ABSTRACT

Investigations into the dynamics of multiple language systems have gained traction in recent years. Research has established that foreign language mastery is achievable in adulthood and that multilingual reading activates parallel processing systems (Marian & Shook, 2012). However, bilingual comprehension mechanisms at the level of complex text remain largely unexplored. Previous studies (Perez et al., 2019) suggest that working memory, cognitive control, and proficiency aid multiple language processing. Nevertheless, there is a gap in knowledge about how contextual resources (primes) aid in the detection of errors in the text via revision of existing ideas and representations about the text. This study sought to use the N400 event-related potential to provide insight into the ease of processing in regard to reading comprehension. It explored semantic error detection as a marker of language comprehension and shed light on the role of context clues in bilingual reading processes.

The Effects of Primes on Semantic Deviation Detection

in English and Spanish Bilinguals

by

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INTRODUCTION

As the words on this page enter your mind, a symphony of neural networks must synchronize to comprehend their meaning. But what happens when those words are in a second language? How do bilingual readers navigate the intricate web of language comprehension? The answer lies in the highly nuanced procedure of reading comprehension and the use of tools such as event-related potentials. While much research has focused on English as a first language (L1), the dynamics of multiple language comprehension have gained traction in recent years, leading to a deeper understanding of bilingual processing.

An Overview of Information Processing Models

Early models of reading comprehension take a bottom-up approach, focusing on the sequence of processing lower-level features of information and then higher-level units (Gough, 1972). According to Gough, reading is a linear process wherein the reader must rely heavily on accurately identifying the word's visual and phonological features before deriving meaning. It assumes that the reader extracts meaning by combining the sounds of the individual letters. As such, the reader’s prior knowledge is less important than the ability to decode the key features of the word itself. The bottom-up model of reading places great importance on decoding, which entails the visual perception and analysis of smaller units such as phonemes-–the individual sounds that differentiate one word from another (Nassaji, 2014). Take the words "bad" and "bat," for instance, where the phonemes "d" and "t" respectively distinguish between the two. Detecting these fundamental building blocks of language is crucial in linking them to their semantic counterparts and ultimately extracting meaning from the text. Therefore, according to the bottom-up model, difficulties in reading comprehension can be attributed to challenges in decoding. While the bottom-up model has been influential in the fields of language and reading research and contributed to the development of many effective reading programs, it has also received criticism for its oversimplification of the process of reading and excluding the role of higher-order cognitive processes, such as attention, memory, and prior knowledge (Liu, 2010).

In contrast to the bottom-up approach, top-down models situate the reader at the forefront of a downstream process. These models argue that a reader's own cognitive abilities and prior knowledge influence reading comprehension (Goodman, 1967; Nassaji, 2014). They place greater emphasis on higher-level syntactic and semantic processing and suggest that difficulties in reading comprehension arise due to a general lack of conceptual knowledge and cue resourcefulness. Under this model, a reader may struggle with recognizing words and phrases despite being proficient at decoding because the information does not align with their world knowledge. For instance, a proficient reader may misread the word their as your in the sentence "She pointed to their hats" not because they inaccurately decoded the lower-level orthographic features of the word but because they hold prior knowledge that both their and your are correct pronouns to refer to *hats* (Goodman, 1967). According to Goodman, methodical readers select only the most pertinent and productive cues from the text to validate their predictions about the upcoming text. Criticisms of this model involve that it views reading as a guessing game, where the reader enters with their own hypotheses and predictions about the text before the reading actually begins (Stanovich, 1980). Consequently, the model fails to account for the reader's individual abilities and differences, where less proficient readers may choose to utilize more lower-level mechanisms to compensate for the lack of productive higher-level mechanisms.

More recent models propose that instead, reading is an interactive process that involves both bottom-up and top-down processing, as well as feedback and interaction between the two (Nassaji, 2014; Stanovich, 1980). They emphasize the bidirectional flow of information between lower-level and higher-level mechanisms related to cognition, linguistic, and non-linguistic processing. This model considers the contributions and limitations of attention and memory, where proficient readers optimize their cognitive resources by intentionally leaving more capacity for higher-level processes, such as recognizing whole words and syntactical structures before relying on simple orthographic and phonological units.

Much of the early literature about L2 processing assumed that reading processes were universal across languages as they relied heavily on the top-down model (Coady, 1979, as cited in Lally, 1998). Accordingly, reading efficiency in the L2 made no particular distinction between L2 proficiency and different levels of processing abilities, since these models assumed that processing abilities were a product of language acquisition instead of a significant contribution to it (Nassaji, 2014). However, Lally (1998) notes a recent paradigm shift in L2 reading comprehension models wherein the contributions of language creativity, cross-language cultural variables, and many other factors come into play in modern studies of L1 and L2 processing. Given that multilingual reading activates language systems in a parallel manner (Marian & Shook, 2012), researchers must also consider how languages and their features interact with one another. Under the Psycholinguistic Grain Size Theory, some languages possess shallow orthographies where the relationship between graphemes and phonemes is more direct (Nassaji, 2014). Spanish is one such language, but the one-to-one relationship in English is less direct.

Evidence (Bice & Kroll, 2020; Wang & Koda, 2007, Wang et al., 2003, as cited in Nassaji, 2014) suggests that larger discrepancies between the orthographies in the L1 and L2 influence word-recognition processes, and readers may need to adjust the strategies they use during reading. Consequently, cross-language effects should be considered when choosing languages to compare.

Processing in the L1 and L2

Qualitative studies on reading comprehension performance in third-grade children (Peets et al., 2022) explored the mechanisms that bilingual children employ while reading, such as decoding, oral language proficiency, and life experience. Findings demonstrate that these mechanisms are unique to bilingual children and contribute to their success in reading comprehension despite proficiency differences as they draw from multiple sources of knowledge. Meanwhile, other behavioral studies on discourse context and semantic processing in the auditory domain explored key differences between the L1 and L2 (Grant et al., 2021). Results suggested that bilinguals operating in their L2 can form inferences, but proficiency modulates the mechanisms they use. For example, highly proficient bilinguals tend to employ top-down, discourse-level information such as semantic and world knowledge instead of bottom-up signals such as syntax or morphemes, the smallest unit of decodable language input (such as un- meaning “not” in the word unlikely). Findings from Chang and Wang (2016) suggest that proficiency levels ultimately affect which kinds of cues, whether preferentially bottom-up or top-down, readers use to retrieve and process language information.

The Reduced Ability to Generate Expectations (RAGE) hypothesis (Perez et al., 2019) makes a similar distinction between top-down and bottom-up resources. It classifies readers into two categories: those who employ proactive control during reading and those who utilize reactive control. Highly proficient readers employ proactive strategies to form active predictions about upcoming words and events. Given their high proficiency levels, these readers need not allocate the bulk of their cognitive resources to lower-level processes such as orthographic and syntactic input recognition, which aligns with previously posited interactive models of reading and resource allocation. For example, in the sentence "*He's sending flowers to his beloved*" highly proficient readers would recognize the orthographic meaning of the apostrophe in *He's* and understand that according to the syntax of the sentence, *flowers* refers to the object of the present progressive verb *sending*. A highly proficient reader would also recognize the unique pronunciation of *beloved* without a symbol, or diacritic, to indicate where to place the emphasis. In contrast, non-native and less proficient readers must employ reactive control, which calls on passive integration of new information due to fewer cognitive resources available during reading. Such a reader might need more time to recognize that the preposition *to* refers to the object *beloved*, and that *beloved* will receive the flowers. Proactive and reactive strategies are key concepts as they influence how well readers integrate primes into their mental representations and detect inconsistencies.

Predictive abilities are key in examining a reader's ability to consolidate contextual cues and form inferences. Readers and text alike participate in a dynamic exchange of information, wherein readers utilize the clues provided by orthographic and semantic inputs and their conceptual knowledge stores to form lexical predictions. As these processes are complex and multi-layered, researchers have developed various tools to study them. Event-related potentials (ERPs) observed in time-locked electroencephalography (EEG) signals are essential in language studies (Bice & Kroll, 2020) as they offer on-line characterizations of information processing.

By analyzing ERP amplitudes and onset latencies, researchers can investigate the factors that modulate language operations.

The N400

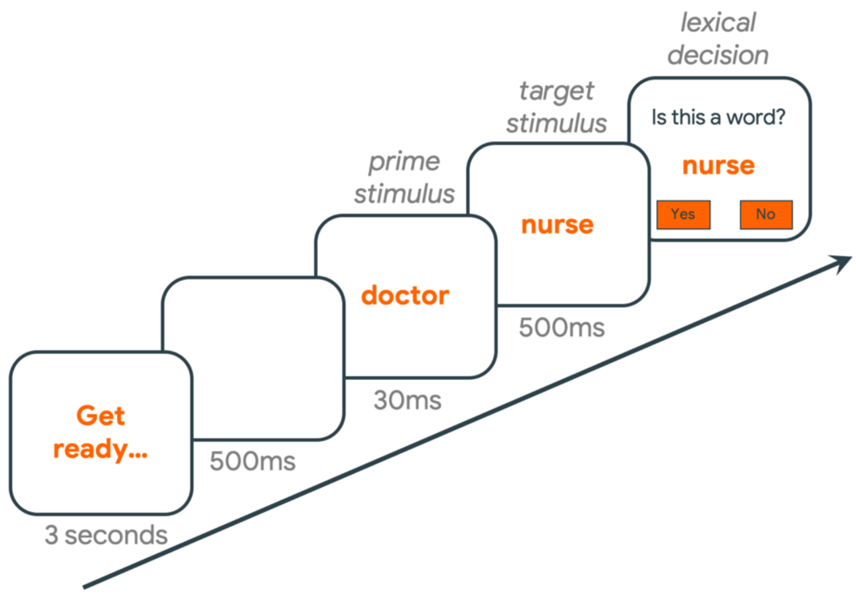
Kutas and Hillyard (1980) discovered the N400 component in a study that involved unexpected words and semantic deviations. The N400 waveform is a negativity peaking around 400 milliseconds and reflects lexical processing, an automatic procedure that involves recognition mechanisms and pairing orthographic inputs to their counterparts in the mental lexicon (Jankowiak & Rataj, 2017).

The N400 is also an indicator of semantic processing, which occurs after a word is perceived and activates similar words to encode their meanings (Lau et al., 2008). While the N400 does not mark any particular mental operation (Kutas & Hillyard, 1980), it signifies critical processes related to reading comprehension, such as prediction formation and meaning integration in real time. Given that more predictable words are easier to process and elicit smaller neural signals (Michaelov et al., 2021), the N400 allows a close examination of the various cognitive capacities that mediate language processing in adults, such as working memory and language proficiency and experience (Hampton Wray & Weber-Fox, 2013). As less proficient readers must allocate their cognitive capacities to lower-level processes, there are fewer working memory resources to engage and expend for proactive control and prediction (Perez et al., 2019) The variation of these factors therefore provides a valuable tool to understand the underpinnings of bilingual information processing.

Given its complex nature, several factors should be considered when using the N400 to explore language processing. Cloze probability is the proportion of respondents who perceive a particular word as a supportive continuation of the preceding context (Kutas & Federmeier, 2011). It indicates the degree to which respondents consider a word as following or related to the preceding word. For example, the word *bread* in the sentence "*She went to the bakery for a loaf of bread"* has a high cloze probability given that there are few words that could possibly fit given the context. In contrast, the word *sofa* in the sentence "*She took a seat on the sofa*" has low cloze probability as any number of words could fit the context. On the other hand, contextual constraint defines the sentence as a whole instead of a word. It is the degree to which a sentence establishes a context and subsequent expectation of a particular word. The sentence "*He produced a beautiful melody by pressing the white porcelain keys of the piano"* exhibits high contextual constraint as the context of the sentence aids the prediction of the word *piano*. Cloze probability and contextual constraint allow researchers to carefully construct sentences that bias a prediction and, in conjunction with the N400, researchers can utilize these tools to examine word prediction and error detection. Given that the N400 functions as a measure of the degree to which comprehenders perceive a word as fitting into an existing mental representation, the amplitude of the N400 is a crucial element to consider; the amplitude is lowered, or attenuated when readers perceive a proper relation between a target word and the given context (Michaelov et al., 2021). In contrast, there is a larger amplitude in response to unexpected endings (Kutas & Hillyard, 1980).

Paradigms and Proficiency

Concerning amplitude differences, lexical priming paradigms provide a consistent, reliable framework to explore lexico-semantic processing as indexed by the N400 (Jankowiak & Rataj, 2017). Lexical priming paradigms utilize a target word that is either related or unrelated to the preceding word, known as the prime (see below).



In traditional lexical priming tasks, a related prime attenuates the N400 amplitude (Tiedt et al., 2020), given that related and previously encountered words elicit smaller neural signals compared to new, unexpected words. Traditional lexical priming studies have demonstrated an N400 effect in the L1 and L2, but only when readers are highly proficient (Jankowiak & Rataj, 2017). This provides insight into the influence of multiple language systems on lexical processing, but how bilinguals integrate primes at the level of multiple-sentence narrative context requires further study.

In addition to the general influence of primes on predictive abilities, it is vital to consider whether an effect is observed in L2 readers with varying proficiency levels and sources of knowledge. Accordingly, research has examined how proficiency influences the formation of mental representations and comprehension. One study employed a reading task in the L1 (Dutch) and a think-aloud reflection in the L2 (English). The results showed that when participants operated in their L2, they tended to make more lower-level, semantic-oriented observations (focused on linguistic elements like the meaning of a word) than content-specific observations that included summaries and relating back to one's experience. The results suggest that proficiency, especially at lower levels, influences the formation of mental representations and comprehension processes. However, as mentioned, the electrophysiological underpinnings of these processes require more investigation.

Perez et al., (2019) called proficiency effects into question by drawing from combined ERP and reaction time (RT) measures to explore the roles of cognitive control and proficiency in high-level text comprehension. Specifically, they investigated whether the ability to revise information during text comprehension was less efficient in the L2 compared with the L1. In this study, RT was used to assess whether readers processed the given context to make a predictive inference and could later detect inconsistent information, with longer reaction times demonstrating successful inference-making. They employed the situation model revision task (see below), in which the first three sentences of the text present a context that biases a predictive inference.

Context (Prime)

It had been snowing and all the children were playing in the park.

Jack and Andy were best friends and worked well as a team.

They had spent 30 minutes rolling up snow and now they were nearly ready.

RT sentence

Andy's hands were frozen because he had forgotten his gloves. (Neutral)

Andy had brought an old woolen scarf and hat to put on. (Non-update)

Andy thought that they now had sufficient missiles to win the fight. (Update)

ERP word

In the end, they were really pleased with their **snowman.**

The RT sentence presents one of three conditions: neutral, non-update, and update. According to the condition, readers may need to uphold or revise their existing predictions by integrating new information to assess whether the final sentence, the ERP sentence, is consistent with the context that was provided. Results showed that highly proficient L1 readers were more equipped to integrate context. They elicited larger N400s and longer reaction times in response to semantic deviations in the update condition. Additionally, L1 comprehenders also showed N400 attenuation in the expected condition, meaning they successfully processed the context information and recognized the consistency of the proceeding sentence.

Both L1 and L2 readers spent more time reading inconsistent information, but L2 readers did not show a difference in RTs between the update and non-update conditions. This suggests that L2 readers did not spend more time processing the sentence, despite encountering a nonsensical statement, which demonstrates that they employed reactive control and did not form a full prediction based on the context.

For L2 readers, the differences in waveforms between the update and non-update conditions were slight, pointing to less efficient context integration. These findings uphold the evidence that proficiency modulates high-level text comprehension, which merits further exploration into how context may or may not facilitate reading comprehension strategies in the less proficient L2.

The Present Study

The N400 is a reliable measure of various types of semantic processing with excellent temporal resolution. Its modulation allows experimental designs to hone in on specific cognitive processes and their subtypes, including processing at the syntactic and semantic levels. Factors that modulate the N400 also provide information on how key elements such as primes and proficiency levels may influence or disrupt cognitive processing. As such, this study aims to employ semantic deviation detection to examine context integration abilities in English and Spanish bilinguals. The study will explore how primes and their contextual information influence comprehension abilities in English and Spanish speakers with varying mastery levels. Since the majority of bilingual comprehension takes place at the level of multiple sentences, such research holds more ecological validity than typical simple sentence experimental paradigms, and it has the potential to change how researchers conceptualize reading comprehension processes.

Studies that have centered on highly proficient bilinguals merit further exploration into the processes underlying the integration of contextual information in the L1 and L2 across mastery levels. Perez et al. (2019) provided valuable insight into the roles of cognitive control and working memory in high-level narrative text comprehension. However, this study will expand on the impact of the presence and absence of primes on word prediction abilities and error detection and shed light on the role of the context itself.

Thus, the N400 component will allow investigation of how readers relate words and meaning, make inferences, and generate expectations. We hypothesize that those with higher proficiency levels in the L1 and L2 will have larger N400 amplitudes and longer reaction times in the update condition as they encounter semantic deviations, regardless of whether or not there was a prime. For those less proficient in the L2, we predict that the prime condition will provide extra contextual support and facilitate reading comprehension, as shown by similar N400s in the L1 and L2 for the update condition.

METHOD

Participants

Participants were required to use English or Spanish as their native and second languages. The study included only participants who have spoken their second language for a minimum of three years. Researchers recruited 39 participants, of which 25 underwent the study in its entirety, and of which 16 were deemed suitable for the final stage of analyses according to the artifact rejection guidelines, which held that only those with accepted trials above 70% would be fit for inclusion in the final analyses. Participants included 16 female and nonbinary students from Mount Holyoke College aged 18 and above.

Recruitment Process

Researchers recruited participants with a background in English and Spanish. This recruitment strategy included of people from various demographic and proficiency levels. A sample size of 30 and above was consistent with practices used in the primary literature (Grant et al., 2021; Perez et al., 2019) to ensure that the recruitment process was feasible, although researchers did not ultimately meet this goal. Participants were recruited via the SONA website and interest flyers, where students signed up using a QR code/Google Form. Compensation included a choice of two SONA credits for a two-hour study or $20.

Materials

A tablet device presented the informed consent and all other forms. Questionnaire materials included the Language History Questionnaire (see Appendix A) and a vocabulary test (see Appendix B) to measure language proficiency. The Language History Questionnaire also collected information about demographics (age, gender, education, parental education, and handedness). Participants completed vocabulary tests composed of critical words from the situation model revision task used in the study to measure L1 and L2 proficiency.

Procedure

EEG Recording

Data collection utilized traditional EEG methodology. Scalp electroencephalograms were recorded from 32 active Ag/AgCl electrodes (actiCAP, Brain Products GmbH, Gilching, Germany) mounted on an elastic cap with references to the average of the left and right mastoids (TP9/TP10) using the Brain Vision actiCHamp (actiCHamp, Brain Products GmbH, Gilching, Germany) system. Impedances were kept below 50 kΩ (typically below 25 kΩ) at the beginning and throughout the experiment. Electrodes were placed at Fp1, Fp2, F3, Fz, F4, F7, F8, FC3, FC4, C3, Cz, C4, C5, C6, TP9, CPz, TP10, P3, Pz, P4, P7, P8, P03, P04, P07, P08, 01, Oz, O2 according to the international 10/10 system. The horizontal electrooculogram (HEOG) recordings were derived from electrodes placed lateral to the external canthi. The vertical electrooculogram (VEOG) recordings recorded from an electrode placed below the right eye (Fp2 was used with this electrode to create a suitable upper/lower eye voltage difference for analysis during offline pre-processing).

Upon providing consent, participants entered the testing area and were informed about the risks and benefits of the study. Participants filled out the Language History Questionnaire as they were capped. Researchers attached electrodes to the cap, inserted gel with blunt needle syringes, and informed participants to avoid moving or blinking too much. Participants then completed the vocabulary test on the tablet device, and researchers explained the task as they began EEG recording. At this time, the lights were dimmed, and environmental noise was reduced. Once participants finished the experiment, research assistants uncapped and debriefed them. The study took approximately 2 hours, after which researchers provided compensation.

Situation Model Revision Task

The study adapted the situation model revision task from Perez et al. (2019). Participants completed a practice block as well as test blocks. Each participant completed 91 trials (45 English and 46 Spanish) with a counterbalanced presentation of prime/no prime blocks. In each block, they completed both a prime and no prime task. The situation model revision task was the same as the original for the prime block, but the no prime trials presented a modification unique to this study. Each trial began with a fixation point that remained on the screen until the participant pressed a key to begin the experiment. In the prime task (see Appendix C), they read three sentences that provided a specific context. The screen presented sentences one at a time as participants read each sentence at their own pace. Then, they pressed a key to present the reaction time (RT) sentence with one of two conditions: non-update or update. The non-update condition was consistent with the inference biased by the context (prime). The update condition mismatched the context, creating a semantic deviation and encouraging an inferential revision in the participant. Participants then read a final sentence that presented a disambiguating word (the ERP word). This sentence was presented word by word with a fixed stimulus-onset asynchrony (SOA) of 600ms per word. In addition, a delay of 700ms following the ERP word was included to ensure a sufficient time window to record activity. The ERP word's condition varied based on the condition of the reaction time sentence. Assuming the final sentence generated a waveform, N400 differences were analyzed for the ERP word. The no prime block (see Appendix D) was the same as the situation model revision task except for one key difference: it did not provide three sentences of context. Participants read only the reaction time and ERP sentence. The study design generated four different conditions: prime/update, prime/non-update, no prime/update, and no prime/non-update, where the former of each pair refers to the prime condition, and the latter refers to the ERP sentence condition. It is presumed that both the prime/update and no-prime update generated N400 waves.

Analytic Strategy

When using EEG/ERP methodology, researchers must consider the ability of electrodes to transmit many types of electrical activity. Although reducing noise sources before recording is most beneficial, post-recording examination allows researchers to improve the signal-to-noise ratio and extract valuable data. The electrical signals elicited by eye and facial movements were eliminated from recordings to provide polished and valuable data. MATLAB ERPlab software (version R2022a) contains the necessary components to process and analyze EEG data.

ERPs measure the voltages generated by the brain in response to specific stimuli or cognitive processes. The active electrode enables signal amplification and is placed where the voltage changes. The reference electrode is placed at a neutral site, where little to no electrical signal is transmitted. ERPs are the value difference between the active and reference sites, so increasing the signal quality from these locations is imperative. Data cleaning includes several vital steps to prepare the data for statistical analysis.

The first step of data analysis was to import the raw EEG data as a .vhdr file, after which it underwent filtering processes. A hi-pass filter of 0.1 Hz and a low-pass filter of 30 Hz were applied to remove the frequencies that do not meet these thresholds of interest. The EEG channel operations were renamed and re-referenced the channels to the mastoid electrodes. The eventlist allowed appropriate data trigger implementation and differentiation between stimuli and responses. Next, the software categorized the trials by condition, or “bins” using the binlist function. The epoch function then created “clean” data segments by using an epoch time range of -200 800 with “pre” as the baseline. Then, artifact detection using simple voltage and moving window peak-to-peak threshold was used to remove extraneous signals such as eye blinks, muscle movements, etc. After this step, the averaged ERPs were computed for each condition within subjects. Participants with less than 50% of trials left following artifact rejection were excluded from further analyses at this stage. After this step, grand average ERP waveforms for all participants were plotted to compare N400 averages across the language of presentation and prime conditions. The grand average of amplitudes across all participants were analyzed over central-parietal sites (Cz, CPz, Fz).

To further analyze N400 differences, repeated measures ANOVA were conducted in SPSS (Version 28.0.1.1). Repeated measures ANOVA allowed researchers to analyze within-subjects and between-subjects changes over time. The language of presentation and the prime condition varied throughout the study. Both variables had two levels, with the presentation language being English or Spanish and the prime condition being either prime/no prime. Two analyses were subsequently conducted, one examining the N400 waveform amplitude and the other examining reaction time for the RT sentence, as these were the dependent variables. Analyses explored N400 differences in response to the ERP word in the target languages (L1 and L2) and between the prime and no prime blocks. Proficiency was tracked as a covariate since proficiency levels influence the degree to which the prime influences the detection of semantic deviations (Perez et al., 2019). The N400 waveform was averaged across participants, with separate groups for the L1 and L2 conditions between subjects and across the prime/no prime blocks for the within-subjects component.

RESULTS

Participants were a combination of native speakers of English, native speakers of Spanish, and native speakers of both languages (14 female, 4 nonbinary, Age: M = 19.2, SE = .94). Mean ages of English and Spanish acquisition were 2.44 (SD = 3.44) and 2.62 (SE = 4.63), respectively. All participants had a minimum of three years of Spanish language experience, whether by classroom instruction, immersion, or self-learning. The means of language experience (in years) with English and Spanish were 16.4 (SD = 4.31) and 15.8 (SD = 4.53), denoting similarities in experience with each language. In the final analyses, participants were not separated based on their native languages. We examined overall differences between trials conducted in English and those conducted in Spanish.

The primary goal of this study was to determine whether amplitude and reaction time differences would be observed under different language, update, and prime conditions. While researchers originally intended to explore reaction time as a tool to measure the integration of primes and detection of inconsistent information, unintentional loss of data due to an error in the experiment's code prevented the exploration. In performing final data analyses on ERP waveforms, an effect of latency seemed to be present. As such, the analyses were modified to explore the influences of language, update, and prime conditions on the onset of the N400 amplitude. Table 1 displays the amplitude means across all the conditions, and Table 2 displays the latency means across all conditions. Significant differences are noted by an asterisk.

Table 1
Means (and standard errors) of amplitudes (in microvolts) for the ERP word presented at the end of each trial

Condition	Mean Amplitude	Standard Error of the Mean
English Update	-0.1*	1.03
English NonUpdate	0.91	1.01
Spanish Update	-0.05*	0.86
Spanish NonUpdate	2.1	0.85
Prime Update	0.57*	0.70
No Prime Update	-0.85	0.97
Prime NonUpdate	1.38	1.05
No Prime NonUpdate	1.48	0.74

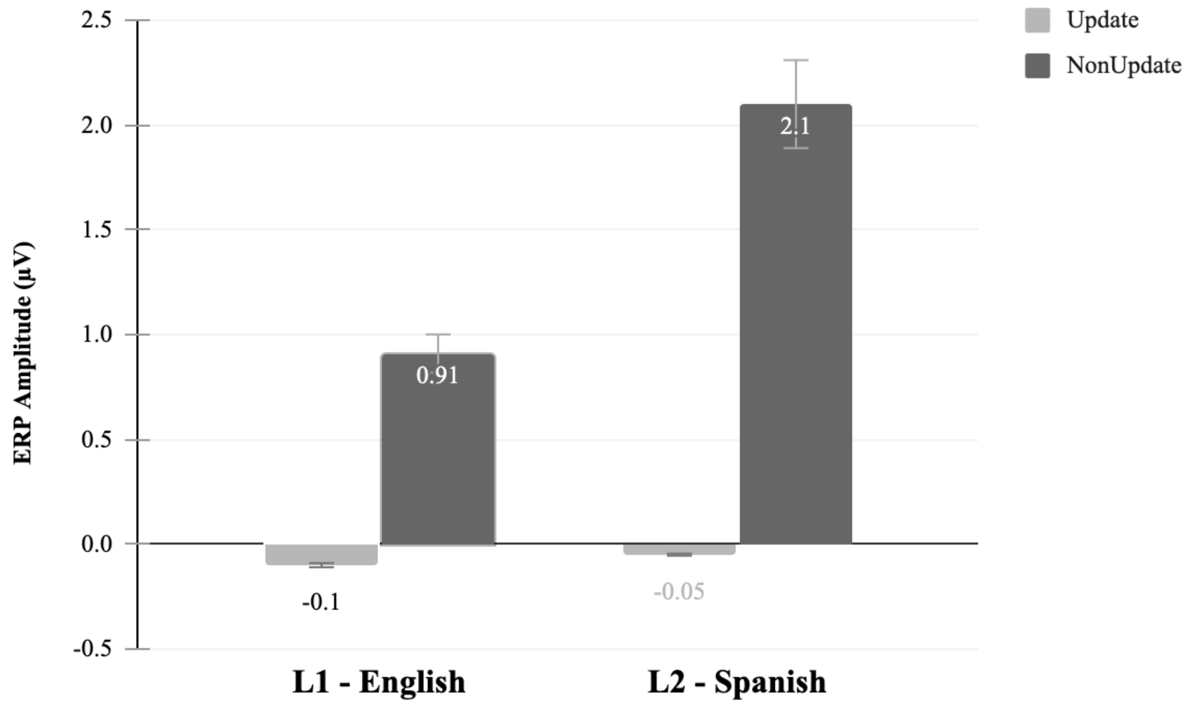
Table 2
Means (and standard errors) of latencies (in milliseconds) for the onset of the N400 effect in response to the ERP word presented at the end of each trial

Condition	Mean Fractional Area Latency	Standard Error of the Mean
English Update	468.1	7.97
English NonUpdate	472.3	7.04
Spanish Update	470.6	7.87
Spanish NonUpdate	460.1	5.95
Prime Update	467.3	8.51
No Prime Update	473.1	6.62
Prime NonUpdate	460.3	6.67
No Prime NonUpdate	464.6	5.04

Amplitude Analyses

Figure 1

Language comparisons of differences in mean amplitudes between the Update and NonUpdate conditions. Negative values denote larger N400 amplitudes, given that the component itself is negative.



Language and Updating

A 2(L1, L2) x2 (Update, NonUpdate) repeated measures ANOVA was used to analyze the main effects and interaction of language and update conditions on N400 amplitude. Language as a main effect did not yield significant results, $F(1,15) = .42$, $p = 0.53$, $\eta 2 = .03$, demonstrating that there were no meaningful differences in amplitude between the L1 and L2. However, a main effect of the update condition was observed, $F(1, 15) = 5.9$, $p = 0.024$*, $\eta 2 = 0.28$, which shows that the N400 amplitude was significantly larger in the update condition as opposed to the nonupdate condition. Figure 1 displays mean amplitude differences illustrating an effect of the update condition. There was not a statistically significant two-way interaction between the language and update conditions $F(1,15) = .92$, $p = .35$, η2 = 0.06.

Figure 2

Priming effects on mean amplitudes between the Update and Nonupdate conditions. The unprimed update trials were more negative than the primed trials, denoting that the prime attenuated N400 amplitudes.

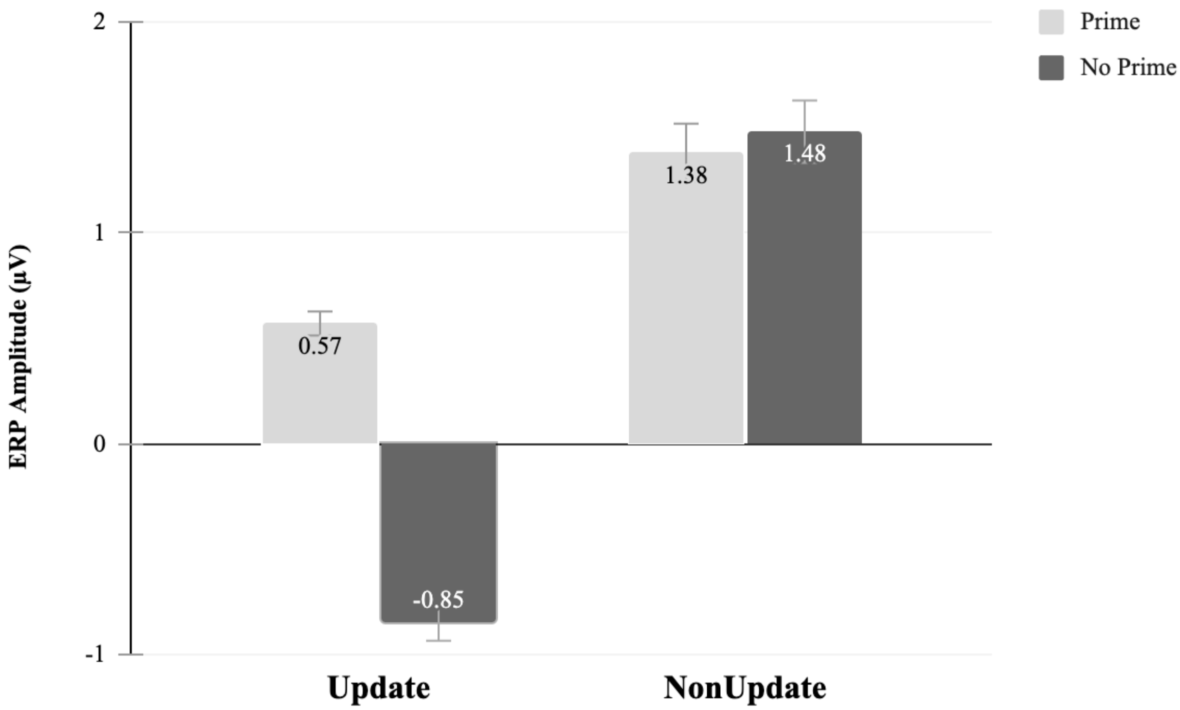


Figure 3

Priming effects on the electroencephalographic waves in the Update condition

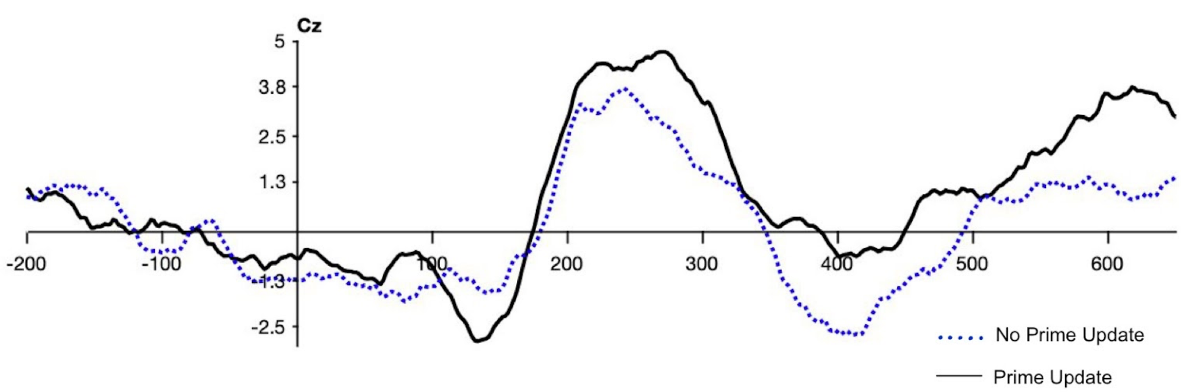
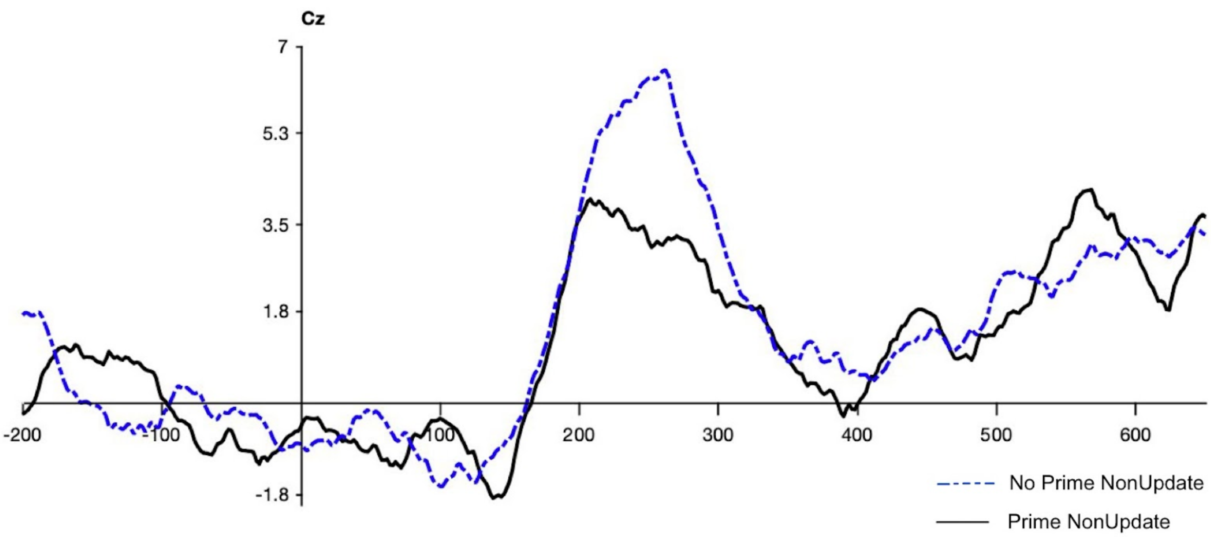


Figure 4

Priming effects on the electroencephalographic wave amplitudes in the NonUpdate Condition



Language and Primes

Another 2 (L1, L2) x 2 (Prime, No Prime) repeated measures ANOVA on N400 amplitude was used to assess the main effects and interaction between language and prime conditions. This analysis intended to explore whether primes significantly attenuated the N400 amplitude and whether there was a difference in attenuation between the L1 and L2. There were no significant differences between languages, $F(1,15) = 0.45$, $p = .835$, $\eta2 = .003$, demonstrating that participants displayed similar N400 amplitudes in the L1 and L2. Although not significant, priming conditions trended toward significant differences between update trials that were primed and not primed, $F(1,15) = 1.95$, $p = .182$, $\eta2 = .115$. Figure 2 shows a sizable difference in amplitude for primed and unprimed trials in the update condition. Figures 3 and 4 illustrate visual differences in amplitude between trials in the update condition presented with and without a prime.

Latency Analyses

A 2 (L1, L2) x 2 (Update, NonUpdate) repeated measures ANOVA assessed the effect of language, $F(1,15) = .37$, $p = .552$, $\eta 2 = .024$, update condition, $F(1,15) = .26$, $p = .617$, $\eta 2 = .017$, and their interaction $F(1,15) = 1.13$, $p = .305$, $\eta 2 = .07$ but did not yield significant results, demonstrating that there were no significant differences in latency between these conditions. A second 2x2 repeated measures ANOVA examined the effects of primes, $F(1,15) = 2.96$, $p = .106$, $\eta 2 = .165$, the presence of the update condition, $F(1,15) = .534$, $p = .476$, $\eta 2 = .034$, and their interaction, $F(1,15) = .012$, $p = .916$, $\eta 2 = .007$. While the main effects and interaction were not statistically significant, the prime effect displayed a trend indicative of a notable difference in N400 onset latency between primed and unprimed update trials, where primed trials had an earlier N400 onset occurrence.

DISCUSSION

The present study aimed to address several critical components of bilingual reading comprehension. Most existing literature on language processing uses simple, single-word paradigms, which constrains the applicability of results to high-level text processing. Thus, our primary goal was to examine whether an N400 effect would be observed in the presence of complex, multiple-sentence paradigms across languages. Our secondary goal was to assess whether primes would serve as an additional, informative layer of context and facilitate the detection of semantic deviations or unexpected sentence endings.

The N400 Effect

As expected, results showed larger N400 amplitudes in the update conditions, demonstrating that highly proficient readers efficiently integrated the provided context and correctly detected semantic errors in the ERP sentence. Results are consistent with previous findings about bilingual reading (Perez et al., 2019), which determined that highly proficient readers employ proactive strategies to readily consolidate contextual information, form inferences, and generate expectations. Importantly, this effect was present even when the ERP sentence presented subtle, one-word semantic errors that could be detected only if readers allocated significant attentional resources to the rest of the context and the entirety of the sentence containing the ERP word. Although attentional control was a factor beyond the scope of this study, visual inspection of the data revealed a notable P300-like wave preceding the N400 wave across all conditions of language, update, and primes. The P300 component reflects active engagement in target detection tasks (Picton, 1992), demonstrating that participants effectively and proactively generated expectations about the following sentence as the contextual stimuli were presented.

Participants displayed high variability in language learning methods; some were native speakers and fortified their knowledge with further classroom instruction, while others were non-native speakers and learned by immersion or self-learning. Despite these differences, participants displayed high mean years of language experience, vocabulary test scores, and large N400 waveforms. Further, as shown by similar update condition N400 amplitudes in Figures 3 and 4, whether readers were native in one language or both did not change the strategies they used as they read, showing that proactive control is not limited to native-like mastery of language and further supporting previous findings that mastery is achievable in adulthood (Marian & Shook, 2012). Similarly, N400 amplitudes also tie to findings that multilingual reading activates parallel language processing systems. If this is the case, these results are important in considering that for less proficient readers, high proficiency in other language(s) may facilitate and support their language learning and reading comprehension, especially when multiple layers of context are provided. The significant N400 effect also demonstrates that complex, multiple-sentence reading paradigms are just as, if not more, effective for exploring how readers form expectations and detect semantic errors across multiple language systems. A multi-layered paradigm may be more useful to assess the true electrophysiological underpinnings of language processing and reading comprehension as it allows manipulation of several variables at once and on-line illustrations of these manipulations. In an educational and diagnostic sense, it is useful to note the specific cognitive processes that readers undergo and to pinpoint both the time-scale and cognitive sequence in which readers may encounter obstacles.

Primes

In exploring how primes affected N400 amplitudes and onset latency, we observed unique trends that denote a possible influence of primes on complex text processing. Although the presence of primes did not uphold our prediction of N400 component attenuation in a statistical sense, Figure 3 illustrates a visual difference between primed and unprimed update trials. Such a difference indicates a possible benefit of layered contextual clues for reading comprehension, wherein the content and structure of the provided information may allow readers to stabilize and add to mental representations of the text. Figure 4 exhibits a lack of an N400 effect in the NonUpdate condition, which aligns with previous findings where such an effect is observed only in response to unexpected words. Results also agree with evidence about how the utilization of context clues might take precedence over lower-level lexical and semantic cues (Grant et al., 2021) and as such, their content and structure hold significance.

Implications

The study explored how bilingual readers incorporate contextual information and respond to semantic deviations. Previous research addressed bilingual high-level text processing concerning working memory and cognitive control (Perez et al., 2019). However, this study was the first to explore the influence of priming on complex text comprehension. Using higher-level text shed light on the nuances of language learning and bilingual reading comprehension. Findings about the update effects regardless of priming conditions allows researchers to develop robust frameworks to further understand multiple language representations in the brain and how their interactions inform text-processing abilities. Results from similar N400 effects among participants with various language backgrounds also implicate language acquisition methods, and further research into contextual information integration may allow improvement of pedagogical approaches to language teaching. In this way, educators may also modify current standardized measures of reading comprehension that exclude second language contributions and their influence on complex cognitive processes. Educators may additionally revise core curricular standards to include multilingual learners and amplify their strengths and differences. Such revisions may allow educators to move away from deficit models where bilinguals less proficient in the L1 are viewed as lacking in intellectual and comprehension abilities when they may, in fact, need support in optimizing their cognitive resources and approaches to reading. Finally, findings also allow researchers to fine-tune the use of ERPs to index multiple language processing beyond simple lexical priming tasks and pinpoint where readers are encountering obstacles, such as at the lower-level or higher-level stages of reading.

Limitations

The goals of this study were complex and layered. While results revealed novel and interesting findings, the unintentional loss of data prevented the exploration of reaction time differences and their indicative abilities. Additionally, given the intensive nature of electrophysiological studies and the limited pool of English and Spanish bilinguals from which to recruit from, effect sizes were smaller than originally intended. In consideration of the participant makeup as a highly educated population, researchers were not able to explore how language proficiency differences may have impacted or mediated amplitude, reaction time, and latency measures and the results are only partially generalizable to the population of English and

Spanish speakers. Equipment malfunction, individual differences in attention, motivation, etc., and other factors likely contributed to noise in the data.

Future Directions

In the future, researchers may opt to draw from a broader range of proficiency levels and include male and nonbinary participants. Priming paradigms with more variety in syntactic structure and vocabulary words might also provide insight about the conditions that elicit an N400 component. In addition, future studies might also explore whether these same effects can be seen in children actively learning and buildings multiple language systems.

APPENDIX A

Education

- College (Bachelor)
- Graduate (Master)
- Graduate (Doctor)
- Other:

Parents' Education

	Elementary School	Middle School	High School	College (Bachelor)	Graduate School (Master)	Graduate School (Doctor)	Other
Father	○	○	○	○	○	○	○
Mother	○	○	○	○	○	○	○

Handedness

- Right-handed
- Left-handed
- Ambidextrous

Indicate your native language(s) and any other languages you have studied or learned.

Your answer

Which language do you most for the following activities? If you use them equally, check both boxes. If you do not engage in the activity, feel free to omit your response.

	Thinking	Talking to yourself	Speaking to others	Texting	Watching television	Expressing emotion (cursing, showing affection, etc)	Praying
English	☐	☐	☐	☐	☐	☐	☐
Spanish	☐	☐	☐	☐	☐	☐	☐

Indicate the way you learned or acquired each language. Check one or more boxes that apply.

	Immersion	Classroom Instruction	Self-learning
English	☐	☐	☐
Spanish	☐	☐	☐

Indicate the age(s) at which you started using each language in terms of listening, speaking, reading, or writing.

Indicate the total number of years you have spent using each language.

Your answer

Country of origin

Your answer

Country of residence

Your answer

If you have lived or traveled in countries other than your country of residence for three months or more, indicate the name of the country, the language you used, and how frequently you used the language.

Your answer

Indicate the language used by your teachers for instruction at each educational level. If you had a bilingual education at any educational level, then simply check the box under "Both Languages."

	English	Spanish	Bilingual
Elementary School	☐	☐	☐
Middle School	☐	☐	☐
High School	☐	☐	☐
College (Bachelor)	☐	☐	☐
Graduate School (Master)	☐	☐	☐
Graduate School (Doctor)	☐	☐	☐

In which language do you communicate best or feel most comfortable in terms of listening, speaking, reading, and writing in each of the following environments? You may be selecting the same language for all or some of the fields below.

	Listening	Speaking	Reading	Writing
English	☐	☐	☐	☐
Spanish	☐	☐	☐	☐

Use the comment box below to provide any other information about your language background or usage.

Your answer

APPENDIX B

Vocabulary Test

Translate the words below by selecting the correct translation. Answer each question carefully. If you do not know the answer, take your best guess.

Jardín *

- ○ Jar
- ○ Garden
- ○ Jukebox
- ○ Oven

Postre *

- ○ Postman
- ○ Poster
- ○ Dessert
- ○ Beverage

Catedral *

- Coffee
- Chocolate
- Cathedral
- Plant

Aperitivo *

- Jar
- Pencil
- Book
- Appetizer

Foto *

- Tablet
- Water
- Photo
- Tea

Ladrón *

- Latter
- Wardrobe
- Brick
- Thief

Bombero *

- Hat
- Bomb
- Lunchbag
- Firefighter

Marido *

- Marine
- Husband
- Scissor
- Tissue

Lata *

- Can
- Stove
- Camera
- Later

Nevando *

- Snowing
- Juggling
- Going
- Playing

Disfraz *

- Different
- Disguise
- Car
- Dress

Cuchillo *

- Knife
- Bank
- Humid
- Brush

Asesino *

- Asinine
- Assessment
- Baker
- Assassin

Vecina *

- Cow
- Cupboard
- Neighbor
- Vase

Satisfecho *

- Satisfied
- Sad
- Regretful
- Dizzy

Edificio *

- Building
- Library
- School
- Baker

Actriz *

- Star
- Actress
- Chef
- Television

Mangas *

- ○ Comic
- ○ Manganese
- ○ Hairnet
- ○ Sleeves

Llorar *

- ○ Dance
- ○ Sing
- ○ Cry
- ○ Sleep

Joyas *

- ○ Joyous
- ○ Jokes
- ○ Joker
- ○ Jewelry

APPENDIX C

Example of prime block in English

Context with Prime

The employee had so much work to do, she had not yet had time to stop for a rest.

She wiped down the tiles, cleaned the soap dish, and then rinsed out her cloths.

Now, as she stood there, she wanted a break.

RT sentence (½)

The cleaner thought about cleaning the toilet and the grimy shower. **(Non-update)**

The cleaner opened the refrigerator and took out some cheese and salad. **(Update)**

ERP word

She left her cleaning things on the floor in the bathroom.

APPENDIX D

Example of no prime block in English

Context

Mrs. Flynn was walking past the flowerbed with her little boy Mike.

RT sentence (½)

It had decorated wings and was gracefully rising from a delicate flower. **(Non-update)**

It had colored feathers and was loudly singing a beautiful melody. **(Update)**

ERP word

Mrs. Flynn pointed to the sky to show Mike the **butterfly.**

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