The Role of the Phonological Syllable in English Word Recognition

Daniel Trinh
The University of Western Ontario

Supervisor
Dr. Debra Jared
The University of Western Ontario

Graduate Program in Psychology
A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

THE ROLE OF THE PHONOLOGICAL SYLLABLE IN ENGLISH WORD RECOGNITION

(Thesis format: Monograph)

by

Daniel Trinh

Graduate Program in Psychology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

ABSTRACT

Three ERP experiments examined the role of syllables during English visual word recognition. A colour congruency paradigm (Carreiras, Vergara, & Barber, 2005) was used in which disyllabic words were presented in two colours that divided each item either at the syllable boundary (congruent condition), or one letter away from the syllable boundary (incongruent condition). Experiment 1 investigated syllable congruency effects for words that either were presented with an orthotactically illegal segment in the incongruent condition (e.g., whi-mper, comr-ade), or were presented with orthotactically legal segments in the incongruent condition (e.g., whi-sper, cont-act). A syllable congruency effect was observed in the ERP data, but only for words presented with an orthotactically illegal segment in the incongruent condition. Experiment 2 contrasted the phonological syllable with the Basic Orthographic Syllabic Structure (Taft, 1979), and the Maximal Onset Principle. Behavioural and ERP results did not offer any evidence in support of the BOSS, and provided mixed evidence for the MOP. Although phonological syllable effects were found in both behavioural and ERP data, the advantage for a syllable division appeared to occur primarily when the initial segment in alternative divisions was pronounced differently in isolation than in the context of the word (e.g., pi-cnic but not pla-ster). Experiment 3 investigated syllable congruency effects for phonologically confounded and phonologically unconfounded words. For phonologically confounded words, pronunciation of the initial segment in isolation matched that of the whole word in the congruent condition, but did not match in the incongruent condition (e.g., po-ny vs pon-y; pon-der vs po-nder). For phonologically unconfounded words, the pronunciation of the initial segment in isolation matched that of the whole word in both congruent and incongruent conditions (e.g., cab-in vs ca-bin), or mismatched in both congruent and incongruent conditions (e.g., ca-ble vs cab-le). A syllable congruency effect was found in the ERP data, but only for phonologically confounded words. These data suggest that readers of English do not parse words into syllables during silent reading. Implications for theories and computational models of English word recognition are discussed.

Keywords: reading, syllables, phonology, word recognition, multisyllabic words, BOSS, maximal onset principle, event-related potentials

ACKNOWLEDGEMENTS

I would like to extend my deepest gratitude to my graduate supervisor, Dr. Debra Jared, for her patience and guidance throughout my graduate studies. This thesis has benefited greatly from her generosity with time, expertise, and attention to detail.

Thank you to my committee members, Dr. Marc Joanisse, Dr. Lisa Archibald, Dr. Steve Lupker, Dr. François Poiré, and Dr. Devin Kearns for providing insightful comments and suggestions at various stages of this thesis.

To my family, who are a constant source of love and encouragement, for which I am immeasurably thankful.

Table of Contents

List of Tables

List of Figures

List of Appendices

General Introduction

There is abundant evidence indicating that phonological representations of words play an important role in reading. Furthermore, it has been shown that in order to become an efficient reader in languages with alphabetic writing systems, one must be able to extract the sound information from printed words (Frost, 1998). Phonological representations have been shown to be activated even by skilled readers when reading silently (e.g., Jared, Levy, & Rayner, 1999; Newman, Jared, & Haigh, 2012). Therefore, it is important to increase our understanding of how phonological information is derived from print. In addition to empirical evidence, computational modeling of reading aloud has provided further insights about the function of phonology underlying word recognition (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 2004; McClelland & Rumelhart, 1981; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989).

However, despite extensive research on visual word recognition, the majority of existing data with which to constrain current computational models of phonological processes in reading have been from studies that have focused on monosyllabic words. This is problematic given that the majority of words in the English language are multisyllabic. As such, even though there has been a recent effort to create a computational model of polysyllabic words in English that includes phonological representations (CDP++, Perry, Ziegler, & Zorzi, 2010; for implementation in Italian and French, respectively, see Perry, Ziegler, & Zorzi, 2014a, 2014b), more data are needed in order to refine this and future models. Additionally, whether current knowledge concerning monosyllabic words can be generalized to multisyllabic words is not well understood. Thus, it is important to broaden research regarding the role of phonology in word recognition to include multisyllabic words as well. Extending the present understanding of visual word recognition to include multisyllabic words requires the consideration of additional factors relevant only to polysyllabic words. One of these factors is the role of the syllable. Specifically, the current study examined whether readers parse words into explicit syllable units prior to activating their phonological representation.

Before reviewing the literature on syllable effects in visual word recognition, it is important to consider how the phonological syllable is defined. Even though intuitively it seems straightforward to syllabify spoken words, in actuality there has not been a consensus of what the precise phonological rules are for syllabification (Treiman & Zukoski, 1990). It is generally understood that each phonological syllable is composed of at least a vowel sound. Furthermore, the phonemes occurring at the beginning or end of an individual syllable must also be able to begin or an end English words, respectively. Principles regarding morphological structure, speaking rate, and sonority contour have also been proposed to determine syllable boundaries, but linguists and psycholinguists have not agreed on one set of rules to syllabify all English words. However, for many words, the rules of a vowel sound with a phonotactically legal beginning and ending has sufficed in determining the phonological syllable.

There is a growing literature examining syllable effects in visual word recognition using a variety of paradigms using both reading aloud as well as silent reading. The most common syllable effects that have been studied include number of syllables, syllable frequency, and syllable priming. As will be evident, there have been robust findings suggesting that the syllable does constitute a sublexical unit important to visual word recognition for languages such as Spanish and French. It is plausible that readers of these languages decompose printed words into syllables and activate phonology syllable by syllable during reading. For English, however, it is much less clear whether printed words are parsed into syllables. This is because syllables are clearly marked in the orthography of Spanish and French words, while this is not always the case in English. Indeed, accurately naming English words aloud does require syllable pauses and appropriate stress assignment, suggesting that such information is present in stored phonological representations. However, it is unclear whether the letters in multisyllabic words must first be parsed into groups corresponding to phonological syllables prior to activating these phonological representations.

Number of Syllables

Early research sought evidence that readers of English parse printed words into syllables by investigating whether word recognition is influenced by the number of syllables in a word. The logic was that if readers parse printed words into syllable units, then when matched for number of letters, words with more syllables should take longer to process than words with fewer syllables. Using tachistoscopic presentation, Spoehr and Smith (1973) found that report accuracy was higher for one than for two syllable words that were matched on word length and word frequency. Butler and Hains (1979) further showed that number of syllables accounted for unique variance in naming latencies of one to five syllable words even when word length was included in the regression analysis. On the other hand, Frederiksen and Kroll (1976) found that the number of syllables did not have an effect on naming words with four to six letters, even though there was a word length effect. With the same stimuli, they also failed to find a number of syllables effect using a lexical decision task. Jared and Seidenberg (1990) found that naming latencies were longer as the number of syllables increased, but only for lower frequency words. They suggested that the effect of number of syllables was not due to readers parsing words into syllables, and argued that the number of syllables effect was a spelling-sound consistency effect. That is, words with more syllables also have more vowels, which tend to be more variable in their pronunciation (in comparison to consonants), and thus would prolong naming latencies. Furthermore, the reason that this effect is not found with higher frequency words was thought to be because they are read more quickly and are less influenced by spelling-sound consistency.

In a French naming study, Ferrand (2000) also found that the number of syllables in a word resulted in longer naming latencies for low-frequency words, but not during a delayed condition in which participants were instructed to wait for a cue (with a 2 s delay) before naming the letter string. According to Ferrand, the delayed naming task showed that the number of syllables effect was not due to articulatory factors, since participants would have formed an articulation plan by the time they were cued to respond. Thus, he argued that the syllabic effect found with the immediate naming task was due to processes leading up to the activation of phonological representations. The number of syllables effect has also been shown with lexical decision and nonword naming (Ferrand & New, 2003), which has led these researchers to conclude that readers recover syllable-sized units in French word recognition (for a similar finding in German, see Stenneken, Conrad, & Jacobs, 2007).

More recent studies examining the number of syllables effect in English have involved performing analyses on large databases. New, Ferrand, Pallier, and Brysbaert (2006) conducted simultaneous multiple regression analyses on lexical decision data from the English Lexicon Project (Balota et al., 2002) and found an effect of number of syllables even after controlling for word length, frequency, and number of orthographic neighbours. Similarly, Muncer and Knight (2012) found an effect of number of syllables that was independent from word frequency and orthographic similarity for five letter words from the British Lexicon Project (Keuleers, Lacey, Rastle, & Brysbaert, 2012). Moreover, Yap and Balota (2009) performed hierarchical regression analyses on naming and lexical decision latencies of 6115 monomorphemic multisyllabic words from the English Lexicon Project. They found an interaction between number of syllables and word frequency for both tasks such that as word frequency increased, the number of syllables effect decreased. Furthermore, they found that latencies for naming and lexical decision correlated with number of syllables independent of word length, word frequency, neighbourhood size, and phonological consistency. However, number of syllables had a very small impact, with β weights of .077 and .049 for naming and lexical decision, respectively, when these other variables were included in the regression analyses.

Summary. Mixed findings for the number of syllables effect in behavioural studies, along with results from multiple regression studies, suggest that syllable effects are subtle in English. This is because these effects are more evident for low frequency words, and in very large data sets.

Syllable Frequency

Previous studies have also examined the role of syllables by manipulating syllable frequency. If readers parse printed words into syllable units, then the frequency of individual syllables might have an impact on naming and recognition times. In the Spanish word recognition literature, words with high frequency syllables have been found to be named faster than words with low frequency syllables (Perea & Carreiras, 1998). Utilizing pseudowords, Carreiras and Perea (2004) manipulated the frequency of the first and second syllable while controlling for lexical stress and bigram frequency. These authors found a facilitative naming effect of syllable frequencies only for the first syllable, such that words with higher frequency initial syllables were named faster than low frequency first syllables.

Spanish studies have also investigated the syllable frequency effect for silent reading (e.g., Álvarez, Carreiras, & de Vega, 2000; Álvarez, Carreiras, & Taft, 2001; Álvarez, de Vega, & Carreiras, 1998; Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998). Using lexical decision, these studies have generally found that words with high frequency syllables produce longer response times and higher error rates than words with lower frequency syllables, for both high and low frequency words. These researchers claim that the syllable frequency effect is inhibitory in lexical decision because words with higher frequency syllables activate more word candidates with the same syllables than words with lower frequency syllables. Since a larger neighbourhood results in longer latencies, the correct identification of words containing higher frequency syllables would be delayed.

Many studies investigating syllable frequency in Spanish have controlled for various factors that may be confounded with the syllable frequency effect, and have shown that it cannot be accounted for by orthographic redundancy (Carreiras, Álvarez, & de Vega, 1993), morpheme frequency (Álvarez, Carreiras, & Taft, 2001), or orthographic neighbourhood density and frequency (Perea & Carreiras, 1998). The syllable frequency effect has also been found in studies examining other languages such as French using lexical decision (Conrad, Grainger, & Jacobs, 2007; Mathey & Zagar, 2001), as well as German utilizing lexical decision and a perceptual identification task (Conrad & Jacobs, 2004) and eye tracking (Hawelka, Schuster, Gagl & Hutzler, 2013).

Barber, Vergara, and Carreiras (2004) further examined the syllable frequency effect in Spanish with ERPs while participants performed a lexical decision task. They manipulated word frequency as well as first syllable frequency, and found that the syllable frequency effect modulated the P200 component, with low frequency syllables eliciting more positive amplitudes than high frequency syllables. Additionally, there was no effect of word frequency at the P200. They also found that high frequency words produced less negativity for the N400 component than low frequency words, while words with high frequency syllables elicited greater negativity than words with low frequency syllables. The finding that word frequency influenced only the N400 component, whereas syllable frequency influenced both the P200 and N400 components, suggests that processing for the syllable and the whole word is associated with different stages of word recognition. The P200 syllable frequency effect may be indicative that syllables are indeed functional sublexical units in visual word recognition.

While there is evidence to suggest that syllable frequency effects in visual word recognition are reliable for French and German, and there is a large amount of support for syllable frequency effects in Spanish, whether they occur in English has received much less attention. A study by Macizo and Van Petten (2007) examined syllable frequency effects on naming and lexical decision in English by performing multiple regression analyses on data for disyllabic words from the English Lexicon Project (Balota et al., 2002). Their results from English naming tasks were similar to the Spanish studies, such that they showed facilitation for naming latencies with words that had higher first and second syllable frequencies after word frequency and word length were entered in a stepwise regression. They also found a facilitation effect of syllable frequency in lexical decision, which is opposite to the effect that occurs in Spanish studies. These authors claimed that if lexical candidates are indeed activated via syllabic units during word recognition, it does not happen rapidly enough to cause inhibitory effects for lexical decision in English. Instead, English readers may recognize whole words based on their spelling before syllabic neighbors can be activated.

Summary. While robust syllable frequency effects have been found in Spanish word recognition, there has been a dearth of studies investigating syllable frequency effects in English reading. The existing examination of syllable frequency in English words suggests that syllable frequency effects may occur in English word recognition. However, as in the number of syllables literature, these syllable effects may be subtle given that the study employed multiple regression analyses over a large data set.

Illusory Conjunction

An alternative approach to determining whether readers parse printed English words into syllables is the illusory conjunction paradigm (Prinzmetal, Treiman, & Rho, 1986). Prinzmetal et al. briefly presented participants with words and pseudowords for which half of each letter string was a different colour, and participants were asked to identify the colour of a letter in the middle of the item. Illusory conjunction refers to when the incorrect colour is reported. These researchers found that illusory conjunction errors occurred more often when the critical letter was in a different colour than the rest of the letters in its syllable compared to when it was in the same colour as its syllable mates, suggesting that syllables are functional units in visual word recognition.

Seidenberg (1987) had a different interpretation of these results, and argued that readers may be sensitive to how often letters occur together. He noted that bigrams (letter pairs) within syllables of a word usually have higher frequencies when compared to bigrams across syllables (e.g., VODKA, “d” and “k” rarely co-occurs within a syllable in English). That is, there tends to be a ‘trough’ in terms of bigram frequency when two letters correspond to a syllable boundary. Seidenberg thought that mixed findings regarding syllable effects in the literature may be due to the use of some stimuli that do not have the bigram trough pattern. To examine this, an experiment was conducted using the illusory conjunction paradigm, and disyllabic words that had a trough pattern at their syllable boundaries. Half of the stimuli had syllable boundaries after the second letter, and the other half of the stimuli had syllable boundaries after the third letter. Each word was briefly presented in two colours such that the critical letter was the same colour as the rest of the letters in its syllable, or it was the opposite colour. Seidenberg found that significantly more errors were made when the critical letter was a different colour than its syllable mates, suggesting that letters within a syllable were perceptually grouped together when the syllable boundary was marked by a low frequency bigram.

To test Seidenberg's (1987) theory, Rapp (1992) also used the illusory conjunction paradigm, and presented subjects with disyllabic words for which half of the words had a syllable break between the second and third letters, and the other half had a syllable break between the third and fourth letters. The syllable boundary for each critical item was between two consonants that could not go together in either syllable according to orthotactic rules, which refers to how common or rare letter combinations occur within a word (e.g., ad-vise, but not a-dvise because "dv" cannot begin an English word, or adv-ise because "dv" cannot end an English word). Sixty percent of these words had a bigram trough, and the rest did not. Rapp found that participants made more illusory conjunction errors when the critical letter was the opposite colour than the letters in its syllable, regardless of presence or absence of a bigram trough. Thus, it may be that readers utilize orthotactic information to determine how words are divided into syllables. However, it is not certain whether this is the case since Rapp's study did not include words for which orthotactic rules do not clearly indicate the syllable boundary. More recently, the bigram trough hypothesis was tested in a Spanish lexical decision experiment (Conrad, Carreiras, Tamm, & Jacobs, 2009). They found that the syllable frequency effect was unaffected by whether or not there was a bigram trough at the syllable boundary (see Carreiras et al., 1993 for a similar finding).

Summary. Earlier examinations of syllable effects using illusory conjunction suggested that syllables do play a role in English word recognition. Moreover, this may be attributed to readers' sensitivity to letter co-occurrences within, and across, syllables. However, further investigation found that effects of syllable structure cannot be attributed solely to orthographic redundancy. Rather, the syllable effects may be a function of orthotactic rules.

Syllable Priming

The role of the syllable in reading has also been investigated with priming experiments. If printed words are parsed into syllables, then presenting a prime that corresponds to the first syllable should facilitate reading compared to a prime that does not correspond to the syllable. For example, Ferrand, Segui, and Grainger (1996) presented French subjects with masked primes that corresponded to the initial syllable of two- and three-syllable target words (e.g., ba-BALADE, par-PARTISAN), and disyllabic nonwords. They also presented primes that contained either one letter more or less than the first syllable of the target stimuli (e.g., bal-BALADE, pa-PARTISAN). In a naming task, they found facilitation for word and nonword targets when the prime was congruent with the initial syllable, compared to when it was not. A similar effect of syllable priming has also been found in naming English words (Ferrand, Segui, & Humphreys, 1997). Ferrand et al. (1997) manipulated the type of word, such that some words had a clear initial syllable boundary (e.g., BALCONY; the /l/ can only belong to the first syllable, because "lc" cannot begin an English word), whereas other words were ambisyllabic (e.g., BALANCE; the /l/ can belong to the first or second syllable). They found facilitation in naming when words were preceded by a prime that was congruent with the first syllable compared to when it was not, but only for words with a clear initial syllable boundary. This finding is similar to Rapp's (1992) study, since Ferrand et al. only found a syllable priming effect with words for which orthotactic rules clearly indicate the syllable boundary (e.g., bal-cony, but not ba-lcony or balc-ony), but not for words with no clear syllable boundary. Neither study found a syllable priming effect in lexical decision.

Even though the studies by Ferrand and colleagues (1996; 1997) seem to suggest a role for syllables in naming for both French and English, attempts to replicate their findings have been mixed. In a naming study using the same stimuli and procedure as Ferrand et al.'s French study, Brand, Rey, and Peereman (2003) were not able to replicate the syllable priming effect. This was also the case when prime exposure was increased to double the original duration, and when the number of participants was increased. Chetail and Mathey (2009), however, were able to replicate Ferrand et al.'s French findings with a naming task, as well as a lexical decision task, by increasing the stimulus-onset asynchrony from 43 ms to 67 ms.

Also in an attempt to replicate Ferrand et al.'s (1997) syllable priming effect, Schiller (1999) conducted an English naming experiment with masked priming in which primes either were congruent with the first syllable of the target (e.g., pi%%%-PILOT; pic%%%-PICNIC), were one letter more than the initial syllable of the target (e.g., pil%%-PILOT), or were one letter less (e.g., pi%%%%-PICNIC). Rather than finding syllable priming effects, he found greater priming effects with an increased overlap in the number of letters between the prime and target. The same results were found using words with different letter structures (Schiller, 2000), and in a study using Dutch words (Schiller, 1998). These findings, along with similar ones using increased prime exposures, led Schiller (2000) to reject Ferrand et al.'s assertion that the syllable has a functional role in English word naming.

Despite the fact that past priming studies have failed to provide strong evidence for the use of syllables in English in general, recent eye tracking research has suggested that syllables may play a role in visual word recognition in English. Ashby and Rayner (2004) presented mid-to-low frequency words that were preceded by two- or three-letter primes. They either were congruent with the target's first syllable (e.g., de-DEMAND), or contained one letter more or less than its initial syllable (e.g., dem-DEMAND). When short primes (40 ms) were presented foveally to the subject, a syllable priming effect was not found. In a second experiment, the primes were presented using a parafoveal preview technique. This technique takes advantage of the parafoveal processing of a target item that occurs when fixating on the word before the target. In particular, participants read sentences in which a preview stimulus (e.g., de, dem) appeared in place of the target item. When the participants' eye movements crossed an invisible boundary between the word before the preview stimulus and the preview item, the preview stimulus was replaced by the target word (e.g., DEMAND). They found that first fixation durations were shorter on a word when it was preceded by a prime that was congruent with its initial syllable when compared to a prime that was incongruent. Thus, Ashby and Rayner asserted that readers do encode syllabic structure if it is available parafoveally.

Ashby and Martin (2008) replicated this syllable effect with lexical decision, and also with a masked priming paradigm while measuring event-related potentials (ERPs). They found more positivity when the prime was congruent with the target's initial syllable in a component within the 250-350 ms time window, than when the prime contained one letter more or less than the first syllable. According to Ashby and Martin, these results provide further evidence that English readers process sublexical syllable units early in visual word recognition that seem to be speech-like phonological representations. They suggest that these representations are used when advance information about a word is stored in memory (e.g., during a saccade), and that readers might automatically activate this information parafoveally during silent reading.

More recently, Ashby (2010) cited a shortcoming to her previous syllable priming experiments. Since the primes that were used did not appear equally often in the congruent and incongruent conditions, the results of those experiments may have been confounded by orthographic features of the primes and targets. In order to minimize any variance that may be caused by orthographic factors, Ashby conducted an ERP study with a visually matched design in which critical items were matched such that they had the same initial trigram, but had a different syllabification (e.g., PONY, PONDER). The masked prime either corresponded to the initial bigram or trigram that was either congruent with the target (e.g., po##-PONY, pon###-PONDER), or incongruent with the target but congruent with its matched item (e.g., pon#-PONY, po####-PONDER). As such, the same masked primes were presented in the congruent and incongruent conditions, and thus any effect found would not be orthographic in nature. Participants silently read target words and responded to semantic judgments on filler items (e.g., "Does it fly?"). The results showed a syllable effect with an onset as early as 100 ms, with the incongruent condition eliciting more negative waveforms than the congruent condition in the N100. Ashby suggested that this effect was due to the prompt activation of phonological syllable information during word recognition.

While the studies by Ashby and colleagues do provide good evidence that readers make use of phonological information during reading, it is not clear whether these effects constitute direct evidence of online syllable processing during silent reading. One reason is that these priming tasks present, albeit briefly, subjects with the syllable explicitly parsed in advance of the target word, which may start to activate phonological information associated with the prime. This phonological information is consistent with that of the target in the congruent condition (e.g., po-PONY, pon-PONDER), but mismatches in the incongruent condition (e.g., pon-PONY, po-PONDER). Thus, the priming effect may be a phonological priming effect rather than a syllable effect.

Summary. Behavioural investigations of syllable effects using syllable priming have yielded mixed results. More recent studies utilizing eye tracking and ERP measurements have found more robust syllable effects. One explanation is that these techniques may be more sensitive to the subtle syllable effects. However, it is uncertain whether these effects are syllabic in nature, or if they can be attributed to phonological matching between the prime and target word.

Syllable Congruency

Additional support for syllabic effects in Spanish has been provided by an ERP study conducted by Carreiras, Vergara, and Barber (2005) using a syllable congruency paradigm and lexical decision. They presented subjects with low-frequency words and pseudowords in two colours, and the colour boundary either matched the target's syllable boundary (congruent), or mismatched the syllable boundary (incongruent). If readers parse printed words into syllables, then it should be easier to read words that are presented with the colour change boundary matching the syllable boundary than to read words in which the colour boundary does not match the syllable boundary. In the incongruent condition, the first coloured segment contained one letter more than the syllable. They found that colour-syllable congruency effects modulated the P200 component. Specifically, the ERP waveforms were more positive for the incongruent condition in comparison to the congruent condition. However, whether the presented stimulus was a word or pseudoword modulated only the N400 component, with pseudowords eliciting more negative amplitudes than words. These data provide further evidence that syllable effects in Spanish occur prior to whole-word effects, and are thus likely to be pre-lexical. Importantly, the syllable congruency paradigm does not provide any preview of word segments prior to the target word. Thus, it does not allow an opportunity for advance activation of phonological information that may affect processing of the target word. However, it should be noted that the syllable boundary of the critical stimuli was confounded with the number of letters in the first coloured segment. In particular, stimuli presented in the congruent condition had two letters in the first segment (e.g, ca-sino), and stimuli presented in the incongruent condition had three letters in the first segment (e.g., cas-ino). As such, these findings may indicate that a smaller number of letters in the first segment elicited less positivity in the P200 than a larger number of letters in the first segment.

Summary of findings

Considering the literature on syllable effects in general, it appears that at least for French and Spanish words, readers do not identify disyllabic words as a whole (Carreiras et al., 2005). Instead, it seems that readers parse words into explicit syllable units during word recognition. Syllable effects have been found in French using tasks involving number of syllables, syllable frequency, and syllable priming. Similarly, effects of syllables have consistently been obtained in Spanish across syllable frequency, illusory conjunction, and syllable congruency experiments. Moreover, a recent computational model of Spanish reading (MROM-S, Conrad, Tamm, Carreiras, & Jacobs, 2010) implemented syllable-sized representations for initial syllables that are intermediate between letter and whole word representations, and has been successful at simulating the inhibitory syllable frequency effect found in lexical decision. Of course, whether this distinction extends to English is a contentious issue.

Although syllable effects in English have been found with a variety of tasks (e.g., number of syllables, illusory conjunction, syllable priming), conflicting results have been obtained using the same paradigms. One methodology in the Spanish literature that has been particularly informative involves measuring ERPs while participants perform a visual word recognition task (e.g., Barber, Vergara, & Carreiras, 2004; Carreiras et al., 2005). A major advantage of this technique is its fine temporal resolution, and thus it may be more sensitive to syllable effects than behavioural tasks. Specifically, ERPs provide measurements of electrical brain activity from the scalp that range from milliseconds to seconds, which is the range during which processing in visual word recognition occurs. ERPs can therefore provide information regarding the fine time courses during which different information in reading becomes available (Barber & Kutas, 2007). Indeed, this approach has been used to find syllable effects in English with priming studies (Ashby, 2010; Ashby & Martin, 2008), indicating that ERPs may be more sensitive to these effects. This type of information is needed to develop computational simulations of multisyllabic word recognition in English.

The CDP++ model

The most recent computational model of English multisyllabic word recognition, the CDP++ model (Perry et al., 2010), does not assume that there are explicit syllable level representations, unlike the MROM-S (Conrad et al., 2010). Rather, this model includes a graphemic parser that divides multisyllabic words into their syllables (see Figure 1 for the overall architecture of the CDP++ model). Specifically, syllable structure is primarily processed in the input representation of a two-layer network of phonological assembly (TLA network), and this part of the model is responsible for producing pronunciations. The TLA sublexical network has disyllabic graphemic and phonemic templates, each consisting of 16 slots representing onset-vowel-coda onset-vowel-coda (CCCVCCCC.CCCVCCCC). Each of the 16 slots may represent all possible graphemes and phonemes, except the onset slots of the first syllable can only correspond to onset graphemes, and the coda slots of the second syllable can only represent coda graphemes. When a word is entered into the CDP++ model during running mode, grapheme information is extracted from the item via the graphemic parser, which operates in two main stages. First, an attentional window moves across the input letter strings from left to right, and the parser detects graphemes from the letters within the attentional window. This initial stage is not thought to be sensitive to syllable structure. During the second stage, the graphemes identified during the first phase are entered into the graphemic buffer in the TLA sublexical network. If the graphemic buffer extracts two vowel graphemes (with the exception of the letter “e” in the coda position), then the model processes the item as a disyllabic word. This stage is affected by word structure such as the letter positions of consonants and vowels, and whether there are intervocalic

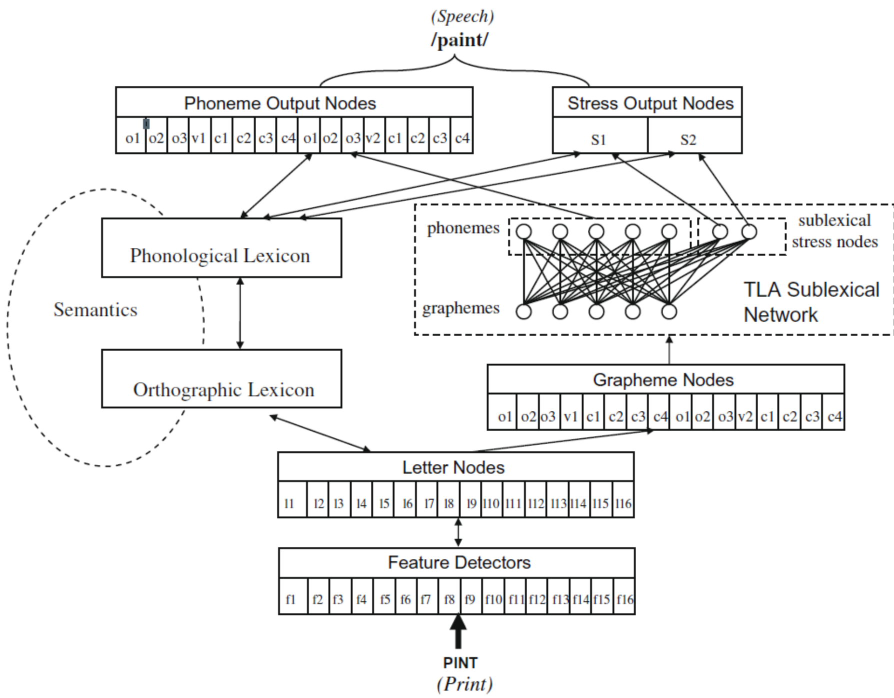


Figure 1. Architecture of the CDP++ model by Perry et al. (2010).

consonants. Although inserting graphemes into the correct graphemic buffer slot is relatively simple for monosyllabic words, processing disyllabic words introduces the difficulty of accurately assigning consonant graphemes into the first or second syllable (e.g., “rapid” can be ra-pid or rap-id).

To address this ambiguity, the CDP++ model has adopted a widely known theory in phonology, the Maximal Onset Principle (MOP; e.g., Blevins, 1995). According to the Maximal Onset Principle, words are syllabified in such way as to create the largest number of onsets within a word. An onset within a word is the consonant(s) that precedes the vowel(s) in any syllable. In the CDP++ model, this means consonant graphemes that appear between two vowels are taken to be the onset of the second syllable (e.g., ra-pid). For words that have multiple consonant graphemes between two vowels, graphemes occurring after the first vowel are inserted into the onset positions of the second syllable. However, this is not the case if there are more than three consonant graphemes, or if an onset grapheme slot is not available. A slot can be unavailable if during training mode, the system does not learn that the particular grapheme can occupy that slot (i.e., it does not occur in English words). For example, the word ANVIL would initially be entered with “nvil” in the second syllable. Since “v” is not a learned grapheme for the second consonant slot of the second syllable, this slot would not be available. In these situations, the graphemes are re-assigned by placing the leftmost consonant into the coda of the first syllable and moving all of the remaining onset graphemes in the second syllable one space to the left.

The current study

Even though the CDP++ model does not explicitly include a syllable level representation, it does posit that multisyllabic words are segmented during processing. Thus, it is important to investigate whether readers in English parse printed words into syllables during visual word recognition. The current study investigated this issue in three ERP experiments using the syllable congruency paradigm. Experiment 1 examined whether syllable effects are more likely to be found for English words that are presented with an orthotactically illegal segment in the incongruent condition than words that are presented with orthotactically legal segments in the incongruent condition. This is because research that has found robust syllable effects has generally been with languages in which the orthography has clear syllable markings (e.g., Spanish). The purpose of Experiment 2 was to contrast the role of the phonological syllable with another well known theory of orthographic representation, the Basic Orthographic Syllabic Structure (Taft 1979), as well as the Maximal Onset Principle (e.g., Blevins, 1995). Importantly, even though the CDP++ model (Perry et al., 2010) has incorporated the Maximal Onset Principle, it is uncertain whether this linguistic constraint can be applied to silent reading as well. Since the Maximal Onset Principle is primarily a theory of speech in English, it is pertinent to examine if it also pertains to orthographic representations. Finally, Experiment 3 investigated whether the more robust syllable effects found in English syllable priming studies (e.g., Ashby, 2010) have been due to syllabic processing, or were a function of phonological matching. Specifically, given the design of priming studies, it is unclear if the effects were due to readers recovering syllabic information from the target word, or comparing the target word to pre-activated phonological information from the prime. As such, it is important to investigate the role of the syllable using ERPs with a task that does not present participants with separate word segments preceding the whole word, as well as explore whether the effects found in priming studies are syllabic in nature.

The ERP components of interest for the current study include the P200 and N250, because they have been found to indicate early phonological processing during visual word recognition. In particular, ERP studies investigating Spanish words have found syllable effects in the P200 component at central and anterior scalp sites, with syllable frequency modulating the component between 150 – 300 ms (Barber et al., 2004), and syllable congruency modulating the component between 180 – 260 ms (Carreiras et al., 2005). Using a pseudohomophone priming paradigm in English, Grainger et al. (2006) found an early phonological effect in the N250 component, specifically between 250 – 300 ms at anterior scalp sites. They suggested that the N250 may reflect the translation of sublexical orthographic code into phonological code. As such, if syllable effects reflecting early phonological processing is found in the current study, they would be expected to occur at the P200 and N250 components.

Experiment 1

Experiment 1 examined whether syllables play a role during visual word recognition in English. If they do, then there should be a processing advantage when words are segmented into syllables than when the segmentation occurs one letter away from the syllable boundary. However, if what appear to be syllable effects simply reflect a preference for orthotactically legal groups of letters, then there should be an advantage for segmentation between syllables vs one letter away from the syllable boundary only when the latter division creates a group of letters that is not a permissible English syllable (e.g., com-rade vs comr-ade, but not whis-per vs whi-sper). This study measured ERPs, and utilized lexical decision and the syllable congruency paradigm that was used by Carreiras et al. (2005) to show syllable effects in Spanish.

Perhaps the most cited reason why evidence for syllabic effects in English are mixed is that it has less clear syllabic boundaries than other languages that have alphabetic orthographies (Macizo & Van Petten, 2007). In contrast, languages such as Spanish and French have syllables clearly marked in the orthography (Carreiras et al., 2005). However, not all printed English words have unclear syllable boundaries (e.g., COMRADE). One possible reason why robust syllable effects have not been found in English reading is that they may depend on the orthography of the word. That is, syllabic effects may indeed occur when reading English words that have clear syllable boundaries, but may be difficult to observe for words that have ambiguous syllable markings. Thus, syllable effects in visual word recognition similar to those found in Spanish studies may also occur for English, but only when syllables are clearly marked in the orthography.

Although the issue of how orthotactic rules influence syllable effects has been addressed in two previous studies, whether such rules play a role in silent reading remains uncertain. In particular, Rapp (1992) found that participants made fewer illusory conjunction errors when the colour change matched the syllable break of words than when the colour change was one letter away from the syllable break. For all critical items, the syllable break was between two consonants that would violate orthotactic rules if they were placed together in either syllable. However, she did not include words with less clearly marked syllable boundaries in the experimental design. Furthermore, the syllable effect was investigated using an illusory conjunction paradigm, and thus it was not apparent whether participants fully processed the whole word, or based their responses on the immediate letters surrounding the target. Since the current experiment employed a lexical decision task, participants were required to process the whole word. In a naming study, Ferrand et al. (1997) found a syllable priming effect for words that had a clear syllable boundary, and did not find a syllable effect with ambisyllabic words. Using the same stimuli, they did not find any syllable priming effects with lexical decision. Indeed, they attributed their findings in the naming experiment to a syllabic facilitation effect during speech output, rather than during lexical access. However, it may be that their experiment was not sensitive enough to capture syllable effects in silent reading. The present study measured ERPs while participants performed lexical decision, and thus provided a potentially more sensitive measurement of syllable effects.

The ERP component of interest is one occurring in the time window of 180 - 260 ms. Carreiras et al. (2005) found a syllable congruency effect in this timeframe that was positive-going (P200), with more positivity for their incongruent condition than the congruent condition. This effect was strongest in the central and anterior areas, but was not significant in the posterior region. For the current experiment, it was hypothesized that a similar syllable congruency effect would be observed in English when the segmentation in the incongruent condition produces a group of letters that is not a permissible English syllable (e.g., com-rade vs. comr-ade), but no syllable congruency effect would be observed when the segmentation in the incongruent condition produces a group of letters that is a permissible English syllable (e.g., whis-per vs. whi-sper).

Method

Participants

Subjects in this experiment were 20 undergraduate students (13 women, 7 men, *M* age = 18.8 years, age range: 17-25 years) from the University of Western Ontario. All participants were native English speakers, with minimal proficiency in a second language as assessed by a language background questionnaire. They were also right-handed, not colour blind, and did not have any history of neurological impairment. Participants were either assigned course credit, or paid $15, for their participation.

Materials

Critical stimuli were 144 disyllabic words that were five to eight letters long (see Appendix A for stimuli). Since the syllable congruency effect was more reliable for low frequency words in Carreiras et al. (2005), critical words in the current experiment were low in printed frequency according to the CELEX database (*M* = 12.72 per million; Baayen, Piepenbrock, & Gulikers, 1995). All critical items had first syllable stress (with the exception of one ambisyllabic item, “indent”).

All words had syllable boundaries between two consonants. Half of the critical stimuli had a syllable break after the third letter (e.g., com-rade, con-tact) and half of the words had a syllable break after the fourth letter (e.g., whim-per; whis-per). For the incongruent conditions, the break was put after the fourth (e.g., comr-ade, cont-act), and third letters (e.g., whi-mper, whi-sper), respectively. In the orthotactically confounded condition, the incongruent division had an orthotactically illegal letter group (e.g., comr-ade, whi-mper; “mr” cannot end a word or syllable and “mp” cannot begin a word or syllable) whereas in the orthotactically unconfounded condition the incongruent division had orthotactically legal letter groups (e.g., cont-act, whi-sper).

Stimuli were presented so that half of each item was in red, and half was in green. For critical items, this colour change was either at the syllable boundary (congruent) or one letter away from the syllable boundary (incongruent). For example, the word “comrade” has its syllable boundary between the “m” and the “r”. It was presented with the first three letters presented in green, and the last four letters in red, in the congruent condition (e.g., com-rade; words were not separated by a hyphen during the actual testing session). The first four letters were presented in green, and last four letters in red, if it was in the incongruent condition (e.g., comr-ade).

It should be noted that although the current stimuli were not chosen based on the bigram trough hypothesis, when positional bigrams were calculated (according to Solso & Juel, 1980), words in the orthotactically confounded condition had a bigram trough pattern. However, words in the orthotactically unconfounded condition also had a bigram trough pattern, especially when intersyllabic bigrams were compared to the bigrams after the syllable change. Position-specific bigram frequencies are shown in Table 1.

In addition to the 144 critical stimuli, there were also 144 disyllabic filler items, and 288 nonwords that were five to eight letters long. Four lists, each containing 576 stimuli, were created in order to counterbalance congruency (congruent vs. incongruent), and colour order (green-red vs. red-green). Specifically, each critical stimulus appeared with the colour change congruent with the syllable on two lists, and incongruent with the syllable on the other two. For one congruent and one incongruent version of each word, the first letters were red and second letters were green. For the other two versions, the

Table 1

Mean position-specific bigram frequencies at, or one letter away from, the syllable boundary for orthotactically confounded and unconfounded words

Condition	Bigram		
	Before change	Straddling change	After change
Orthotactically confounded	771.01	128.88	557.57
Orthotactically unconfounded	623.46	491.65	1137.39

first letters were green and the second were red. Thus, across the four lists each word appeared in congruent red-green, congruent green-red, incongruent red-green, and incongruent green-red forms. Similarly, in each list, half of the filler items and nonwords were presented in red-green, and the other half in green-red. The stimuli were divided into two blocks, such that each had 72 critical items, 72 filler stimuli, and 144 nonwords. Furthermore, there were an equal number of stimuli that were red-green and green-red in the first block, and in the second block.

A language background questionnaire was used in order to obtain information about participants' language history. The questionnaire asked how many languages a participant knows, and in the order they learned them. Furthermore, because it was pertinent to the experimental manipulations, participants were asked if they were colour blind.

Procedure

Participants first completed the language background questionnaire, and then were fitted with the electrode cap. They were informed that in the experiment, letter strings would appear one at a time in the centre of the computer screen and that their task was to decide whether or not the string was a real English word. To respond, they either pressed the "1" button on a handheld keypress with their left hand if they did not think the letter string was a real English word, or the "2" button with their right hand if they thought the letter string was a real English word. Each testing session began with an instruction screen, then 14 practice trials to acquaint them with the task. Participants were given a short break after the first block, and then completed the second block. Subjects were asked to respond as quickly and accurately as possible.

Participants were randomly assigned to one of the fours lists, and only saw each stimuli once in the entire testing session. Stimuli were presented, and behavioural data were recorded, using E-Prime software (version 1.1; Psychology Software Tools, Inc.). The background during the entire computer task was white. For each stimulus, a fixation cross was presented for 500 ms, followed by a blank screen for 150 ms. A stimulus was then shown in the middle of the screen in lower case letters (18 point, Courier New), and remained on the screen until a response was made. If a button was not pressed after 2000 ms, the stimulus was skipped. This was followed by an intertrial interval of 1000 ms. All stimuli were presented in random order for each participant within each block. The entire session was about an hour long.

Electrophysiological Recording

Continuous EEG data was sampled at 500 Hz using Acquire 4.2 (Neurosoft Inc., El Paso, TX) from Ag/AgCl sintered electrodes using a 32-channel cap (Quik-Caps, Neuroscan Labs: El Paso, TX). Figure 2 shows the electrode positions of the 32-channel cap. A nose-tip electrode was used as a reference. Electrodes were also used to record horizontal and vertical eye movements (on the outer canthi, and above and below the left eye, respectively). Impedances were kept below 5 kΩ (except C4, which had an average impedance of 7 kΩ). EEG recordings were filtered on-line with a 60 Hz notch filter. Data were also filtered off-line using a zero phase shift digital filter (12 dB, band-pass frequency: 0.1 to 30 Hz) before analysis. Event-related potentials were epoched from -200 to 800 ms, time-locked to the onset of the word presentation. All trials were baseline corrected to the average voltage for a 200 ms pre-stimulus interval. Eye-blinks and other

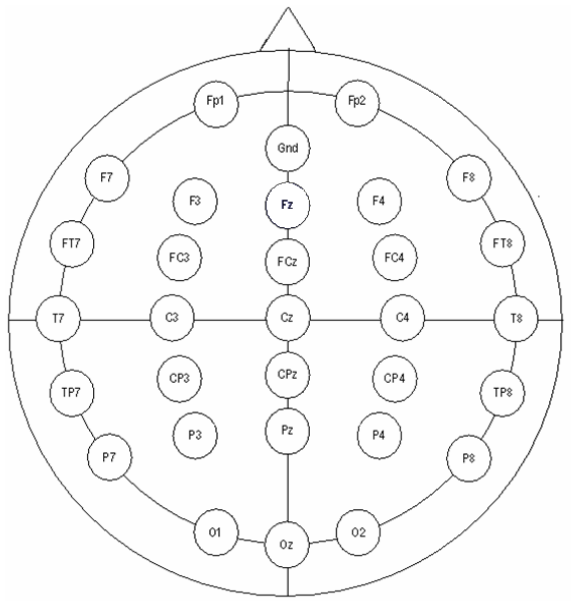


Figure 2. Representation of the 32-electrode cap used to record EEG activity in Experiment 1.

artifacts for all trials were removed with a maximum voltage criterion of ± 75 µV on all scalp electrodes. Data analyses were conducted on the remaining trials.

Results

Behavioural analyses

Only correct responses were included in the data analyses for the reaction time data. Latencies below 300 ms were excluded, and data greater than 2.5 standard deviations from each subject's mean overall reaction time were also excluded. Specifically, less than 3% of data were removed. Furthermore, all error data were square root transformed before analysis. The mean reaction times and percent errors for each condition are shown in Table 2.

Data analyses for behavioural data were 2 (congruency) X 2 (orthotactic confound) repeated measures analysis of variance (ANOVA). Statistical results are reported only for the main effect of congruency, and for the congruency X orthotactic confound interaction, because they are important to the hypotheses of the current study. Analyses were conducted using both participant (F_1) and item (F_2) means.

There was no significant main effect of congruency, either in the reaction time data or the error data, all *F*s < 1. The interaction between congruency and orthotactic confound was also not significant, either in the latency data, $F_1(1, 19) = 2.37$, $MSE = 286.96$, *ns*, $F_2 < 1$, or in the error data, *F*s < 1.

ERP Analyses

Statistical analyses were performed using 15 scalp sites (F3, FZ, F4, FC3, FCZ, FC4, C3, CZ, C4, CP3, CPZ, CP4, P3, PZ, P4) that represented a scalp coverage similar to that analysed by Carreiras et al. (2005). Although the early ERP component (P200)

Table 2

Mean decision latencies (ms) and error (%) for each experimental condition

Syllable boundary	Congruent		Incongruent		Congruency effect	
	RT	error	RT	error	RT	error
Orthotactically confounded	638	8.7	641	8.5	3	-0.2
Orthotactically unconfounded	636	8.9	627	8.2	-9	-0.7
Main effect	637	8.8	634	8.35	-3	-0.45

examined by Carreiras et al. was positive going, the ERP component found in the present study was negative going, diverging around 200 ms and converging at about 350 ms. This component will be referred to as the N250. Voltage values across subjects were averaged to establish the mean amplitude of this component using a time interval of 200 - 350 ms.

Analyses of the ERP data were 2 (congruency) X 2 (orthotactic confound) X 15 (electrode) repeated measures ANOVAs. Where appropriate, statistical values for ERP were Greenhouse-Geisser (1959) corrected for violation of the assumption of sphericity. Figure 3 shows the congruency effects for orthotactically confounded words, and Figure 4 displays congruency effects for orthotactically unconfounded words.

The analyses of the mean voltage between 200 – 350 ms revealed that there was no significant main effect of syllable congruency, $F < 1$. A significant interaction was found between congruency and orthotactic confound, $F(1, 19) = 4.58$, $MSE = 38.06$, $p < .05$. There was no congruency X orthotactic confound X electrode interaction, $F(14, 266) = 1.46$, $MSE = 2.30$, *ns*.

Analyses with 50 ms time windows were performed to investigate the effects in greater detail. The interaction between congruency and orthotactic confound was significant in the 250 – 300 ms time window, $F(1, 19) = 5.96$, $MSE = 50.24$, $p < .03$, and in the 300 – 350 ms time window, $F(1, 19) = 4.50$, $MSE = 40.20$, $p < .05$. The congruency effect in the orthotactically confounded condition approached significance in the 250 – 300 ms time window, $F(1, 19) = 4.05$, $MSE = 59.21$, $p = .058$. That effect was particularly evident in the frontal right (FZ, F4, FCZ, FC4, CZ, C4) electrodes, $F(1, 19) = 4.91$, $MSE = 26.48$, $p < .04$. There was no effect of congruency for words in the

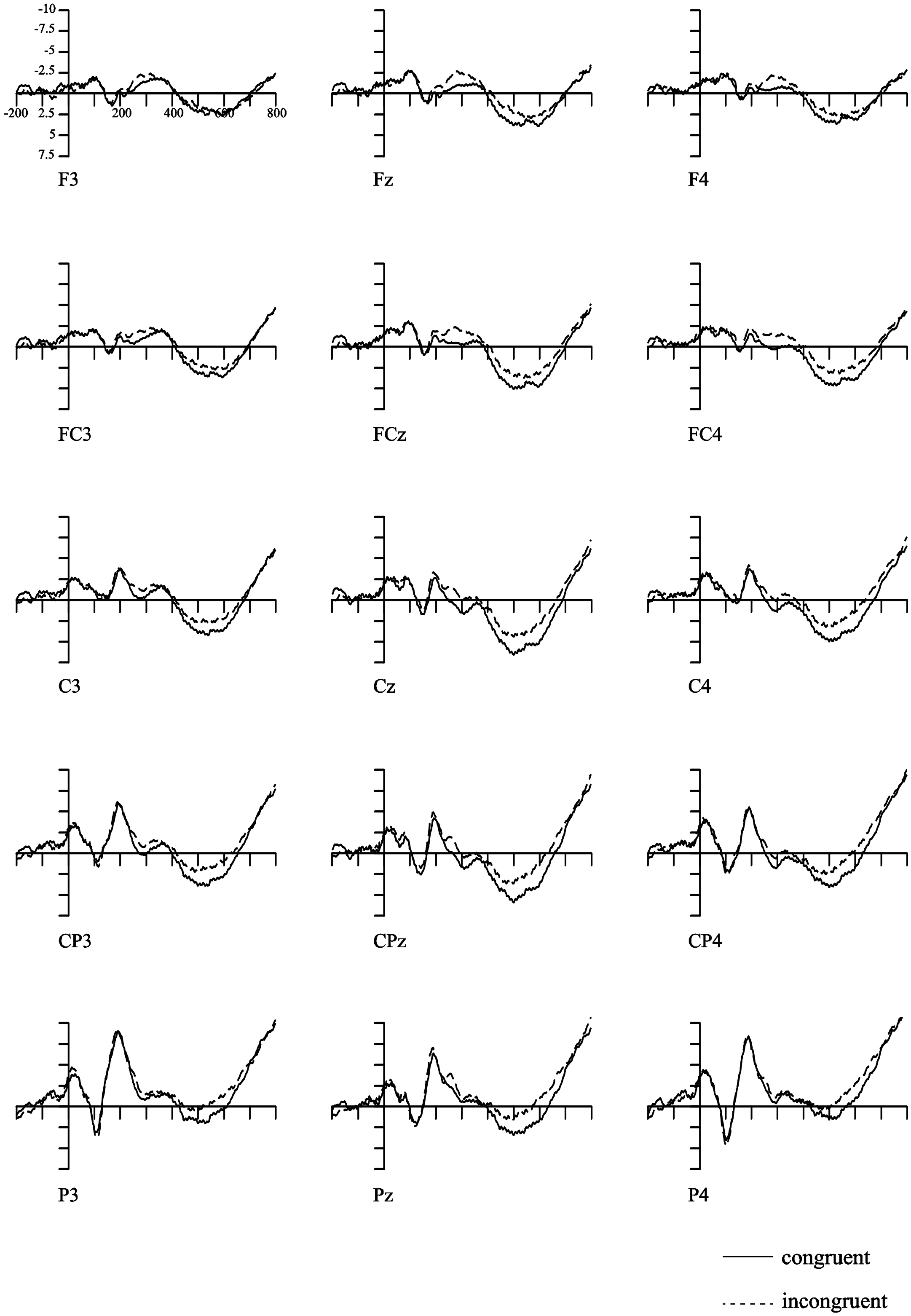


Figure 3. Syllable congruency effects in the orthotactically confounded condition.

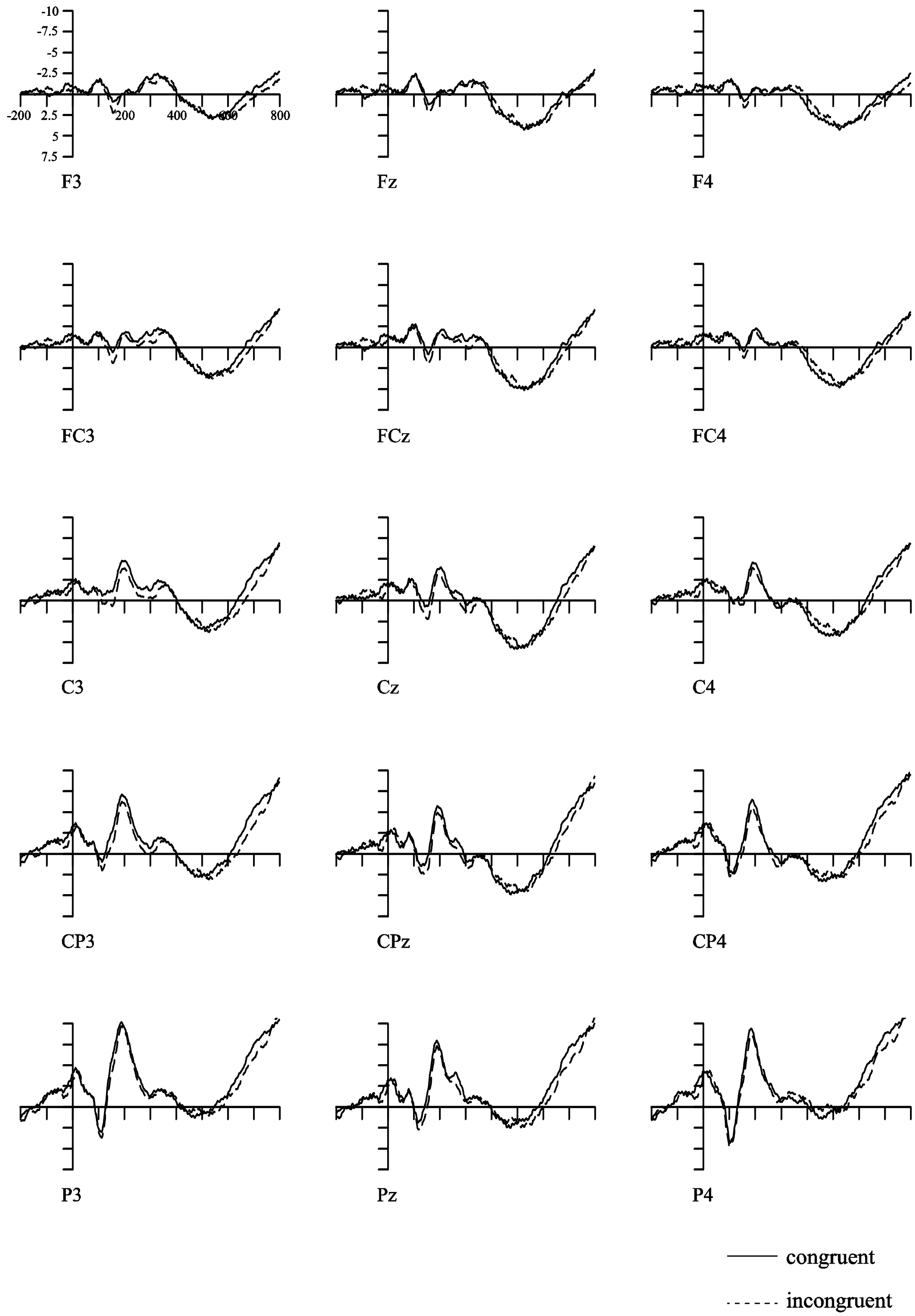


Figure 4. Syllable congruency effects in the orthotactically unconfounded condition.

orthotactically unconfounded condition in any of the time bins, either across all 15 electrodes or in the frontal right electrodes.

Discussion

The behavioural results of Experiment 1 did not provide any evidence of a syllable congruency effect for words in the orthotactically confounded, and unconfounded, conditions. This is similar to Carreiras et al. (2005), who did not find syllable congruency effects in their behavioural measures.

On the other hand, a syllable congruency effect was found in the ERP data. Specifically, the congruency effect occurred across the scalp in the 200 – 350 ms timeframe, and was most prominent in the anterior right electrodes in the 250 – 300 ms time window. Importantly, this congruency effect was only found for words in the orthotactically confounded condition, with more negativity for the incongruent condition than the congruent condition. There was no reliable syllable congruency effect for words in the orthotactically unconfounded condition.

The syllable congruency effect in the current study occurred at a slightly later timeframe than the syllable congruency effect found by Carreiras et al. (2005). In particular, Carreiras and colleagues found their congruency effect in the 180 – 260 ms time window, and interpreted this effect to indicate prelexical processing of syllable units during visual word recognition in Spanish. However, the syllable boundary in the critical stimuli was confounded by number of letters in the first segment. That is, the congruent condition had fewer letters in the initial segment than the incongruent condition. This confound did not occur in the current experiment because both congruent and incongruent conditions had three letters in the initial segment for half of the critical stimuli, and four letters in the initial segment for the other half. The syllable congruency effect in the present experiment was strongest in the 250 – 300 ms time window, and while this suggests that syllables may also play a role when reading in English, the nature of this role may differ from syllabic processing in Spanish. In fact, since this congruency effect was only evident for words in the orthotactically confounded condition, and not for words in the orthotactically unconfounded condition, the results from Experiment 1 suggests that it is unlikely for English visual word recognition to routinely involve parsing words into syllables.

While the syllable congruency effect observed in the N250 indicates that syllable effects are more likely to be observed for words presented with an orthotactically illegal segment in the incongruent condition than words presented with orthotactically legal segments, it is uncertain whether the effect is orthographic or phonological in nature. One possibility is that this effect is both orthographic and phonological in nature. Holcomb and Grainger (2006) described an ERP component that they also called an N250 that started around 175 ms and peaked around 250 ms, with the largest effects occurring in the anterior region. They hypothesized that this component reflects the processing of relative letter positions (i.e. bigrams and trigrams) as ordered letter combinations are formed. This information may be used to generate sublexical phonological codes, and subsequently access whole-word orthographic representations. Alternatively, the syllable congruency effect could be phonological in nature. Grainger, Kiyonaga, and Holcomb (2006) employed a pseudohomophone priming paradigm to examine the time course of phonological code activation. They found phonological effects in the 250 – 300 ms timeframe, particularly at the anterior electrodes. Given that this component has the same characteristics as the one found in the current experiment, it may be that the syllable congruency effect was indeed a phonological effect. Specifically, the greater negativity for the incongruent stimuli could reflect the difficulty in generating a phonological representation, since one of the word segments included a consonant cluster that either could not begin or end a word (e.g., comr-ade). In contrast, the phonology for words in the orthotactically unconfounded condition (e.g., whi-sper) may be easier to compute because the consonant cluster did not contain an illegal letter cluster.

Findings from the current study have shown that syllable effects similar to those found in Spanish studies may also occur for English during silent reading, but only for words presented with an orthotactically illegal segment in the incongruent condition. However, for English words, it seems that these syllable effects reflect the ease of phonological computation rather than the use of syllable units. As such, it does not seem as though English visual word recognition includes syllable-sized sublexical units between orthographic and lexical representations, as hypothesized for Spanish words (Carreiras et al., 2005; Conrad et al., 2010). Since English readers may not explicitly parse words into syllables, it remains questionable if other information extracted from print provides stronger cues to whole-word representations than the syllable. Two such theories are the Basic Orthographic Syllabic Structure (Taft, 1979) and the Maximal Onset Principle (e.g., Blevins, 1995). This question was addressed in Experiment 2.

Experiment 2

The findings from Experiment 1 suggest that syllable effects can be found in English word recognition, but are more easily observed for words presented with an orthotactically illegal segment in the incongruent condition (e.g., comr-ade). While the phonological syllable boundary is clearly defined for these words, the syllable break also coincides with two other theories of syllable structure; namely, the Basic Orthographic Syllabic Structure (BOSS, Taft, 1979) and the Maximal Onset Principle (e.g., Blevins, 1995).

The Basic Orthographic Syllabic Structure was proposed by Taft (1979, 1987) as an orthographic sublexical unit intended to maximize the utility of the initial syllable. He argued that while syllables are involved in reading, the nature of these syllables is not phonological. Instead, Taft believed that English words are syllabified based on orthographic information, because phonologically defined syllables commonly conflict with the morpheme structure of a word. For example, the phonological syllable boundary of the word ACTOR is between the “c” and the “t”, and the morphological boundary is between the “t” and the “o”. The BOSS was defined as, “include in the first syllable as many consonants following the first vowel of the word as orthotactic factors will allow without disrupting the morphological structure of that word” (Taft, 1979, p. 24). The BOSS of the word ACTOR, then, is “act”, which corresponds to its morphological structure. It should be noted that while the BOSS frequently conflicts with the phonological syllable, there are words for which the BOSS and phonological syllable structures are the same. For example, both the BOSS and phonological syllable divides the word COMRADE between the “m” and the “r”. This is because splitting the word between the “r” and the “a” would violate orthotactic rules, since words in English do not end in “mr”.

The Maximal Onset Principle is a theory of syllable structure described by linguists (e.g., Blevins, 1995) that divides multisyllabic words in order to maximize the number of consonants in the syllable-initial position without violating orthotactic rules (Treiman & Zukowski, 1990). For example, the phonological syllable boundary of the word PUBLISH is between the "b" and the "l". According to the MOP, the boundary is between the "u" and the "b". Similar to the BOSS, the maximal onset boundary is frequently inconsistent with the phonological syllable boundary. However, there are words for which these boundaries match (e.g., com-rade, because "mr" cannot begin an English word). Even though the MOP is primarily a theory of spoken English, it is important to investigate the MOP in word recognition because it is the only linguistic constraint adopted by the CDP++ model (Perry, Ziegler, & Zorzi, 2010).

Previous experiments comparing combinations of the phonological syllable, BOSS, and MOP in English reading have found mixed results. For example, Taft (1979) presented subjects with polysyllabic words and nonwords that were divided into two segments by a physical gap (e.g., LANT ERN) in the first experiment, and by case transition (e.g., MUSTard) in the second experiment. Words were split either according to the phonological syllable structure (e.g., LAN TERN, MUStard), or BOSS structure (e.g., LANT ERN, MUSTard). In both experiments, he found that subjects responded significantly faster to words in the BOSS condition than in the phonological syllable condition, suggesting that the BOSS plays a more important role in reading English disyllabic words. Taft (1987) replicated this effect in a priming study using primes that corresponded to the target word's BOSS (e.g., SPID primed SPIDER) or initial phonological syllable (e.g., SPI). He also provided evidence that faster response to the BOSS was not simply because it provides extra graphemic information by showing that reaction times were not faster for word segments that corresponded to the BOSS plus the following letter.

Lima and Pollatsek (1983) attempted to replicate Taft's findings with a similar experimental design to Taft's (1979) original study of the BOSS. Using a lexical decision task, they presented subjects with disyllabic words that were divided by a physical gap either according its BOSS structure, phonological syllable structure, or BOSS plus the following letter. They also presented subjects with whole words. The results showed that while the reaction times for the BOSS and phonological syllable conditions were faster than the BOSS plus one letter condition, the latencies between the BOSS and phonological syllable conditions were not significantly different. They also asked subjects to perform a lexical decision task with a priming paradigm. Primes either corresponded to the BOSS, initial phonological syllable, word minus the BOSS, or second phonological syllable. Again, they did not find a difference between the BOSS and phonological syllable conditions (for similar results, see Jordan, 1986; Katz & Baldasare, 1983).

More recently, Taft (2001, 2002) suggested that the mixed findings for the BOSS effect may be attributed to individual differences in participants' reading abilities. In particular, he claimed that since the BOSS is an orthographic sublexical unit, it may play a more important role than the phonological syllable in visual word recognition for better readers. This is because there is evidence to suggest that poorer readers are more dependent on phonological processing than better readers (e.g., Jared, Levy, & Rayner, 1999). As such, the phonological syllable may play a more important role than the BOSS for poorer readers in English. He supported these hypotheses using a lexical decision task, in which words were divided by a physical gap according to the phonological syllable boundary or BOSS boundary. When the full set of data from 102 undergraduate participants were analysed, the results showed no difference between the phonological syllable and BOSS conditions. Taft further analysed the data of the 24 highest scorers, and 26 lowest scorers on a reading comprehension task, and found that the reaction times were significantly faster for the BOSS condition than the phonological syllable condition for the better readers. The poorer readers were faster to respond to the phonological syllable condition than BOSS condition.

Taft's hypotheses were further supported in a second study. Using the same testing paradigm, Taft (2002) presented participants with words that were divided such that they either maximized the coda or onset in a long vowel condition (e.g., rad io, ra dio), or short vowel condition (e.g., rad ish, ra dish). For items in the long vowel condition, words with a maximized coda (e.g., rad io) are consistent with the BOSS, while words with a maximized onset (e.g., ra dio) are consistent with the phonological syllable. For items in the short vowel condition, words with a maximized coda (e.g., rad ish) are consistent with the BOSS and phonological syllable, while words with a maximized onset (e.g., ra dish) are inconsistent with both theories. The results showed that in the short vowel condition, reaction times were significantly faster for items presented with a maximized coda (e.g, rad ish), which corresponded to both BOSS and phonological syllable boundaries, than items presented with a maximized onset (e.g., ra dish). For words in the long vowel condition, reaction times were not significantly different between stimuli with a maximized coda or onset. However, words in the long vowel condition that were divided according to the BOSS correlated with higher reading comprehension scores, while no correlation was found for words in the short vowel condition.

Although evidence for the BOSS has mainly been found by Taft and his colleagues, some findings in support of the BOSS have also been provided by other researchers. Chen and Vaid (2007) presented participants with stimuli that had a space that divided words with respect to the MOP (e.g., ri der), or BOSS (e.g., rid er). They also manipulated frequency, and categorized participants as better and poorer readers based on SAT verbal scores. They found that words in the BOSS condition were responded to faster than the MOP condition, but only for low frequency words. They did not find a difference between better and poorer readers. These results, along with those from Taft (2001, 2002), suggest that the BOSS might play a role in English word recognition. However, whether these effects are due to BOSS processing, or are a function of their testing paradigms has been a matter of debate.

As evident in the BOSS literature, the most common testing paradigm used is a lexical decision task with stimuli divided by a physical gap. Perry (2012) examined predictions made by the CDP++ model (Perry, Ziegler, & Zorzi, 2010) regarding its graphemic parser, and how presenting a space to divide words during experimental testing may influence the processing of these words. In particular, syllable structure is not thought to be processed during the initial phase of graphemic parsing during which the graphemic parser identifies graphemes via the attentional window. Word structure information (i.e., letter positions of consonants and vowels, intervocalic consonants) is important to the second phase of parsing, during which the graphemes processed in the first phase are entered into the graphemic buffer. Perry hypothesized that providing a space to divide words during a testing paradigm may interfere with the attentional window, since the window must identify the space and its surrounding letters in a serial fashion. The time that it takes to detect the space may differentially benefit the slowest upstream processes to the grapheme buffer, one of which is the insertion of intervocalic consonants, since they may be slower to process in the graphemic buffer than vowels. Vowels may be faster to place in the graphemic buffer because they can only go into one slot of each syllable, and intervocalic consonants may be slower to place because information about the consonant and network dynamics is required to position them correctly. Critical items in Perry's lexical decision experiment were either –VCV words that had a phonological syllable break before a single consonant (e.g., ca-valry), or were –VCC words that had a syllable break before two consonants that do not form a BOSS (e.g., le-prosy). Stimuli were presented with a space between the phonological syllable break (e.g., ca valry, le prosy), the BOSS boundary (e.g., cav alry, lep rosy), or one letter after the BOSS (e.g., cava lry, lepr osy). If providing a space facilitates the placement of consonants in the grapheme buffer, then latencies should be fastest in conditions that maximise the consonants in the first segment of the item. Indeed, response times were found to be fastest for –VCV words presented in the BOSS condition (e.g., cav alry), and for –VCC words in the after BOSS condition (e.g., lepr osy). Furthermore, there was a weak phonological syllable effect as the syllable condition was faster than the after BOSS condition for –VCV words (e.g., ca valry vs cava lry). Perry interpreted these results to be consistent with the predictions made by the CDP++ model regarding the graphemic parser, such that providing a space to divide words during testing benefits the placement of intervocalic consonants. One implication of these results is that since the testing paradigm and –VCV words used by Perry are very similar to those used in experiments to show BOSS effects (e.g., Chen & Vaid, 2007; Taft 2001, 2002), it may be that these effects are actually a function of maximising consonants in the first segment of a word.

Although previous experiments have explored some combination of the phonological syllable, BOSS, and MOP, these segments have not been examined within one experiment. The purpose of Experiment 2 was to investigate whether one of these word structures provides stronger cues to whole-word representations in English visual word recognition. The current experiment employed the syllable congruency paradigm and ERP measurement used in Experiment 1. Also similar to Experiment 1, all words had a phonological syllable boundary between two consonants. Words were displayed with a colour change either at the syllable boundary, one letter before the syllable boundary, or one letter after the syllable boundary. In addition, depending on where the colour change occurred, the critical items were also divided based on its BOSS or according to the MOP, or a combination of the three theories. These divisions allowed for the investigation of the phonological syllable, BOSS, and MOP. Specifically, the critical items consisted of four word types (see Table 3 for examples of stimuli for each Word Type). When words were divided at the syllable in Word Type 1, the colour change also matched the BOSS and maximal onset boundaries (e.g., vod-ka), and did not follow any of the theories when the colour change was at one letter before or after the syllable (e.g., vo-dka, vodk-a). When words were divided at the syllable in Word Type 2, the colour change also matched the BOSS boundary (e.g., pub-lish). The colour change matched the maximal onset boundary when it was at one letter before the syllable (e.g., pu-blish), and

Table 3

Experimental conditions for Experiment 2

Word type	Division	Theory: Syllable	Theory: BOSS	Theory: MOP
1	Before CC (e.g., vo-dka, pi-cnic)	–	–	–
	Between CC (e.g., vod-ka, pic-nic)	X	X	X
	After CC (e.g., vodk-a, picn-ic)	–	–	–
2	Before CC (e.g., pu-blish, me-tro)	–	–	X
	Between CC (e.g., pub-lish, met-ro)	X	X	–
	After CC (e.g., (publ-ish, metr-o)	–	–	–
3	Before CC (e.g., the-rmal, thu-nder)	–	–	–
	Between CC (e.g., ther-mal, thun-der)	X	–	X
	After CC (e.g., therm-al, thund-er)	–	X	–
4	Before CC (e.g., dra-stic, pro-sper)	–	–	X
	Between CC (e.g., dras-tic, pros-per)	X	–	–
	After CC (e.g., drast-ic, prosp-er)	–	X	–

none of the theories were followed when the colour change occurred one letter after the syllable (e.g., publ-ish). When words were divided at the syllable in Word Type 3, the colour change also matched the maximal onset boundary (e.g., lan-tern). None of the theories were followed when the colour change occurred one letter before the syllable (e.g., la-ntern), and the colour change matched the BOSS boundary when the colour change was at one letter after the syllable (e.g., lant-ern). When words were divided at the syllable (e.g., dras-tic) in Word Type 4, the colour change did not match any other theory. The colour change matched the maximal onset boundary when the colour change was at one letter before the syllable (e.g., dra-stic), and matched the BOSS boundary when the colour change was at one letter after the syllable (e.g., drast-ic).

These four word types allow for various predictions regarding the processing of words according to the phonological syllable, BOSS, or MOP. If the phonological syllable is important to visual word recognition in English, then responses to words presented with the colour change at the syllable across all four word types should be faster than responses to words presented with the colour change occurring one letter before, or after, the syllable. Furthermore, syllable congruency effects would be expected to occur in the ERP data at a time window showing syllable effects in previous experiments, such as 180 – 260 ms (Carreiras et al., 2005) or 250 – 300 (Experiment 1). If BOSS processing is important to English reading, then participants should respond faster to stimuli with the colour change at the BOSS boundary than when it occurs one letter before the BOSS boundary. This is especially the case for Word Types 3 and 4, since these BOSS conditions do not share the same boundary as the phonological syllable or MOP. If the MOP is important to English word processing, then responses to items presented with the colour change matching the maximal onset boundary should be faster than items with the colour change after the maximal onset boundary. This is particularly true for Word Types 2 and 4, in which the MOP conditions are not confounded with the phonological syllable or BOSS. As the MOP is a phonological theory, MOP effects in the ERP data would be expected to be found in the same time windows as the phonological syllable.

Method

Participants

The 30 participants (23 women, 7 men, *M* age = 20.7 years, age range: 18-25 years) in this experiment were students from the University of Western Ontario. They were English speakers who had minimal proficiency in a second language as assessed by a language background questionnaire. All participants were also right-handed, not colour blind, and did not have any history of neurological impairment. Subjects were either assigned course credit, or were paid $15, for their time.

Materials

One hundred and sixteen disyllabic words were selected from the CELEX database (*M* = 7.97 per million; Baayen, Piepenbrock, & Gulikers, 1995) as critical items. Due to difficulty finding an equal number of stimuli for each of the experimental conditions, an additional four words were added from a separate source (Webster's New World Speller/Divider, 1971). All words were five to eight letters long, and had first syllable stress. The syllable boundary for each critical word was between two consonants. Critical items were chosen to fit the criteria of the four Word Types described above. Each Word Type consisted of 30 items (see Appendix B for critical stimuli).

The stimuli also included 120 filler items, and 240 nonwords. All stimuli were separated into two blocks, and each block had 60 critical items, 60 fillers, and 120 nonwords. Each stimulus was presented so that half of the word was red and half was green. Critical items had the colour change before, between, or after the consonant cluster. Six lists were created in order to counterbalance where the split occurred in relation to the consonant clusters for each of the four word types (before vs between vs after), and colour order (red-green vs green-red). That is, each stimulus was presented with segmentation that occurred before, between, and after the consonant cluster. In each of these conditions, the colour change was either red-green or green-red in separate lists across the six versions of the task. There was an equal number of stimuli that were red-green and green-red for critical words, filler items, and nonwords in each block. The same questionnaire as described in Experiment 1 was also used in the current experiment.

Procedure

The procedures for the current experiment were the same as Experiment 1. However, instead of a handheld keypress, participants either pressed a button labelled WORD on a Serial Response Box (Psychology Software Tools, Inc.: Pittsburgh, PA) with their right hand if they thought the letter string was a word, or a button labeled NONWORD with their left if they did not think the letter string was a word. Participants were randomly assigned to each of the six lists, and were only presented each stimulus once in the testing session. The duration of the testing session was about an hour long.

Electrophysiological Recording

A different system was used during data collection for Experiment 2 than Experiment 1. Continuous EEG data was collected at 512 Hz through the Active-Two

Biosemi system with a 32-channel cap (Electro-cap, Inc: Eaton, OH). The electrode configuration is shown in Figure 5. Four electrodes were applied to the face including the outer canthi, as well as above and below the left eye to monitor eye movements. ERPs were processed off-line using the EMSE Software Suite (Source Signal Imaging: San Diego, CA), and were filtered using a band-pass filter in the range of 0.1 to 30 Hz. The mastoid electrodes were digitally referenced. Trials were epoched from -200 to 800 ms, and time-locked to the onset of the word presentation. ERPs were also baseline corrected to the average voltage for a 200 ms pre-stimulus interval. Eye-blinks and other artifacts were removed with a maximum voltage criterion of ± 75 µV on all electrodes. Data analyses were conducted on the remaining trials.

Results

Behavioural analyses

Treatment of the behavioural data was the same as in Experiment 1. Less than 3% of data were removed. The mean reaction times and percent errors for each condition are shown in Table 4. Statistical results are reported for the main effect of each word structure theory, and its interaction with Word Type. Analyses were conducted using both subject (F_1) and item (F_2) means. Only reaction time analyses are presented because there were no main effects or interactions in the error data for all three word structure theories, in both the subjects and items analyses, Fs < 1.

Phonological syllable. Data analyses were 3 (Colour Change Location) X 4 (Word Type) repeated measures analysis of variance (ANOVA) to examine syllable congruency effects. There was a significant main effect of Colour Change Location, $F_1(2, 58) = 10.21$, $MSE = 3324.71$, $p < .01$, $F_2(2, 232) = 10.01$, $MSE = 2771.79$, $p < .01$.

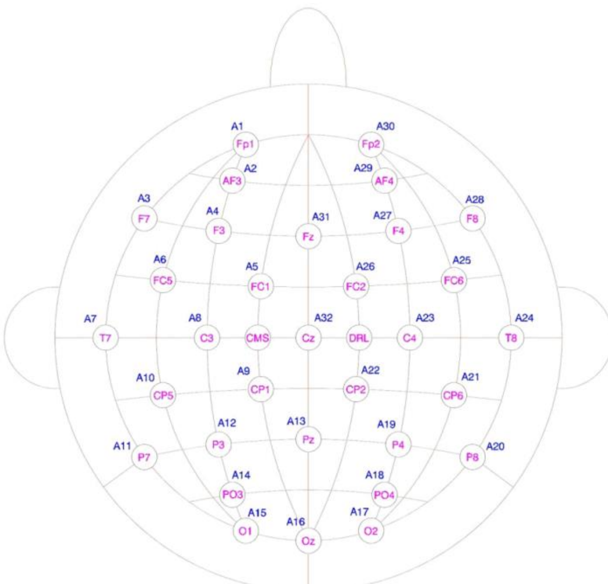


Figure 5. Representation of the 32-electrode cap used to record EEG activity in Experiment 2.

Table 4

Mean decision latencies (ms) and error (%) for each experimental condition.

	Before		Congruent		After	
	RT (*SE*)	error	RT (*SE*)	error	RT (*SE*)	error
			Syllable			
All four Types	650 (15.40)	7.1	642 (13.34)	7.2	674 (16.09)	7.8
			BOSS			
All four Types	651 (15.40)	6.9	655 (14.77)	7.8		
Type 1 (syll)*	641 (16.63)	6.0	620 (13.84)	5.7		
Type 2 (syll)	686 (20.44)	14.3	671 (15.22)	15.7		
Type 3*	632 (15.98)	2.0	662 (18.60)	3.3		
Type 4	646 (14.80)	5.3	669 (18.47)	6.7		
			Maximal onset			
All four Types			645 (14.49)	6.7	657 (13.97)	7.8
Type 1 (syll)*			620 (13.84)	5.6	650 (14.10)	7
Type 2			686 (20.44)	14.3	671 (15.22)	15.7
Type 3 (syll)*			632 (15.98)	2.0	662 (18.60)	3.3
Type 4			644 (15.26)	5.0	646 (14.80)	5.3

(syll) = coincides with syllable boundary *$p < .05$

Pairwise comparisons revealed that words presented with the colour change after the syllable were significantly slower than words presented with the colour change at the syllable for both subjects ($p < .01$) and items analyses ($p < .001$). There were no differences between words divided at the syllable and before the syllable. The interaction between Colour Change Location and Word Type was not significant, *F*s < 1.

Basic Orthographic Syllabic Structure. The data were re-categorized in order to perform 2 (BOSS) X 4 (Word Type) ANOVAs that compared the behavioural results for BOSS and before BOSS conditions. There was no main effect of BOSS, *F*s < 1. However, the interaction between BOSS and Word Type was significant, $F_1(3, 87) = 4.81$, $MSE = 2076.86$, $p < .01$, $F_2(3, 116) = 3.51$, $MSE = 2370.81$, $p < .02$. Simple main effect analyses were conducted to further examine BOSS effects in each Word Type. In Word Types 1 and 2, the BOSS and phonological syllable division occurred in the same position. For Word Type 1, this was the maximal onset division as well. Type 1 words with the colour change at the BOSS boundary had significantly faster decision latencies than those with a before the BOSS boundary, $F_1(1, 29) = 5.05$, $MSE = 1275.44$, $p < .04$. There was no difference between the BOSS and before BOSS conditions for Word Type 2. In Word Type 3 and 4, the BOSS division and syllable did not occur in the same position. For Word Type 3, the BOSS condition was significantly slower than the before the BOSS condition, $F_1(1, 29) = 6.25$, $MSE = 2144.70$, $p < .02$, $F_2(1, 116) = 4.66$, $MSE = 2370.81$, $p < .04$. Similarly, for Word Type 4, there was a marginal effect in which BOSS was slower than before BOSS, $F_1(1, 29) = 3.83$, $MSE = 1998.65$, $p = .06$, $F_2(1, 116) = 3.83$, $MSE = 2370.81$, $p = .053$.

Maximal Onset Principle. The data were also re-categorized in order to conduct 2 (maximal onset) X 4 (Word Type) ANOVAs that compared the maximal onset and after maximal onset conditions. The main effect of maximal onset was significant by participants, $F_1(1, 29) = 7.14$, $MSE = 1173.67$, $p < .02$, but not by items, $F_2(1, 116) = 2.84$, $MSE = 2389.90$, *ns*. Words presented with the colour change at the maximal onset boundary ($M = 645$, $SE = 14.49$) were responded to faster than words presented with the colour change after the maximal onset boundary ($M = 657$, $SE = 13.96$). The interaction between maximal onset and Word Type was also significant by participants, $F_1(3, 87) = 3.35$, $MSE = 2180.52$, $p < .03$, but not by items, $F_2(3, 166) = 2.03$, $MSE = 2389.90$, *ns*. For Word Types 1 and 3, the maximal onset and syllable divisions were in the same place. The maximal onset condition was significantly faster than the after maximal onset condition in Word Type 1, $F(1, 29) = 14.35$, $MSE = 926.16$, $p < .01$, and in Word Type 3, $F(1, 29) = 6.25$, $MSE = 2144.71$, $p < .02$. In contrast, for Word Types 2 and 4, in which the maximal onset and phonological syllable boundaries were in different positions, there were no maximal onset effects, Fs < 1.

ERP Analyses

The ERP data were collected with different systems in Experiments 1 and 2. Statistical analyses for the current experiment were performed using 13 scalp sites (F3, FZ, F4, FC1, FC2, C3, CZ, C4, CP1, CP2, P3, PZ, P4) that represented a scalp coverage similar to the coverage in Experiment 1. The ERP components of interest occurred in the 130 – 180 ms (P200) and 180 – 260 ms (N250). Inspection of the waveforms indicated that an additional component was present from 270 – 370 ms (N280). Voltage values across subjects were averaged to establish the mean amplitude of these components.

Phonological syllable. Figure 6 displays the time windows for the congruency effects in the before, between, and after syllable conditions at electrode CZ. Figure 7 shows the waveforms for the syllable and before syllable conditions for each of the 13 electrodes, and Figure 8 displays the waveforms for the syllable and after syllable conditions for each of the 13 electrodes. Analyses on the ERP data were 3 (Colour Change Location) X 4 (Word Type) X 13 (electrode) repeated measures ANOVAs to investigate syllable congruency effects. Where appropriate, statistical values were Greenhouse-Geisser (1959) corrected for violation of the assumption of sphericity.

For the P200 component, there was a marginal effect of Colour Change Location, $F(2, 58) = 2.83$, $MSE = 170.91$, $p = .069$. Further analysis revealed that words presented with the colour change at the syllable boundary elicited significantly more positivity than the before syllable condition ($p < .03$), whereas there was no difference between the syllable and after syllable conditions. There was a main effect of Colour Change Location in the N250, $F(2, 58) = 3.37$, $MSE = 153.00$, $p < .05$. Pairwise comparisons showed that the before syllable condition yielded significantly more negativity than the between syllable condition ($p < .03$). No difference was found for the between and after syllable conditions. Although it appears that there is a divergence for the between syllable and after syllable conditions in the 270 – 370 ms time frame, there was no main effect of Colour Change Location, $F(2, 58) = 2.53$, $MSE = 143.77$, *ns*. Furthermore, there were no pairwise differences between any of the conditions. In summary, the before syllable and between syllable conditions differed in the P200 and N250, but no differences were observed for the between syllable and after syllable conditions.

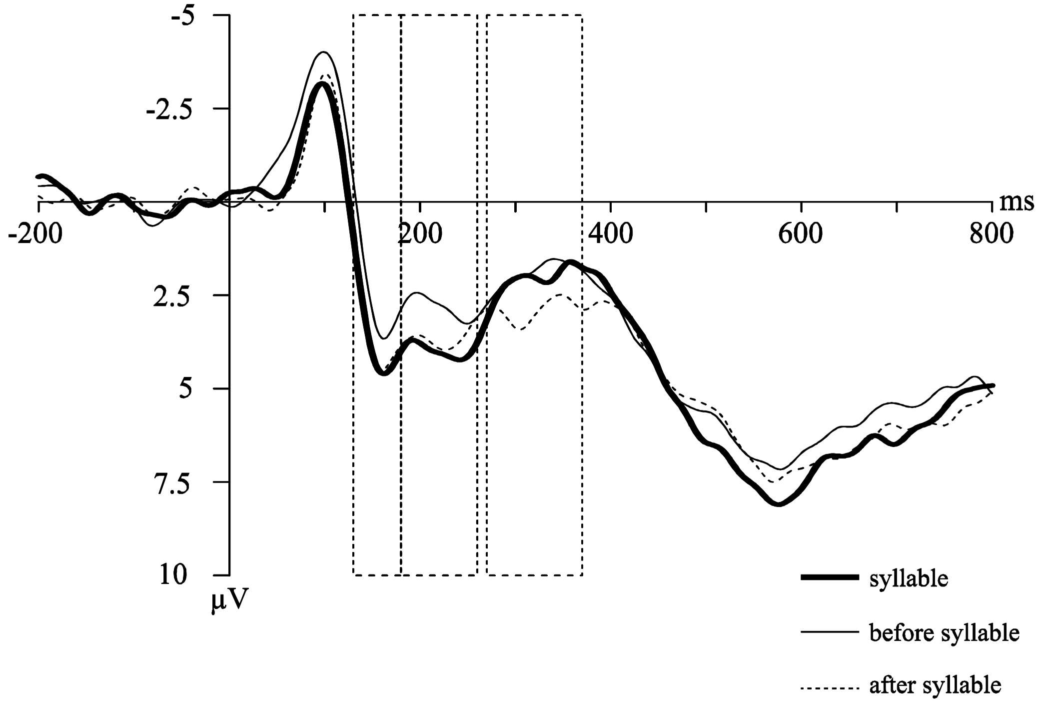


Figure 6. Waveform of the congruency effects in the before, between, and after syllable conditions at CZ.

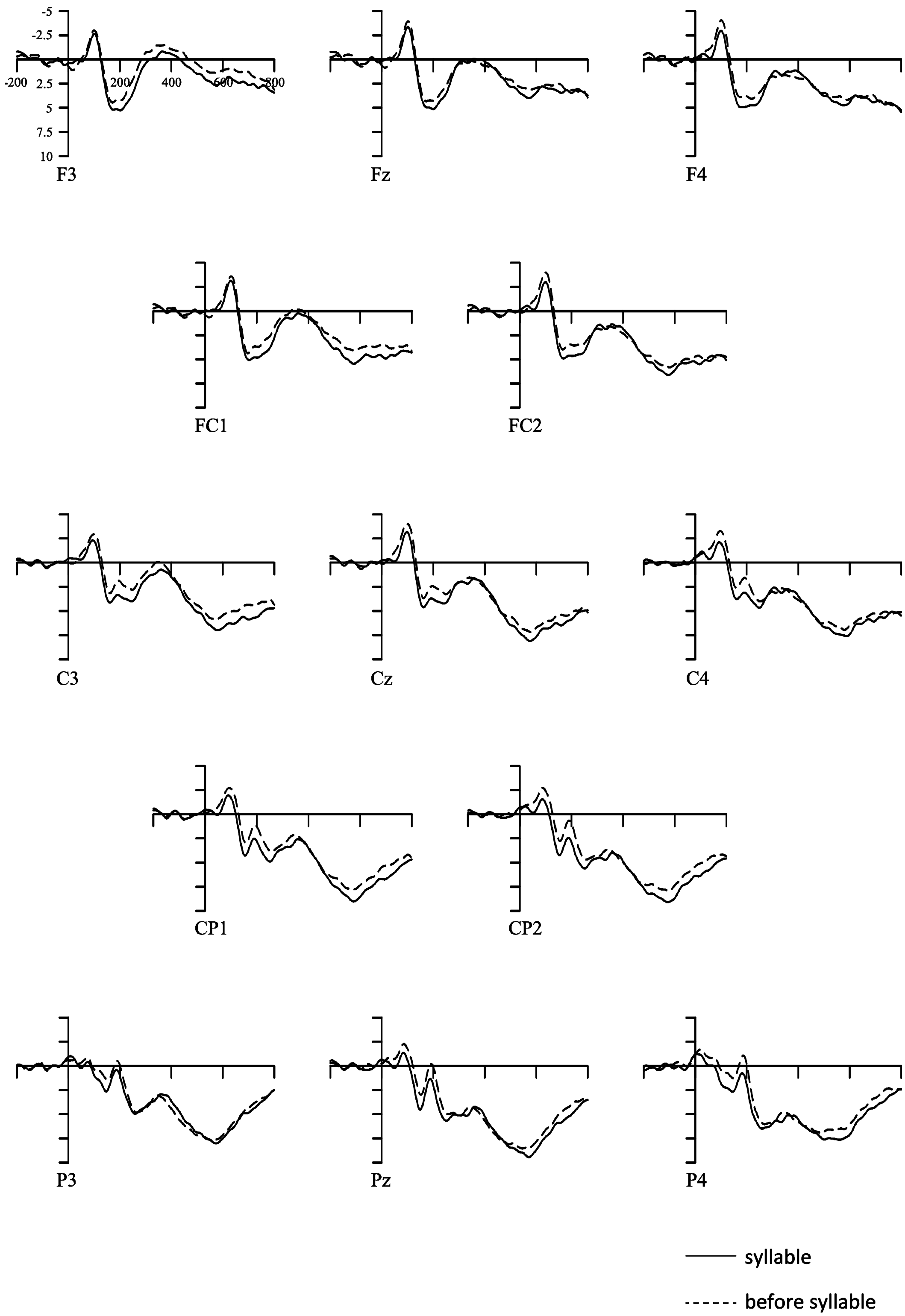


Figure 7. Syllable congruency effects in the between syllable and before syllable conditions.

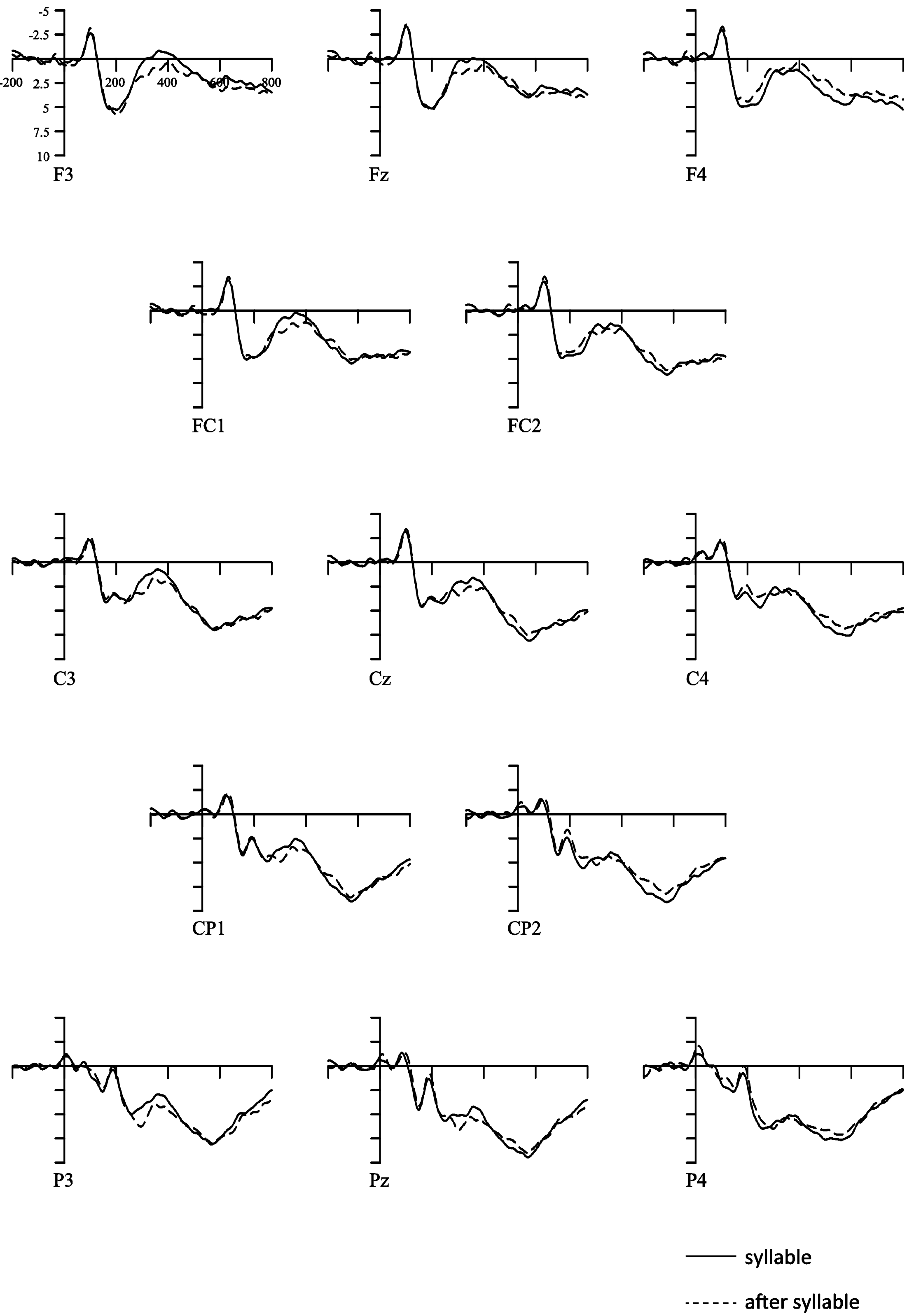


Figure 8. Syllable congruency effects in the between syllable and after syllable conditions.

Basic Orthographic Syllabic Structure. In order to examine BOSS effects, the data were re-categorised to perform 2 (BOSS) X 4 (Word Type) ANOVAs. The time windows for the congruency effects of the before BOSS and BOSS conditions can be found in Figure 9, and Figure 10 shows the data for each of the 13 electrode sites separately. There was no main effect of BOSS in any of the ERP components of interest, *F*s < 1.

Although there were not enough stimuli in each condition to examine BOSS effects within each Word Type in the ERP data, the data did allow for analysis of BOSS effects across a combination of two Word Types. Importantly, this enabled the investigation of words for which the BOSS division is also the syllable division (Word Types 1 and 2; com-rade, pub-lish), and words for which the BOSS division is not confounded by the phonological syllable or maximal onset (Word Types 3 and 4; furn-ace, cust-om). Figure 11 displays the congruency effects for words in which the BOSS boundary matches the phonological syllable boundary, and for words in which the BOSS boundary does not match the phonological syllable boundary. For words in which the BOSS and phonological syllable occur in the same position (Word Types 1 and 2), the before BOSS condition elicited more negativity than the BOSS condition in the N250 component, $F(1, 29) = 5.56$, $MSE = 97.77$, $p < .03$. There was a marginal BOSS effect in the P200 component, $F(1, 29) = 3.54$, $MSE = 110.03$, $p = .07$, and no effect in the N280 (270 – 370 ms) component, $F < 1$. For words in which the BOSS division does not occur at the same position as the phonological syllable or maximal onset, there were no differences at any of the ERP components of interest, all *F*s < 1. In summary, there were differences between the BOSS condition and the before BOSS condition in the N250

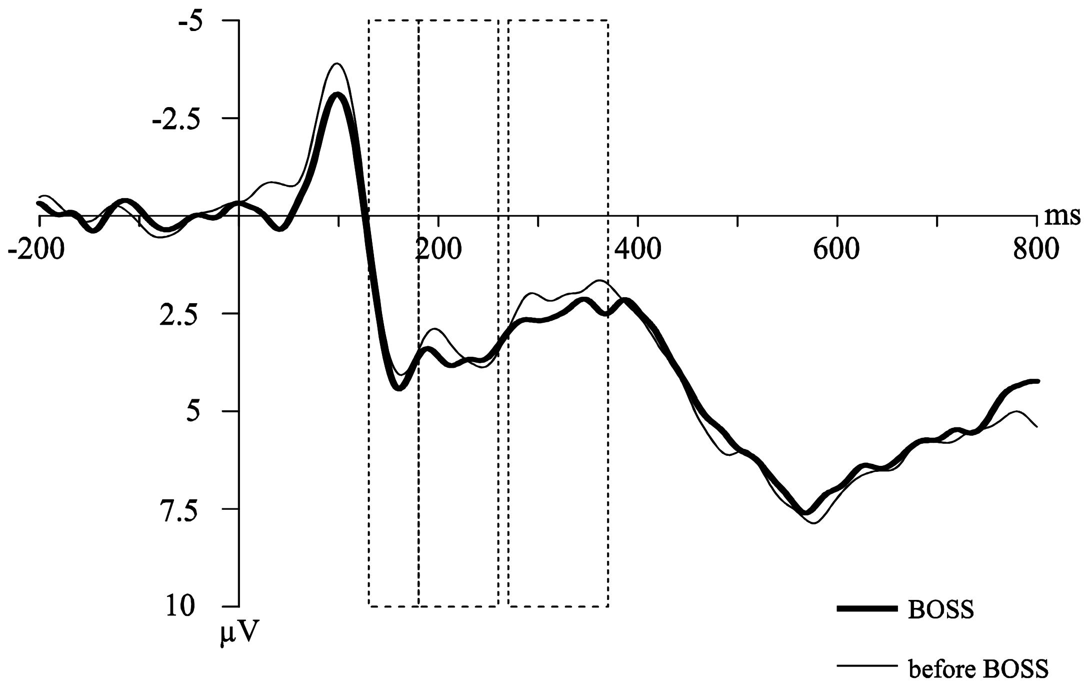


Figure 9. Waveform of the congruency effects in the BOSS and before BOSS conditions at CZ.

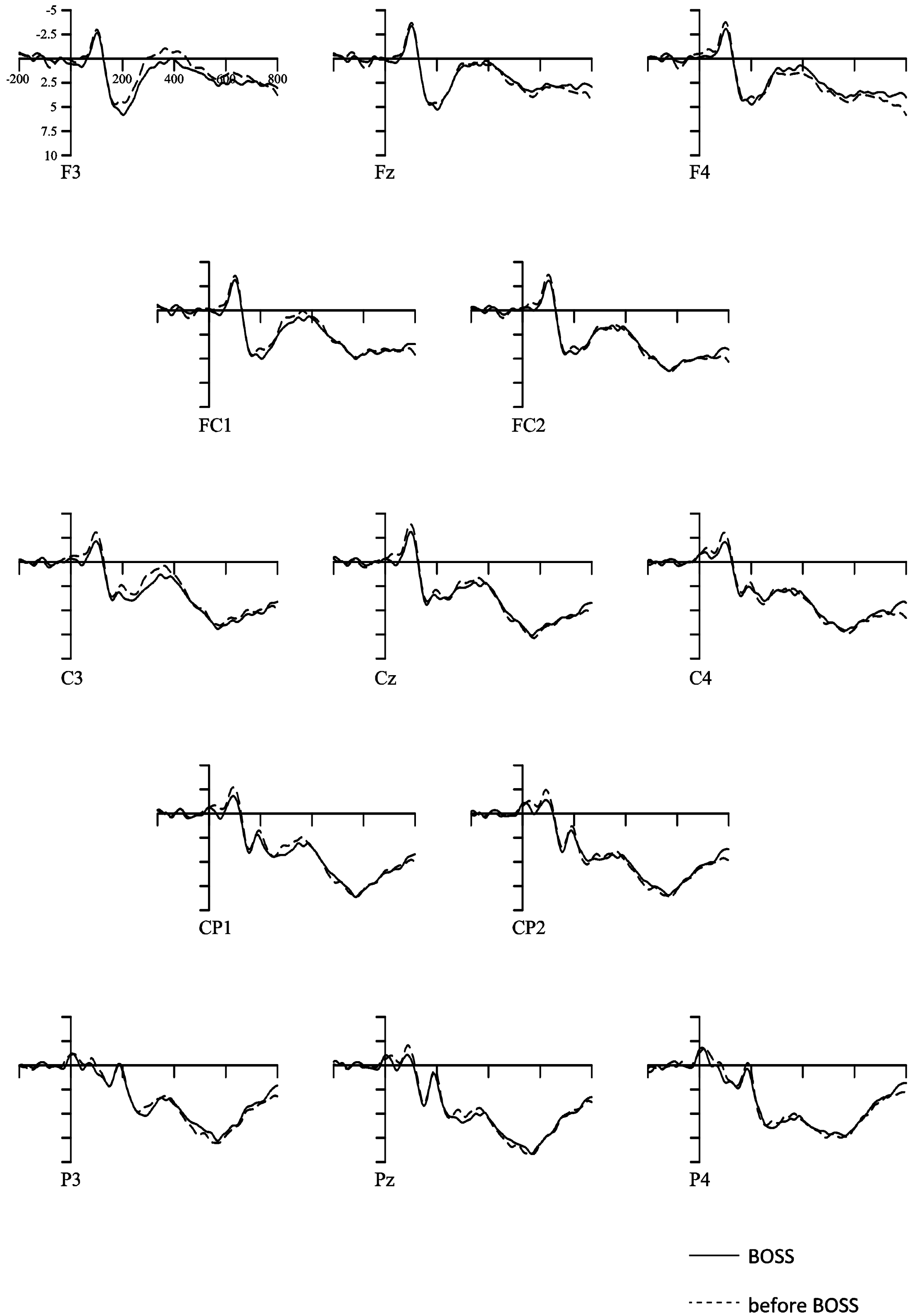


Figure 10. Congruency effects in the BOSS and before BOSS conditions.

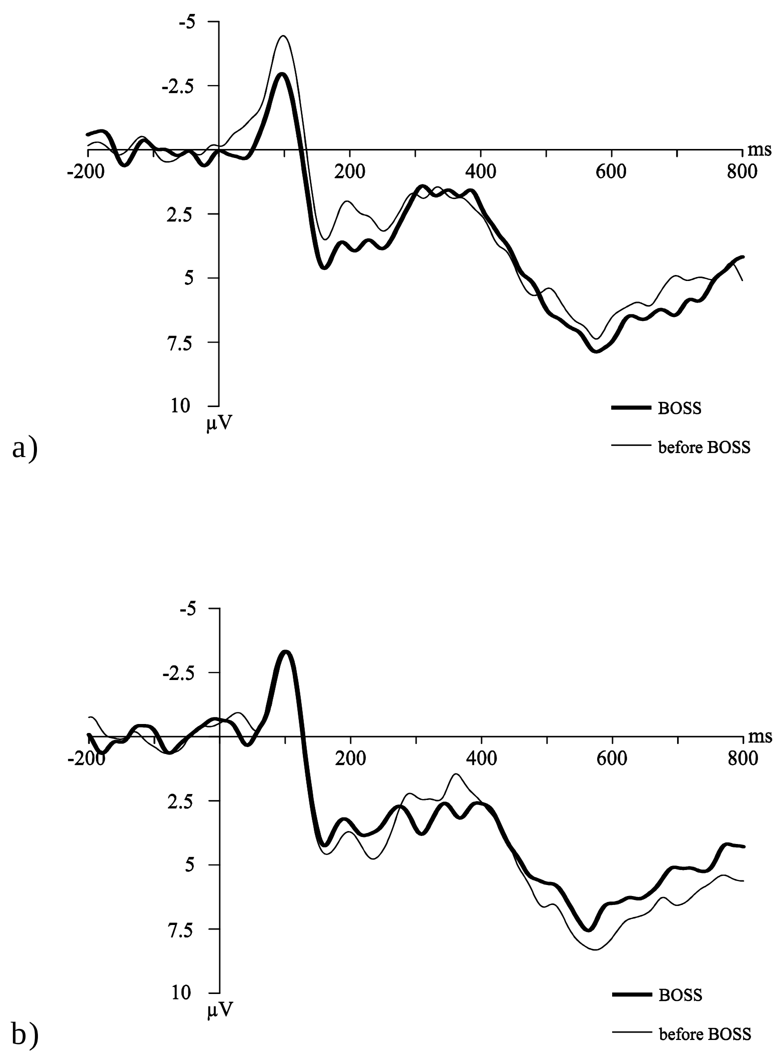


Figure 11. Waveform of the congruency effects at CZ for words in which a) the BOSS boundary matches the phonological syllable boundary, and b) the BOSS boundary does not match the phonological syllable boundary.

component, but only for words in which the BOSS boundary was also the phonological syllable boundary.

Maximal Onset Principle. The data were also re-categorised in order to conduct 2 (maximal onset) X 4 (Word Type) ANOVAs to compare the maximal onset and after maximal onset conditions. Figure 12 shows the time windows for the congruency effects of the maximal onset and the after maximal onset conditions, and Figure 13 displays the data separately for each of the 13 electrodes. As with the BOSS, the analyses included the examination of words for which the maximal onset division was also the phonological syllable condition (Word Types 1 and 3; com-rade, fur-nace), and words for which the maximal onset division was not confounded by the syllable or BOSS (Word Types 2 and 4; pu-blish, cu-stom). Figure 14 displays the congruency effects for words in which the maximal onset boundary matches the phonological syllable boundary, and for words in which the maximal onset boundary does not match the phonological syllable boundary.

In the P200 component, words presented with the colour change one letter after the maximal onset boundary elicited significantly more positivity than words presented with the colour change at the maximal onset boundary, $F(1, 29) = 5.45$, $MSE = 95.76$, $p < .03$. While there was no difference between the maximal onset and after maximal onset conditions for words in which the maximal onset division matched the syllable (Word Types 1 and 3), $F < 1$, there was a significant difference for words in which the maximal onset division did not match the syllable or BOSS division (Word Types 2 and 4), $F(1, 29) = 7.53$, $MSE = 101.75$, $p < .02$. There was no main effect of maximal onset in the N250 component, $F(1,29) = 2.08$, $MSE = 100.70$, *ns*, and there was no congruency effect for words in which the maximal onset and phonological syllable boundaries occurred in

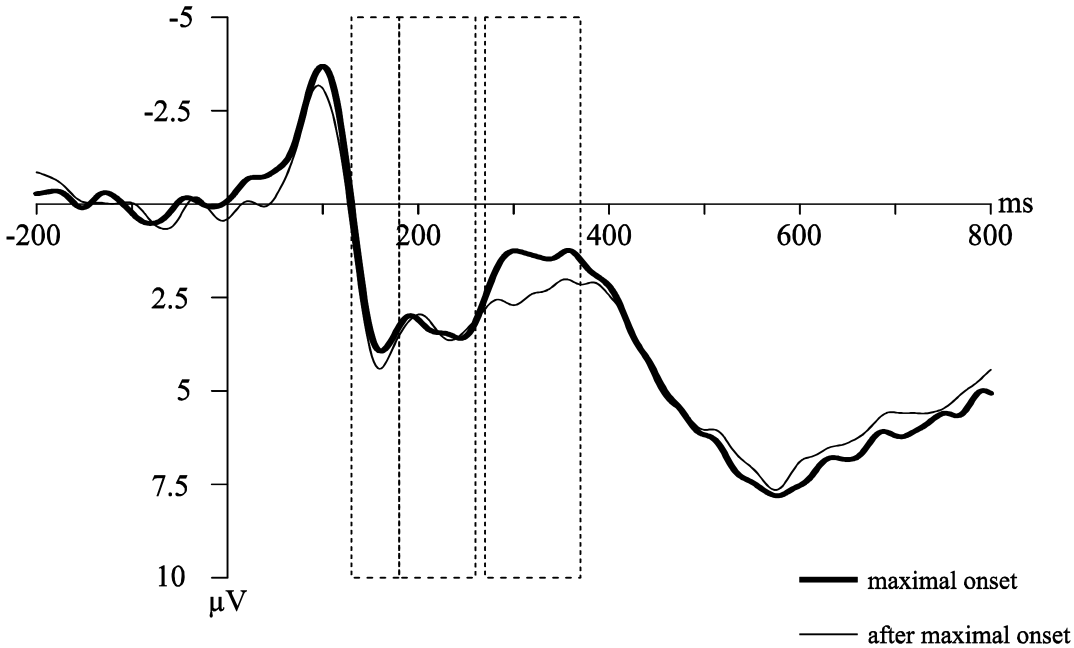


Figure 12. Waveform of the congruency effects in the maximal onset and after maximal onset conditions at CZ.

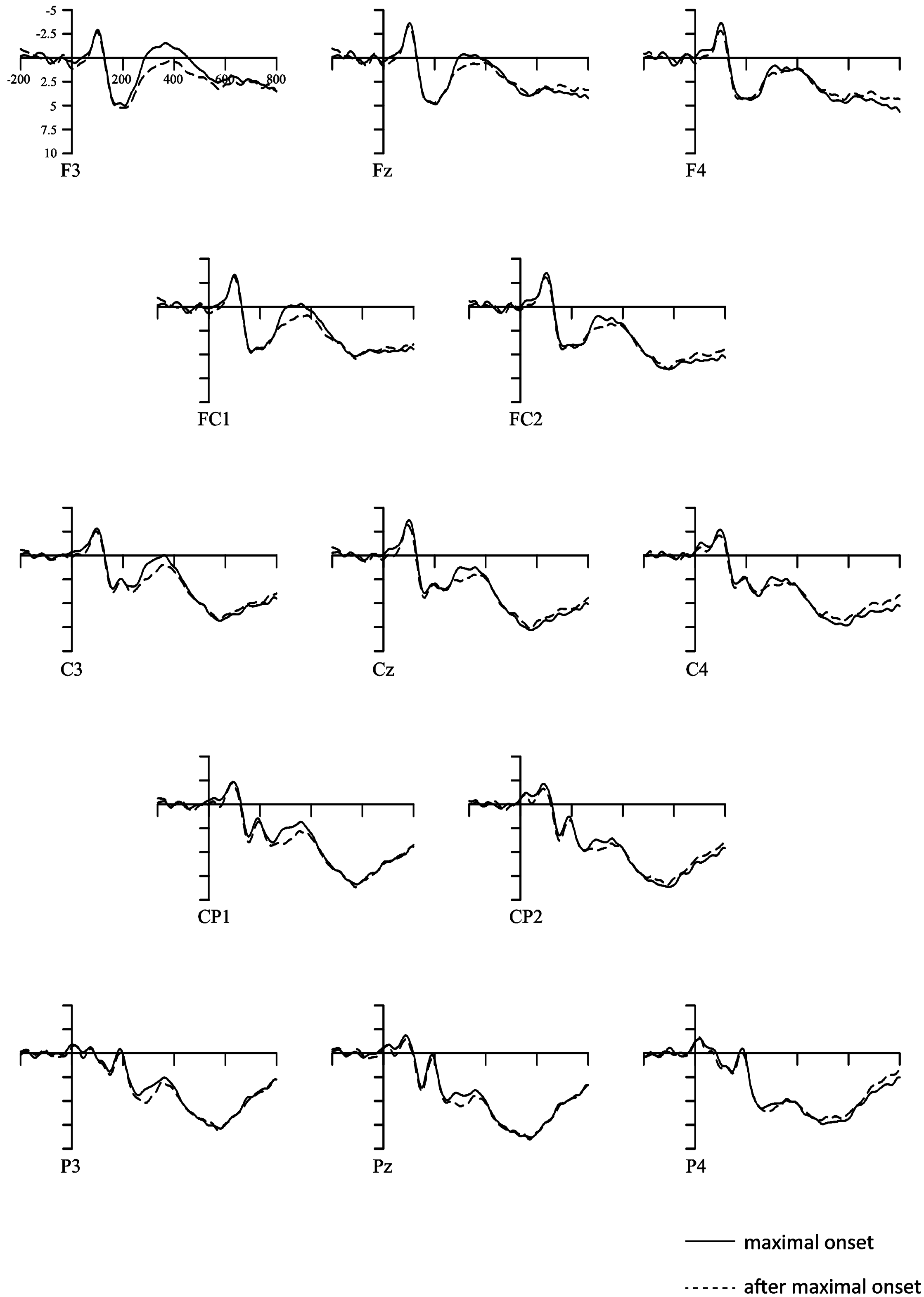
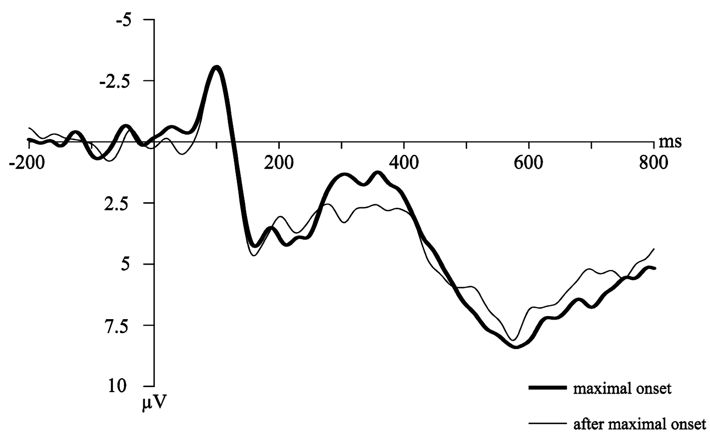


Figure 13. Congruency effects in the maximal onset and after maximal onset conditions.

a)



b)

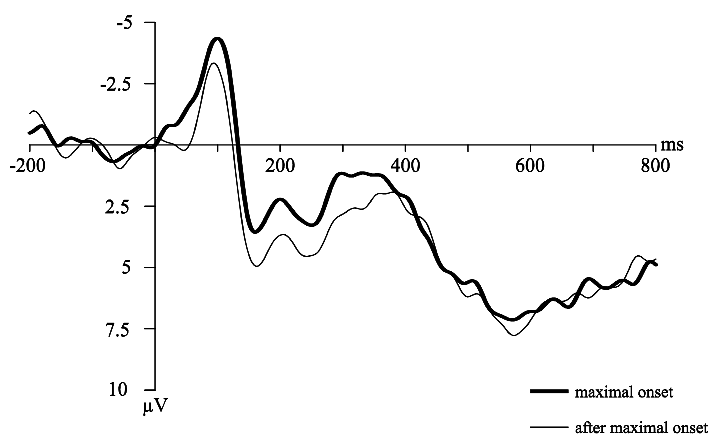


Figure 14. Waveform of the congruency effects at CZ for words in which a) the maximal onset boundary matches the phonological syllable boundary, and b) the maximal onset boundary does not match the phonological syllable boundary.

the same position, $F < 1$. However, for words in which the maximal onset division did not match the phonological syllable or BOSS (Word Types 2 and 4), the maximal onset condition elicited more negativity than the after maximal onset condition, $F(1, 29) = 5.33$, $MSE = 134.97$, $p < .03$. In the N280 component, the maximal onset condition elicited more negativity than the after maximal onset condition, $F(1, 29) = 8.01$, $MSE = 133.47$, $p < .01$. This effect was significant for words in which the maximal onset boundary matched the phonological syllable boundary, $F(1, 29) = 4.38$, $MSE = 111.73$, $p < .05$, and was marginally significant for words in which the maximal onset boundary did not match the phonological syllable or BOSS division, $F(1, 29) = 3.56$, $MSE = 163.44$, $p = .069$. In summary, there were differences between the maximal onset condition and after maximal onset condition in the P200 and N250 components, but only for words in which the maximal onset boundary did not match the phonological syllable or BOSS boundaries. In contrast, the maximal onset condition and after maximal onset condition differed in the N280, but only for words in which the maximal onset boundary was also the phonological syllable boundary.

Discussion

The goal of Experiment 2 was to examine whether the phonological syllable, BOSS, or MOP divisions facilitate English word recognition. The data from both behavioural and ERP measures do not offer any evidence in support of the BOSS, but provided mixed evidence for the phonological syllable and MOP.

The current experiment found phonological syllable effects in both behavioural and ERP data. The behavioural data showed that words presented with the colour change matching the syllable boundary were responded to faster than words presented with the colour change occurring after the syllable. However, the syllable condition was not significantly faster than the before syllable condition.

Although the before syllable and syllable conditions did not differ in the reaction time data, they were significantly different in the ERP data. Specifically, words presented with the colour change matching the syllable evoked less negativity than words presented with the colour change before the syllable in the P200 and N250 components. The syllable effect in the P200 component of the current experiment seems to be opposite to that of Carreiras et al. (2005). That is, the current data show that the syllable condition evoked more positivity than the before syllable condition, while Carreiras et al. found that their incongruent condition elicited more positivity than their congruent condition. However, upon closer inspection, the results of the two studies are quite comparable. In particular, the critical stimuli used in Carreiras et al. were disyllabic and trisyllabic Spanish words with CV.CV and CV.CV.CV structures. Stimuli presented in the congruent condition had the colour change after the first vowel (e.g., ca-sino), while stimuli presented in the incongruent condition had the colour change after the subsequent consonant to the first vowel (e.g., cas-ino). With the exception of four items, words of the current experiment in the before syllable condition also had the colour change after the first vowel (e.g., co-mrade), and words in the syllable condition had the colour change after the subsequent consonant to the first vowel (e.g., com-rade). Thus, rather than a syllable effect, the findings from the current study and Carreiras et al. may indicate that a smaller number of letters in the first segment is less effortful to process than a larger number of letters in the first segment, at least in the P200 component. It is worth noting that the P200 in the current experiment occurred in an earlier time frame (130 – 180 ms) than in Carreiras et al. (180 – 260 ms).

Unlike Carreiras et al. (2005), the current study also found effects in a slightly later component, the N250, which is similar to the N250 component found in Experiment 1 (see Table 5 for summary of results from Experiments 1 and 2). Since the syllable condition elicited less negativity than the before syllable condition, it suggests that processing of words with the colour change before the syllable was more effortful than processing of words with the colour change at the syllable. An alternative interpretation of the results is that even though the two-letter segments require less effort to process earlier (P200) during English word recognition than three-letter segments, the open vowel may introduce ambiguity to phonology resulting in more effortful processing later (N250) in word recognition. That is, the phonology of the two letter segment containing an open vowel (e.g., pi) may conflict with the pronunciation of the whole word (e.g., picnic), whereas the pronunciation of the first vowel is more constrained by the subsequent consonant in the three letter segment (e.g., pic). The N250 effect may reflect the effort to reconcile the pronunciation discrepancy between the two letter segment and whole word.

There was no evidence for BOSS processing in the behavioural or ERP measurements. In particular, both subjects and items analyses in the behavioural data showed that participants responded more slowly to words with the colour change at the BOSS boundary than to words with the colour change before the BOSS boundary in Word Types 3 and 4. Importantly, these BOSS conditions were not confounded by the phonological syllable or MOP. Even though the BOSS condition was significantly faster than the before BOSS condition in Word Type 1, the BOSS boundary in this condition

Table 5

Summary of results from Experiments 1 and 2

		ERP component	
		P200	N250
Experiment 1			
	orthotactically confounded	–	X
	orthotactically unconfounded	–	–
Experiment 2			
Phonological syllable			
	before vs at	X	X
	at vs after	–	–
BOSS			
	at vs before	–	–
MOP			
	at vs after	X	–

was also the same as the syllable and maximal onset breaks. Similarly, the ERP data showed that the before BOSS condition elicited more negativity than the BOSS condition in the N250 component, but only for words (Word Types 1 and 2) in which the BOSS was confounded by the phonological syllable.

Evidence for the maximal onset principle was mixed. Although the behavioural data showed that participants were faster to respond to words in the maximal onset condition than after maximal onset condition, this finding may be attributed to a syllable effect rather than a maximal onset effect. Specifically, the maximal onset condition was only significantly faster than the after maximal onset condition for Word Types 1 and 3. The maximal onset boundary was also the syllable and BOSS boundaries for Word Type 1, as well as the syllable boundary for Word Type 3. For Word Types 2 and 4, in which the maximal onset condition was not confounded by the syllable or BOSS, there were no maximal onset effects.

In the ERP data, the maximal onset condition evoked less positivity than the after maximal onset condition in the P200 component. This suggests that words divided after the maximal onset were more effortful to process than words divided at the maximal onset boundary. Moreover, this effect was not confounded by the phonological syllable, because further analysis showed that this maximal onset effect was only significant for words in which the maximal onset boundary and phonological syllable occurred in different positions.

Conversely, in the N250 component, the maximal onset condition elicited more negativity, or was more effortful to process, than the after maximal onset condition. The maximal onset condition also evoked more negativity, or required more effort to process, than the after maximal onset condition in the N280 component. The effects in the N250 and N280 components are likely phonological in nature, as they have comparable scalp distributions to the phonological effects found in the same time window by Grainger et al. (2006). In their study, the pseudohomophone priming paradigm resulted in phonological effects as early as 250 ms in the anterior electrodes, and continued through the 300 – 350 ms and 350 – 400 ms time windows across the scalp.

The effects in the N250 and N280 components are puzzling, since decision latencies were faster for the between maximal onset condition than the after maximal onset condition, while the ERP congruency effects suggest that the between maximal onset condition was more effortful to process than the after maximal onset condition. One possible explanation of this discrepancy is that lexical decision latencies might not map straightforwardly onto ERP components. Grainger and Jacobs (1996) have suggested that lexical decisions are based either on activation of a specific lexical unit or on a global lexical activation. It may be that the lexical decision data reflect global processing, and participants answered “yes” before competition amongst lexical candidates for words presented in the maximal onset condition was resolved. The ERP data might reflect this competition.

With respect to the CDP++ model, the only linguistic constraint implemented in the graphemic buffer is the MOP. The behavioural findings from the current experiment provide little support for the notion that words are divided according to the MOP. Although reaction times were faster for words in the maximal onset condition than the after maximal onset condition, this was only the case when the maximal onset boundary also matched the syllable. As such, it does not seem that the MOP is the optimal, or only, phonological constraint that should be implemented in the model.

Experiment 3

The ERP results of Experiment 1 demonstrated that syllable effects can be found in English visual word recognition, but only for words presented with an orthotactically illegal segment in the incongruent condition (e.g., comr-ade). The behavioural and ERP findings from Experiment 2 also suggested that syllable effects can be found in English reading. However, these data did not yield a unique pattern of results in support of syllable processing. That is, syllable break was not superior to both the before syllable and after syllable conditions. Taken together, it does not seem that the syllable has a privileged status in English reading. This is in contrast to evidence provided by English syllable priming studies (e.g., Ashby, 2010; Ashby & Martin, 2008).

In an experiment measuring ERPs with a masked priming paradigm, Ashby and Martin (2008) found more positivity within the 250 - 350 ms time window of their ERP data when primes were congruent with targets' first syllable (e.g., pi-PILOT, yon-YONDER) than primes that contained one letter more or less than the initial syllable (e.g., pil-PILOT, yo-YONDER). Ashby (2010) conducted a similar masked priming experiment with ERP, but a visually matched design was also used in order to minimize any variance that may be due to orthographic factors. Critical items were matched on initial trigram, but had different syllable boundaries (e.g., po-ny, pon-der). Primes either were congruent with the initial syllable of the target (e.g., po##-PONY, pon###-PONDER), or incongruent with the initial syllable of the target (e.g., pon#-PONY, po####-PONDER). This design ensures that the same set of primes appears in the congruent and incongruent conditions. The data showed a syllable effect in which the incongruent condition elicited more negativity than the congruent condition in the N100, suggesting that participants may have rapidly activated phonological syllable information during the task. However, an alternative explanation for these effects is that participants began to generate phonological information during the prime presentation, which was subsequently contrasted with the phonology of the target word (e.g., po-PONY, pon-PONDER). In their incongruent form, many of the primes' pronunciation did not match the phonology of the target words (e.g., pon-PONY, po-PONDER). As such, what seemed like a syllable effect may instead be attributed to phonological matching. A similar effect was found in the N250 component of Experiment 2. Words presented with the colour change matching the syllable boundary evoked less negativity than words presented with the colour change before the syllable, which may have reflected enhanced competition between the phonology of the first segment and the whole word (e.g., pi and picnic) when the subsequent consonants are less available to constrain the pronunciation of the first vowel.

To test this hypothesis, the present experiment included words for which the syllable segmentation provided a good indication of pronunciation (phonologically confounded), or did not provide a good indication of pronunciation (phonologically unconfounded). Furthermore, a visually matched design was used. Specifically, each word in the phonologically confounded condition had an initial syllable that, in isolation, had the same pronunciation as the syllable in the context of the word. For example, the first syllable of the word PONY is PO, which if pronounced on its own (pō according to the Nelson Canadian Dictionary; /po/ in International Phonetic Alphabet) would have the same pronunciation as it would within the whole word (pō'nē; /po ni/). If the initial trigram was pronounced on its own (pŏn; /pɒn/), it would not match the pronunciation of the word. Similarly, the first syllable of the word PONDER is PON, which if pronounced on its own (pŏn; /pɒn/) would match the phonology of the word (pŏn'dər; /pɒn dər/). However, if the initial bigram was pronounced on its own (pō; /po/), it would not match the pronunciation of the word. As evident in the design, all words in the phonologically confounded condition had syllable boundaries that were confounded with phonology.

In contrast, half of the stimuli in the phonologically unconfounded condition had syllable boundaries that matched its pronunciation, and half did not (e.g., cab-in, ca-ble). For example, the first syllable of CABLE is CA, and if pronounced on its own (kă; /kæ/) would not match the phonology of the word (kā'bəl; /keɪ bəl/). Similarly, if the initial trigram was pronounced on its own (kăb; /kæb/), it also would not match the phonology of the word. The first syllable of CABIN is CAB, which would have the same pronunciation as the whole word (kăb'ĭn; /kæb ɪn/) if pronounced on its own (kăb; /kæb/), or if only the initial bigram was pronounced (kă; /kæ/). As such, words in the phonologically unconfounded condition had syllable boundaries that were not confounded with phonology. For half of the items, both the initial bigram and trigram mismatched the pronunciation of the whole word (e.g., ca-CABLE, cab-CABLE). For the other half of the items, both the initial bigram and trigram matched the pronunciation of the whole word (e.g., ca-CABIN, cab-CABIN).

If the phonological syllable plays an important role in English reading, then participants should respond faster to words presented in the congruent condition than incongruent condition, regardless of whether the stimuli belongs to the phonologically confounded or phonologically unconfounded conditions. Furthermore, there should be syllable congruency effects in the ERP waveforms in a phonological component (e.g., P200, N250) across the phonologically confounded and phonologically unconfounded conditions. In contrast, if a phonological match between the prime and target is responsible for the syllable priming effect in Ashby's studies, then the results should yield an interaction between syllable congruency and phonological confound. Specifically, latencies should be faster for congruent words than incongruent words in the phonologically confounded condition. There should also be a congruency effect in the ERP data. However, there should not be differences in the phonologically unconfounded condition, since the CV words in this condition do not provide a good indication of pronunciation regardless of congruency presentation, and CVC words in this condition provide equally good indications of pronunciation in both congruent and incongruent forms.

Method

Participants

This experiment included 28 subjects (19 women, 9 men, *M* age = 21.5 years, age range: 18-27 years) from the University of Western Ontario. Participants were native English speakers, with minimal proficiency in a second language as assessed by a language background questionnaire. They were also right-handed, not colour blind, and did not have any history of neurological impairment. Participants were paid $15 for their participation.

Materials

Critical stimuli were 240 disyllabic and trisyllabic words, four to nine letters long, selected from the CELEX database (*M* = 17.42 per million; Baayen, Piepenbrock, & Gulikers, 1995). Since pronunciation was particularly important to the current experiment, the phonological syllable boundary and pronunciation for each critical stimulus were checked with the Nelson Canadian Dictionary of the English Language. This dictionary was used because it included pronunciations particular to Canadian English, and shows words divided into phonological syllables. Appendix C shows the critical items, as well as the pronunciation for each word according the symbols used in their phonology legend. The phonological representations of the CV word segments were determined with a questionnaire asking participants to pronounce each word segment on its own, without regard to how it would fit in a whole word. These subjects did not participate in the ERP experiment.

The critical stimuli were divided into two experimental conditions: the phonologically confounded condition, and the phonologically unconfounded condition. Both of these experimental conditions were made up of 60 words with the initial syllable consisting of a CV letter structure (CV words), and 60 words with the initial syllable consisting of a CVC letter structure (CVC words). In the phonologically confounded condition, each CV word had a first syllable that, when read on its own, matched its pronunciation in the context of the word according to the Nelson Canadian Dictionary (e.g., pō; /po/ in PONY). When the initial trigram was read on its own, the pronunciation did not match its phonology in the context of the word (e.g., pŏn; /pɒn/ in PONY). Similarly, each CVC word in the phonologically confounded condition had a first syllable that, when read on its own, matched its pronunciation in the context of the word according to the Nelson Canadian Dictionary (e.g., pŏn; /pɒn/ in PONDER). When the initial bigram was read on its own, the pronunciation did not match its phonology in the context of the word (e.g., pō; /po/ in PONDER). In contrast, in the phonologically unconfounded condition, each CV word had a first syllable that, when read on its own, did not match its pronunciation in the context of the word (e.g., kă; /kæ/ in CABLE). When the initial trigram was read on its own, it also did not match its pronunciation in the context of the word (e.g., kăb; /kæb/ in CABLE). Each CVC word had a first syllable that, when read on its own, matched its pronunciation in the context of the word (e.g., kăb; /kæb/ in CABIN). When the initial bigram was read on its own, it also matched its phonology in the context of the word (e.g., kă; /kæ/ in CABIN). In each of the phonologically confounded and phonologically unconfounded conditions, 50 of the 60 CV and CVC words were matched exactly for initial trigram (e.g. po-ny, pon-der; ca-ble, cab-in), and the remaining 10 words were matched for initial bigram (e.g., mo-saic, mon-arch; ra-diate, rap-id) but the third consonant differed.

As in Experiments 1 and 2, stimuli in the Experiment 3 were presented so that half of each item was in red, and half was in green. For both the phonologically confounded and phonologically unconfounded conditions, the colour change occurred either at the syllable boundary (congruent), or after the initial trigram for CV words and after the initial bigram for CVC words (incongruent).

In addition to the 240 critical stimuli, there were also 120 disyllabic and trisyllabic filler items, and 360 nonwords that were four to nine letters long. Four lists, each containing 720 stimuli, were created in order to counterbalance congruency (congruent vs. incongruent), and colour order (green-red vs. red-green). The stimuli were divided into four blocks, such that each included 60 critical stimuli, 30 filler items, and 90 nonwords. There were an equal number of stimuli that were red-green and green-red in each block. The same questionnaire as described in Experiment 1 was also used in the current experiment.

Procedure and electrophysiological recording

The procedures for the current experiment were the same as Experiment 2. Participants were randomly assigned to each of the four lists, and were only presented each stimulus once in the testing session. The duration of the testing session was about an hour long. The continuous EEG data was collected and processed according to the same system and parameters as in Experiment 2.

Results

Behavioural analyses

Treatment of the behavioural data was the same as in Experiments 1 and 2. Less than 3% of the data were removed. Table 6 displays the reaction times and percent errors for each experimental condition. Data analyses were 2 (congruency) X 2 (phonological confound) repeated measures analysis of variance (AVOVA). Analyses were performed using both subject (F_1) and item (F_2) means.

There was no significant main effect of congruency, either in the latency data or error data, all *F*s < 1. The interaction between syllable congruency and phonological confound was also not significant either in the reaction time data, *F*s < 1, or in the error data, $F_1 < 1$, $F_2(1, 238) = 1.22$, $MSE = .18$, *ns*. Pairwise comparisons revealed that there

Table 6

Mean decision latencies (ms) and error (%) for each experimental condition

Syllable boundary	Congruent		Incongruent		Congruency effect	
	RT	error	RT	error	RT	error
Confounded	601	9.5	599	10.5	-2	1.0
Unconfounded	590	9.4	590	9.2	0	-0.2
Main effect	595	9.45	594	9.85	-1	0.4

were no significant syllable congruency effects for phonologically confounded and phonologically unconfounded words, in either the latency data or error data, all *F*s < 1.

ERP Analyses

Statistical analyses for the current experiment were performed using the same 13 scalp sites (F3, FZ, F4, FC1, FC2, C3, CZ, C4, CP1, CP2, P3, PZ, P4) as in Experiment 2. As syllable congruency effects were strongest in six left anterior electrodes (F3, FZ, FC1, C3, CZ, CP1), analyses on these sites will also be reported. Data analyses will be reported for the P200 (150 – 200 ms) component. Analyses will not be reported for the N250, because the ERP waveforms did not differ at this component. Voltage values across subjects were averaged to establish the mean amplitude of this component.

Analyses on the ERP data were 2 (congruency) X 2 (phonological confound) X 13 (electrode) repeated measures ANOVAs. Where appropriate, statistical values were Greenhouse-Geisser (1959) corrected for violation of the assumption of sphericity. Figure 15 shows the time windows for the congruency effects of the syllable congruent and syllable incongruent conditions at electrode FZ, and Figure 16 displays the waveforms for the syllable congruent and syllable incongruent conditions at each of the 13 electrodes. Figure 17 displays the time windows for the congruency effects for phonologically confounded words, and Figure 18 shows the data for each of the 13 electrodes separately. The time windows of the congruency effects for phonologically unconfounded words can be found in Figure 19, and Figure 20 shows the data for each of the 13 electrodes.

In the 150 – 200 ms time window, the main effect of syllable congruency was not significant across the 13 electrodes, $F(1, 27) = 2.68$, $MSE = 35.47$, *ns*, nor was there an

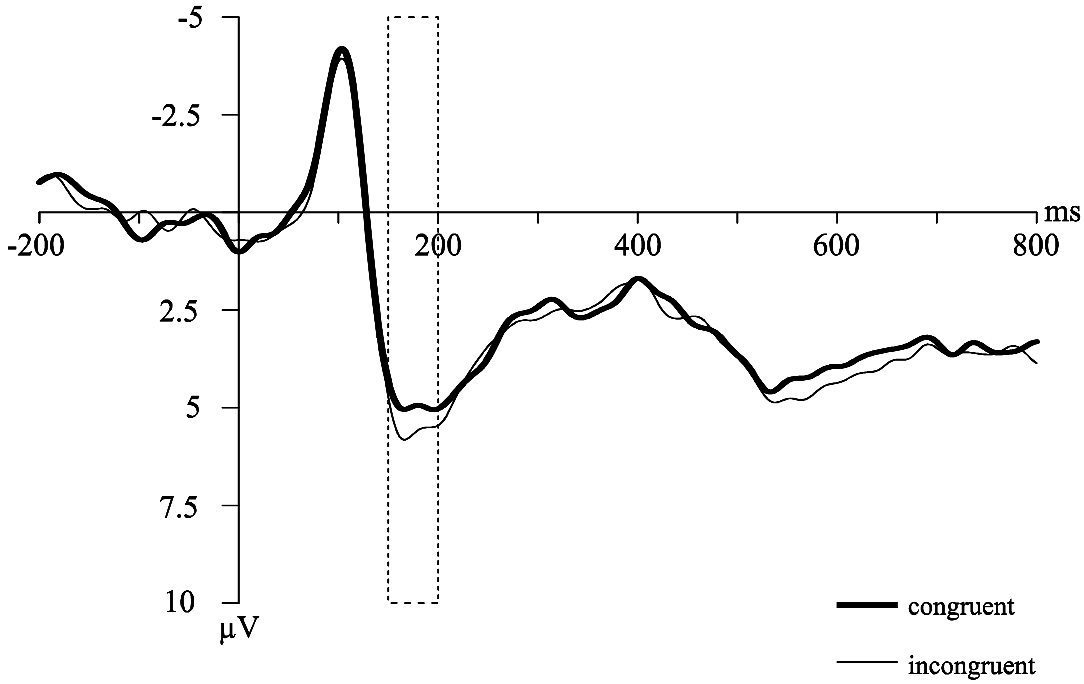


Figure 15. Waveform of the congruency effects in the syllable congruent and syllable incongruent conditions at FZ.

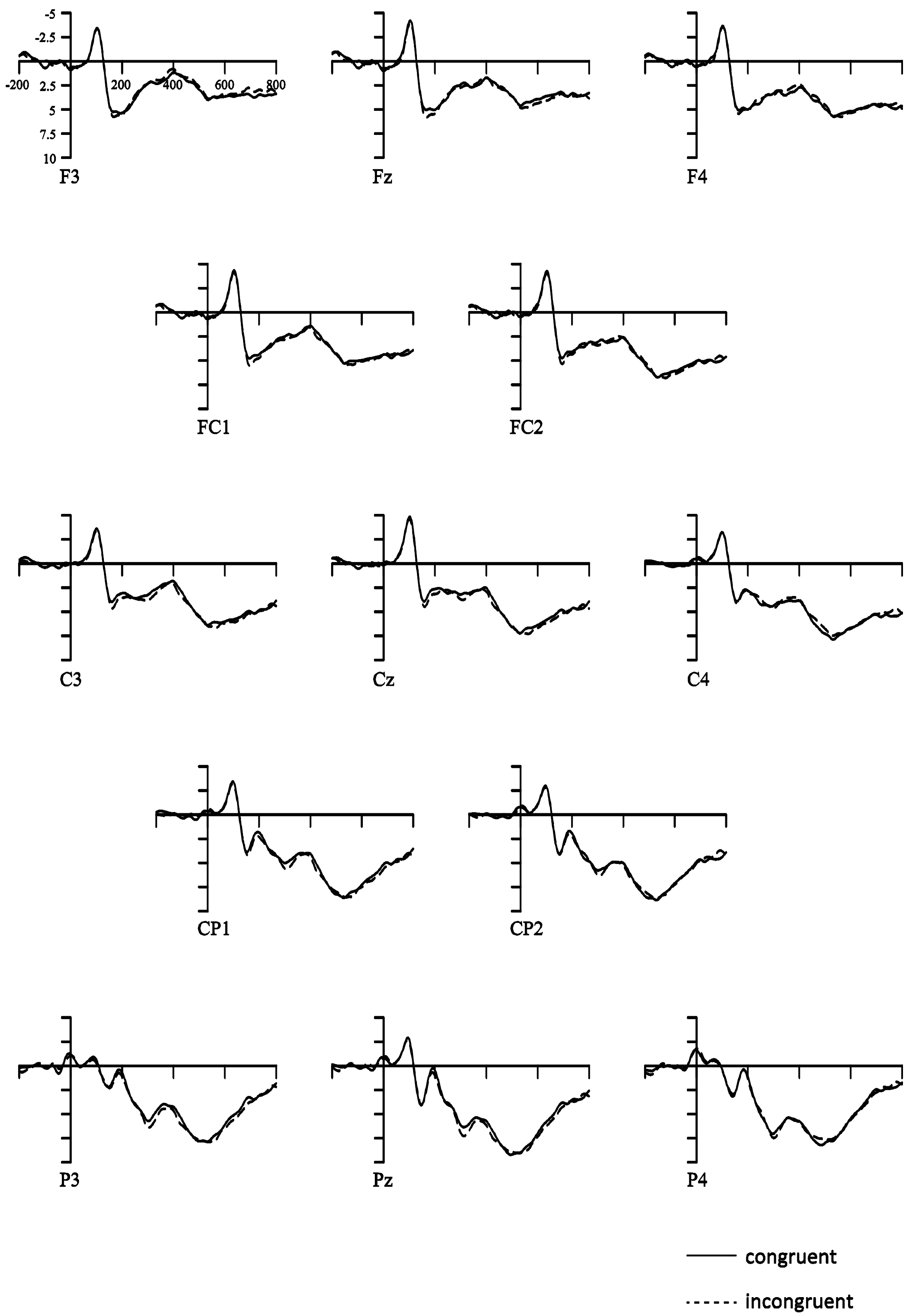


Figure 16. Congruency effects for the syllable congruent and syllable incongruent conditions.

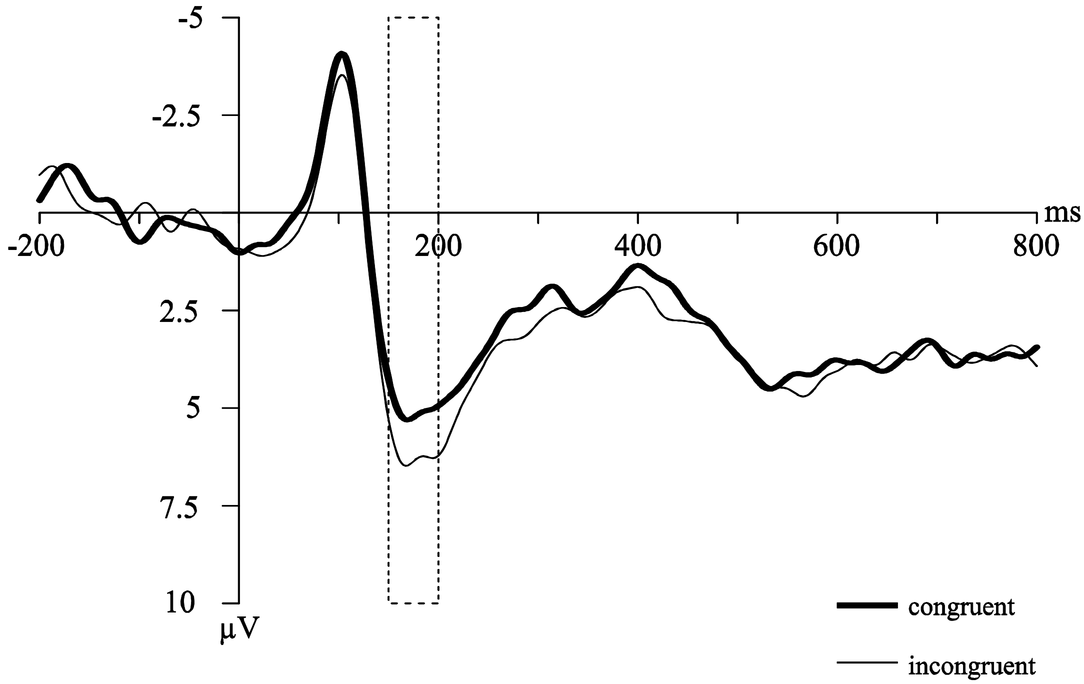


Figure 17. Waveform of the syllable congruency effects for phonologically confounded words at FZ.

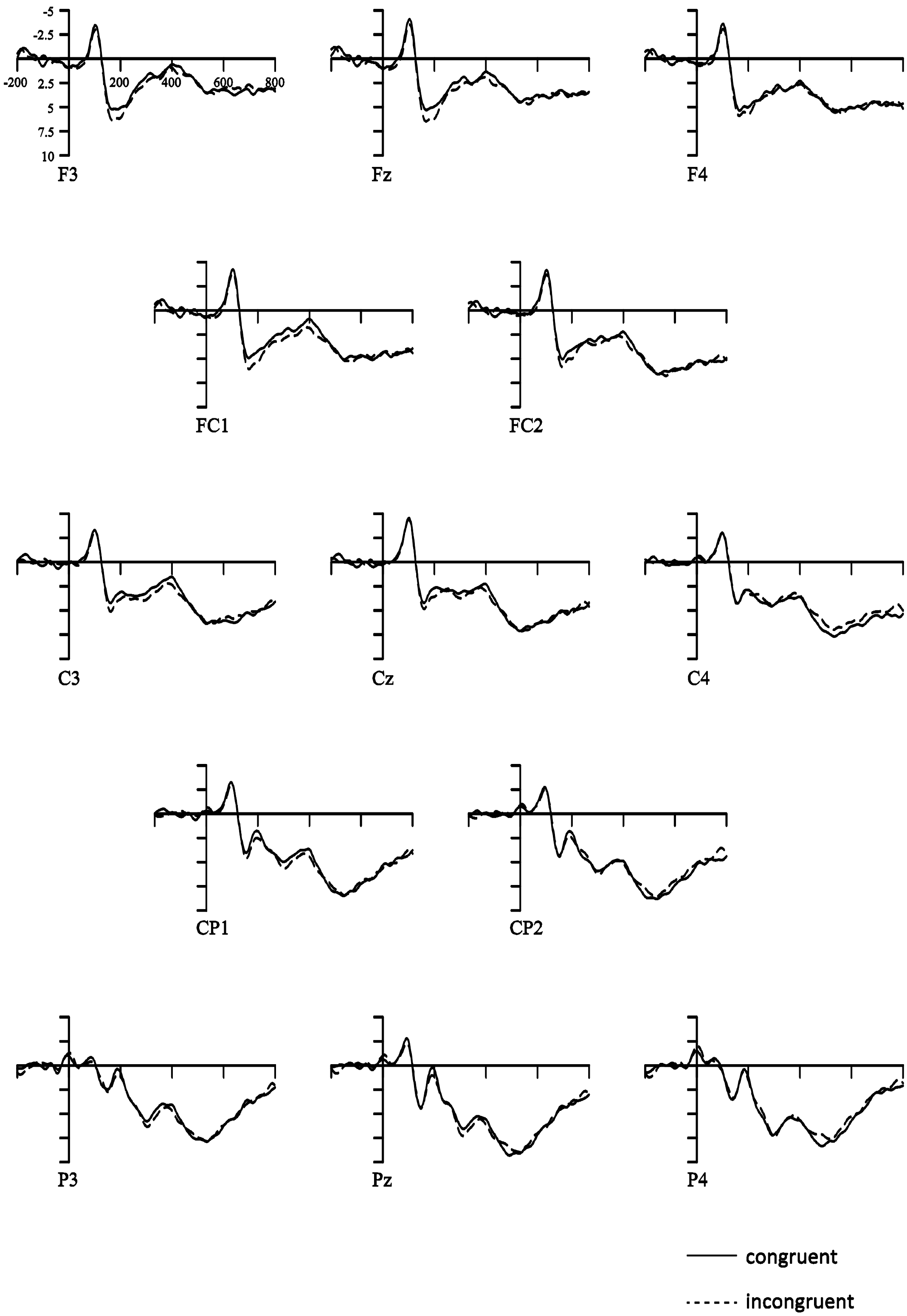


Figure 18. Syllable congruency effects for phonologically confounded words.

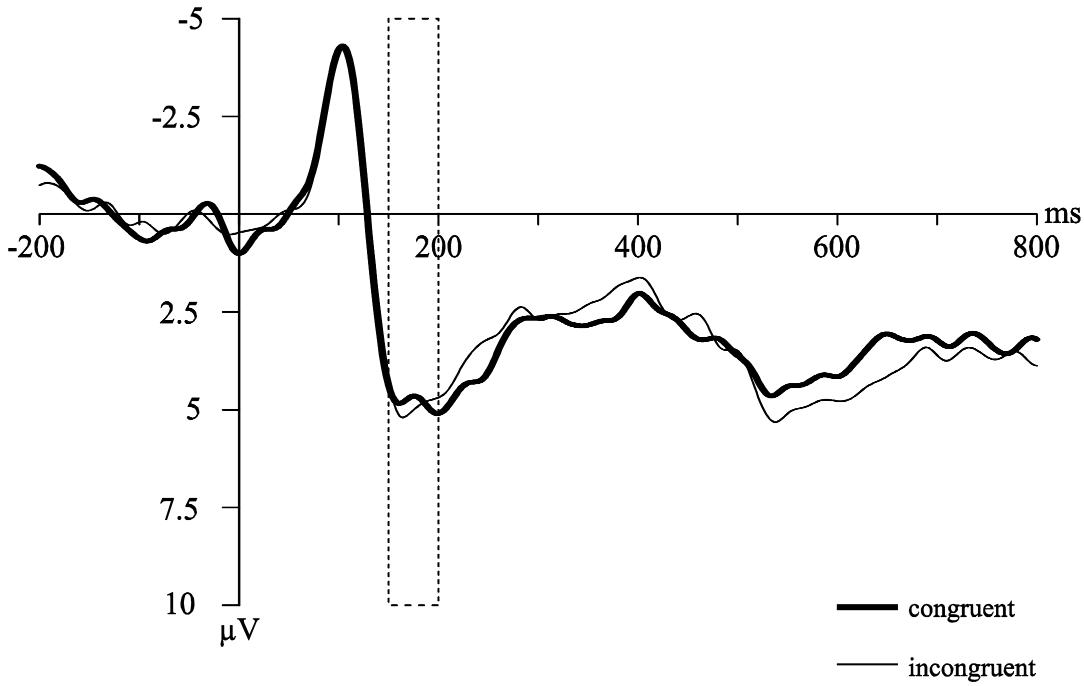


Figure 19. Waveform of the syllable congruency effects for phonologically unconfounded words at FZ.

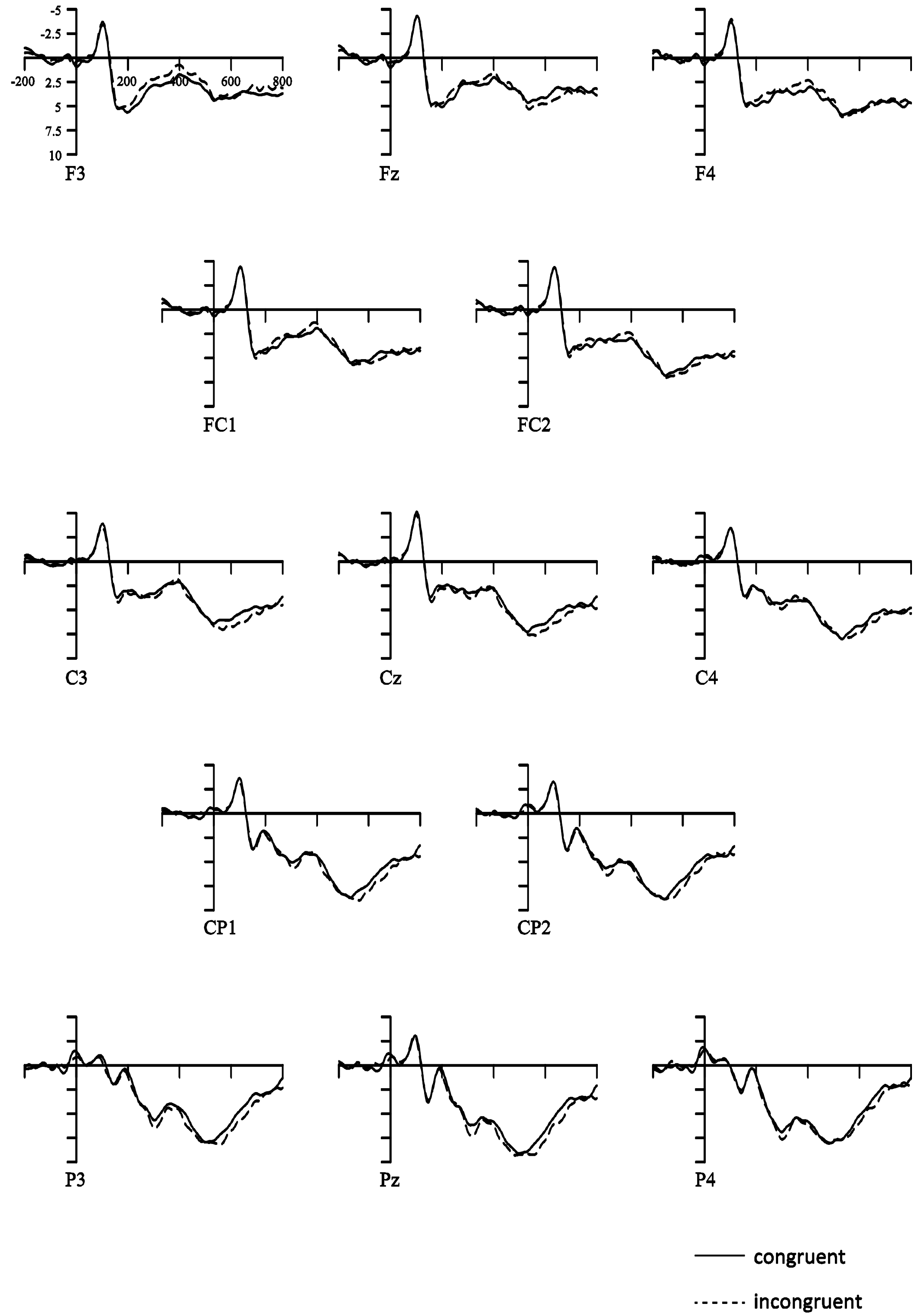


Figure 20. Syllable congruency effects for phonologically unconfounded words.

interaction between syllable congruency and phonological confound, $F(1, 27) = 1.09$, $MSE = 69.12$, *ns*. Further analyses showed that there were no syllable congruency effects for phonologically confounded words, $F(1, 27) = 2.97$, *ns*, or for phonologically unconfounded words, $F < 1$. However, there was a significant main effect of syllable congruency in the six left frontal electrodes, $F(1, 27) = 4.44$, $MSE = 19.18$, $p < .05$, such that the incongruent condition was more positive than the congruent condition. Furthermore, there was a syllable congruency effect for phonologically confounded words, $F(1, 27) = 5.01$, $p < .04$, but not for phonologically unconfounded words, $F < 1$. Specifically, phonologically confounded words in the incongruent condition yielded more positivity than the congruent condition.

A closer inspection of Figures 18 and 20 suggest that syllable congruency effects might be present in the 250 – 350 ms, and 350 – 450 time windows. However, data analyses revealed that there were no significant syllable congruency effects in the 250 – 350 ms time window over the 13 scalp sites, all *F*s < 1, or over the 6 left anterior scalp sites, all *F*s < 1.3. Similarly, no significant syllable congruency effects were found in the 350 – 450 ms time frame over the 13 scalp sites, all *F*s < 1. Over the six left frontal electrodes, there was no main effect of syllable, $F < 1$, or interaction between syllable congruency and phonological confound, $F(1, 27) = 1.79$, $MSE = 36.17$, *ns*. Furthermore, there were no syllable congruency effects in the phonologically confounded condition, $F(1, 27) = 1.91$, *ns*, or phonologically unconfounded condition, $F < 1$.

Discussion

The results of Experiment 3 provide further evidence that the phonological syllable does not have a privileged status in English word recognition (see Table 7 for

Table 7

Summary of results from Experiments 1-3

	ERP component	
	P200	N250
Experiment 1		
orthotactically confounded	–	X
orthotactically unconfounded	–	–
Experiment 2		
Phonological syllable		
before vs at	X	X
at vs after	–	–
BOSS		
at vs before	–	–
MOP		
at vs after	X	–
Experiment 3		
phonologically confounded	X	–
phonologically unconfounded	–	–

summary of results from Experiments 1-3). If English readers do routinely parse words into syllables, then the syllable congruency effect should have been found for words in both phonologically confounded (e.g., PONY, PONDER) and phonologically unconfounded conditions (e.g., CABLE, CABIN). Instead, the syllable congruency effect was only found for words in the phonologically confounded condition. Since the stimuli in the phonologically confounded condition are very similar to those used in the English syllable priming studies (e.g., Ashby, 2010; Ashby & Martin, 2008), it seems that the syllable congruency effects found in these studies reflect phonological matching of the prime and target rather than syllabic processing. In particular, the effects found in these studies may have been due to a phonological match or mismatch of the target word (e.g., PONY) to pre-activated phonological information generated from the prime (e.g., po, pon), and not to the processing of syllables of the target word.

More specifically, a syllable congruency effect was found in the ERP data which occurred in the 150 – 200 ms time window over the left anterior scalp sites. In particular, words presented with the colour change at the syllable boundary elicited less positivity in the P200 component than words presented with the colour change at one letter away from the syllable boundary, but only in the phonologically confounded condition. That is, the syllable congruency effect was only found for words in which the syllable boundary was confounded with its phonology (e.g., PONY, PONDER). Furthermore, the syllable congruency effect showed that stimuli presented with the initial word segment matching the syllable boundary and the pronunciation of the whole word in the congruent condition (e.g., PO-NY, PON-DER) required less effort to process than stimuli presented with the initial word segment mismatching the syllable boundary and the pronunciation of the whole word in the incongruent condition (e.g., PON-Y, PO-NDER). A syllable congruency effect did not occur for phonologically unconfounded words, for which the syllable boundary was not confounded with phonology (e.g., CABLE, CABIN). Specifically, the ERP data revealed no differences for stimuli presented with the initial word segment mismatching the syllable break and the pronunciation of the whole word in both congruent and incongruent conditions (e.g., CA-BLE, CAB-LE), or for stimuli presented with the initial word segment matching the syllable break and the pronunciation of the whole word in both congruent and incongruent conditions (e.g., CAB-IN, CA-BIN).

There are temporal differences between the P200 syllable congruency effect and the syllable congruency effects that have been found in English syllable priming studies. Specifically, the syllable congruency effect found in the current study occurred in the 150 – 200 ms time frame, whereas syllable priming effects were found in the 250 – 350 ms time frame in Ashby and Martin (2008), and as early as 100 – 120 ms in Ashby (2010). Ashby claimed that the earlier syllable priming effect in her 2010 study may be due to the minimization of the variance of visual properties within the critical stimuli because primes were exactly matched in the syllable and non-syllable conditions. A combination of a visually matched design and a masked priming paradigm may explain why the syllable congruency effect found by Ashby (2010) occurred earlier than the syllable congruency effect found in the current experiment. That is, the N100 syllable congruency effect found by Ashby may reflect processing of the masked prime and the subsequent phonological comparison to the target. In contrast, the current experiment found a P200 syllable congruency effect because the participant was not provided with an initial segment prior to the whole word presentation.

The behavioural data from the current experiment did not provide any evidence of a syllable congruency effect for words that belonged to the phonologically confounded or phonologically unconfounded conditions. It should be noted that since Ashby and Martin (2008) and Ashby (2010) employed a passive reading task in their ERP experiments, these experiments did not yield behavioural data.

General Discussion

Three ERP experiments utilizing the syllable congruency paradigm were conducted to investigate the role of the phonological syllable in English reading. Specifically, this study examined the circumstances under which syllable effects can be found in English, and whether the phonological information processed early in word recognition includes syllable information.

Experiment 1 investigated syllable effects for English words that were presented with an orthotactically illegal segment in the incongruent condition (e.g., comr-ade), and words presented with orthotactically legal segments (e.g., whi-sper). A syllable congruency effect was found in the ERP data for words that were presented with an orthotactically illegal segment in the incongruent condition. In particular, the syllable effect occurred at the N250 component, and words presented with the colour change one letter away from the syllable boundary (e.g., comr-ade) elicited more negativity, or were more effortful to process, than words presented with the colour change at the syllable boundary (e.g., com-rade). There was no syllable congruency effect for words in the orthotactically unconfounded condition. Since the words in the orthotactically confounded condition contained a consonant cluster at the syllable break that either could not begin or end a word (e.g., the mr cluster in comrade cannot begin or end a word), while the words in the orthotactically unconfounded condition had a consonant cluster that could begin or end a word (e.g., the sp cluster in whisper can begin or end a word), the syllable congruency effect may not have been due to the use of syllable units. Rather, it seems that the syllable effect reflected the ease with which readers could generate a phonological representation.

Experiment 2 examined syllable effects for each of the phonological syllable, Basic Orthographic Syllabic Structure, and Maximal Onset Principle theories of word segmentation. There was no evidence in support of the BOSS in either the behavioural data or ERP data, suggesting that readers do not parse words according to the BOSS during reading. Evidence for the MOP was mixed. While the behavioural data showed that words with the colour change at the maximal onset boundary (e.g., com-rade) were responded to significantly faster than words with the colour change at one letter after the maximal onset boundary (e.g., comr-ade), this congruency effect only occurred for words in which the maximal onset boundary was confounded with the syllable boundary. There was no congruency effect for words in which the maximal onset break was not confounded by the syllable break. Moreover, although the ERP data showed that the maximal onset condition was less effortful to process in comparison to the after maximal onset condition in the P200 component, the maximal onset condition was more effortful to process in comparison to the after maximal onset condition in the N250 and N280 components.

There was also mixed evidence for the phonological syllable. In the behavioural data, participants responded significantly faster to words presented with the colour change at the syllable break (e.g., com-rade) when compared to words presented with the colour change occurring one letter after the syllable break (e.g., comr-ade), but not when compared to words that had the colour change one letter before the syllable break (e.g., co-mrade). In the ERP data, words presented with the colour change at the syllable boundary elicited less negativity than words presented with the colour change before the syllable break in the P200 and N250 components. However, there were no differences in the ERP data for words in the syllable break condition compared to the after syllable break condition. Because there was no unique pattern of results in the behavioural or ERP data indicating that the syllable congruent condition differed from both incongruent conditions, there was no clear evidence to show that English words are parsed into syllables during reading. Instead, the ERP findings in Experiment 2 were similar to that of Experiment 1, such that the congruency effects appeared to reflect the effort required to process the phonology of the word. The congruency effect seems to be due to the difficulty in reconciling the phonology between a more ambiguous initial word segment containing an open vowel (e.g., pi) with the pronunciation of the whole word (e.g., picnic), than a more constrained initial segment containing the subsequent consonant to the first vowel (e.g., pic).

Experiment 3 explored whether syllable effects can be attributed to phonological matching rather than syllabic processing. Specifically, syllable congruency effects were examined for words in which the syllable boundary was confounded with phonology (e.g., PO-NY, PON-DER), and words for which the syllable boundary was not confounded with phonology (e.g., CA-BLE, CAB-IN). A P200 syllable congruency effect was found, such that words presented with the colour change at the syllable boundary required less effort to process than words presented with the colour change one letter away from the syllable boundary. Importantly, this syllable congruency effect was found only for words that had an initial segment that, in isolation, matched the pronunciation of the whole word in the congruent condition (e.g., po-PONY, pon-PONDER), but did not match the pronunciation of the whole word in the incongruent condition (e.g., pon-PONY, po-PONDER). Like Experiments 1 and 2, the congruency effect found in Experiment 3 did not seem to be due to syllabic processing. An alternative interpretation is that the congruency effect reflected the ease with which the pronunciation of the whole word was computed with an initial segment that matched its phonology, than with a first segment that did not match its phonology.

Taken together, the present experiments demonstrate that while syllable effects can be found in English word recognition, the phonological syllable does not have a privileged role in reading. If the phonological syllable plays an important role in English word recognition, then a syllable congruency effect would be expected to occur for all stimuli across the three experiments. Instead, syllable congruency effects were found only for words that, when presented in their congruent form, had an initial segment that provided a better orthographic cue to the whole word pronunciation when compared to its incongruent form.

Relation to Previous Syllable Studies

Findings from the current study increase our understanding of existing syllable effects in English reading. For example, syllable effects have been observed in previous studies examining how orthotactic rules influence syllable processing. An illusory conjunction effect was found for words that had syllable boundaries between two consonants that would violate orthotactic rules if they were placed together in either syllable (Rapp, 1992). Specifically, fewer illusory conjunction errors were made when the colour change matched the syllable break than when it mismatched the syllable break. However, this study did not include words for which the syllable boundaries were less clearly marked in the orthography. Ferrand et al. (1997) observed a syllable priming effect for words that also had syllable boundaries between two consonants that would violate orthotactic rules if they were placed together in either syllable, but not for ambisyllabic words. However, they did not include words in which the syllable break occurred between two consonants that did not violate orthotactic rules if they were placed together. Furthermore, the syllable priming effect was found only in a naming task, but did not occur with lexical decision. The results of Experiment 1 showed that syllable effects can be captured for English words during a silent reading task using ERPs because it is a more temporally sensitive measurement. Even though all critical stimuli had a syllable break between two consonants, a syllable congruency effect was found only for words that had syllable boundaries clearly marked according to orthotactic rules. Since this study measured ERPs, Experiment 1 also provided an explanation regarding the nature of how orthotactic rules influence syllable processing. In particular, the syllable congruency effect demonstrated that more effort was required to process words when two consonants that violated orthotactic rules were placed together in a segment than when the two consonants were separated. Nevertheless, it does not seem as though the syllable effect was due to the computation of syllable units. Rather, the timing of the N250 syllable congruency effect suggests that it reflected the difficulty in generating the phonology of a word segment containing a consonant cluster that violated orthotactic rules.

Results of the present study also increase our understanding of the syllable effects found in English syllable priming studies. Syllable priming studies measuring ERPs (e.g., Ashby, 2010; Ashby & Martin, 2008) have provided some of the more robust syllable findings in English reading research. Ashby and Martin (2008) found that masked primes that were congruent with the targets' initial syllable (e.g., pi-PILOT, yon-YONDER) elicited more positivity in the 250 – 350 ms time window than masked primes that were incongruent with the first syllable (e.g., pil-PILOT, yo-YONDER). Using a visually matched design in which primes were exactly matched in the syllable congruent and syllable incongruent conditions, Ashby (2010) found a similar syllable priming effect in the N100 component. Specifically, masked primes that were congruent with the initial syllable of the target (e.g., po##-PONY, pon###-PONDER) elicited less negativity than masked primes that were incongruent with the first syllable of the target (e.g, pon#-PONY, po####-PONDER), suggesting that phonological syllable information is activated early during word recognition. Experiment 3 investigated whether these findings can be attributed to syllable activation, or are due to a phonological match or mismatch of the target word (e.g., PONY) to phonological information computed from the prime (e.g., po, pon). The ERP results of Experiment 3 found a syllable congruency effect, but only for stimuli similar to those used by Ashby (2010). That is, a syllable congruency effect was found for words that had a first syllable that, in isolation, had the same pronunciation as the syllable in the context of the whole word (e.g., po-PONY, pon-PONDER). In its incongruent form, the initial segment of these words mismatched the pronunciation of the first syllable in the context of the word (pon-PONY, po-PONDER). For words that had a first segment that matched the pronunciation of the initial syllable of the word in both congruent and incongruent forms (e.g., ca-CATALOGUE, cat-CATALOGUE), and words that had a first segment that mismatched the pronunciation of the initial syllable of the word in both congruent and incongruent forms, (e.g., ca-CATER, cat-CATER), there was no syllable congruency effect. These results demonstrate that the syllable effects in English priming studies (e.g., Ashby, 2010; Ashby & Martin, 2008) can better be attributed to phonological matching, and not syllable activation.

The findings of the current study provide some clarification for studies that have found syllable effects in English reading, but have also questioned whether readers parse words into syllable units. For example, in a naming study investigating the number of syllables effect, Jared and Seidenberg (1990) found longer latencies as number of syllables increased, but only for lower frequency words. They attributed this effect to spelling-sound consistency, rather than a syllable effect, because words with more syllables also have more vowels. Since vowels tend to be more variable in their pronunciation than consonants, the increased number of vowels may have led to the increased latencies. Similarly, the syllable congruency effects in the N250 component of Experiment 2, and the P200 component of Experiment 3, seem to reflect the effort required to reconcile the phonology of an initial word segment (e.g., pi) that mismatched the pronunciation of the whole word (e.g., picnic). This is especially the case with letter segments containing an open vowel.

Macizo and Van Petten (2007) performed multiple regression analyses on data for disyllabic words from the English Lexicon Project (Balota et al., 2002). For the lexical decision data, they found a facilitation effect of syllable frequency in lexical decision. This is opposite to the inhibitory effect found in Spanish (e.g., Álvarez, Carreiras, & de Vega, 2000; Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998), which is thought to be due to higher frequency syllables activating more word neighbours than lower frequency syllables. Longer latencies, then, reflect correctly identifying the correct word amongst a larger word neighbourhood. Macizo and Van Petten (2007) suggested that if word neighbours are activated via syllable units in English, it does not occur fast enough to affect whole word recognition. All three experiments of the current study found syllable congruency effects that occurred about 200 ms after word presentation. Studies exploring the time course of word processing have suggested that this time frame reflects phonological processing (Grainger et al., 2006; Holcomb & Grainger, 2006). This explanation fits well with the current study because the syllable congruency effects found at this time frame are hypothesized to reflect the difficulty in generating a phonological representation when word segments violate orthotactic rules (Experiment 1), or when the phonology of a word segment mismatches the phonology of the whole word (Experiments 2 and 3). Importantly, these syllable congruency effects were found only when the colour change in the congruent conditions provided a better cue to pronunciation than the colour change in the incongruent conditions. If readers explicitly parse words into syllable units, then syllable congruency effects should have been found when the colour change in the congruent condition did not provide a better cue to pronunciation than the colour change in the incongruent condition. It seems that for

English word processing, the initial vowel information in the weak phonological code is ambiguous, and is more refined when there is a subsequent consonant to constrain the vowel's pronunciation. However, this code does not include explicit syllable units.

In contrast, there is growing evidence to suggest that Spanish readers group letters into syllables prior to word recognition (e.g., Carreiras et al., 2005). More robust syllable effects have been found in Spanish syllable congruency and syllable frequency experiments because Spanish words generally have syllable boundaries clearly marked in the orthography. For example, Carreiras et al. (2005) found that words presented with a colour change that mismatched the syllable boundary elicited more positivity at the P200 component, or was more effortful to process, than words presented with a colour change that matched the syllable boundary. However, findings from Experiment 2 of the current study suggest that the syllable congruency effect found in Carreiras et al. may be due the congruent condition containing a smaller number of letters in the first segment than the incongruent condition. Nonetheless, neither number of letters or phonological matching provide an alternative explanation for the syllable frequency effect (e.g., Álvarez, Carreiras, & de Vega, 2000; Álvarez, Carreiras, & Taft, 2001; Álvarez, de Vega, & Carreiras, 1998; Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998). Furthermore, the MROM-S (Conrad et al., 2010) has been able to simulate the syllable congruency effect by including syllable-sized sublexical units between orthographic and lexical representations in Spanish word recognition. As such, it seems that the syllable plays different roles in English and Spanish. While early phonological representations are not specific enough to include syllable information in English, it seems that the phonological syllable is fully specified early in Spanish word recognition.

Theoretical Implications

These early phonological effects observed in the current study can be explained by the *strong phonological theory* (Frost, 1998), which proposes that phonological processing begins as a coarse code, and becomes more defined over time. The results of the current study show that phonology arises early during word processing in English, even for silent reading. However, this early phonological processing does not seem to involve explicit syllable information. Moreover, phonological processing might not proceed to the fully developed phonological code of the whole word during silent reading.

Alternatively, Chateau and Jared (2003) proposed that in addition to learning spelling-sound relationships for individual letters, English readers acquire spelling-sound relationships of larger orthographic segments when they inform pronunciation beyond that of individual letters. It may be that while English readers do not parse all words into explicit syllable units, there are learned spelling-sound relationships of orthographic segments that correspond to the phonological syllable boundary for some words. For the syllable congruency effects found in the current study, the colour change may have emphasized a word segment that matched a learned orthographic unit in the congruent condition, but not for the incongruent condition.

In English, the most recent computational model of polysyllabic word recognition is the CDP++ model (Perry et al., 2010). Even though this model does not include explicit syllable units between orthography and lexical representations as the MROM-S (Conrad et al., 2010) does for Spanish reading, the graphemic parser in the CDP++ model does divide disyllabic words into two syllables. Recall that grapheme information is extracted in two stages. During the first stage, the parser detects graphemes via an attentional window. Then the graphemes are entered into the graphemic buffer in the TLA sublexical network. An item is processed as a disyllabic word if the graphemic buffer extracts two vowel graphemes (with the exception of the letter “e” in the coda position). Furthermore, graphemes are inserted according to the Maximal Onset Principle (e.g., Blevins, 1995). Experiment 2 investigated whether the MOP plays a role in English reading, and did not find evidence that readers parse words according to the MOP during word recognition. Although there was a maximal onset congruency effect in the behavioural data showing that reaction times were faster for words presented in the congruent condition than incongruent condition, this was only the case for stimuli in which the maximal onset break was also the phonological syllable break. In the ERP data, even though a maximal onset congruency effect suggested that the maximal onset condition required less effort to process than the after maximal onset condition in the P200 component, the opposite was found in the N250 and N280 components. It should be noted that Experiment 2 also yielded mixed results in the behavioural data and ERP data for the phonological syllable using the same set of stimuli. As such, there was no evidence to suggest the English readers parse words according to the maximal onset principle or phonological syllable during word recognition.

Given the results of the current study, and the general mixed findings for the phonological syllable in the English word recognition literature, it is apparent that English readers do not explicitly divide words into segments during word processing. The CDP++ model (Perry et al., 2010) and any future computational models of English visual word recognition will need to reflect this notion. With respect to the CDP++ model’s graphemic parser, it may not be necessary for the grapheme nodes to simulate syllabification of a disyllabic word. In particular, the grapheme nodes include 16 slots representing onset-vowel-coda onset-vowel-coda (CCCVCCCC.CCCVCCCC), and the model processes an item as a disyllabic word if the grapheme buffer extracts two vowel graphemes. While the initial placements of these vowels are indeed important, it does not seem as though the consonants in between these vowels need to be labeled as coda or onset. These labels are currently used because consonants are placed in these slots according to the MOP. However, the recognition that an item is disyllabic largely depends on the extraction of the vowel graphemes. Thus, it seems prudent for vowel graphemes to be placed correctly, as well as the onset of the word before the first vowel and the coda of the word after the second vowel. In contrast, the consonants in between the vowels may be placed without shifting these consonants to fit any theory of word segmentation (e.g., the slots might simply be CCCVCCCCVCCCC). Of course, the model would need to determine whether the consonants between the two vowels are pronounced with the preceding or following vowel. One solution may be for hidden units to learn the relationships between spelling and sound of letters that frequently co-occur, especially those that are predictive of pronunciations. This would reflect the view that English readers learn spelling-sound relationships for larger orthographic units when these segments provide more information about pronunciation than individual letters (Chateau & Jared, 2003).

Future Directions

Even though more recent computational models of English word recognition have included phonological representations of multisyllabic words (e.g., CDP++, Perry, Ziegler, & Zorzi, 2010), more data are required to refine our understanding of how phonological information is processed from the orthography during reading, and what this phonology entails. The present study has provided evidence that English readers do not explicitly segment polysyllabic words into syllable units during silent reading. Furthermore, the phonological syllable does not play an important role during early phonological representations during word recognition. Future studies should examine what types of phonological information are important to the early stages of reading. For example, research should examine whether English readers learn spelling-sound correspondences of larger orthographic units that provide information about pronunciation beyond that of individual letters. At the moment, words are syllabified at the grapheme level in the CDP++ model, but it is unclear how stored phonological knowledge affects this process. Future research will need to examine the extent to which the phonological lexicon influences early phonological processing during word recognition. Similarly, future modelling research will need to consider whether feedback from phonological representations to hidden units might be helpful in creating some hidden unit letter clusters that resemble syllables. For example, some stored phonological representations may provide syllabification clues from stress patterns. Future computational models will also need to examine whether differences between English and Spanish reflect qualitative processing differences, or differences in the statistical relationships between spelling and sound. At the moment, the MROM-S (Conrad et al., 2010) includes syllable units between orthographic and lexical representations for Spanish words. Perhaps this syllable processing could be captured by a model like the

CDP++ model by syllable or syllable-like units that may emerge in the hidden units since Spanish syllables are clearly marked in the orthography.

Moreover, since there is evidence that early phonological processing occurs around 200 ms after a word is read, future research will need to employ temporally sensitive measurements such as ERP. Currently, the present study and syllable priming experiments (e.g., Ashby, 2010) have been the only studies investigating these effects in English. It should be noted that both the syllable congruency and syllable priming paradigms present words that have already been segmented. Even though an advantage of the syllable congruency paradigm is that it does not require participants to process the initial word segment prior to target presentation, and thus prevents phonological matching of the initial segment with the whole word, future research should explore whether effects found in the present study can be confirmed with methodologies that more closely resemble natural reading. Additionally, future computational models of English word recognition will need to account for these data. At the moment, constraints on models of reading have only been based on behavioural data. Taking into account the time course information that measurements like ERPs provide will help refine the internal dynamics of these models (Barber & Kutas, 2007).

Conclusion

Findings from the present study demonstrate that the phonological syllable does not have a privileged status in English word recognition. While syllable congruency effects were found in the ERP data across the three experiments, these effects were only evident for words that, in its congruent form, had an initial segment that provided a better orthographic cue to whole word phonology than its incongruent form. This finding indicates that English readers process phonological information early during word recognition, even during silent reading. However, this phonological processing does not seem to include syllable information. Furthermore, it was found that English readers do not parse words according to the BOSS boundary or maximal onset boundary during word recognition. These findings present a challenge to the CDP++ model (Perry, Ziegler, & Zorzi, 2010), which includes a graphemic parser that syllabifies disyllabic words according to the maximal onset principle. The current study presents the kind of data that are important to enhancing theories of English word recognition, and the refinement of computational models of multisyllabic word recognition.

References

Álvarez, C. J., Carreiras, M., de Vega, M. (2000). Syllable-frequency effect in visual word recognition: Evidence of sequential-type processing. *Psicólogica, 21*, 341-374.

Álvarez, C. J., Carreiras, M., & Taft, M. (2001). Syllables and morphemes: Contrasting frequency effects in Spanish. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 545–555.

Álvarez, C., de Vega, M., & Carreiras, M. (1998). The syllable as an activational unit in reading trisyllabic words. *Psicothema, 10*(2), 371–386.

Ashby, J. (2010). Phonology is fundamental in skilled reading: Evidence from ERPs. *Psychonomic Bulletin & Review, 17*(1), 95-100.

Ashby, J., & Martin, A.E. (2008). Prosodic phonological representations early in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 34*(10), 224-236.

Ashby, J., & Rayner, K. (2004). Representing syllable information during silent reading: Evidence from eye movements. *Language and Cognitive Processes, 19*(3), 391-426.

Baayen, H., Piepenbrock, R., & Gulikers, L. (1995). The CELEX lexical database (Release 2). Philadelphia, PA: Linguistic Data Consortium, University of Pennsylvania.

Balota, D. A., Cortese, M. J., Hutchison, K. A., Neely, J. H., Nelson, D., Simpson, G. B., Treiman, R. (2002). *The English Lexicon Project: A Web-based repository of descriptive and behavioral measures for 40,481 English words and nonwords.* St. Louis: Washington University. Available at elexicon.wustl.edu.

Barber, H., Vergara, M., & Carreiras, M. (2004). Syllable-frequency effects in visual word recognition: Evidence from ERPs. *NeuroReport, 15*, 545–548.

Barber. H., & Kutas, M. (2007). Interplay between computational models and cognitive electrophysiology in visual word recognition. *Brain Research Reviews, 53*, 98-123.

Blevins, J. (1995). The syllable in phonological theory. In J. A. Goldsmith, *The handbook of phonological theory*, (pp. 206-244). Cambridge: Blackwell.

Brand, M., Rey, A., & Peereman, R. (2003). Where is the syllable priming effect in visual word recognition? *Journal of Memory and Language, 48,* 435-443.

Butler, B., & Hains, S. (1979). Individual differences in word recognition latency. *Memory & Cognition*, *7*(2), 68-76.

Carreiras, M., Álvarez, C. J., & de Vega, M. (1993). Syllable frequency and visual word recognition in Spanish. *Journal of Memory and Language, 32*, 766–780.

Carreiras, M., & Perea, M (2004). Naming pseudowords in Spanish : Effects of syllable frequency. *Brain and Language, 90,* 393-400.

Carreiras, M., Vergara, M., & Barber, H. (2005). Early event-related potential effects of syllabic processing during visual word recognition. *Journal of Cognitive Neuroscience, 17,* 1803-1817.

Chateau, D., & Jared, D. (2003). Spelling-sound consistency effects in disyllabic word naming. *Journal of Memory and Language, 48*, 255-280.

Chetail, F., & Mathey, S. (2009). Syllabic priming in lexical decision and naming tasks: The syllable congruency effect re-examined in French. *Canadian Journal of Experimental Psychology, 63*(1), 40-48.

Chen, H., & Vaid, J. (2007). Word frequency modulates the Basic Orthographic Syllable Structure (BOSS) effect in English polysyllable word recognition. *Language and Cognitive Processes, 22*(1), 58-82.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: dual-route and parallel-distributed-processing approaches. *Psychological Review, 100*, 589–608.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256.

Conrad, M., Carreiras, M., Tamm, S., & Jacobs, A.M. (2009). Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels. *Journal of Experimental Psychology: Human Perception and Performance, 35*(2), 461-479.

Conrad, M., Grainger, J., & Jacobs, A. (2007). Phonology as the source of syllable frequency effects in visual word recognition: Evidence from French. *Memory and Cognition, 35*(5), 974-983.

Conrad, M., & Jacobs, A. (2004). Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition. *Language and Cognitive Processes, 19*, 369–390.

Conrad, M., Tamm, S., Carreiras, M., & Jacobs, A.M. (2010). Simulating syllable frequency effects within an interactive activation framework. *European Journal of Cognitive Psychology, 22*(5), 861-893.

Ferrand, L. (2000). Reading aloud polysyllabic words and nonwords: The syllabic length effect reexamined. *Psychonomic Bulletin & Review, 7*(1), 142-148.

Ferrand, L. & New, B. (2003). Syllabic length effects in visual word recognition and naming. *Acta Psychologica*, *113*, 167-183.

Ferrand, L., Segui, J., & Grainger, J. (1996). Masked priming of words and picture naming: The role of syllabic units. *Journal of Memory and Language*, *35*, 708–723.

Ferrand, L., Segui, J., & Humphreys, G.W. (1997). The syllable's role in word naming. *Memory & Cognition*, *25*(4), 458-470.

Frederiksen, J. & Kroll, J. (1976). Spelling and sound: Approaches to the internal lexicon. *Journal of Experimental Psychology: Human Perception and Performance, 2*(3), 361-379.

Frost, R (1998). Toward a strong phonological theory of visual word recognition: true issues and false trails. *Psychological Bulletin, 123*(1), 77-99.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*(3), 518–565.

Grainger, J., Kiyonaga, K., & Holcomb, P.J. (2006). The time course of orthographic and phonological code. *Psychological Science*, *17*(12), 1021-1026.

Harm, M.W., & Seidenberg, M.S. (2004). Computing the meanings of words in reading: division of labor between visual and phonological processes. *Psychological Review, 111*(3), 662–720.

Hawelka, S., Schuster, S., Gagl, B., & Hutzler, F. (2013). Beyond single syllables: The effect of first syllable frequency and orthographic similarity on eye movements during silent reading. *Language and Cognitive Processes, 28*(8), 1134-1153.

Holcomb, P.J., & Grainger, J. (2006). On the time course of visual word recognition: An event-related potential investigation using masked repetition priming. *Journal of Cognitive Neuroscience, 18*(10), 1631-1643.

Jared, D., & Chateau, D. (2003). Spelling-sound consistency effects in disyllabic word naming. *Journal of Memory and Language, 48*, 255-280.

Jared, D., Levy, B. A., & Rayner, K. (1999). The role of phonology in the activation of word meanings during reading: Evidence from proofreading and eye movements. *Journal of Experimental Psychology: General, 128*(3), 219-264.

Jared, D. & Seidenberg, M.S. (1990). Naming multisyllabic words. *Journal of Experimental Psychology: Human Perception and Performance, 16*(1), 92-105.

Jordan, T. R. (1986). Testing the BOSS hypothesis: Evidence for position-insensitive orthographic priming in the lexical decision task. *Memory & Cognition, 14*(6), 523-532.

Katz, L., & Baldasare, J. (1983). Syllable coding in printed-word recognition by children and adults. *Journal of Educational Psychology, 75*(2), 245-256.

Keuleers, M., Lacey, P., Rastle, K., & Brysbaert, M. (2012). The British Lexicon Project: Lexical decision data for 28,730 monosyllabic and disyllabic English words. *Behaviour Research Methods, 44*, 287–304.

Lima, S.D., & Pollatsek, A. (1983). Lexical access via an orthographic code?

The Basic Orthographic Syllable Structure (BOSS) Reconsidered. *Journal of Verbal Learning and Verbal Behavior*, *22*, 310-332.

Macizo, P. & Van Petten, C. (2007). Syllable frequency in lexical decision and naming of English, *Reading and Writing, 20*(4), 295-331

Mathey, S., & Zagar, D. (2002). Lexical similarity in visual word recognition: The effect of syllabic neighborhood in French. *Current Psychology Letters, 8*, 107–121.

Merriam-Webster's collegiate dictionary (10th ed.). (1993). Springfield, MA: Merriam-Webster.

McClelland, J.L., & Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88*, 375–407.

Muncer, S.J., & Knight, D.C. (2012). The bigram trough hypothesis and the syllable number effect in lexical decision. *The Quarterly Journal of Experimental Psychology, 65*(11), 2221-2230.

Nelson Canadian Dictionary of the English Language (1997). Toronto, ON; ITP Nelson.

New, B., Ferrand, L., Pallier, C., & Brysbaert, M. (2006). Reexamining the word length effect in visual word recognition: New evidence from the English Lexicon Project. *Psychonomic Bulletin & Review, 13*(1), 45-52.

Newman, R.L., Jared, D., & Haigh, C.A. (2012). Does phonology play a role when skilled readers read high-frequency words? Evidence from ERPs. *Language and Cognitive Processes, 27*(9), 1361-1384.

Plaut, D.C., McClelland, J.L., Seidenberg, M.S., & Patterson, K.E. (1996). Understanding normal and impaired word reading: computational principles in quasi-regular domains. *Psychological Review, 103*, 56–115.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighborhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 134–144.

Perry, C. (2012). Graphemic parsing and the basic orthographic syllable structure. *Language and Cognitive Processes*, 1-22.

Perry, C., Ziegler, J.C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. *Cognitive Psychology, 61*(2), 106-151.

Perry, C., Ziegler, J.C., & Zorzi, M. (2014a). CDP++.Italian: Modelling sublexical and supralexical inconsistency in a shallow orthography. *PLoS ONE, 9*(4): e94291.

Perry, C., Ziegler, J.C., & Zorzi, M. (2014b). When silent letters say more than a thousand words: An implementation and evaluation of CDP++ in French. *Journal of Memory and Language, 72*, 98-115.

Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461–475.

Rapp, B.C. (1992). The nature of sublexical orthographic organization: The bigram trough hypothesis examined. *Journal of Memory and Language, 31*, 33–53.

Schiller, N.O. (1998). The effect of visually masked syllable primes on the naming latencies of words and pictures. *Journal of Memory and Language, 39*(3), 484-507.

Schiller, N.O. (1999). Masked syllable priming of English nouns. *Brain and Language*

68, 300–305.

Schiller, N.O. (2000). Single word production in English: The role of subsyllabic units during phonological encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(2), 512-528.

Seidenberg, M.S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Colheart (Ed.), *Attention and Performance XII, The Psychology of Reading* (pp. 245-263). Lawrence Erlbaum Associates Ltd.

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*, 523–568.

Solso, R. L., Juel, C.L. (1980). Positional frequency and versatility of bigrams for two-through nine-letter English words. *Behavior Research Methods & Instrumentation*, *12*(3), 297-343.

Spoehr, K., & Smith, E. (1973). The role of syllables in perceptual processing. *Cognitive Psychology*, *5*(1), 71-89.

Stenneken, P., Conrad, M., & Jacobs, A.M. (2007). Processing of syllables in production and recognition Tasks. *Journal of Psycholinguistic Research, 36*, 65-78.

Taft, M. (1979). Lexical access via an orthographic code: The Basic Orthographic Syllable Structure (BOSS). *Journal of Verbal Learning and Verbal Behavior, 18*, 21-39.

Taft, M. (1987). Morphographic processing. The BOSS re-emerges. In M. Coltheart (Ed.), Attention and performance XII (pp. 265 -279). Hove, UK: Lawrence Erlbaum Associates Ltd.

Taft, M. (2001). Processing of orthographic structure by adults of different reading ability. *Language and Speech, 44*(3), 351-376.

Taft, M. (2002). Orthographic processing of polysyllabic words by native and nonnative English speakers. *Brain and Language*, *81*, 532-544.

Treiman, R., & Zukowski, A. (1990) Toward an understanding of English syllabification. *Journal of Memory and Language*, *29*, 66-85.

Webster's New World Speller/Divider (1971). New York, NY: Simon and Schuster.

Yap, M.J., & Balota, D.A. (2009). Visual word recognition of multisyllabic words. *Journal of Memory and Language*, *60*, 502-529.

Appendix A
Stimuli from Experiment 1

Orthotactically confounded		Orthotactically unconfounded	
butler	album	basket	alter
canvas	anvil	custom	amber
magnet	argue	dismal	anger
napkin	atlas	fasten	angel
nutmeg	elbow	foster	arson
picnic	emcee	gospel	enter
silver	optic	hostel	index
velvet	organ	master	orbit
vulgar	ulcer	musket	urban
walnut	banjo	pistol	disco
walrus	cargo	roster	dowry
wisdom	circa	rustic	metro
blanket	fancy	blister	nasty
counter	genre	booklet	pasta
crimson	larva	brisket	absent
frantic	mercy	cluster	almond
scarlet	rugby	crystal	ambush
shelter	sixty	drastic	antics
thermal	vodka	droplet	aspect
thunder	enzyme	glisten	empire
tractor	excess	plaster	engine
transit	expert	plastic	indent
trumpet	infant	prosper	insect
whimper	injure	whisper	octane
comfort	invite	contact	umpire
comrade	adverse	furnace	anguish
conjure	excerpt	gesture	impulse
harvest	conquest	harness	compound
jasmine	converse	hormone	distance
pigment	discount	lantern	linguist
publish	gargoyle	mustard	sentence
salvage	sergeant	nurture	sentient
sibling	vanquish	torture	tortoise
solvent	platform	varnish	pristine
welcome	tranquil	verdict	trespass
witness	shrapnel	vintage	squadron

Nonwords			
panval	tocat	bulren	scaborn
pilnit	tompal	nulgem	dabone
wanqut	umpil	vungat	cobet
cranquir	tuprol	blarlot	camon
coulret	tunrot	scorret	sapler
shenser	menave	cratot	saupy
crangit	mebat	mirat	dormic
largan	pobet	morfome	tomel
ladva	wokon	cosmert	wotle
vomra	wannol	jabline	hettal
pommade	panken	sabling	ropal
pilvent	taplen	atbam	ponlan
sorgant	fopune	alcass	janler
ergeen	fogund	unmert	caten
infeen	lesped	enzure	macust
encant	thesole	incurt	minvus
ergert	thumise	cenant	velot
cartome	jumore	berkant	lipdon
guspom	jaroge	bosker	mattal
postel	gesser	fustor	lamard
pespol	lebber	mistal	grufam
treplass	rulume	blirten	cranan
droclit	valome	crasty	cambine
prastit	harane	santact	murblen
plistan	hushor	noctal	rumal
dasto	shoupod	cortoct	croter
parna	crupon	tortane	folper
fartace	brafone	tarlat	flery
vannern	buffude	arten	chedron
vambish	ruddale	ursan	gelline
anteb	prebal	arbun	fosner
antir	turnal	mebish	shollar
intid	clunet	empine	culple
angesh	clobble	monpind	porpin
entish	monils	contond	colsan
sectes	tantive	saptent	calume
envet	nanute	epsort	macclin
conret	densule	dasnot	smalone
vonerse	wrellar	malner	wassar
shanpush	witkle	salvur	tummage

sharnil	twimler	wolsure	techern
nalvet	glickle	conlure	wrakle
vesdet	shulsom	pulcash	spollage
wasden	shoffen	walcon	volnice
sarvast	bliston	antad	cavane
salnege	whotly	oprim	prudder
wibess	mannel	cremsal	shannet
ergoss	chapner	thumat	fletel
argat	pertune	tranpet	fothmer
fruder	reating	benvet	stolpan
whindar	perning	girness	dommin
whanser	cledder	sidert	shumish
fungby	gluttle	atrone	chumble
ragon	blittor	plasert	cremel
elmin	labant	pasent	trellan
ompare	chamour	ipsane	vipash
dotane	glimond	selnin	spechin
dosince	dramete	linser	scorite
sortive	ashlute	henser	pronile
fauden	shautton	roshen	forgil
famter	cratile	gosture	lisson
murtic	frassile	mestare	selcon
rusnis	clauble	vustad	seabling
harture	saunrut	vardit	scruttle
vurtuge	bample	andex	pontuve
vingal	scrimen	bindsen	trovure
anbit	spranact	broslet	stretome
clostie	othan	prosler	sanrum
clistur	thrantle	drosry	prectum
glespen	sundase	dimess	procrat
whespor	parsach	pimulse	doncrite
mitet	truncha	ropnist	crittide

Appendix B
Stimuli from Experiment 2

Word Type 1	Word Type 2	Word Type 3	Word Type 4
vanquish	giblets	octane	fluster
solvent	mascot	nurture	trespass
vodka	gosling	tortoise	custard
vulgar	grisly	tractor	drastic
rugby	chaplain	index	custom
walrus	measly	umpire	musket
shrapnel	sibling	vintage	pasta
napkin	midriff	trumpet	hostel
velvet	poplar	frantic	crystal
witness	fabric	impulse	foster
atlas	droplet	varnish	brisket
tranquil	tabloid	ambush	casket
conquest	tablet	furnace	rustic
canvas	oblong	thunder	pistol
platform	rescue	shelter	aspect
banjo	goblin	linguist	pesky
larva	quadrant	hormone	blister
kidney	leaflet	album	prosper
picnic	dowry	transit	pasture
infant	publish	scarlet	nasty
enzyme	citrus	almond	mustang
nutmeg	goblet	whimper	pristine
comrade	sapling	thermal	mystic
invite	metro	verdict	plaster
wisdom	petrol	alter	whisky
injure	igloo	censor	roster
dogma	triplet	lantern	hostage
butler	rascal	harness	gospel
harvest	squadron	torture	whisper
expert	ugly	sentence	gesture

Nonwords			
gelline	ruddale	ursan	vambish
fosner	prebal	arbun	anteb
shollar	turnal	mebish	antir
culple	clunet	empine	intid
porpin	clobble	monpind	angesh
colsan	monils	contond	entish
calume	tantive	saptent	sectes
macclin	nanute	epsort	envet
smalone	densule	dasnot	conret
wassar	wrellar	malner	vonerse
tummage	witkle	salvur	shanpush
techern	twimler	vungat	sharnil
wrakle	glickle	blarlot	nalvet
spollage	shulsom	scorret	vesdet
volnice	shoffen	cratot	wasden
cavane	bliston	mirat	sarvast
prudder	whotly	morfome	salnege
shannet	mannel	cosmert	wibess
fletel	chapner	jabline	ergoss
fothmer	pertune	sabling	argat
stolpan	reating	atbam	fruder
dommin	perning	alcass	whindar
shumish	cledder	unmert	whanser
chumble	gluttle	enzure	fungby
cremel	blittor	incurt	ragon
trellan	labant	cenant	elmin
vipash	chamour	berkant	pilvent
spechin	glimond	bosker	sorgant
scorite	dramete	fustor	ergeen
pronile	ashlute	mistal	infeen
forgil	shautton	blirten	encant
lamard	tocat	crasty	ergert
grufam	tompal	santact	cartome
cranan	umpil	noctal	guspom
cambine	tuprol	cortoct	postel
murblen	tunrot	tortane	pespol
rumal	harane	tarlat	treplass
croter	hushor	arten	droclit
folper	shoupod	wolsure	prastit
flery	crupon	conlure	plistan

chedron	brafone	pulcash	dasto
scaborn	buffude	walcon	parna
dabone	menave	antad	fartace
cobet	mebat	oprim	vannern
camon	pobet	cremsal	ompare
sapler	wokon	thumat	dotane
saupy	wannol	tranpet	dosince
dormic	panken	benvet	sortive
tomel	taplen	girness	fauden
wotle	fopune	sidert	panval
hettal	fogund	attone	pilnit
ropal	lesped	plasert	wanqut
ponlan	thesole	pasent	cranquir
janler	thumise	ipsane	coulret
caten	jumore	selnin	shenser
macust	jaroge	linser	crangit
minvus	gesser	henser	largan
velot	lebber	roshen	ladva
lipdon	rulume	bulren	vomra
mattal	valome	nulgem	pommade

Appendix C
Stimuli from Experiment 3

Phonologically Confounded

Stimuli	Pronunciation	Stimuli	Pronunciation
bonus	bō'nəs	bonsai	bōn-sī', bōn'sī, -zī
butane	byōō'tān	butler	bŭt'lər
closure	klō'zhər	closet	klŏz'ĭt, klôz'ĭt
cola	kō'lə	colic	kŏl'ĭk
colon	kō'lən	column	kŏl'əm
comatose	kō'mə-tōs	combat	kəm-băt', kŏm'băt
copious	kō'pē-əs	copy	kŏp'ē
cosy	kō'zē	costume	kŏs'tōōm, -tyōōm, chōōm
helium	hē'lē-əm	helmet	hĕl'mĭt
holistic	hō-lĭs'tĭk	hologram	hŏl'ə-grăm
holy	hō'lē	holiday	hŏl'ĭ-dā
media	mē'dē-ə	medical	mĕd'ĭkəl
medium	mē'dē-əm	meditate	mĕd'ĭ-tāt
menial	mē'nē-əl	mental	mĕn'tl
meteor	mē'tē-ər, -ôr	metaphor	mĕt'ə-fôr, -fər
metre	mē'tər	metal	mĕt'l
mobile	mō'bəl, -bēl, -bīl	mobster	mŏb'stər
modem	mō'dĕm	moderate	mŏd'ər-ĭt
molar	mō'lər	molecule	mŏl'ĭ-kyōōl
motor	mō'tər	motley	mŏt'lē
museum	myōō-zē'əm	muster	mŭs'tər
music	myōō'zĭk	musket	mŭs'kĭt
nomad	nō'măd	nominate	nŏm'ə-nāt
nova	nō'və	novice	nŏv'ĭs
phoney	fō'nē	phonics	fŏn'ĭks
pilot	pī'lət	pilgrim	pĭl'grəm
polarize	pō'lə-rīz	polish	pŏl'ĭsh
polio	pō'lē-ō	politic	pŏl'ĭ-tĭk
pony	pō'nē	ponder	pŏn'dər
postal	pō'stəl	posture	pŏs'chər
poster	pō'stər	postulate	pŏs'chə-lāt
posy	pō'zē	posit	pŏz'ĭt
prefix	prē'fĭks	preface	prĕf'ĭs
premium	prē'mē-əm	premise	prĕm'ĭs
preview	prē'vyōō	prevalent	prĕv'ə-lənt

probation	prō-bā'shən	probable	prŏb'ə-bəl
profile	prō'fīl	profit	prŏf'ĭt
programme	prō'grăm, -grəm	prognosis	prŏg-nō'sĭs
propane	prō'pān	proper	prŏp'ər
regroup	rē-grōōp'	regulate	rĕg'yə-lāt
retail	rē'tāl	retina	rĕt'n-ə
robot	rō'bŏt, -bət	robin	rŏb'ĭn
rosary	rō'zə-rē	roster	rŏs'tər
rumour	rōō'mər	rumble	rŭm'bəl
solar	sō'lər	solemn	sŏl'əm
solo	sō'lō	solid	sŏl'ĭd
somatic	sō-măt'ĭk	somber	sŏm'bər
sonar	sō'nŏr	sonic	sŏn'ĭk
studio	stōō'dē-ō, styōō'-	study	stŭd'ē
sucrose	sōō'krōs	suction	sŭk'shən
bogus	bō'gəs	botany	bŏt'n-ē
cobalt	kō'bŏlt, -bôlt	colony	kŏl'ə-nē
foliage	fō'lē-ĭj, fō'lĭj	foreign	fôr'ĭn, fŏr-
hotel	hō-tĕl'	hormone	hôr'mōn
lotus	lō'təs	lobster	lŏb'stər
mosaic	mō-zā'ĭk	monarch	mŏn'ərk, -ŏrk
motive	mō'tĭv	modest	mŏd'ĭst
noble	nō'bəl	novel	nŏv'əl
pirate	pī'rĭt	pivot	pĭv'ət
polo	pō'lō	populate	pŏp'yə-lāt

Phonologically Unconfounded

Stimuli	Pronunciation	Stimuli	Pronunciation
basic	bā'sĭk	basket	băs'kĭt
basis	bā'sĭs	bastion	băs'chən, -tē-ən
cable	kā'bəl	cabin	kăb'ĭn
canine	kā'nīn	canvas	kăn'vəs
capable	kā'pə-bəl	captain	kăp'tən
caper	kā'pər	capital	kăp'ĭ-tl
cater	kā'tər	catalogue	kăt'l-ŏg, -ôg
cranium	krā'nē-əm	cranberry	krăn'bĕr-ē
fable	fā'bəl	fabric	făb'rĭk
famous	fā'məs	famine	făm'ĭn
fragrance	frā'grəns	fragment	frăg'mənt
gradation	grā-dā'shən	gradual	grăj'ōō-əl

gradient	grā'dē-ənt	graduate	grăj'ōō-āt
gravy	grā'vē	gravel	grăv'əl
halo	hā'lō	halibut	hăl'ə-bət
haven	hā'vən	havoc	hăv'ək
hazy	hā'zē	hazard	hăz'ərd
label	lā'bəl	labyrinth	lăb'ə-rĭnth
latex	lā'tĕks	lateral	lăt'ər-əl
legal	lē'gəl	legacy	lĕg'ə-sē
legion	lē'jən	legend	lĕj'ənd
lemur	lē'mər	lemon	lĕm'ən
lenient	lē'nē-ənt	lentil	lĕn'təl
major	mā'jər	majesty	măj'ĭ-stē
mania	mā'nē-ə, mān'yə	manage	măn'ĭj
mason	mā'sən	mascot	măs'kŏt, -kət
matrix	mā'trĭks	matinee	măt-n-ā'
matron	mā'trən	matador	măt'ə-dôr
napalm	nā'pŏm	napkin	năp'kĭn
nasal	nā'zəl	nasty	năs'tē
nation	nā'shən	natural	năch'ər-əl, năch'rəl
navy	nā'vē	navigate	năv'ĭ-gāt
patron	pā'trən	patent	păt'nt
rabies	rā'bēz	rabid	răb'ĭd
radar	rā'dŏr	radish	răd'ĭsh
radio	rā'dē-ō	radical	răd''ĭ-kəl
raven	rā'vən	ravage	răv'ĭj
sabre	sā'bər	sabotage	săb'ə-tŏzh
sacred	sā'krĭd	sacrifice	săk'rə-fīs
salient	sā'lē-ənt	salary	săl'ə-rē
saline	sā'lēn, -līn	salvage	săl'vĭj
savour	sā'vər	savage	săv'ĭj
station	stā'shən	static	stăt'ĭk
table	tā'bəl	tablet	tăb'lĭt
taper	tā'pər	tapestry	tăp'ĭ-strē
vacancy	vā'kənt	vacuum	văk'yōō-əm, -yōōm, yəm
vagrant	vā'grənt	vagabond	văg'ə-bŏnd
valence	vā'ləns	value	văl'yōō
vapour	vā'pər	vapid	văp'ĭd
wager	wā'jər	wagon	wăg'ən
bacon	bā'kən	balance	băl'əns
drapery	drā'pə-rē	drastic	drăs'tĭk
hazel	hā'zəl	habit	hăb'ĭt

lazy	lā'zē	lavish	lăv'ĭsh
maple	mā'pəl	manic	măn'ĭk
patriot	pā'trē-ət, -ŏt	palace	păl'ĭs
radiate	rā'dē-āt	rapid	răp'ĭd
razor	rā'zər	rascal	răs'kəl
stadium	stā'dē-əm	stamina	stăm'ə-nə
vacation	vā-kā'shən, və-	valid	văl'ĭd

Phonology Legend		IPA vowel equivalent
ā	p**ay**	/eɪ/
ă	p**a**t	/æ/
ə	**a**bout, it**e**m	/ə/
ē	b**e**	/i/
ĕ	p**e**t	/ɛ/
ī	p**ie**	/aɪ/
ĭ	p**i**t	/ɪ/
îr	p**ier**	/ɪər/
ō	t**oe**	/o/
o͝o	t**oo**k	/ʊ/
ŏ	p**o**t, f**a**ther	/ɒ/
ôr	p**our**	/oʊr/
ûr	**ur**ge	/ɜr/
ŭ	c**u**t	/ʌ/

Nonword			
whindar	grufam	gastade	perning
whanser	cranan	scomat	cledder
fungby	cambine	teparn	gluttle
ragon	murblen	camod	blittor
elmin	rumal	wodire	labant
ompare	croter	hetox	chamour
dotane	folper	scoral	glimond
dosince	flery	jabed	dramete
sortive	chedron	blorat	ashlute
fauden	gelline	mavase	shautton
bulren	fosner	dralid	bemoter
nulgem	shollar	graful	paupify
vungat	culple	braple	hevaret
blarlot	porpin	hadesh	degrion

scorret	colsan	wogent	dentrinate
cratot	calume	glingle	lantiment
mirat	macclin	frottad	lavency
morfome	smalone	shorin	skelible
cosmert	wassar	harple	mironen
jabline	tummage	sacoun	bimulase
sabling	techern	casont	tumultin
atbam	wrakle	feggar	steloter
alcass	spollage	grummade	wogasion
unmert	volnice	lethane	essinate
enzure	cavane	walode	deciant
incurt	prudder	pragen	archipact
cenant	shannet	vollun	paritage
berkant	fletel	nassime	binamal
bosker	fothmer	misage	tenerame
fustor	stolpan	daban	gonamic
mistal	dommin	stamod	beffatic
blirten	shumish	pholin	nocolant
crasty	chumble	shammid	intapone
santact	cremel	crundle	dircudate
noctal	trellan	charish	lantetic
cortoct	vipash	prabler	cattory
tortane	spechin	pallobe	remitat
tarlat	scorite	spaline	igurion
arten	pronile	caspal	tranipine
ursan	forgil	chalit	bortany
arbun	tocat	panval	etarnel
mebish	tompal	pilnit	lunisty
empine	umpil	wanqut	evounter
monpind	tuprol	cranquir	levidant
contond	tunrot	coulret	morfotion
saptent	menave	shenser	loxagen
epsort	mebat	crangit	disitor
dasnot	pobet	largan	appience
malner	wokon	ladva	tominent
salvur	wannol	vomra	granerous
wolsure	panken	pommade	invicane
conlure	taplen	pilvent	eromen
pulcash	fopune	sorgant	naminace
walcon	fogund	ergeen	anipurn
antad	lesped	infeen	ecolant

oprim	thesole	encant	annoval
cremsal	thumise	ergert	vintoly
thumat	jumore	cartome	pummation
tranpet	jaroge	guspom	drevilant
benvet	gesser	postel	helicate
girness	lebber	pespol	densitive
sidert	rulume	treplass	graffient
attone	valome	droclit	heberal
plasert	harane	prastit	intecule
pasent	hushor	plistan	turcater
ipsane	shoupod	dasto	grimary
selnin	crupon	parna	masible
linser	brafone	fartace	cirdenor
henser	buffude	vannern	asterate
roshen	ruddale	vambish	frapilot
scaborn	prebal	anteb	tarosy
dabone	turnal	antir	seviad
cobet	clunet	intid	huniam
camon	clobble	angesh	hoprion
sapler	monils	entish	bacrano
saupy	tantive	sectes	taridy
dormic	nanute	envet	banagite
tomel	densule	conret	pragabone
wotle	wrellar	vonerse	balinter
hettal	witkle	shanpush	numion
ropal	twimler	sharnil	vatamen
ponlan	glickle	nalvet	lopasy
janler	shulsom	vesdet	caminet
caten	shoffen	wasden	rotibate
macust	bliston	sarvast	jopatin
minvus	whotly	salnege	locatare
velot	mannel	wibess	meratole
lipdon	chapner	ergoss	grameate
mattal	pertune	argat	flanary
lamard	reating	fruder	thacreny

Appendix D
Ethics for Experiment 1

Western

Department of Psychology The University of Western Ontario
Room 7418 Social Sciences Centre,
London, ON, Canada N6A 5C1

Use of Human Subjects - Ethics Approval Notice

Review Number	09 09 31	**Approval Date**	09 09 29
Principal Investigator	Debra Jared/Daniel Trinh	**End Date**	10 04 30
Protocol Title	Event-related potential investigation of cognitive processes in reading words		
Sponsor	n/a		

This is to notify you that The University of Western Ontario Department of Psychology Research Ethics Board (PREB) has granted expedited ethics approval to the above named research study on the date noted above.

The PREB is a sub-REB of The University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario. (See Office of Research Ethics web site: http://www.uwo.ca/research/ethics/)

This approval shall remain valid until end date noted above assuming timely and acceptable responses to the University's periodic requests for surveillance and monitoring information.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the PREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of research assistant, telephone number etc). Subjects must receive a copy of the information/consent documentation.

Investigators must promptly also report to the PREB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to the PREB for approval.

Members of the PREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the PREB.

Clive Seligman Ph.D.

Chair, Psychology Expedited Research Ethics Board (PREB)

The other members of the 2008-2009 PREB are: David Dozois, Bill Fisher, Riley Hinson and Steve Lupker

CC: UWO Office of Research Ethics

This is an official document. Please retain the original in your files

Appendix E
Ethics for Experiment 2

Western

Department of Psychology The University of Western Ontario
Room 7418 Social Sciences Centre,
London, ON, Canada N6A 5C1

Use of Human Subjects - Ethics Approval Notice

Review Number	11 03 05	**Approval Date**	11 03 10
Principal Investigator	Deb Jard/Daniel Trinh	**End Date**	11 07 31
Protocol Title	Event –related potential examination of cognitive processes involved in single word reading		
Sponsor	n/a		

This is to notify you that The University of Western Ontario Department of Psychology Research Ethics Board (PREB) has granted expedited ethics approval to the above named research study on the date noted above.

The PREB is a sub-REB of The University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario. (See Office of Research Ethics web site: http://www.uwo.ca/research/ethics/)

This approval shall remain valid until end date noted above assuming timely and acceptable responses to the University's periodic requests for surveillance and monitoring information.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the PREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of research assistant, telephone number etc). Subjects must receive a copy of the information/consent documentation.

Investigators must promptly also report to the PREB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to the PREB for approval.

Members of the PREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the PREB.

Clive Seligman Ph.D.

Chair, Psychology Expedited Research Ethics Board (PREB)

The other members of the 2010-2011 PREB are: Mike Atkinson (Introductory Psychology Coordinator), David Dozois, Vicki Esses, Riley Hinson Albert Katz (Department Chair), and Tom O'Neill (Graduate Student Representative)

CC: UWO Office of Research Ethics

This is an official document. Please retain the original in your files

Appendix F
Ethics for Experiment 3

Western

Department of Psychology The University of Western Ontario
Room 7418 Social Sciences Centre,
London, ON, Canada N6A 5C1

Use of Human Subjects - Ethics Approval Notice

Review Number	13 05 11	Approval Date	13 05 15
Principal Investigator	Deb Jared/Daniel Trinh	End Date	13 08 31
Protocol Title	Event-related potential examination of cognitive processes involved in single word reading		
Sponsor	n/a		

This is to notify you that The University of Western Ontario Department of Psychology Research Ethics Board (PREB) has granted expedited ethics approval to the above named research study on the date noted above.

The PREB is a sub-REB of The University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario. (See Office of Research Ethics web site: http://www.uwo.ca/research/ethics/)

This approval shall remain valid until end date noted above assuming timely and acceptable responses to the University's periodic requests for surveillance and monitoring information.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the PREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of research assistant, telephone number etc). Subjects must receive a copy of the information/consent documentation.

Investigators must promptly also report to the PREB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to the PREB for approval.

Members of the PREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the PREB.

Clive Seligman Ph.D.

Chair, Psychology Expedited Research Ethics Board (PREB)

The other members of the 2012-2013 PREB are: Mike Atkinson (Introductory Psychology Coordinator), Rick Goffin, Riley Hinson Albert Katz (Department Chair), Steve Lupker, and Adam Piraino (Graduate Student Representative)

CC: UWO Office of Research Ethics

This is an official document. Please retain the original in your files

VITA

Name:	Daniel Trinh
Post-secondary education and degrees:	York University Toronto, Ontario, Canada 2002 – 2006, B.A. (Specialized Honours)
	The University of Western Ontario London, Ontario, Canada 2006 – 2008, M.Sc.
Awards:	NSERC Postgraduate Scholarship- Masters 2007 – 2008
	Continuing Student Scholarship 2005 – 2006
	York University Entrance Scholarship 2002 – 2003
Related work experience:	Psychometrist Parkwood Hospital, 2010 - 2012
	Teaching Assistant The University of Western Ontario, 2006 – 2012
	Research Assistant Baycrest, Psychology & Neurorehabilitation, 2006
	Psychology Resource Center Assistant York University, 2005 – 2006

Conference presentations:

Trinh, D., & Jared, D. (2013, November). The role of the phonological syllable in English word recognition. Talk presented at the Lexical Processing Workshop, London, ON.

Trinh, D., & Jared, D. (2012, November). Do skilled readers use phonological syllables in reading English words? Evidence from ERP. Poster presented at the 53rd Annual Meeting of the Psychonomic Society, Minneapolis, MN.

Trinh, D., & Jared, D. (2009, November). Do English readers use orthographic cues to recover phonological syllables? Evidence from ERP. Poster presented at the 50th Annual Meeting of the Psychonomic Society, Boston, MA.

Trinh, D., & Jared, D. (2009, March). Effect of orthographic cues in activating phonological syllables during reading. Talk presented at the Western Interdisciplinary Student Symposium on Language Research, London, ON.

Trinh, D., & Jared, D. (2008, June). The Role of Syllables in the Reading of Polysyllabic Words. Poster at the 18th Annual Meeting of the Canadian Society for Brain, Behaviour and Cognitive Science, London, ON.