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CONSISTENCY EFFECTS IN LEXICAL DECISION: AN ELECTROPHYSIOLOGICAL STUDY

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Abstract

Many previous behavioral studies have investigated aspects of the lexical decision task and processing of different types of words and pseudowords in this task. While these studies offer important insight into how individuals recognize and process lexical stimuli, there is only limited information about the neural correlates of these events. This study aims to further the existing literature by using event-related potentials to evaluate electrophysiological processing of specific types of stimulus items. In this English lexical decision task, monolingual, native English speaking participants were asked to decide whether or not a stimulus was an English word and respond with a button press. Over the course of the experiment, different conditions (word types) were presented to the participant. Lexical decisions were made in response to words that were cognates in Spanish and English, English words, English-like pseudowords, and Spanish-like pseudowords. The real English words and English-like pseudowords were further broken down into trials with consistent or inconsistent spelling patterns. Consistent words were defined as words with more "friends" (other words in which the word body is pronounced the same) than "enemies" (other words in which the word body is pronounced differently). Inconsistent words had more enemies than friends. Consistent and inconsistent pseudowords were matched to a set of consistent and inconsistent real words. One purpose of conducting this experiment was to compare the electrophysiological effects of processing consistent versus inconsistent stimuli. Another purpose was to determine if the native English speakers could use the spelling patterns as a cue when processing pseudowords. Event-related potential (ERP) data and behavioral measures were collected and analyzed. Results were consistent with previous studies showing that pseudowords produce slower, less accurate responses than real words and larger amplitude ERPs at the N400 component. Comparisons within the real word types and pseudoword types showed small, but fairly consistent differences between conditions suggesting that participants may have been sensitive to the properties of the specific item types.

Key Words: lexical decision, electrophysiology, consistency, pseudowords

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A basic question in language research is how the lexicon, or mental dictionary, develops. One experimental design that has been used in the history of lexical research is the lexical decision task (LDT). In a lexical decision task, a participant is asked to determine whether or not a letter string is a real word. Participants are typically faster to accept real words than to reject pronounceable pseudowords (i.e., nonwords that follow the spelling conventions of the language) (Forster, 1976). This result has been taken to mean that individuals must complete an exhaustive search to rule out pseudowords as a possible entry in their lexicon. This search may entail checking the orthography, or spelling pattern, of all known words. However, pseudowords may also be converted to their phonological or sound form, which can also be checked against the sounds of all known words. When random letter strings are used as nonwords, however, performance tends to be very rapid, as skilled readers can quickly rule these out as possible words based on knowledge of native language spelling patterns (e.g., Forster and Shen, 1996; Grainger and Jacobs, 1996). Both behavioral and electrophysiological data can be collected while participants perform this type of task (as reviewed below), and both types of data have provided insight into the development of the lexicon.

The current study aims to observe the effects of different word and pseudoword types on the monolingual lexicon. However, three decades ago Grosjean (1982) approximated that about one half of the world's population was bilingual, and we can predict that this number has not decreased, meaning that more than half of those living today speak more than one language. In spite of this occurrence, much of the research on the language processing system has focused on monolinguals. Researchers have predicted possible organization schemas of the bilingual lexicon, although discrepancies exist in the literature. One basis for this study to provide accurate, in depth comparisons to bilingual data in the future, so this literature review will also discuss some implications of the LDT for the bilingual lexicon. Many studies in bilingual research have used the LDT and included L1 and L2 words and nonwords, cognates, and interlingual homographs. Evaluating these types of items can be used to assess the questions regarding language selectiveness, consistency, neighborhood density, etc. Even within a single language, the specific types of words and nonwords used in the LDT can be manipulated to better understand how lexical items are processed.

Consistency Effects

One subject in the behavioral literature that is of relevance to the current study is the issue of consistency. In languages such as English, words are observed to vary in their consistency. Specifically, some spelling patterns are always pronounced a certain way, and are therefore considered consistent (e.g., the "ate" in late, mate, gate), while other spelling patterns are variable in their pronunciation across contexts, and are therefore considered inconsistent (e.g., the "ost" in most vs. cost). Furthermore, words can vary in their consistency in terms of *feedforward* and *feedback*. A word is said to be feedforward consistent if the word body has only one possible pronunciation for its spelling. A word is said to be feedback consistent if the word has no alternative spelling for its pronunciation. While these are related concepts, they are not identical. In regards to feedforward consistency, the rime "ang" would be considered to be consistent because it can only be pronounced in one way (as is "gang"), however, the rime "aid" would be inconsistent because it can be pronounced as in "plaid," "maid," or "said." Feedback consistency works in the opposite direction. For example, the pronunciation "arm" could only be spelled as in "charm" or "harm" and would be considered consistent, while the pronunciation "ad" could be spelled as in "rod," "odd," or "squad," and would be considered inconsistent. In tasks where words must be named, there are clear effects of consistency. Many researchers have found that in general, inconsistent words take longer to name than consistent words. Inconsistent words have also been found to lead to more errors in naming (Glushko, 1979; Cortese and Simpson, 2000). Specifically, feedforward consistency has been found to have an effect on word naming (more so than feedback consistency). This could be because one must access the correct pronunciation for a word when naming, so more than one choice (feedforward inconsistencies) would slow down this process (Ziegler, Montant, and Jacobs, 1997). However, there has been much variability in the research linking these consistency effects with the lexical decision task, possibly because pronunciation is not involved in this task.

Stone, Vanhoy, and Van Orden (1997) studied this variable in an English lexical decision task using consistent and inconsistent real words and nonwords. They describe that inconsistencies in spelling/pronunciation of a word slow down recognition (reaction time) of the word until the inconsistency is resolved. In one experiment, they found that when feedforward consistency was controlled, there was a feedback effect such that slowed reaction times were observed to feedback inconsistent words (more than one spelling for a pronunciation). In a second experiment, they found that when both feedfoward and feedback consistency were controlled, there were considerable reaction time differences between feedforward consistent and inconsistent words (something that had not been found previously). This result indicates that phonology does affect lexical decisions under certain conditions and challenges the delayed phonology hypothesis, which states that the phonologic process responsible for consistency is slow in comparison to the lexical process. However, there is much disagreement over these effects in the literature.

Ziegler, Montant, and Jacobs (1997) aimed to further Stone et al.'s (1997) newly found consistency effect, by again using lexical decision to find feedback effects. They argued that in the previous literature, mapping between phonology and spelling could have been underestimated in visual tasks. Although feedback processing (going from phonology to spelling) would not be as direct in a visual task as feedforward processing (from spelling to phonology), their study aimed to show that this second order effect was still relevant. After matching consistent and inconsistent words on written frequency (i.e., how often the word appears in the language) and number of orthographic neighbors (i.e., the number of words that differ in spelling from a given word by only one letter), this study aimed to replicate the feedback and feedforward consistency effects in French. A naming task was also used to determine the orthographic nature of the feedback effect.

Ziegler et al. (1997) did replicate the previous Stone et al. (1997) study in finding both feedforward and feedback effects for the lexical decision task. Also, like Stone et al., they did not find feedback effects for nonword trials. However, their results differed from the previous study because reaction times of bidirectional inconsistent words were found to be even slower than those for feedforward or feedback inconsistent words alone. In word naming, they also found both effects to be present, however, the feedback effect was significantly less robust than that of feedforward consistency. This finding partially supports the view that there is a generalized component in word perception that relies on both orthography and phonology. It also shows that there is a degree of task dependence in consistency effects. Task specific mechanisms, such as spelling verification, might control which effects will be seen. Ziegler et al. also proposed a lexical mechanism for feedback consistency (in addition to the sublexical route proposed by Stone et al.). In this mechanism, the pronunciation of a word body leads to activations of all the phonological neighbors of that word. While real words can be activated using this route, nonwords are activated using global activation, which will not show feedback consistency effects.

Lacruz and Folk (2004) examined these feedforward and feedback effects in lexical decision in relation to the overall frequency of the words. Their findings indicated no real interaction between feedback consistency and frequency, however, in the feedforward condition, an interaction was observed. Specifically, low-frequency feedforward inconsistent words were processed more slowly than consistent words. This effect was present, but much smaller with high-frequency words. Overall, both feedforward and feedback effects could be seen, without taking frequency into consideration. This is interesting to note because of the visual nature of the task. It seems to be that both spelling-to-sound and sound-to-spelling are considered, even when pronunciation of the word is not required.

Another, different, school of thought on this topic stems from the question of the degree of interaction between phonology and orthography in word recognition tasks. Peeerman, Content, and Bonin (1998) essentially aimed to further study the previously found feedback effect in lexical decision using French words. They matched these words on frequency, and performed a series of tasks that include the following: lexical decision, naming, writing, an exact replication of Ziegler et al. (1997), and a subjective frequency rating task. Unlike the studies mentioned previously, these researchers did not find substantial consistency effects in the lexical decision or naming tasks. Their writing task did show consistency effects, which was expected. Ziegler et al. (1997) was replicated and further studied to find that consistency does not affect ratings of subjective frequency. Overall, this study concluded that even if the feedback consistency effect exists at all in French, it is too small to actually calculate. It raises caution against the degree of bidirectional mapping that actually occurs in recognition tasks, such as lexical decision.

Some researchers have compared the visual modality to the auditory modality and have found no effects of either feedforward or feedback consistency in the visual mode. Ziegler, Petrova, and Ferrand (2008) used three experiments to test for all effects in both modes, and failed to replicate most of the consistency findings of the previously mentioned studies. Feedback effects in the auditory mode were the only effects found to be significant, calling into question the idea of bidirectional coupling and orthographic-phonographic feedback loops in processing. Because of these competing ideas in this area, it is necessary to explore these effects in more detail. The current study will help strengthen research in this area by applying electrophysiological methods (i.e., event-related potentials) to evaluate the neural correlates of such processing.

Nonword Processing in Lexical Decision Tasks

Discrepancies also exist in the behavioral literature when it comes to nonword rejection in lexical decision, which is another area that the current study will address. Lemhofer and Dijkstra (2004) considered nonword effects in Dutch-English bilinguals. In a pure-English lexical decision task including nonwords with English spelling patterns and neutral nonwords, they found that participants were slower to reject English-like nonwords than neutral nonwords. In a generalized task in which participants were to accept as real words either Dutch or English words, Dutch-like nonwords were added to the other two types. This paradigm showed that neutral nonwords were the fastest to reject, followed by Dutch-like and then English-like nonwords. This supports the assumption that not all nonwords are treated equally. Namely, different rejection criteria are applied in different language contexts. This result could be due to language-specific access, and may rely somewhat on the orthographic neighbors of the stimuli. If a nonword has many orthographic neighbors, it may appear more wordlike, deterring a fast decision from being made. On the other hand, if the nonword neighborhood is small, a decision could be made faster by ruling out any possible matches to the lexical entry. Lemhofer and Dijkstra (2004) interpreted their result that the slowest responses were found to be the English-like nonwords because the deadline for the rejection of English stimuli (L2) was set later. This could be because the second language of bilinguals tends to become active more slowly than the first language (L1).

A study by Lemhofer and Radach (2009) aimed to give more insight into the nonword rejection criteria set by bilinguals. These researchers took the classical approach that the more word-like the nonword is, the harder (and longer it will take) to reject. They worked with German-English bilinguals, and found that in a pure-English lexical decision task, English-like nonwords were rejected more slowly than German-like nonwords in the same task, while in a pure-German task, German-like nonwords were rejected more slowly than the English-like nonwords. In a mixed task, English-like nonwords (L2) were rejected slower than those in German. The pure-language task data showed that bilinguals were utilizing some kind of language specific criteria for rejection, suggesting a language-selective way of processing. This finding also fits well with the "wordlikeness" classical approach. For monolinguals, as in the current study, this language-selective approach could also facilitate the rejection of nonwords. If the nonwords were in a different language, according to this approach, they could be rejected faster based on their opposition to the monolingual's first language. For nonwords that correspond with the target language, monolinguals would probably show the effects of "wordlikeness" in their responses (i.e., slower rejection times). The "mixed" experiment brings another factor into the decision criteria for bilinguals. Instead of relying on "wordlikeness," language dominance seems to be the deciding factor. This study furthers Lemhofer and Dijkstra (2004) by again proving that the nonword stimuli are treated differently depending on the context.

Cognate Effects

One final issue that should be briefly mentioned in preparing for the current study is the processing of cognates, words that share both form and meaning across two languages. Instead of examining this word type in the current study as creating a unique phenomenon, we will be including cognates simply to be certain that they are processed just as any other real word would be in the monolingual word perception system. However, because this study could lend itself to future studies including bilinguals, the effects of cognates will be discussed briefly in this literature review.

Dijkstra and Van Heuven (2002) proposed the BIA+ model, in part to explain cognate facilitation of reaction time in the bilingual lexicon. Because it has been found that lexical decisions are facilitated by cross-linguistic orthographic and semantic similarity, the researchers proposed a shared representation of form similar cognates in the bilingual's lexicon. In the BIA+ model, word recognition is not only affected by orthographic representations, but also by phonological and semantic representations. When the orthographic word is activated, it then activates similar phonological and semantic representations (L1 is faster at this than L2 based on subjective frequency).

Cognate representation is further discussed in the literature by Dijkstra et al. (2010). While four theoretical models can be discussed with regard to cognate representation in the bilingual lexicon, Dijkstra et al. support a localist connectionist framework with their research.

In their English lexical decision task with Dutch-English bilingual participants, orthographic similarity of the cognates was the superior predictor in the facilitatory effect (frequency was also facilitatory). Responses became faster as orthographic similarity increased, the fastest time being for completely identical cognates. This decreased reaction time was still present for non-identical cognates; however, a prominent degradation in performance occurred when going from completely identical to close similarity. In accordance with the localist connectionist model, non-identical cognates seem to have separate representations that are both activated upon exposure (causing faster reaction times than language-specific words), and in turn are acted upon by lateral inhibition. Identical cognates may or may not have a single representation, however, this model describes separate representations with no lateral inhibition (and therefore a discontinuous drop in reaction times) acting upon the words. Identical cognates would also have the greatest amount of global activation in the lexicon, causing them to be recognized the fastest. We have employed a set of identical Spanish-English cognates in the current study, in preparation for future studies using this task with Spanish-English bilinguals.

Event-Related Potential Technique (ERPs)

The event-related potential technique is an approach to measure cortical electrophysiology related to neural firing. This measurement technique is used to detect the brain’s responses to external and internal stimuli by way of electrodes connected to the scalp (Molfese, Molfese, & Kelly, 2001). In contrast to electroencephalography (EEG), ERPs focus on a smaller portion of the ongoing activity of the brain. Measurements are “time-locked” to record only the activity that follows the onset of a stimulus (auditory, visual, etc.). This procedure is repeated over many stimuli and averaged to filter out background brain activity. This averaging allows for very fine discriminations in time (usually measured in milliseconds), as well as measurements of very specific responses (perceptions, decisions, etc.) and their relationships to stimulus events (Molfese et al.). Some limited spatial information can also be discriminated based on the location of the electrodes on the scalp, although scalp locations do not necessarily reflect underlying neuroanatomical locations. Because different stimuli cause different responses in different electrode regions, the corresponding brain waves can be used to supplement behavioral measures, such as the afore-mentioned language tasks.

ERP responses reflect changes in the activity in the brain and can be seen as a waveform in a time domain. These changes manifest themselves as fluctuating amplitudes (heights) of waves or as changes in the latency (time elapsed after stimulus onset) of the wave peaks (Molfese et al., 2001). Within the waveform, the measurements are described according to their components in one of two ways. The first classification system identifies the positive and negative wave peaks and the sequence in which they occur. For example, "N1" would refer to the first negative peak. The second, and more recent system, names the positive and negative peaks by their latency from stimulus onset. For example, "N100" would be the negative peak that occurs 100 milliseconds (ms) after the stimulus (Molfese et al.).

The N400 Component

One of these components, the "N400," has been determined to be closely linked with lexical processing and is the most relevant to our current study. This response, a negative peak around 400 ms post-stimulus onset, has been shown in response to both auditory as well as visual stimuli, and is most well known for occurring following an incongruence in semantics during sentence comprehension (Key, Dove, & Maguire, 2005). Kutas and Hillyard (1980) first identified this component while presenting sentences ending with congruous versus incongruous words. (e.g., I am going to hit the ball with a bat, versus, I am going to hit the ball with a bean.)

The final words in the incongruent sentences elicited a larger N400 peak amplitude than those that ended with an expected word. Since this first observation, many studies have shown that this same type of effect can occur at the word level. For example, in a semantic priming study, Holcomb and Neville (1990) found that the N400 response was larger when a target word was preceded by an unrelated prime rather than a related prime. (e.g., apple-sun, versus, moon-sun). Processing of any word will generate an N400 peak, although the amplitude of this peak will vary with the context of the word (Van Petten and Kutas, 1990). In fact, N400 peaks generated by pseudowords have been determined to be similar to, if not larger than, the amplitudes generated by real word stimuli (Bentin et al, 1999). This word level response is more in line with the response generated in the current lexical decision task.

Bentin et al (1999) employed a series of different tasks (phonetic, lexical decision, semantic) to study reactions to many types of visually presented words, including pseudowords. In their semantic decision task, the researchers found an N450 amplitude (a component that is likely related to – or identical to – the N400) that distinguished between meaningful and meaningless words. The N450 for pseudowords was significantly larger that of real words. Although this effect was not found in their lexical decision task, they deduced that the cause was a deeper word processing. This deep processing would be present in analyzing orthography and semantics of the pseudowords, giving rise to the ERP difference. This information is important to consider in order to understand the processing differences between real word stimuli and pseudowords.

In order to understand and compare the N400 component among different stimuli, Holcomb, Grainger, and O'Rourke (2002) used this component to study the effects of neighborhood size (i.e,. the number of words that differ by only one letter from the target word) in the lexical decision task. They compared the facilitatory effect of words with large orthographic neighborhoods to the inhibitory effect of pseudowords from large neighborhoods (this effect has been seen in multiple behavioral studies including Grainger and Jacobs, 1996). Holcomb et al. predicted that because of the large semantic association with the N400, words and pseudowords from larger neighborhoods should produce a larger effect on this component, and they did find this effect in their data. They found that in general, stimuli from larger neighborhoods did exhibit a larger negativity in their N400 component compared to stimuli from smaller neighborhoods, whether or not the stimuli were real words. This offers a qualitatively different view than the behavioral studies, with the effect in the same direction for both words and pseudowords. This previous study offers a validation for global activation of the lexicon, as well as the semantic aspect of the N400. The current study hopes to further facilitate this understanding.

The N400 component has shown itself to be relevant to effects of consistency as well. Although these effects have been studied more in the behavioral literature, the minimal ERP data is worth mentioning. Perre and Ziegler (2008) used an auditory lexical decision task to study orthographic effects on word recognition. By manipulating word consistency, they were able to track the effects of orthography (if using a lexical route) over the word presentation. If the effects were actively lexical, the event-related potential data should show an N400 effect of word recognition as well as a specific pattern at the time of the word inconsistency. This study found that this lexical route to recognition was true in this auditory task. Another component, an N320, was determined to be of importance in the effects of consistency. This negativity was "time-locked" to the arrival of word inconsistency, showing that orthography is being activated during presentation of a stimulus ("online"). The size of this N320 was also modulated by orthographic transparency and the bidirectional mapping between orthography and phonology. Perre and Ziegler also observed that at the N600, the inconsistency registered at the N320 was resolved. In the current study, this aspect may be important with respect to inconsistent words as well as pseudowords, where the inconsistency comes online at the N320, but is not seen to resolve at the N600. The current study goes beyond Perre and Ziegler by including these consistency manipulations for both real words and pseudowords. The written stimulus form used in the current study also can further their auditory-based results.

The Current Study

The current study will utilize the Event-Related Potential technique to collect and analyze participant's brainwaves during a lexical decision task. Data from monolingual, native English speaking participants will be included. This study aims to further the research on electrical techniques in the lexical decision task. It also will take into consideration different stimulus types and effects. This study differs from most previous ERP research in that it includes both consistent and inconsistent real words, as well as pseudowords, allowing for comparisons between the two. Like Lemhofer and Dijkstra (2004), we also included different language types of pseudowords (English- and Spanish-like) in a pure language lexical decision task to determine if participants can use language-specific cues to facilitate nonword rejection in the LDT. Finally, the inclusion of English-Spanish cognates provides a way to both collect baseline data on these stimuli for future studies and to compare Spanish-like pseudowords to Spanish-like real words (i.e., cognates) in our monolingual participants.

In this study, participants were required to make very fast and precise lexical decisions based on these stimuli. The goal of this experiment was to extend our knowledge of the monolingual word processing mechanism by studying reactions to different conditions from which we previously mostly have behavioral data.

The objectives of this study include:

1. Examining differences in native English speaker's ERP's when processing consistent and inconsistent stimuli in a lexical decision task.
2. Examining and comparing the processing of different types of pseudowords.

Methods

Participants

The results of this study are based on data from eight adults (ages 18 to 25), all recruited from the Pennsylvania State University community. Six females and two males participated in the study, and all participants were right-handed. All participants were English monolinguals. Based on their self-ratings of language history, none considered themselves fluent in a second language, and they all rated themselves moderate to high in English proficiency. Their ratings of English language skills based on five categories (reading, spelling, writing, speaking, and speech comprehension) ranged from 5 to 10 (1 being the weakest rating, and 10 being the highest). All participants had normal or corrected-to-normal vision and hearing and did not have a history of neurological disorders. Participants were compensated thirty dollars for their participation.

Materials

The lexical decision task contained 300 experimental items equally divided into 'yes' and 'no' trials. 'Yes' trials consisted of 100 English words and 50 Spanish-English cognates. Among the 100 English words, there were 50 words with regular and consistent spelling-sound mappings and 50 words with irregular and inconsistent spelling-sound mappings (additional detail about how these categories were operationalized is provided below). Cognate stimuli had complete orthographic overlap between Spanish and English, but varied in their degree of phonological overlap. ‘No’ trials consisted of 100 pseudowords based on English spelling patterns and 50 pseudowords based on Spanish spelling patterns. Among the 100 “English” pseudowords, 50 were matched to words with regular and consistent spelling-sound mappings and 50 were matched to words with irregular and inconsistent spelling-sound mappings. Because Spanish is a language with a shallow orthography, all Spanish words and pseudowords could be classified as regular and consistent within Spanish, although their English interpretation may vary. All stimuli had consonant onsets and were matched on length across conditions. Each condition included both monosyllabic and bisyllabic trials. Examples of all stimulus types can be seen in Table 1. All stimuli were combined into two possible list orders. Half of the participants were presented with each of these lists (Order 1 and Order 2) to counteract possible order effects.

English Words. The English stimuli were divided in terms of their spelling-sound consistency, as defined on the basis of word bodies, in the case of monosyllabic stimuli, and syllable form, in the case of bisyllabic stimuli. Word bodies were operationalized as containing consistent or inconsistent rimes (the vowel sound in the word and any consonants that follow). All words containing the same orthographic rime, with varying onsets, were found for each stimulus item. These words were divided into friends, words that had the same spelling-sound mappings, and enemies, words in which the pronunciation of the rime differed from the original stimulus’ pronunciation. To determine a word’s friends and enemies, the length and rime of the stimulus word were held constant (bisyllabic words had to have the rime in one of their syllables). Lists were generated of all words that shared the length and rime and their pronunciations, and each word was counted based on its phonological similarity to the stimulus word. Therefore, all words that were produced with the same phonology as the stimulus were counted as friends, and all those that were produced differently were counted as enemies. Words with more than 50 percent friends were classified as consistent, while words with more than 50 percent enemies were classified as inconsistent. For example, MATCH has five friends (BATCH, CATCH, HATCH, LATCH, PATCH) and one enemy (WATCH). Its total percentage of friends is 83.3 percent; therefore, it is classified as consistent.

Consistency and regularity (i.e., the extent to which a word followed English spelling-to-sound rules) effects were confounded in this study. All consistent words also had regular spelling-to-sound mappings. All inconsistent words also had irregular spelling-to-sound mappings. This was operationalized by subjective judgment from a native English speaker following English spelling-sound conversion rules. All English consistent and inconsistent words were matched on length and Kucera and Francis (1967) written frequency (KFFRQ) values (see Table 1).

Cognate Words. Spanish-English cognates, words that share orthography and semantics across languages, were chosen based on their complete orthographic overlap between the two languages. These words varied phonologically, but did not differ significantly in their frequencies within Spanish and English. The frequency of these words was also matched with consistent and inconsistent English word frequency (see Table 1).

Pseudowords. English and Spanish pseudowords were generated by changing the initial consonant of English or Spanish words, making sure that the pseudowords thus created were orthographically legal in their respective language. The regularity and consistency of the English words used for creating English pseudowords was manipulated in a similar fashion to the English real words. Thus, English pseudowords were created from both English regular and consistent words, and from English irregular and inconsistent words. These trials also consisted of monosyllabic and bisyllabic words and were matched on length to the other stimuli (see Table 1).

Table 1. Lexical Decision Task: Samples of stimuli, average length, and average Kucera & Francis (1967) written frequency.

Type of Trial		Stimulus Examples	Average #of Letters	Average KF Frequency
Yes	Cognates	CANON	5.04	33.70
	English Regular/Consistent Words	LUMP	5.44	28.18
	English Irregular/Inconsistent Words	JOURNEY	5.60	32.98
No	Spanish Pseudowords	MENOR	4.96	*188.28
	English Regular/Consistent Pseudowords	ZEAST	5.38	*130.46
	English Irregular/Inconsistent Pseudowords	LONKEY	5.22	*363.69

*Note: These frequencies are based on the real words that the pseudowords were derived from. The real pseudoword frequencies are actually equal to zero.

Experiment Overview and Procedure

All subjects participated in one experimental session lasting approximately two and a half hours. Informed consent was obtained for each participant before running the experiment. Participants were required to fill out two questionnaires prior to starting. The first questionnaire gathered information about handedness and verified that participants met all inclusion criteria. The second questionnaire asked for information about the participant’s language history and dominance, including ratings of proficiency in each known language.

After filling out the questionnaires, participants were fitted with electrodes for monitoring their EEG (see description of procedure below). After the electrodes were in place, they completed a rhyme judgment task that will be described elsewhere. After the rhyme judgment task was complete, the lexical decision task was run. Participants sat in a chair facing a computer screen that presented words, one at a time. Each participant was presented with the series of 300 experimental items (see stimulus section) and asked to make a lexical decision about whether or not each item was an English word. Participants were instructed to respond using a game controller, hitting one specified button for a "yes" response, and another for a "no" response. Response hand was counterbalanced across participants. There were two breaks during the experiment, each after 100 stimuli. During these breaks, the participant was instructed to rest their eyes before beginning the next section of stimulus items. Each participant was also presented with a series of eighteen practice trials before beginning the experimental trials. These allowed the participant to become accustomed to the format of the task. After the lexical decision task was completed, participants also completed additional tests of cognitive and linguistic processing. However, these measures will be described elsewhere.

In this lexical decision task, all stimulus items were presented on a black screen in white capital letters. They were presented for a duration of 350 ms and followed by a blank screen for 850 ms. This blank screen was followed by a fixation cross (+) displayed for a duration of 1200 ms. This was then followed by another blank screen for 300 ms, before the next stimulus item appeared. The time course for these events can be seen in Figure 1. In order to minimize disruptions in EEG recording during the trials, participants were instructed to blink only when they saw the fixation cross on the screen.

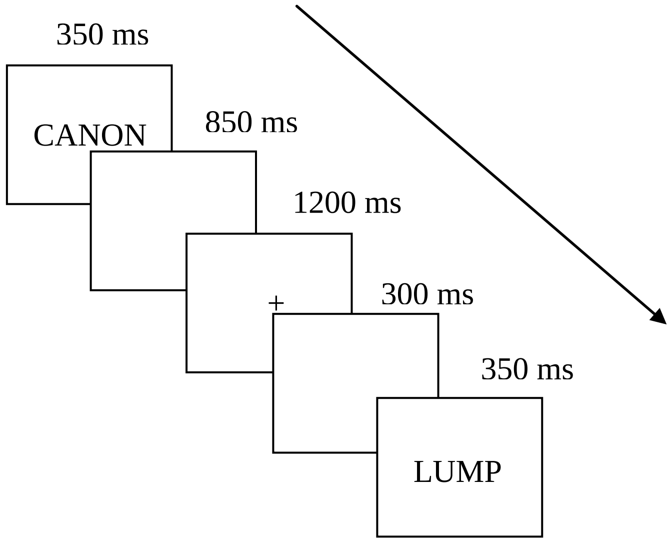

Figure 1. Lexical Decision Task: Time course and organization of stimuli from the onset of one critical item to the next.

EEG Recording

This experiment utilized an electrode cap (Electro-Cap International) for recording EEG. The cap had embedded scalp electrodes that recorded activity from twenty-nine channels. Standard International 10-20 system locations were used to measure eleven of the electrodes. Three of these eleven were midline sites in the frontal (Fz), central (Cz), and parietal (Pz) regions. The remaining eight out of these eleven were measured from the left and right hemisphere frontal (F2/F4), central (C3/C4), temporal (T3/T4), and parietal (P3/P4) sites. Ten other electrode sites, using the Modified Combinatorial Nomenclature system, were used. Two of these were on the midline and represented the frontal pole (FPz) and occipital pole (Oz). These additional ten locations also included the following: four left and right hemisphere fronto-central sites (FC1/FC2, FC5/FC6) and four centro-parietal sites (CP1/CP2, CP%/CP6). In addition, eight modified 10-20 system sites were measured from the following locations: 33% of the distance from FPz to T3/T4 (FP1'/FP2'), 67% of the distance from FPz to T3/T4 (F7'/F8'), 33% of the distance from Oz to T3/T4 (O1'/O2'), and 67% of the distance from Oz to T3/T4 (T5'/T6'). There were also two loose eye electrodes used to measure the electro-oculogram (EOG) and monitor eye movement. The LE electrode, placed below the left eye, recorded eye blinks, and the HE electrode, next to the right eye, recorded horizontal eye movement. A left mastoid electrode (A1) was used as a reference for all other electrodes, and a right mastoid electrode (A2) recorded any differential mastoid activity. These placements are represented in Figure 2. Before running the experiment, impedances for the scalp and mastoid electrodes were lowered to less than 5 kilo-ohms (kΩ). Eye electrode impedances were lowered to less than 20 kΩ. An SA amplifier with EEG bandpass of .1 to 40 hertz (Hz) was used to amplify electrode measurements, and the electrical signal was continuously sampled at rate of 200 Hz during the experiment.

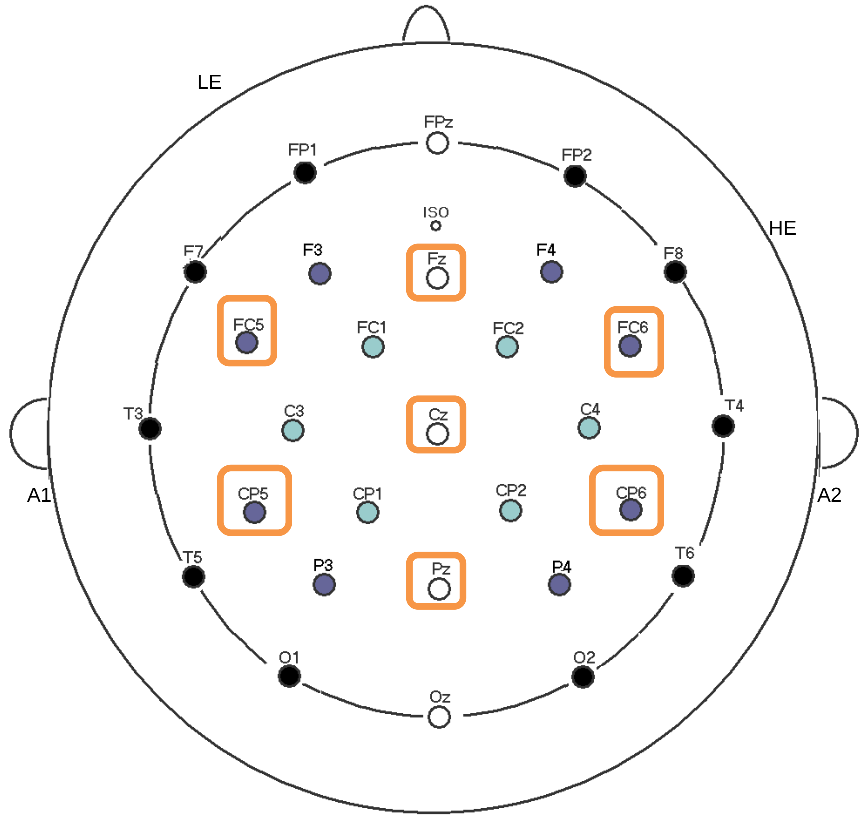

Figure 2. 32-channel electrode montage. The boxed sites are the ones that are included in the analyses described in this paper.

Data Analysis

ERP data analysis. Because data were only available for 8 participants, electrophysiological measures for the lexical decision task were evaluated using a descriptive approach. Each subject's data were extracted from the continuous EEG from all electrode sites for the critical conditions. ERP's for each subject were averaged separately for each condition (cognates, English consistent words, English inconsistent words, Spanish pseudowords, consistent pseudowords, and inconsistent pseudowords). ERP waveforms began with a 100 ms baseline prior to stimulus onset and were evaluated through 900 ms post-stimulus onset. The plotted ERPs include only correct response trials. The eight participants all showed at least 50% accuracy in the lexical decision task (accuracy data are described in more detail in the Results section). An automatic artifact rejection algorithm was used to automatically reject trials with excessive blinking or head movement, and these trials were not included in the averages for each participant. After the automatic algorithm was applied, data were manually checked to ensure that these criteria were appropriate for each participant. For two participants, certain channels were completely eliminated from the averages because they either had no signal or very inconsistent signal quality. These channels are not considered in the analyses described below. Data from one individual was recovered by increasing the blocking threshold for all electrodes from 25 to 30, since the lower value appeared to be too strict for that individual's pattern of brainwaves. For another individual the vertical eye electrode threshold was increased from 1000 to 1900, because EKG was being detected on this channel and forcing excessive trial rejections. For all participants, at least 20 usable trials (i.e., accurate and artifact-free) were recovered for each critical condition. Finally, data from all eight subjects was grand-averaged for presentation.

Three components of interest were found based on visual inspection of the EEG waveforms for comparisons including all real words versus all pseudowords, consistent versus inconsistent real words, consistent versus inconsistent pseudowords, and Spanish versus consistent pseudowords. Small early differences appeared at the P200 component. The epoch for the P200 was set from 150 ms to 300 ms post-stimulus onset. However, the main difference across conditions was found in the N400 component. The N400 epoch was set from 300 ms to 450 ms post-stimulus onset. Visual analysis also found an interesting N500 component in the waveform. The epoch for this component was set from 450 ms to 600 ms.

Mean amplitudes were calculated for each subject based on these three epochs for all conditions. Seven electrode sites were chosen for analysis of these amplitudes (Fz, Cz, Pz, FC5, CP5, FC6, and CP6). Waveforms for each of these electrode sites are plotted, which show the grand average for each point in time from the pre-stimulus baseline out to 900 ms. Mean amplitudes for the three epochs of interest (P200, N400, N500), averaged across these seven electrodes, are reported in the text.

Behavioral data analysis. Behavioral data was also collected during the lexical decision task and analyzed using both descriptive and inferential statistics. Mean reaction times and accuracies were averaged for each participant based on the six critical conditions. Grand-means were then averaged for reaction times and accuracies across subjects. PASW Statistics 18 (SPSS, Inc.) was used to create paired samples *t*-tests comparing the variables of interest mentioned above. Significant results are reported as those with a *p* value of less than 0.05, while results with a *p* value of less than 0.1 are reported as "trends."

Results

ERP Waveforms

All real words and all pseudowords. The ERPs for all real English words (including Spanish-English cognates, inconsistent words, and consistent words) and all pseudowords (including pseudowords based on Spanish words, inconsistent English words, and consistent English words) showed the following: A negative peak at approximately 125 ms (N1); a large positive peak at approximately 225 ms (the P200); a large negative peak at approximately 375 ms (the N400); and a smaller negative peak at 500 ms (N500) (refer to Figure 3). After the N500, the waveforms tended to become positive-going for the remainder of the 900 ms recording epoch.

The waveforms for the real words and pseudowords were very similar from stimulus onset until right before 200 ms. At this point, a little before 200 ms, the waveforms begin to diverge while remaining in the positive direction for the P200. Over the course and peak of the P200, the real words were more positive (i.e., had a larger amplitude P200) than the pseudowords. Across all seven electrode sites of interest, the mean amplitude for the P200 window was 1.87 μV for the real words and 1.06 μV for the pseudowords. Throughout the remainder of the waveform, pseudowords were more negative than real words. This difference was emphasized in the N400, as the pseudowords reached peak negativity at an earlier time and to a much greater extent than the real words. Across the seven electrode sites of interest, the mean amplitude for the N400 window was -0.72 μV for the real words and -2.41 μV for the pseudowords. The N500 also showed a major difference between conditions (especially across the midline sites), with the pseudowords displaying a much more negative peak than the real words. Across the seven electrode sites of interest, the mean amplitude for the N500 window was 2.56 μV for the real words and 0.70 μV for the pseudowords. The difference seen between conditions in the waveform was much greater across the N400 and N500 than the P200. The waveform for pseudowords remained slightly more positive than that of the real words until the end of the window at 900 ms.

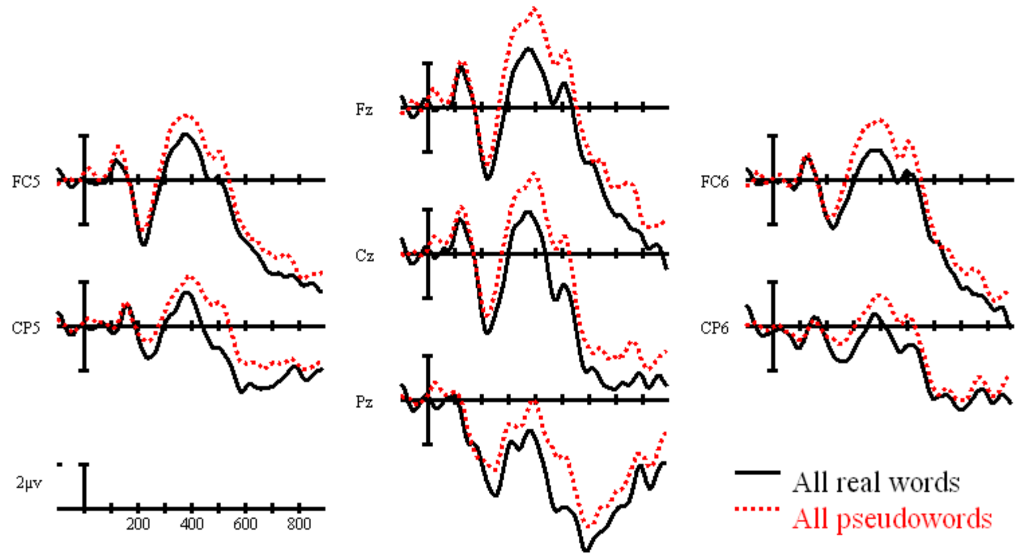

Figure 3: Grand average ERPs for all real words and all pseudowords for the lexical decision task. Note that negative is plotted up.

Consistent words and inconsistent words. The ERPs for consistent English words and inconsistent English words showed the following components: A small negative peak at approximately 125 ms (N1); a large positive peak at approximately 225 ms (the P200); a large negative peak at approximately 375 ms (the N400); and a smaller negative peak at 500 ms (N500) (refer to Figure 4).

The waveforms for consistent English words and inconsistent English words were very similar from stimulus onset through the N1 component. The waveforms began to diverge slightly in the middle of the P200, with the inconsistent words becoming more negative at the more frontal sites but more positive at the more posterior sites. The P200 also ended slightly later for the inconsistent than the consistent words. Across the seven electrode sites of interest, the mean amplitude for the P200 window was 1.95 µV for the consistent words and 1.80 µV for the inconsistent words. These two conditions seemed to follow each other very closely going into the N400. Over the N400 component, the degree of negativity remained very similar for both of these conditions. However, the inconsistent words showed an interesting shift, as the N400 appeared to end earlier than that for the consistent words (processed faster) at the midline sites. This could be due to the inconsistent words being treated as whole linguistic units instead of broken segments, and will be explored further in the discussion. Across the seven electrode sites of interest, the mean amplitude for the N400 window was -1.23 µV for the consistent words and -0.83 µV for the inconsistent words. The waveforms for these conditions appeared to converge after this difference in the N400 and continue on with no real difference over the N500 except at more posterior sites, where the N500 was larger for consistent words. Across the seven electrode sites of interest, the mean amplitude for the N500 window was 2.46 µV for the consistent words and 3.00 µV for the inconsistent words.

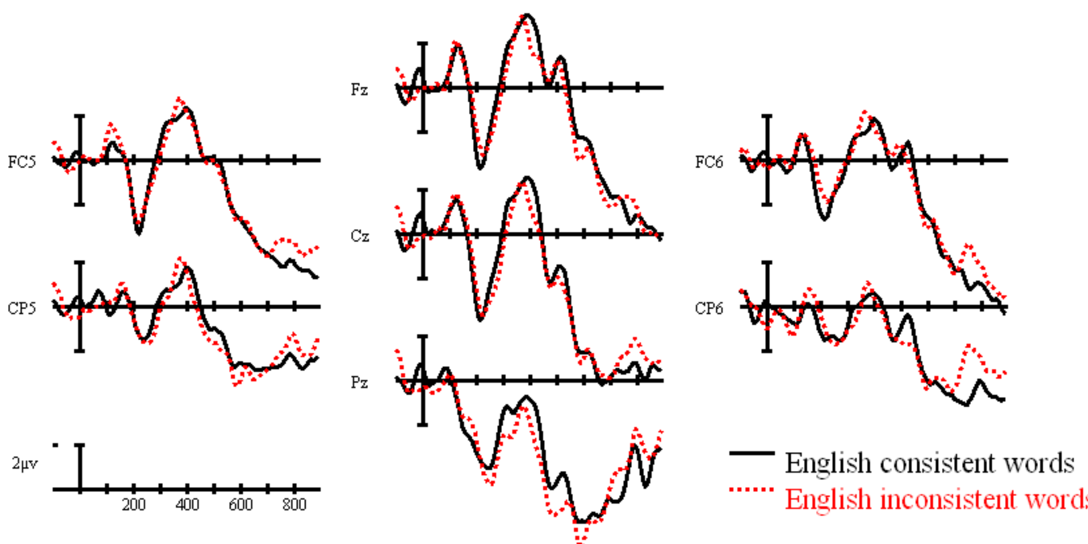

Figure 4: Grand average ERPs for English consistent and inconsistent words for the lexical decision task. Note that negative is plotted up.

Consistent pseudowords and inconsistent pseudowords. The ERPs for consistent pseudowords and inconsistent pseudowords showed the following components: A small negative peak at approximately 150 ms (N1); a positive peak at approximately 225 ms (the P200); a large negative peak at approximately 400 ms (the N400); and a smaller negative peak at 500 ms (N500) (refer to Figure 5).

The waveforms for consistent and inconsistent pseudowords were very similar from stimulus onset through the N1 component. The P200 also seemed to occur and finish at the same time for these two items, however, a slight difference in positivity can be seen between the conditions for this component. The consistent pseudowords tended to be a little more positive than the inconsistent pseudowords across the electrode sites during the P200. Across the seven electrode sites of interest, the mean amplitude for the P200 window was 1.28 µV for the consistent pseudowords and 0.94 µV for the inconsistent pseudowords. These two waveforms also diverged for the N400, as in general, inconsistent pseudowords tended to have a slightly larger (except at Fz and CP5) and earlier N400 peak than did the consistent pseudowords. Across the seven electrode sites of interest, the mean amplitude for the N400 window was -2.33 µV for the consistent pseudowords and -2.18 µV for the inconsistent pseudowords. This pattern is similar for the consistency effects in the real English words and will be discussed further. Finally, the N500 component was somewhat less prominent overall for pseudowords than for real words. Within the pseudowords, the inconsistent condition was less negative than the N500 for the consistent pseudowords. Across the seven electrode sites of interest, the mean amplitude for the N500 window was 0.42 µV for the consistent pseudowords and 0.94 µV for the inconsistent pseudowords.

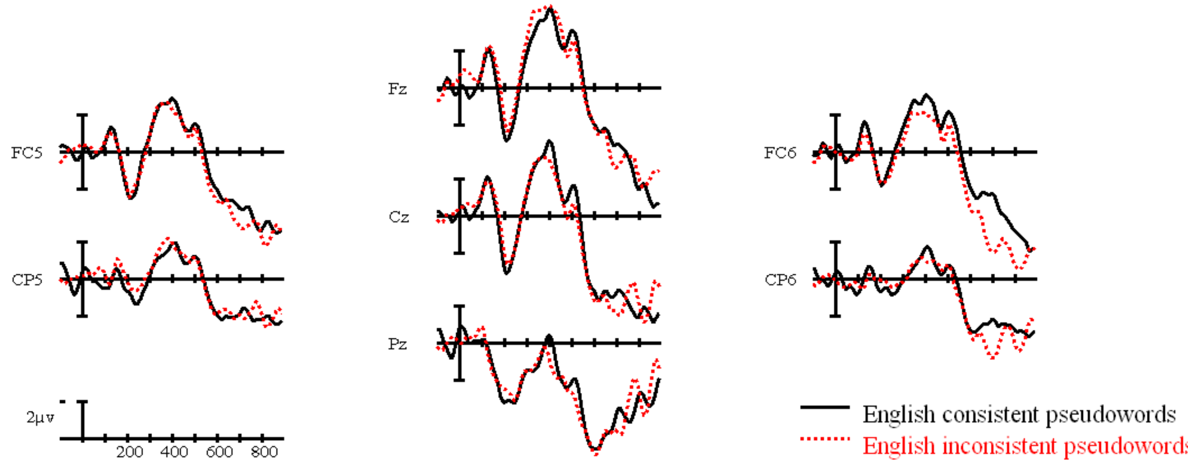

Figure 5: Grand average ERPs for consistent pseudowords and inconsistent pseudowords for the lexical decision task. Note that negative is plotted up.

Consistent pseudowords and Spanish pseudowords. To further analyze possible pseudoword effects, we also compared Spanish pseudowords to these two previous pseudoword conditions. Waveforms comparing the three types of pseudowords can be seen in Figure 6. However, after comparing all three of the pseudoword conditions across electrode sites, consistent pseudowords and Spanish pseudowords were chosen for a more in depth analysis under the assumption that a pseudoword following Spanish spelling conventions may be decoded more similarly to a pseudoword following English consistent spelling patterns than English inconsistent spelling patterns. The ERPs for the consistent pseudoword and Spanish pseudoword conditions showed the following components: A small negative peak at approximately 125 ms (N1); a positive peak at approximately 225 ms (the P200); a large negative peak at approximately 400 ms (the N400); and a smaller negative peak at 500 ms (N500) (refer to Figure 7).

The waveforms for consistent pseudowords and Spanish pseudowords began to diverge soon after stimulus onset. The N1 occurred earlier and appeared to be more negative in Spanish pseudowords than in the consistent pseudowords. The waveform for the Spanish pseudowords continued to remain more negative through the P200 and N400 epochs. This seemed to be especially true for the left FC5 and CP5 electrode sites. There was more of a difference in the peaks of the waveforms on these two sites than on the midline or right electrode sites (especially on the N400). Across the seven electrode sites of interest, the mean amplitude for the P200 window was 0.84 µV for the Spanish pseudowords and 1.28 µV for the English consistent pseudowords and for the N400 window the mean amplitude was -2.79 µV for the Spanish pseudowords and -2.33 µV for the English consistent pseudowords. For the N500, along the midline sites, there was a clearly more negative peak for the English consistent pseudowords than for the Spanish pseudowords. Across the seven electrode sites of interest, the mean amplitude for the N500 window was 0.66 µV for the Spanish pseudowords and 0.42 µV for the English consistent pseudowords.

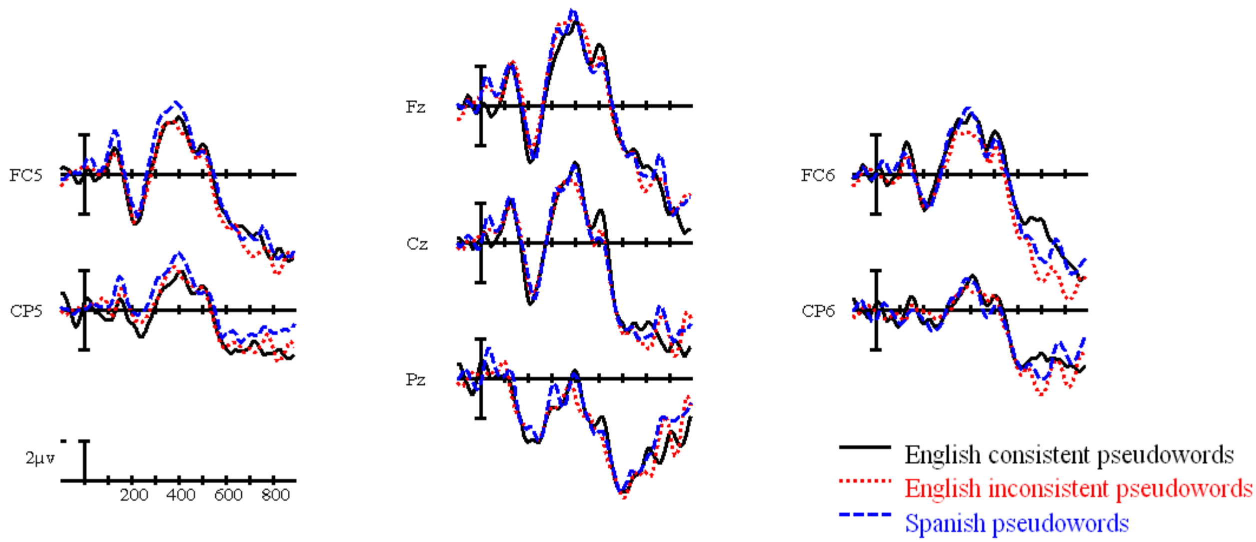

Figure 6: Grand average ERPs for consistent pseudowords, inconsistent pseudowords, and Spanish pseudowords for the lexical decision task. Note that negative is plotted up.

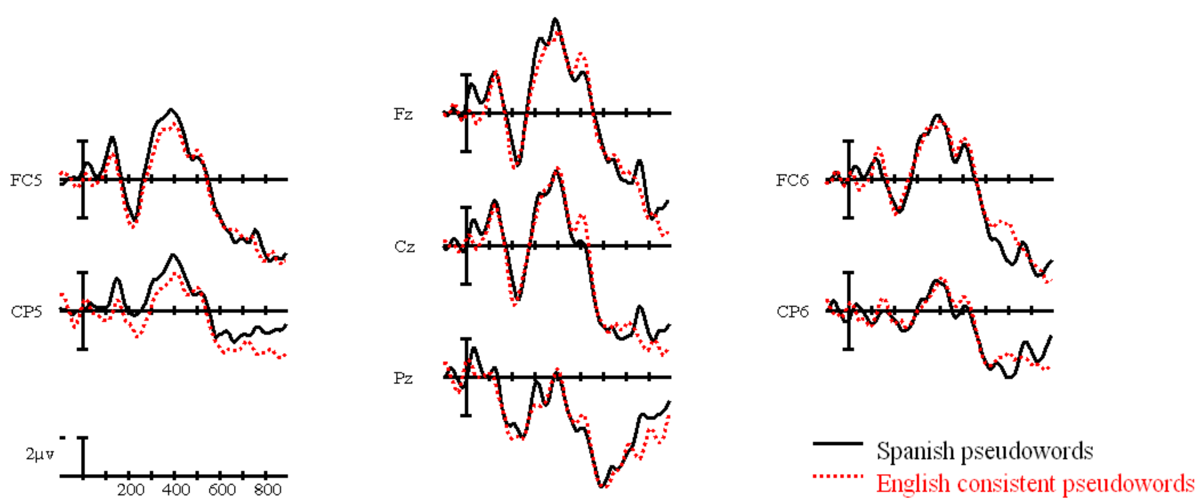

Figure 7: Grand average ERPs for Spanish pseudowords and English consistent pseudowords for the lexical decision task. Note that negative is plotted up.

Behavioral Results

The grand mean reaction times for the eight subjects on the critical conditions were as follows: Spanish-English cognates= 716.22 ms, English consistent words= 694.35 ms, English inconsistent words= 688.75 ms, Spanish pseudowords= 761.28 ms, consistent pseudowords= 798.22 ms, and inconsistent pseudowords= 774.58 ms. The mean percent accuracy scores for the eight participants across these same critical conditions were as follows (out of 50 trials): Spanish-English cognates= 86.00%, English consistent words= 84.86%, English inconsistent words= 86.00%, Spanish pseudowords= 83.71%, consistent pseudowords= 78.00%, and inconsistent pseudowords= 83.14%. Figure 8 displays the grand mean reaction times and grand mean percent accuracies in bar graph form.

The figure clearly shows a difference in the mean reaction times and percent accuracies for all real words and all pseudowords. Responses to pseudowords were slower and less accurate than to real words overall. Pseudowords, on average took approximately 78.26 ms longer for a response and were less accurate by approximately 4.00%.

Reaction time analysis. This slower reaction time for pseudowords as compared to real words was statistically significant (t (7) = -2.719, p = 0.030). Within the three types of pseudowords, consistent pseudowords showed the slowest reaction times, while Spanish pseudowords seemed to be reacted to the fastest. However, t-tests comparing the different pseudoword types to each other did not reach statistical significance. For the real words, cognates were responded to slowest, followed by English consistent and then English inconsistent words. However, the two non-cognate conditions were very similar. For analysis purposes, we combined the consistent and inconsistent real words to compare the group as a whole to the cognate group. The apparent difference in reaction times to cognates almost reached significance and is reported as a trend (t (7) = 2.123, p = 0.071).

Accuracy analysis. The analysis of mean percent accuracies did not show any significant differences among the real words. However, within the pseudoword conditions, Spanish pseudowords were responded to more accurately than consistent pseudowords. It could be that the Spanish spelling was used to quickly and accurately eliminate the possibility of these being words for the monolingual participants. The percent accuracy difference between the Spanish pseudowords and English consistent pseudowords was approximately 5.71%. This showed to be statistically significant (t (7) = 2.607, p = 0.035). Although not significant, the accuracy difference between consistent and inconsistent pseudowords was very close to being reported as a trend (t (7) = -1.896, p = .100).

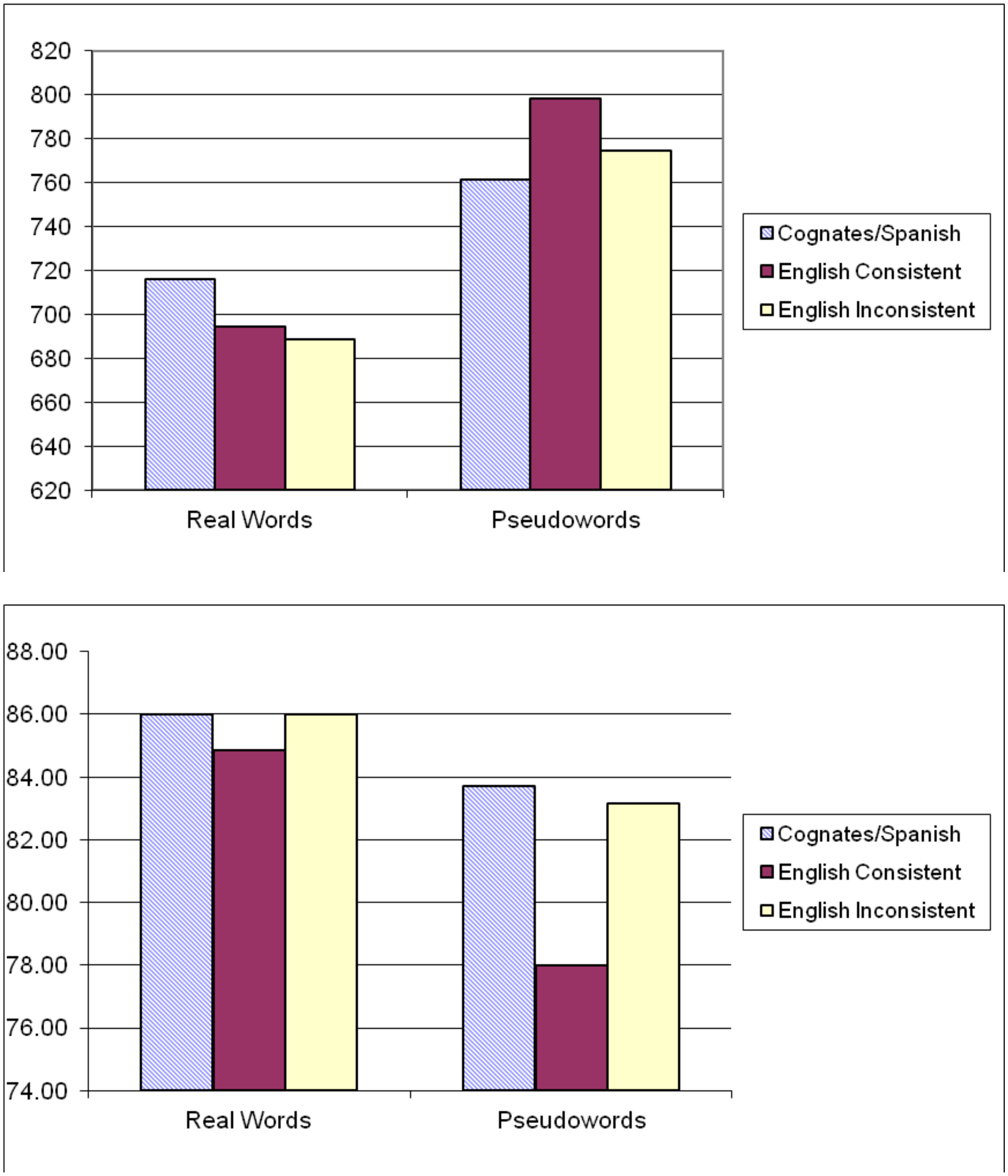

Figure 8. Mean reaction times in milliseconds (top) and percent accuracy scores (bottom) for the six critical conditions in the lexical decision task.

Discussion

The purpose of the current study was to use ERP and behavioral measures to study the differences in processing of consistent and inconsistent real words and pseudowords, as well as differences in the processing of pseudowords that followed non-English spelling patterns, in a group of native English speakers. This paper focuses on a lexical decision task, in which the participants were asked to decide whether or not a stimulus was a real English word. The critical conditions included three types of "yes" trials (Spanish-English cognates, English consistent words, and English inconsistent words) and three types of "no" trials (Spanish pseudowords, English consistent pseudowords, and English inconsistent pseudowords). The N400, a negative ERP component that peaks at approximately 400 ms in the waveform, was the main component of interest in this study as we compared the critical conditions. However, upon visual inspection, two other components, the P200 and the N500, were analyzed as well. In addition to the types of descriptive analyses performed for the ERP data, comparing the means for the critical item types, inferential statistics were performed on the behavioral data, specifically for mean reaction times and percent accuracies for the critical conditions.

In our general analysis of all real words compared to all pseudowords, the ERP data for the lexical decision task was consistent with that of many previous studies. As prior ERP research has shown, including Bentin et al (1999) and Holcomb, Grainger, and O'Rourke (2002), we found that the pseudowords elicited a larger negativity across the N400 component than did the real words. It has been argued that enhancements in this component may be consistent with deeper word processing and analyzing of the pseudowords based on orthography. This study replicates other ERP lexical decision tasks which allows for more definite conclusions to be made about the critical manipulations of word and pseudoword type. Furthermore, although not the focus of our analyses, direct comparisons of each real word type to the most similar pseudoword type also showed the same effect, where the N400 was larger for the real words (consistent, inconsistent, Spanish-English cognates) than for the comparable pseudowords (consistent, inconsistent, Spanish-like). With respect to behavioral data, our results for real words compared to pseudowords also paralleled the work of others such as Lemhofer and Dijkstra (2004), as we found that pseudowords were responded to more slowly and with less accuracy than real words.

This study differed from the previous ERP research in that consistency was considered a critical variable among real words as well as pseudowords. To our knowledge, consistency effects in the ERPs of real words or pseudowords have never been reported from a visual lexical decision task. As mentioned in the results section, the N400 of inconsistent words seemed to peak earlier and end slightly faster than that of the consistent words. The specific reason for this faster peak is unknown, however, it may be that the participants were not segmenting the inconsistent words into linguistic units, but instead, were processing them faster as whole units. Consistent words, on the other hand, may be lexically processed slightly slower, which is in line with a hypothesis that these words are more likely to be broken down and processed in smaller units. However, it should be noted that the consistency effects for real words in the current data were very slight, so caution should be used in interpreting the results. In the behavioral data, although inconsistent words were responded to slightly faster and with slightly better accuracy than inconsistent words, we did not find statistically significant consistency effects for the real words. This finding was in line with Peerman, Contentm and Bonin (1998) and Ziegler, Petrova, and Ferrand (2008) in that our lexical decision task failed to produce significant feedforward effects in the visual modality. However, it is also possible that we did not find statistically significant results due to the small number of subjects included in the current study.

Interestingly, although our predicted consistency effects were not significant over the eight participants, the cognates in our study showed an unpredictable effect. Although not completely statistically significant (reported as a trend in the data), the cognates showed slower reaction times than both consistent and inconsistent words. These words should have been treated no different than the other real words in the monolingual lexicon, so this slight difference is puzzling and should be further analyzed across more subjects. If this result holds up, it would be problematic for future studies which may use this task with Spanish-English bilinguals, since a difference between cognates and the other stimuli were found even in non-bilingual participants. ERPs for the cognates were not analyzed in the current study, but it would also be important to determine in the future if the electrophysiological data showed evidence that these items were processed differently from the other types of real words.

In line with the result for real words, the consistency effect across the N400 component in pseudowords was not large. However, like the previously mentioned real words, inconsistent pseudowords showed an N400 peak that finished slightly faster than that of the consistent pseudowords. Again, this could be due to whole word processing of inconsistent words compared to segmented processing of consistent words. This difference in the waveform should be analyzed further across more subjects. The behavioral data for pseudowords showed some differences in comparing consistency. Although not significant, on average, consistent pseudowords were reacted to more slowly and with less accuracy than the inconsistent pseudowords. The criteria that the participants used to make their lexical decisions (based on consistency) are unknown and should be further studied, especially because the same (but smaller, and again non-significant) finding was present among the real word trials.

Interestingly, we did find a statistically significant difference in accuracy between Spanish pseudowords and English consistent pseudowords. The Spanish trials were responded to more accurately and faster (although the reaction time difference was not significant) than the consistent pseudowords. In fact, the Spanish pseudowords had the fastest reaction times and greatest percent accuracies out of all of the pseudoword trials. It is possible that because the participants were monolingual, they were using the Spanish orthography patterns to make their decisions without even accessing the lexicon for these words. Lemhofer and Dijkstra (2004) explored this same issue in bilingual participants in the behavioral literature, and our study can be compared to their results. In both studies, the more English-like a word was (in an English LDT), the slower it was processed. These researchers predicted that the rejection of pseudowords in the target language would be slower because the deadline for rejection is set later. This is in the same vein as the classical “wordlikeness” approach that Lemhofer and Radach (2009) report. In the monolingual lexicon, English-like pseudowords are much more “wordlike” than those that are spelled with Spanish rules, and therefore, are processed more slowly.

Overall this study has found some interesting results in regards to both the ERP and behavioral literature. The study replicated previous ERP studies in their N400 differences between real words and pseudowords, and found some interesting waveform trends in both consistent and inconsistent real words and pseudowords. The study also found some behavioral trends with the inclusion of both cognates and Spanish pseudowords. Future research efforts should seek to examine these conditions over more participants to confirm and extend the current results. This further research is necessary to gain insight into word processing among monolinguals and may serve as the foundation for future studies evaluating the bilingual lexicon as well.

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