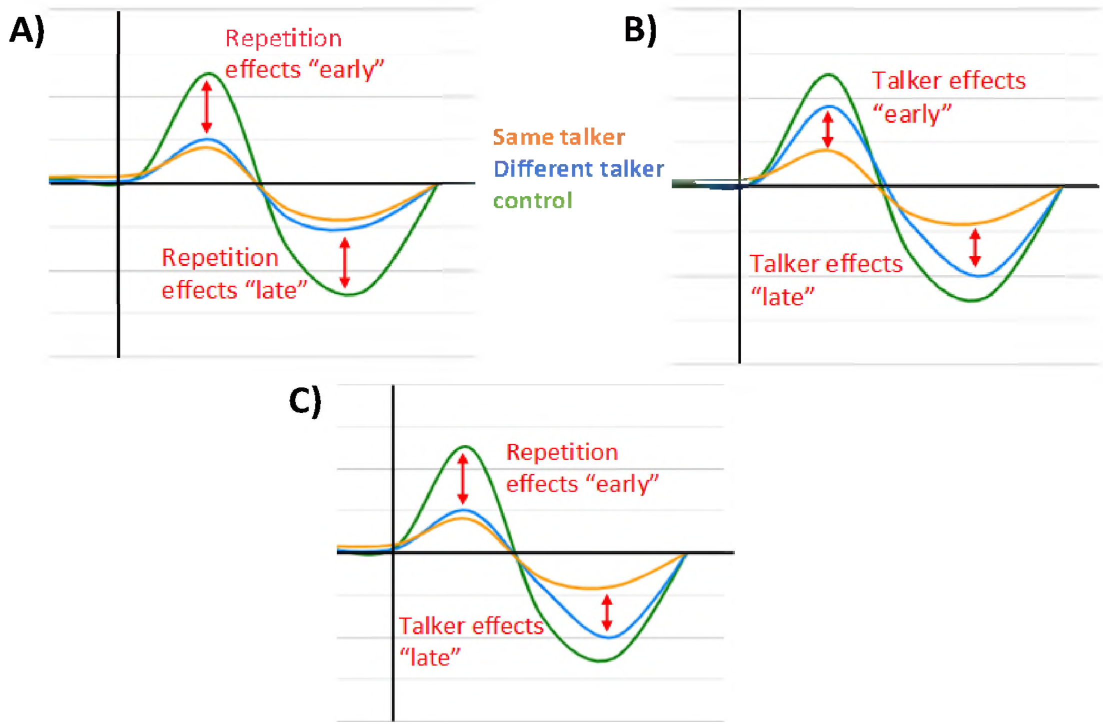

Figure 2. ERP mock-ups of predictions for all words. Arrows and labels represent significant repetition or talker effects in hypothetical early or late time-windows.

ERP predictions

If, as abstractionist theories of representation posit, episodic details are not stored in the mental lexicon, then we should expect no differences in the waveforms between same- and different-talker conditions at any point in the epoch (across all component time windows; Figure 2A). Conversely, if episodic details are integral to all stages of spoken-word processing, then we should expect a divergence of waveforms between same- and different-talker conditions for the duration of the epoch (Figure 2B). According to the time-course hypothesis, there should be no differences in same- and different-talker waveforms in earlier time-windows; rather, these differences should manifest in later time windows (Figure 2C).

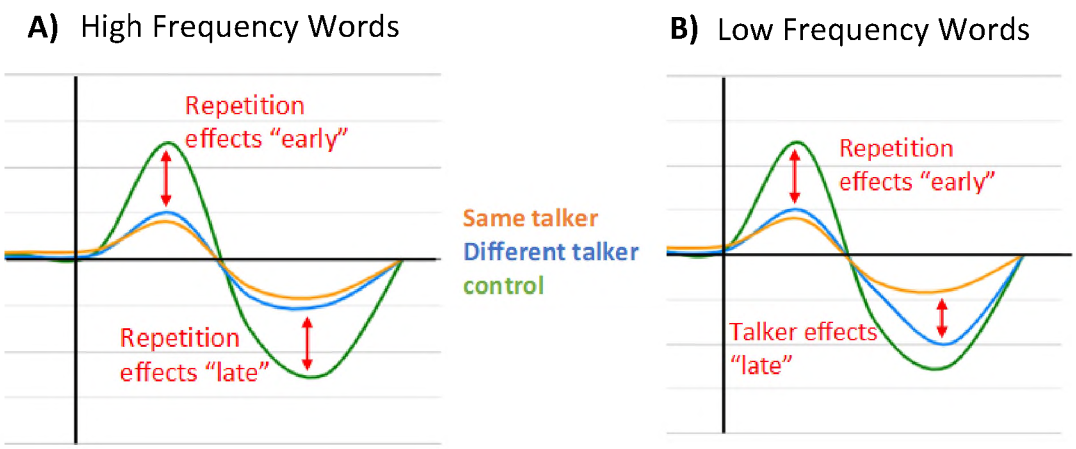

Figure 3. ERP mock-ups of predictions with word frequency distinction. Arrows and labels represent significant repetition or talker effects in hypothetical early or late time-windows, where talker effects appear “late” in low-frequency words, but not high-frequency words.

Regarding the manipulation of word frequency, both high and low frequency words were expected to have differing waveforms that demonstrate repetition effects (Figure 3). However, if the time-course hypothesis is supported, then we would expect low frequency words to display talker effects in later time-windows, but not in earlier time-windows. Talker effects in later time-windows of low frequency words would indicate later access to episodic details when processing is more difficult (Figure 3B). The talker effects, then, would be missing, or less robust, in high frequency words, as they would not allow for the processing time needed to access episodic details (Figure 3A).

CHAPTER II

METHOD

Participants

Participants were 23[2] right-handed undergraduate students from Cleveland State University, with no reported hearing, speech, or motor impairments. Participants were recruited from the Department of Psychology research participation database, SONA, in exchange for research participation credit. Five participants were excluded due to not finishing the study, indicating a presence of a neurological or psychiatric disorder, or both.

Materials and Apparatus

Stimuli

Stimuli for the study included 300 audio-recorded disyllabic American English words and 300 audio-recorded disyllabic nonwords (see Appendix A). Of the 300 American English words, 150 were high frequency (lgSUBTLWF range: 3.08-4.88; M= 3.604±0.43) and 150 were low frequency (lgSUBTLWF range: 0.48-2.99;

[2] We had originally planned to collect data from 45 participants, but due to the COVID-19 pandemic, we were unable to complete data collection.

M= 2.258±0.47). High and low frequency words differed significantly in their frequencies (t_{149}= 24.425, p< .001). Words and frequencies were obtained from SUBTLEX$_{US}$ corpus (Brysbaert & New, 2009). Nonwords were created by use of the pseudo word generator Wuggy (Keuleers & Brysbaert, 2010).

Each stimulus was recorded once by a male native speaker of American English and once by a female native speaker of American English. All sound clips were digitally manipulated using the "stretch and pitch" effect in Adobe Audition (Adobe Audition, version 10) to ensure that the duration of every word and nonword stimulus had a duration of exactly 600ms.

Procedure

Participants were given an informed consent to read and sign. Once consent was given, an EEG cap was applied. The cap consisted of 16 electrodes (F1, F2, F3, F4, Fz, C3, C4, Cz, T7, T8, P3, P4, Pz, O1, O2, Oz) and two mastoid channels. EEG was continuously recorded through a BioSemi Active II amplifier at 512 Hz.

Participants were seated in front of a computerized testing station and instructed to listen to each word and nonword played over the computer speakers. Participants performed a lexical decision task, where participants were instructed to indicate as quickly and accurately as possible if the stimulus was a word or nonword. Participants were instructed to press one of two buttons using their index (word) and middle (nonword) fingers of their right hand. Participants were also instructed to keep their gaze on the crosshair in the center of the computer screen. The crosshair remained present through the duration of the experiment.

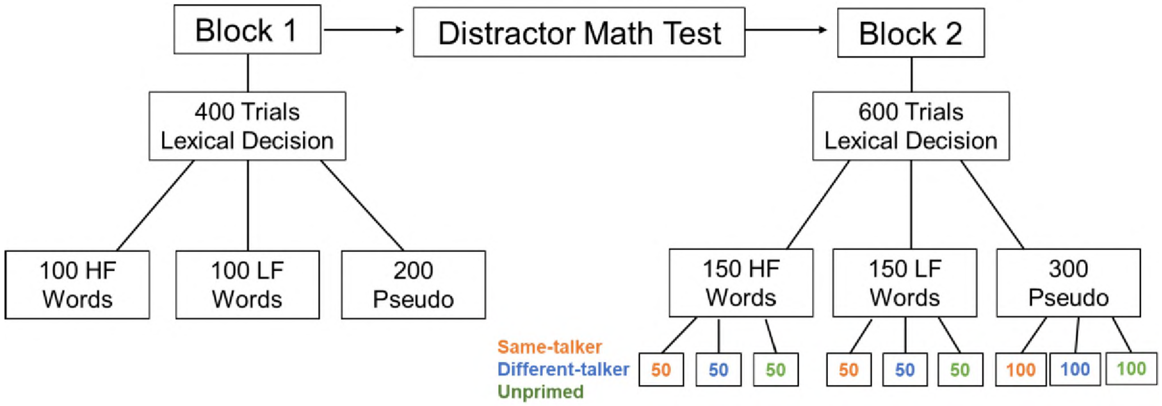

Figure 4. Task design. Participants indicated if each stimulus was a word or nonword during block 1 priming. After a distractor task, participants indicated if each stimulus was a word or nonword during block 2 testing. Spoken words and nonwords were repeated by the same talker (orange), a different talker (blue), or were unprimed (green).

Each word and nonword was presented for 600ms, followed by a randomly jittered inter-trial interval of 2,000-3,000ms before the presentation of the next word. In order to cue participants to focus on the incoming word, the central fixation switched in color from gray to black between 400 and 700ms, randomly jittered, prior to the onset of each word. After each sound clip was finished playing, the central fixation point switched from black to gray.

Participants completed two blocks of a long-term priming experiment (Figure 4). Block 1 consisted of 200 real word trials and 200 pseudo-word trials (intermixed), for a total of 400 trials. Real word trials consisted of 100 high frequency word trials and 100 low frequency word trials. Block 2 consisted of 300 trials of real words and 300 trials of pseudo words for a total of 600 trials. Real words consisted of 150 high frequency words and 150 low frequency words. Of the 150 high frequency real words, 50 were same-talker primed, 50 were different-talker primed, and 50 were unprimed. Of the 150 low frequency real words, 50 were same-talker primed, 50 were different-talker primed, and 50 were unprimed. Of the 300 pseudowords, 100 were same-talker primed, 100 were different-talker primed, and 100 were unprimed. Words and pseudowords were counterbalanced in different lists, so that across participants, each word and nonword was experienced in each priming and talker condition. During both blocks, participants were allowed breaks of varying duration. Between blocks, participants were given a 3-minute distractor math test using pencil and paper. After completion of block 2, participants were debriefed. The experimental session lasted approximately 65 minutes.

EEG Acquisition and Analysis

EEG preprocessing and ERP analysis was conducted using the EMSE software suite (Cortech Solutions). EEG signal was re-referenced to the mean of the mastoid channels. A high-pass filter was applied to remove frequencies below .01Hz. Blink artifacts were removed from the trace using a principle components algorithm. Epochs from -200 to 1000ms were extracted for ERP analysis. Trials with inaccurate lexical decision responses and remaining ocular or muscle artifact were discarded. Only trials from block 2 were analyzed.

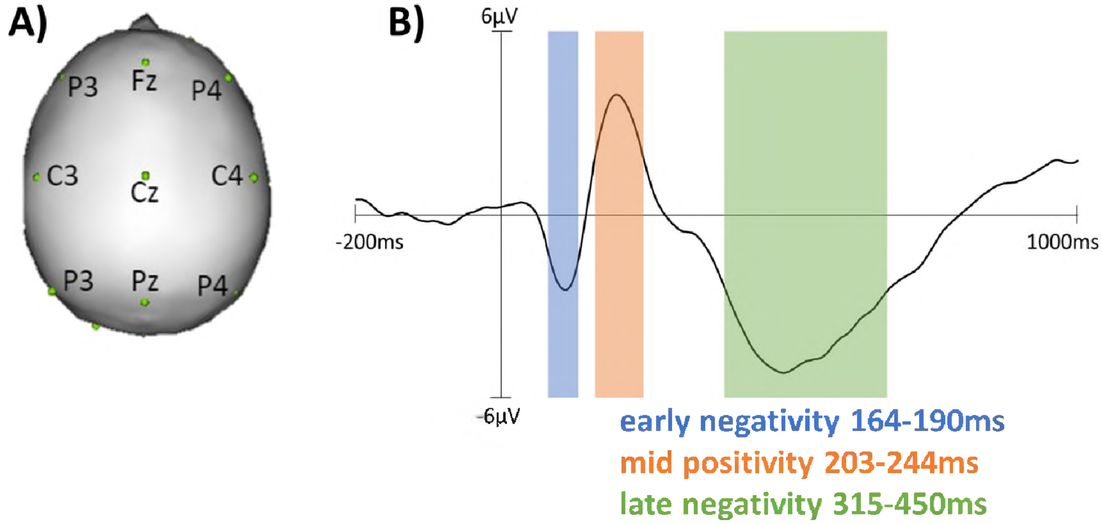

Figure 5. Spatiotemporal scheme to be employed in ERP analysis. A) Electrode locations from which amplitudes were extracted. B) Amplitudes were extracted from three time windows each aligned to distinct ERP components. The components were identified in the above grand average ERP, which was generated from all trials in the first block of trials. An early negativity (164-190ms), mid positivity (203-244), and late negativity (315-450ms) were identified based on the rising and falling half-maximal values for each component. These time windows will then be used to extract amplitudes from the second block of trials for inferential analysis.

To generate ERPs, amplitudes from each epoch were averaged separately for each priming condition. Time windows for inferential analysis were selected by identifying a set of grand averaged ERP components generated in response to all trials (i.e., collapsed between real and nonwords) in block 1 (Figure 5B). Once time windows were identified using block 1, amplitudes from block 2 were extracted from those identified time windows for analysis.

Analysis Overview

All statistical analyses were limited to target words of block 2. All analyses of RT were limited to correct responses. In order to examine behavioral results, we conducted a 2 (high frequency, low frequency) x 3 (same-talker, different-talker, unprimed) repeated measures ANOVA for accuracy and RT of responses to the lexical decision task in order to examine if repetition and/or talker priming occurred more strongly in one frequency type over the other. We additionally conducted a 2 (high frequency, low frequency) x 2 (same-talker, unprimed) repeated measures ANOVA for accuracy and RT of responses in order to examine the presence of repetition effects, and whether repetition effects were stronger in high or low frequency words. We similarly conducted a 2 (high frequency, low frequency) x 2 (same-talker, different-talker) repeated measures ANOVA for accuracy and RT in order to examine the presence of talker effects, and if there was an interaction of talker effects with word frequency, such that talker effects occurred more strongly in one frequency type over the other.

We further had a priori predictions regarding which type of word frequency would elicit talker or repetition effects. Specifically, we predicted that repetition effects would be evident in both high and low frequency words for accuracy, RT, or both. We predicted that talker effects would emerge in accuracy, RT, or both for low frequency words. In order to test these predictions, we conducted planned analyses in the form of dependent-samples *t*-tests on accuracy and RTs for both high frequency and low frequency words comparing the two priming conditions.

Regarding the ERP measurement[3], we predicted (as motivated by the time-course hypothesis) that ERP amplitudes would be modulated by repetition priming in earlier time windows than talker priming. To test this hypothesis, we conducted a 2 (same-talker repetition, unprimed) x 9 (electrode location) repeated measures ANOVA for each of the three identified time windows. Degrees of freedom were corrected for sphericity violations using the Greenhouse-Geisser (1959) algorithm when appropriate. Additionally, we predicted that low frequency words would demonstrate talker effects in

[3] The discussed inferential analyses were unable to be completed due to the COVID-19 pandemic. More information follows in the results section.

the latter of the three time-windows. To test this hypothesis, we conducted a 2 (same-talker repetitions, different-talker repetitions) x 9 (electrode locations) repeated measures ANOVA for high and low frequency words in each of the three identified time windows. Finally, we conducted a 2 (same-talker, different-talker) x 2 (high frequency, low frequency) x 9 (electrode location) ANOVA in each of the three time-windows in order to determine if talker effects are greater in low frequency words compared to high frequency words.

CHAPTER III

RESUTLS

Variables

Three independent variables were manipulated in this study: priming type, frequency, and ERP time-window. Levels of priming type consisted of different-talker repetitions, same-talker repetitions, and unprimed controls. The levels of frequency included high and low frequency words. Three ERP time-windows were identified for analysis: early (164-190ms), middle (203-244ms), and late (315-450ms). All participants participated in each level of each independent variable, counterbalanced across participants.

Three dependent variables were measured: accuracy of lexical decision, reaction time of lexical decision, and ERP amplitudes. Due to the COVID-19 pandemic, we were unable to complete data collection or access much of our ERP data. Consequently, all inferential analyses are currently limited to those involving the behavioral dependent variables (i.e., accuracy & reaction time of lexical decision), and these behavioral analyses are tentative. When we are able to access the laboratory and recruit additional participants, we plan to complete data collection, analyze the complete dataset, and complete the ERP analyses.

Behavioral Results

All statistical analyses were limited to target words in block 2, and RT analyses were additionally limited to words with correct responses. Repetition effects were analyzed by comparing different-talker repetitions to unprimed words. Talker effects were analyzed by comparing same-talker to different-talker repetitions.

Process of Outlier Correction and Rejection

Prior to analysis, all reaction times (RT) were winsorized at the trial level by identifying reactions that were beyond ±2 *SD* of RT in the priming and word frequency conditions. Any identified outliers were replaced with the value of ±2 *SDs.* Total winsorized RTs were < 5% of all obtained RTs.

Once RTs were winsorized at the trial level, mean accuracy and RT on the participant level were examined in order to identify potential participant outliers. Outlier cutoffs were two standard deviations above or the below the mean for RT, accuracy, or both in all priming and frequency conditions. One participant was identified as being an outlier on the accuracy measurement and was subsequently removed from the analysis. The final sample size of participants included in analyses was 17.

Finally, grand mean RT and accuracy were examined by individual items in order to identify outlier stimuli. The same outlier criteria of two standard deviations above or the below the mean in accuracy, RT, or both was used. No items exceeded the criteria in RT, but 15 items exceeded the criteria for accuracy, and consequently these stimuli were removed from the analyses. Of the total stimuli used, only 5% were removed. Excluded items are indicated in the stimulus table (see Appendix A).

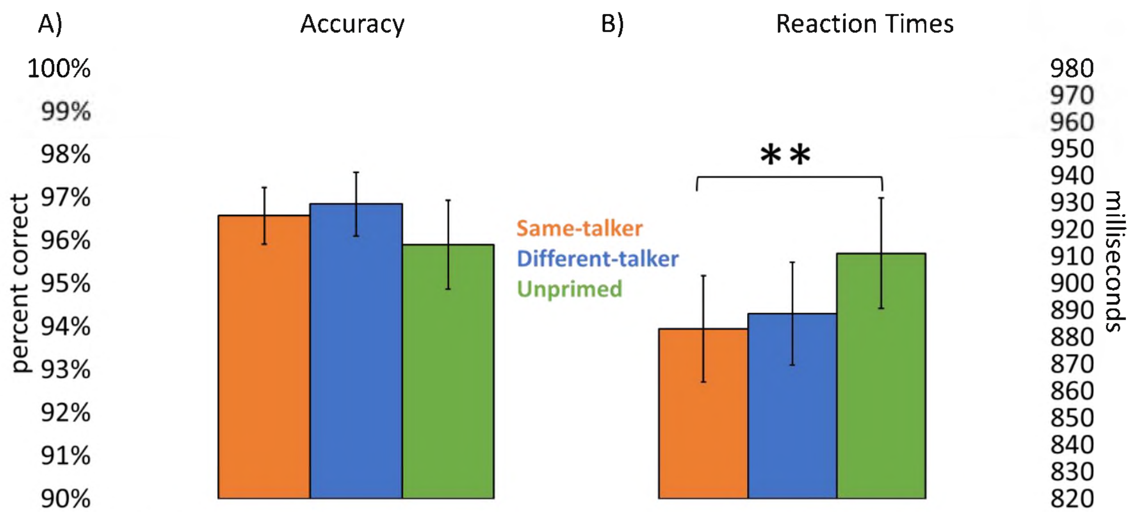

Figure 6. Behavioral results in response to all words. There were no significant talker or repetition effects found in accuracy (A). Participants were significantly quicker to respond to words repeated by the same speaker compared to unprimed words, comprising significant repetition effects in RT (B). No talker effects were found in RT.
*p<.05. **p<.01.

Nonwords

Mean RTs of nonwords in same-talker (*M*= 965.26ms, *SD*= 135.26), different-talker (*M*= 946.43ms, *SD*= 120.15), and unprimed (*M*= 937.13ms, *SD*= 108.91) conditions were calculated. Mean accuracy (percentages correct) of responses to nonwords in same-talker (*M*= .96, *SD*= .03), different-talker (*M*= .97, *SD*= .03) and unprimed (*M*= .97, *SD*= .04) conditions were calculated.

Real Words

Overall, participants responded more slowly to low frequency words, compared to high frequency words (t_{49}= -5.887, p< .001). Accuracy and RT for responses to the lexical decision task of all words from block 2 are displayed in Figure 6. Planned comparisons of responses collapsed across frequency groups indicate that significant repetition effects for accuracy were not found (t_{16}= .840, p= .413, η^2= .042) between same-talker and unprimed conditions. Significant repetition effects between same-talker and unprimed words in RT were found (t_{16}= -6.023, p< .001, η^2= .694). There was no evidence of talker priming for all words in either accuracy (t_{16}= -.449, p= .659, η^2= .012) or RT (t_{16}= -1.158, p= .264, η^2= .077).

In order to examine if repetition, talker effects, or both emerged, and were stronger in low frequency words compared high frequency words, 2 (high frequency, low frequency) x 3 (same-talker, different-talker, unprimed) repeated measures ANOVAs were conducted on accuracy and RT. Regarding accuracy, there was no main effect of word frequency ($F_{(1,32)}$= .001, p= .975, η^2= .000) or priming type ($F_{(2,32)}$= .918, p= .410, η^2= .054). There was no significant interaction between word frequency or priming type on response accuracy ($F_{(2,32)}$= .346, p= .710, η^2= .021).

Regarding RT, there was a significant main effect of frequency ($F_{(1, 32)}$= 29.317, p< .001, η^2= .647) and a significant main effect of priming type ($F_{(2, 32)}$= 17.237, p< .001, η^2= .519). There was no significant interaction between word frequency and priming type ($F_{(2, 32)}$= 1.438, p= .082, η^2= .082).

Since there were significant main effects of word frequency and priming on participants' RTs, 2 (high frequency, low frequency) x 2 (same-talker, unprimed) and 2 (high frequency, low frequency) x 2 (same-talker, different-talker) repeated measures ANOVAs were conducted on accuracy and RT in order to determine if there were significant

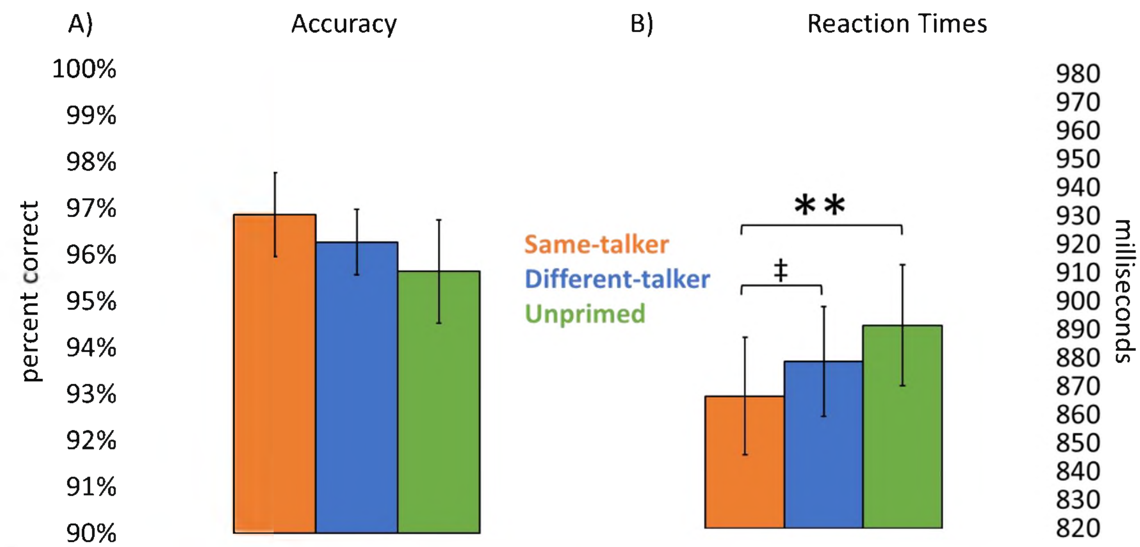

Figure 7. Behavioral results in response to high frequency words. There were no significant repetition or talker effects found in accuracy (A). Participants were significantly quicker to respond to words repeated by the same speaker compared to unprimed words (B), comprising significant repetition effect. There was also a trend for participants to respond marginally quicker to words repeated by the same speaker compared to words repeated by a different speaker, demonstrating a trend toward talker effects.
*p< .05. **p< .01. ‡p= .052.

talker, repetition effects, or both, and if those effects were greater in one word frequency condition over another.

Repetition Effects. Regarding the repetition effect comparisons, there was no significant main effect of word type ($F_{(1,16)}$= .003, p= .958, η^2= .000) or priming type ($F_{(1,16)}$= .687, p= .419, η^2= .041) on accuracy. There was no significant interaction between word frequency or priming type on accuracy ($F_{(1,16)}$= .705, p= .413, η^2= .042). However, there was a significant main effect in RT of word frequency ($F_{(1,16)}$= 47.304, p< .001, η^2= .747) and a significant main effect of priming ($F_{(1,16)}$= 35.251, p<. 001, η^2=

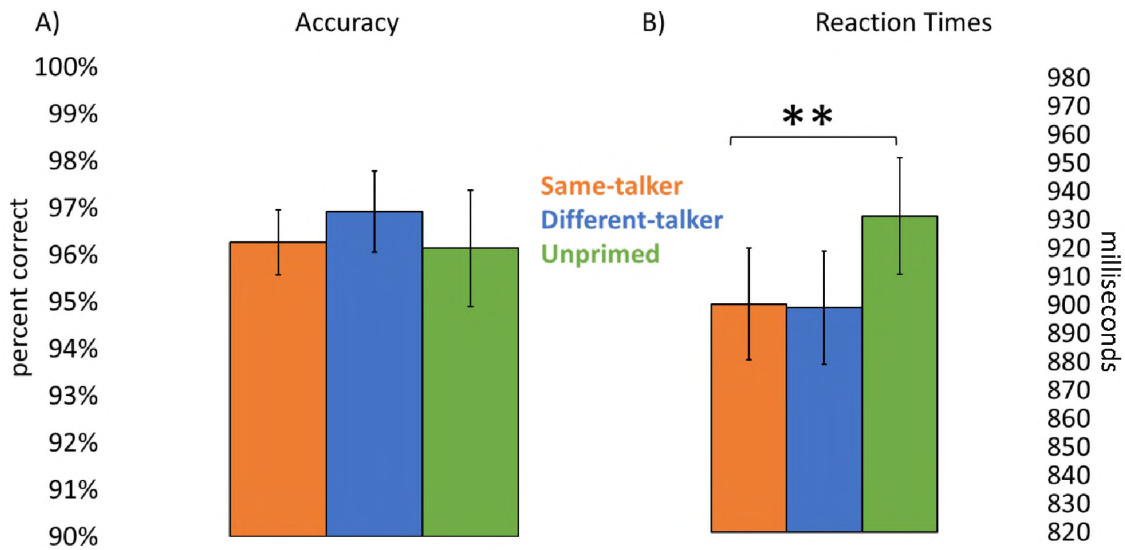

Figure 8. Behavioral results in response to low frequency words. There were no significant repetition or talker effects found in accuracy (A). Participants were significantly quicker to respond to words repeated by the same speaker compared to unprimed words (B), comprising significant repetition effect. There was no evidence of talker effects, as participants were not quicker to respond to same-talker repetitions compared to different-talker repetitions.
*p< .05. **p< .01.

.688). There was no significant interaction between word frequency and priming type on RT ($F_{(1,16)}$= .209, p= .654, η^2= .013).

Talker Effects. Regarding the talker effect comparison, there was no significant main effect of frequency type ($F_{(1,16)}$= .163, p= .692, η^2= .010) or priming type ($F_{(1,16)}$= .207, p= .256, η^2= .013) on response accuracy. There was no significant interaction between frequency type and priming type on accuracy ($F_{(1,16)}$= .257, p= .619, η^2= .016). Regarding RT, however, there was a significant main effect of frequency type ($F_{(1,16)}$= 9.247, p= .008, η^2= .366). The main effect of priming type, however, was not significant ($F_{(1,16)}$= 1.300, p= .271, η^2= .075). The interaction between frequency and priming type was not significant ($F_{(1,16)}$= 3.640, p= .075, η^2= .185).

Planned Comparisons by Frequency Type

Accuracy and RT for responses to high frequency words in block 2 are displayed in Figure 7. No significant repetition effects were found for accuracy (t_{16}= 1.126, p= .277, η^2= .073), but significant repetition effects in RT were evident (t_{16}= -2.967, p= .009, η^2= .355). There was no evidence of talker priming in accuracy (t_{16}= .096, p= .932, η^2= .001), but there was a trend toward significant talker priming in RT (t_{16}= -2.1, p= 0.52, η^2= .216).

Accuracy and RT for responses to low frequency words in block 2 are displayed in Figure 8. There was no evidence for significant repetition priming in accuracy (t_{16}= .133, p= .896, η^2= .001). However, there was significant repetition priming in RT (t_{16}= -4. 003, p= .001, η^2= .500). There was no evidence for talker priming in accuracy (t_{16}= -.797, p= .437, η^2= .038) or RT (t_{16}= .214, p= .833, η^2= .003).

ERPs

Due to the COVID-19 pandemic, we were unable to access the laboratory and did not have access to the EEG data and analysis software. We were able to generate qualitative grand average ERP figures of each priming condition for high and low frequency words. [4] When we are able to access the laboratory and recruit additional participants, we plan to complete data collection and analyze the complete dataset, including the planned ERP analyses.

[4] See Appendix B for more information.

CHAPTER IV

DISCUSSION

Behavior

We predicted that repetition effects would occur in accuracy, reaction times, or both for high and low frequency words. This prediction was supported in RTs, but not accuracy. For both high and low frequency words, participants responded quicker to words repeated by the same speaker compared to unprimed words. We further predicted that talker effects would occur in accuracy, reaction times, or both for low frequency words, and that talker effects would be absent or attenuated in high frequency words. This predication was not supported. In fact, marginally significant talker effects were observed in RT to high frequency words but were absent in RT of low frequency words, the opposite as was predicted. There was a trend for participants to respond quicker to words repeated by the same speaker compared to words repeated by different speakers when the words were of high frequency. However, when words were of low frequency, participants were not quicker to respond to words repeated by the same speaker compared to words repeated by different speakers. Nevertheless, the marginal talker effects found in RT of high frequency words may be a Type 1 error, as our sample size was underpowered; nevertheless, given the large effect size, this could be a true effect.

The presence of significant repetition effects in RT for both high and low frequency words provide evidence for abstractionist theories of spoken representation. Specifically, it suggests the presence of a mental lexicon of spoken words, where elements related to word form that allows a listener to distinguish one word from another are stored in memory (McQueen et al., 2006; Mullennix & Pisoni, 1990). Since participants were quicker to respond to repeated words at test compared to unprimed words, this suggests that the mental lexicon was primed, thus allowing easier access to the words upon test. The absence of facilitated processing when the words were repeated by the same speaker compared to words repeated by different speakers suggests that information related to anything other than basic word form (e.g., a specific speaker's voice) does not make it into the mental lexicon, which is proposed by episodic representational theories of the mental lexicon (Goldinger, 1996, 1998; Goh, 2005; Kouider & Dupoux, 2008; Luce & Lyons, 1998).

Nevertheless, marginal evidence for talker effects occurred in high frequency words. There was a trend for participants to respond quicker to words repeated by the same speaker compared to words repeated by different speakers when the words were of higher frequency. Thus, although the overall results provide evidence consistent with abstract representational theories, the trend toward talker effects in the high frequency word condition provides some evidence consistent with episodic representational theories. In this condition, there was an additive benefit of words being repeated by the same speaker, which suggests that information beyond that related to simple word form is stored in the mental lexicon. Overall, the presence of both repetition and talker effects supports hybrid theories of the mental lexicon, which propose that the mental lexicon is composed of both abstract and episodic representations (e.g., Goh, 2005; M^c^Lennan & Luce, 2005; Kouider & Dupoux, 2008).

The Time-Course Hypothesis

One such hybrid approach to the mental lexicon of spoken words is the time-course hypothesis (Luce & Lyons, 1998; McLennan & Luce, 2005), discussed earlier. According to the time-course hypothesis, both abstract and episodic details comprise the mental lexicon, and access to episodic details occurs after a relative delay. Our predictions regarding the time-course hypothesis were not supported. Specifically, we predicted that talker effects would occur for low frequency words, to which longer reaction times were expected, but not for high frequency words, to which faster reaction times were expected, since low frequency words would extend processing time, which in turn should allow talker effects to emerge. In fact, we found the opposite pattern. Repetition effects were evident for both high and low frequency words, but talker effects emerged for high frequency words only, despite longer reaction times to low frequency words, as predicted. Although these findings still suggest a hybrid approach to the mental lexicon for spoken words, since both abstract and episodic details seem to have been accessed during spoken word recognition, the results do not align with our original predictions regarding the time-course hypothesis.

The time-course hypothesis postulates that episodic details are stored in the mental lexicon along with abstract details, but that access to these details occurs after a relative delay. One instance with which to extend processing time to the extent that access to episodic details is evident is to manipulate ease of processing. The current study manipulated word frequency in order to manipulate ease of processing, where low frequency words were expected to take longer to process to the extent that talker effects emerge in this condition, but not in high frequency words. However, it may be that word frequency does not actually manipulate processing efforts in our target block of the current priming paradigm. Specifically, word frequency may have influenced processing, but during encoding, rather than recognition. Indeed, Diana and Reder (2006) found a low frequency word advantage during memory retrieval compared to high frequency words, which they propose resulted from a disadvantage for low frequency words during encoding. Specifically, the researchers hypothesize that low frequency words require more effort and processing during encoding, which consequently leads to facilitated recognition during subsequent recognition tasks.

In the current study, however, RT for low frequency words were consistently significantly longer compared to high frequency words. This suggests that the frequency manipulation was successful in affecting overall processing time; however, processing effort may be differentiated in the current paradigm. It could have been that frequency did manipulate processing of low frequency words, but during encoding and not retrieval. If as Diana and Reder (2006) propose, low frequency words were encoded more deeply during the priming block than high frequency words, then the subsequent access to the mental lexicon during the recognition block for low frequency words may have actually been facilitated relative to what they would have been without the priming block. Thus, the additive benefit of same talker repetitions compared to different talker repetitions in the current study may have been canceled out for low-frequency words. Nevertheless, the current study was not designed to examine differences in processing effort between encoding and recognition[5], which may be an avenue for future research to provide clarity into the storage of and access to mental representations of spoken words. The results of the current study ultimately demonstrate that spoken word recognition, and the mental lexicon of spoken words, is nuanced and complex.

Although Diana and Reder (2006) found that low frequency words extend processing time during encoding but not for recognition memory, Dufour and colleagues (2017) implemented a word frequency manipulation in order to manipulate ease of processing. Additionally, the researchers also found evidence consistent with the time-course hypothesis, where talker effects emerged in ERP measurements for low-frequency words, but not for high-frequency words. This is seemingly in direct contrast to the results found in the current study. However, Dufour and colleagues (2017) do not report behavioral evidence in the form of accuracy or RT, making it difficult to directly compare the two studies.

ERPs

Although inferential analyses of ERP data are planned, three clear ERP components are evident (see Figure 5B): early negativity (164-190ms), mid positivity (203-244ms), and late negativity (315-450ms). The first component aligns with the common N100 component, which likely reflects neural processes that are sensitive to stimulus detection (Makinen et al., 2004). The second component likely reflects the P200 component, which is a positive deflection that often occurs after sound onset and is thought to correspond to early sensory detection (Paulmann et al., 2013), similar to the N100. The final component aligns with the N400 component, which is a negative

[5] Since the study was not explicitly designed to examine processing differences between encoding and recognition, related interpretations are speculative.

deflection that occurs around 400ms after the presentation of either visual or spoken words and is believed to reflect lexical access and identification (Holcomb, 1993). We plan to analyze differentiations of these ERP components between word type, priming conditions, or both. These analyses will provide further insight into the time-course of lexical access during spoken word recognition in a long-term priming paradigm.

Limitations

There were various limitations that may have had unanticipated influences on the current data. Firstly, the study was long, taking approximately 65 minutes to complete. The duration of the experimental protocol could have led to participant fatigue, which could have influenced responses to stimuli. Furthermore, the sample size was relatively small, especially for a measure as sensitive as ERPs, which benefits from more participants due to trial loss during EEG data processing; thus, the effects of interest could be hidden by a lack of power. In order to increase the power of the study, we plan to collect more data, as originally proposed, once we are able to in the laboratory following the COVID-19 pandemic.

Although there were important limitations of the current study, the strong behavioral repetition effects and trend toward talker effects in high frequency words with a large effect size, as well as the clear ERP components and high response accuracy to all stimuli demonstrate a well-designed study with carefully selected and normed stimuli. Once the study is sufficiently powered, clearer effects and interpretable ERP patterns may emerge.

Future Directions

The current study provided a step in furthering the literature and the understanding of the representations of words in the brain, with particular emphasis on the time-course hypothesis. In order to further this progress, future studies may wish to implement other on-line or physiological measurements. For example, using imaging to attempt a localization of episodic and abstract representations of the mental lexicon. In addition, implementing other online measurements, such as mouse tracking, will advance the literature and provide new tests of the time-course hypothesis by providing further insight into the access of episodic and abstract details during spoken word recognition in real time.

In addition to expanding the measurements implemented in spoken word recognition, future research might want to implement different ease of processing manipulations in order to test the time-course hypothesis. If, as Diana and Reder (2006) suggest, low frequency words provide a benefit at memory recognition, then word frequency as an ease of processing manipulation to study word recognition may not be eliciting the effects during the critical time of processing. Consequently, a different ease of processing manipulation may be required in order to more directly test the time-course hypothesis in spoken word recognition. For example, McLennan and Luce (2005) implemented a more difficult shadowing task (i.e., a delayed shadowing task) in order to extend processing time of spoken word recognition, which successfully elicited talker effects. Thus, rather than manipulating the stimuli by frequency as the main processing manipulation, it may be more effective to manipulate the processing task in order to study the time-course hypothesis.

Conclusion

In the current study, we aimed to further the understanding of the mental lexicon for spoken words by examining the time-course hypothesis in spoken word recognition. Clear repetition effects were obtained in RTs to words repeated by the same speaker compared to unprimed words, demonstrating the inclusion of - and access to - abstract details in the mental lexicon. Evidence of talker effects in RTs to high frequency words suggests that episodic details, such as a specific speaker's voice, are also stored in the mental lexicon. Taken together, these data provide evidence for a hybrid approach to the mental lexicon, in which both abstract and episodic details are stored and accessed during spoken word processing. The time-course of this access, however, was unclear in the current tentative analyses with a reduced dataset.

Nevertheless, the current study provides further insight into how we store information related to the lexicon of spoken words. Furthering our understanding of human language is a critical area of research, as language provides the communicative abilities that have allowed humans to create complex societies and civilizations. Thus, it is essential to understand the nuances of language in order to better understand ourselves.

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Appendix A

Table 1

List of experimental stimuli

Word	Frequency Type	Nonword	Klattese
affair	HF Word	adsect	@dsEkt
answer	HF Word	afress	@frEs
actor	HF Word	ackoon	@kun
before	HF Word	anball	@nbal
tension	LF Word	uden	^dEn
terror	LF Word	udfer	^dfX
apple	HF Word	agolt	^g^lt
button	HF Word	attite	^tYt
army	HF Word	aloit	alOt
body	HF Word	arkler	arklX
children	HF Word	badret	b@drEt
college	HF Word	bamache	b@m@S
command	HF Word	bannil	b@nIl
garbage	HF Word	bulvy	b^lvi
garden	HF Word	buncer	b^nsX
contact	HF Word	banoo	b^nu
contract	HF Word	barnake	barnek
excuse	HF Word	bomple	bcmpL

Word	Frequency Type	Nonword	Klattese
corner	HF Word	bempy	bempi
color	HF Word	banctall	benktal
country	HF Word	beser	besX
control	HF Word	beable	bibL
daughter	HF Word	bisbout	bIsbWt
courage	HF Word	bezird	bizRd
defense	HF Word	blapple	bl@pL
early	HF Word	blolest	blolEst
escape	HF Word	blozer	blozX
driver	HF Word	blirkard	blRkard
evening	HF Word	boafty	bofti
freedom	HF Word	brumbie	br^mbi
female	HF Word	briffic	brIfIk
feeling*	HF Word	booclet	bukle
license*	HF Word	chadew	C@du
inside	HF Word	caffeash	c@fiS
knowledge	HF Word	captike	c@ptYk
murder	HF Word	conler	canlX
lady	HF Word	carmoun	carmun
captain	HF Word	awblor	cblor
model*	HF Word	chonter	CcntX
magic	HF Word	chavince	CcvIns
master	HF Word	chempy	Cempi

Word	Frequency Type	Nonword	Klattese
candy	HF Word	augent	cgInt
message	HF Word	chibunt	Cib^nt
member*	HF Word	chibre	Cibri
middle	HF Word	chidbren	CIdbrEn
minute	HF Word	chimter	CImtX
many	HF Word	cheetif	CitIf
money	HF Word	clodan	clodIn
mission	HF Word	chomi	Comi
center	HF Word	awtusc	ct^sk
poison	HF Word	dotplin	datplIn
outfit	HF Word	daben	debEn
partner*	HF Word	dafer	defX
people	HF Word	devat	dev@t
patient	HF Word	debol	dibol
penny	HF Word	derom	dirOm
pizza	HF Word	dola	dol^
police	HF Word	drestoon	drEstun
picture	HF Word	dirtner	dRtnX
planet	HF Word	dooven	duvEn
problem	HF Word	elyne	Elin
baseball	HF Word	anant	en@nt
brother	HF Word	ascin	esIn
promise	HF Word	esplact	Espl@kt

Word	Frequency Type	Nonword	Klattese
question	HF Word	famron	f@mran
labor	LF Word	phankle	f@nkL
reason	HF Word	fanver	f@nvX
respect	HF Word	fleadup	fled^p
river	HF Word	flidic	flIdIk
second	HF Word	flinak	flIn@k
silence	HF Word	fobbil	foZX
single	HF Word	funer	funX
research	HF Word	finum	fYnum
sister	HF Word	fyecesse	fYsEs
station	HF Word	ghatter	g@tX
success	HF Word	gubber	g^bX
special	HF Word	gallel	galEl
stomach	HF Word	goncer	gcnsX
student	HF Word	gotel	gctL
soldier	HF Word	gabir	gebX
something	HF Word	gady	gedi
stranger	HF Word	gopan	gop@n
subject	HF Word	grodit	grodIt
sugar	HF Word	habber	h@bX
summer	HF Word	happhe	h@pfi
table	HF Word	hommy	hami
support	HF Word	hayple	hepL

Word	Frequency Type	Nonword	Klattese
system*	HF Word	henic	hinIk
suspect	HF Word	heenpred	hinprEd
talent	HF Word	hosu	hosu
target	HF Word	hygease	hYJis
taxi	HF Word	hyscod	hYskcd
teacher*	HF Word	imbert	ImbXt
today	HF Word	inzat	Inz@t
story	HF Word	gonser	jcnsX
traffic	HF Word	jexuar	Jekswar
travel	HF Word	jillind	jIlInd
village	HF Word	jolvet	jolvEt
unit	HF Word	jimer	jYmX
husband	HF Word	cadlive	k@dlIv
issue	HF Word	caffus	k@f^s
hotel	HF Word	cactage	k@kt@J
jacket	HF Word	camret	k@mrEt
jury	HF Word	canwo	k@nwo
warning	HF Word	kubter	k^btX
other	HF Word	cuxer	k^ksX
office	HF Word	cuppom	k^pam
morning	HF Word	coddee	kadi
mother	HF Word	coddin	kadIn
mountain	HF Word	confipt	kanfIpt

Word	Frequency Type	Nonword	Klattese
movie	HF Word	conflart	kanflart
music	HF Word	contith	kantIT
number	HF Word	cottud	kat^d
notice	HF Word	cotoque	katok
nature	HF Word	coppent	kcpEnt
nothing	HF Word	corot	kcrat
vision	HF Word	kelder	kEldX
language	HF Word	caymee	kemi
visit	HF Word	kenma	kEnm^
navy	HF Word	corfress	korfrEs
monster	HF Word	coatle	kotL
ocean	HF Word	crither	krIDX
open	HF Word	curtike	kRtYk
myself	HF Word	coodin	kUdIn
offer	HF Word	cuisant	kwIs@nt
winner	HF Word	lappent	l@pEnt
winter	HF Word	lattee	l@ti
biscuit	LF Word	ludon	l^dcn
woman	HF Word	laubul	lcb^l
asthma	LF Word	lommy	lcmi
apron	LF Word	lomil	lcmIl
bandit	LF Word	lospler	lcsplX
basket	LF Word	lostle	lcstL

Word	Frequency Type	Nonword	Klattese
wedding	HF Word	lagit	legit
worry	HF Word	lelloor	lElUr
window	HF Word	langorth	lengcrT
yellow	HF Word	lerrade	lered
accent	LF Word	limpa	lImp^
writing	HF Word	lensean	lInsin
autumn	LF Word	lonay	lone
welcome	HF Word	lakyon	lxkyN
blizzard*	LF Word	mackand	m@k@nd
blossom	LF Word	manone	m@non
bonus	LF Word	manvet	m@nvEt
fusion	LF Word	mubsle	m^bsL
fungus	LF Word	mubber	m^bX
gender	LF Word	mumit	m^mIt
glitter	LF Word	munall	m^nal
goalie	LF Word	munder	m^ndX
gossip	LF Word	munfler	m^nflX
bucket	LF Word	masize	m^sYz
bounty	LF Word	marfon	marf|n
breakup	LF Word	marwon	marwan
domain*	LF Word	mollo	mclo
cartoon	LF Word	megret	mEgrEt
carrot	LF Word	mecteen	mEktin

Word	Frequency Type	Nonword	Klattese
cactus	LF Word	matrok	metrck
cherry	LF Word	micket	mIkEt
comment	LF Word	mikfure	mIkfUr
carpet	LF Word	meantave	mintev
conflict	LF Word	misspeaf	mIspif
crouton	LF Word	mistice	mIstYs
cuisine	LF Word	mobar	mobar
diver	LF Word	mogy	mogi
curtain*	LF Word	mocar	mokar
doodle	LF Word	momate	momet
decease	LF Word	moemer	momX
extract	LF Word	mopo	mopo
fighter	LF Word	moru	moru
debut	LF Word	mocer	mosX
fossil	LF Word	motean	motin
grammar	LF Word	murting	mRtiG
halo	LF Word	mybolf	mYbolf
cologne	LF Word	mider	mYdX
habit	LF Word	mutine	myutin
hammer	LF Word	nacore	n@kUr
harvest	LF Word	nainer	nenX
hazard	LF Word	noder	nodX
hobby	LF Word	notave	notev

Word	Frequency Type	Nonword	Klattese
hostel	LF Word	nougle	nugL
hygiene	LF Word	odan	od@n
input*	LF Word	ozy	ozi
insect	LF Word	pabick	p@bIk
jaguar	LF Word	pashel	p@SEl
motive	LF Word	pudvis	p^dvIs
lineup	LF Word	pokron	pakr|n
junction	LF Word	pemmer	pEmX
karma	LF Word	pencein	pensIn
ivy	LF Word	papsty	pepsti
layout	LF Word	pidlic	pIdlIk
leisure	LF Word	pilern	pIlXn
lemon	LF Word	pintem	pIntEm
lettuce	LF Word	pipcent	pIpsEnt
lever	LF Word	plisty	plIsti
limit	LF Word	poetike	potYk
lipid	LF Word	practame	pr@ktem
lobster	LF Word	prammin	pr@mIn
logic	LF Word	predhel	prEd^L
lotion	LF Word	predlem	prEdlEm
mischief	LF Word	proquim	prokwIm
mentor	LF Word	prohvy	provi
mermaid	LF Word	prooble	prubL

Word	Frequency Type	Nonword	Klattese
monarch	LF Word	prupent	prupEnt
lava	LF Word	pidle	pYdL
motor	LF Word	radin	r@dIn
mummy	LF Word	ransa	r@ns^
muscle	LF Word	ranver	r@nvX
mutant	LF Word	rato	r@to
panda	LF Word	runcet	r^nkEt
parade	LF Word	russage	r^sej
oyster	LF Word	ronyor	ranycr
novel	LF Word	refet	rEfEt
odor	LF Word	regide	rigId
option	LF Word	rehest	rihEst
neon	LF Word	reekerth	rikRT
noodle	LF Word	reenut	rin^t
organ	LF Word	retift	ritIft
program	HF Word	ertfing	RtfG
palate	LF Word	rooson	rusN
parrot	LF Word	sacksar	s@ksar
polar	LF Word	shalser	S@lsX
retreat	LF Word	sudvess	s^dvEs
pastry	LF Word	sarby	sarbi
peanut	LF Word	scointure	scOntyR
level	HF Word	cery	seri

Word	Frequency Type	Nonword	Klattese
plasma	LF Word	setver	sEtvX
letter	HF Word	cebor	sibor
moment	HF Word	cillor	sIlor
penguin	LF Word	scroggle	skrcgL
pony	LF Word	snummer	sn^mX
profit	LF Word	sornfing	sOrnfiG
pretzel	LF Word	soetser	sotsX
profuse*	LF Word	spedit	spEdIt
puzzle	LF Word	spevool	spEvul
raven	LF Word	spimmar	spImar
pupil	LF Word	speesure	spisur
rebound	LF Word	spovist	spovIst
recess	LF Word	sprosar	sprcsX
rival	LF Word	surspire	sRspYr
pilgrim	LF Word	serty	sRti
refill	LF Word	stareen	starin
retail	LF Word	staros	staros
rocket	LF Word	tany	t@ni
statue*	LF Word	tumser	t^msX
swimmer	LF Word	tuttuce	t^t^s
suffix	LF Word	tutber	t^tbX
sparrow	LF Word	tonsue	tcnsu
rooster	LF Word	tavo	tcvo

Word	Frequency Type	Nonword	Klattese
scholar	LF Word	tengus	tEng^s
slogan	LF Word	tiflet	tIflEt
rumor	LF Word	teentain	tintEn
solo	LF Word	tobive	tobYv
sculpture	LF Word	terfee	tRfi
serpent	LF Word	thrishork	TrISork
seizure	LF Word	tertet	tRtEt
tantrum	LF Word	tuvy	tuvi
tissue	LF Word	unem	unEm
igloo	LF Word	oosil	usIl
tofu	LF Word	velcine	vElsin
tourist	LF Word	victap	vIkt@p
trophy	LF Word	wenjer	wEnjX
twilight	LF Word	whentle	wEntL
tulip	LF Word	weun	wi^n
triplet	LF Word	weekep	wikEp
whistle	LF Word	wixand	wIksInd
vegan	LF Word	witom	wIt^m
worker	LF Word	worven	worvIn
wizard	LF Word	woesin	wosIn
wrinkle	LF Word	wrilive	wrYlYv
behind	HF Word	anfee	xnfi
yogurt	LF Word	yogull	yog^L

Word	Frequency Type	Nonword	Klattese
attack	HF Word	ammay	@me
cousin	HF Word	bintel	bIntL
lawyer	HF Word	caysin	kesIN
practice	HF Word	dritter	drItX
present	HF Word	drocket	drakEt
pressure	HF Word	dupric	duprIk
prison	HF Word	elbur	ELbR
season	HF Word	flimper	flImpX
service	HF Word	flobuse	flobyus
seven	HF Word	foasure	foZX
sorry	HF Word	gaket	g@kEt
spirit	HF Word	geesy	gisi
study	HF Word	graxer	greksX
toilet	HF Word	jefan	jif@n
belief	LF Word	lowjis	lojIs
berry	LF Word	loyin	lOIn
chaos	LF Word	menaph	mEn@f
crater	LF Word	missunt	mIs|Nt
dolphin	LF Word	mollart	maLart
hybrid	LF Word	nuek	nuEk
manure	LF Word	prelker	prElkX
maple*	LF Word	prilem	prIlIm
mixture	LF Word	protoch	protctC

Word	Frequency Type	Nonword	Klattese
oven	LF Word	rishet	rISEt
polo	LF Word	shisser	SIsX
rebel	LF Word	spotret	spotre
spinach	LF Word	trapore	tr@pUr
tattoo*	LF Word	tweaper	twipX
timber	LF Word	uneesh	^niS

Note. Klattese refers to the phonemic transcription of the nonword stimuli.

*item was excluded from analyses

Appendix B

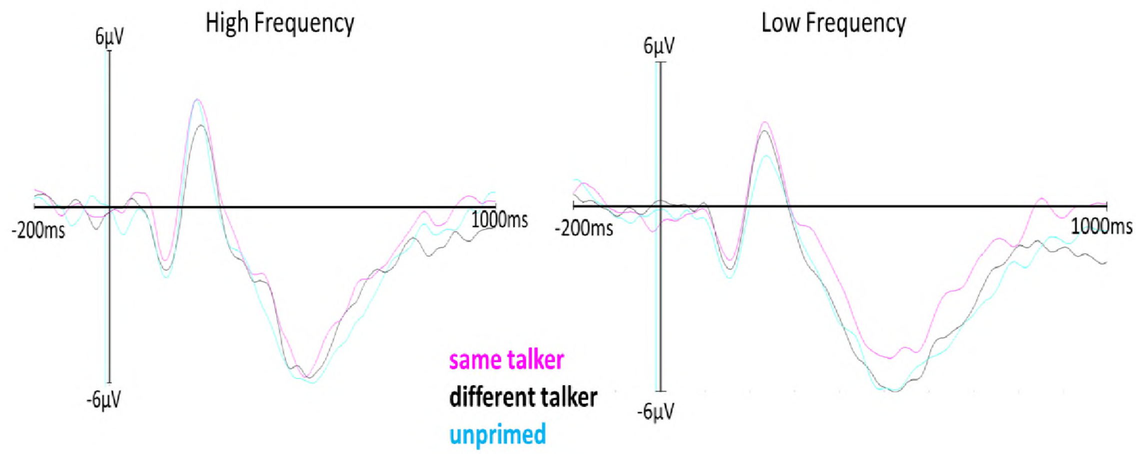

Figure 9. ERP waveform comparisons of word frequency and priming condition. Both high and low frequency ERP waveforms were taken from Cz electrode channel. ERPs reflect grand average waveforms across all participants in the relevant word frequency and priming conditions.

Due to the COVID-19 pandemic, data collection was terminated prematurely and access to EEG data and analysis software was lost. The figures presented in Figure 8 represent purely qualitative analyses of grand average ERP waveforms. Inferential analyses will be forthcoming once access to data is re-established and data collection is completed; therefore, we will not yet interpret the presented ERP waveforms.