*Lexical processing in child and adult beginning second language learners**

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Abstract

The objective of the present study was to investigate the neural processes underlying second language (L2) learning using child and adult English monolinguals in the early stages of L2 acquisition. The Revised Hierarchical Model (RHM) of L2 processing (Kroll & Stewart, 1994) predicts that both the child and adult beginning L2 learners will show no effect of semantic interference when presented with semantically related pairs because of their novice learner status. However, based on recent research with Dutch child learners of English, we predicted that the child participants would show semantic interference (Brenders, van Hell & Dijkstra, in revision; Poarch, van Hell, & Kroll, 2015). Stimuli consisted of three types of pairs: correct translations (*perro-dog*), incorrect semantically related translations (*perro-cat*) and incorrect unrelated translations (*perro-table*). Participants were asked to indicate correctness of the translation pairs of Spanish and English words while EEG was recorded. Event-related brain potentials (ERPs) were analyzed using mean amplitude, time-locked to the second word of the pair (English). We found a significant effect of semantic relatedness in both the child and adult participants. Preliminary patterns suggest conceptual activation is possible, even in beginning L2 learners. Further research should investigate how to best revise our current theories of second language processing to accommodate these findings.

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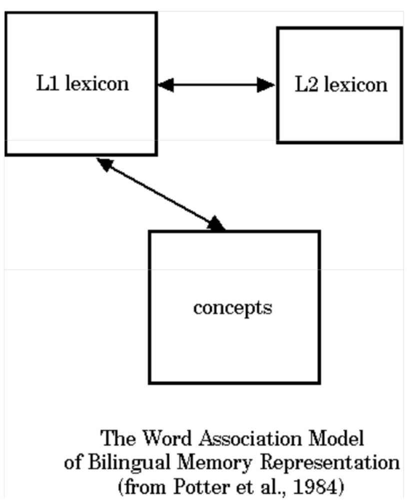
Introduction

In the field of psycholinguistics, the mental lexicon is most easily defined as the mental "dictionary" containing all the words a person knows in a given language. This mental lexicon is typically considered to contain only one language; therefore, a bilingual is thought to have multiple lexicons. Additionally, it is assumed that these two lexicons share one conceptual system that stores the meaning of words. When processing language, words in the lexicon are mapped onto concepts to access meaning (Traxler, 2011). However, it is debated whether bilinguals with varying proficiency find meaning directly from the second language (L2) word or via mediation of the first language (L1) word (for a review, see Van Hell & Kroll, 2013). For example, when a beginning learner of Spanish reads or hears the word *mesa* (table), does their word processing system map the word *mesa* directly to its meaning or does the system first translate the word into *table* and then access meaning from the word *table*?

Potter, So, Von Eckardt, and Feldman (1984) proposed two models to explain these two alternates. These models describe the mapping of L2 words to meaning and make the assumption that the L1 and L2 share one conceptual system but have separate lexicons. The first model of L2 processing—the concept mediation model—assumes that L2 words are mapped directly onto the meaning through the conceptual link between the second language word and the concept. The word association model claims that to find meaning from an L2 word, the system relies on the L1 lexicon. Therefore, this model states that meaning is found by first mapping the L2 word to its translation in the L1 and meaning is accessed using the person's already well established L1 word to concept mappings.

The Revised Hierarchical Model (RHM) model of L2 processing states that mode of conceptual access depends on proficiency. This model predicts that in the early stages of learning a second language, learners process L2 words using the word association model such that meanings for L2 words are accessed by translating them to their L1 words (see Figure 1). As L2 proficiency increases, the RHM proposes that more proficient L2 learners follow the links proposed by the concept mediation model such that the conceptual system is activated directly when processing in both their L1 and their L2 (Kroll & Stewart, 1994).



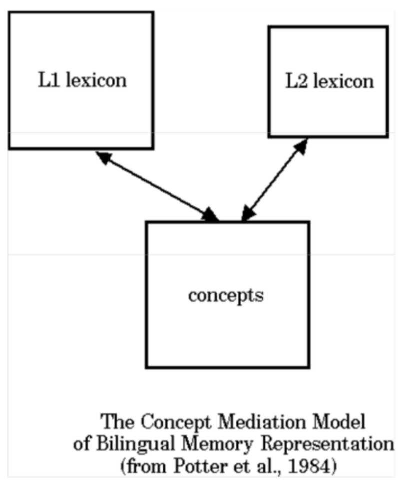


Figure 1: Word Association vs. Conceptual Mediation

De Groot (1992) developed the translation recognition task as a method to study the RHM consistently with people of differing L2 proficiency levels. The translation recognition task involves the presentation of a word in one language followed by the presentation of a word in a second language that is either a correct or an incorrect translation of the first. Participants are then asked to indicate whether the second word they viewed was a correct or incorrect translation of the first.

An adaption of this task to study proficiency and semantic interference was developed by Talamas, Kroll and Dufour (1999) in which half of the incorrect pairs were related in semantic category or form. For example, an incorrect pair that shares semantic category is *man-mujer* (woman) instead of *man-hombre* (man) because the words *man* and *woman* are semantically related. An example of an incorrect pair that shares word form was *man-hambre* (hunger) as opposed to the correct translations *man-hombre* (man) due to the orthographic relatedness of the correct translation—*hombre*—and the incorrect word form related translation—*hambre*.

Using these stimuli, this study tested the RHM by comparing more fluent English-Spanish bilinguals with less fluent bilinguals. The RHM would predict that because conceptual activation will increase with increased proficiency, the more fluent English-Spanish bilinguals would show slower reaction times and make more errors for pairs that share a semantic category compared to unrelated controls. This is based upon the prediction that increased conceptual activation will lead to semantic interference. Additionally, the RHM predicts that in the less fluent bilinguals, due to low proficiency and reliance on lexical mediation, the word form pairs should produce slower reaction times and more errors in comparison to unrelated controls, and no semantic interference effects would be observed.

Talamas et al. (1999) found evidence for both predictions, providing support for the theorized transition from lexical to conceptual representation of the L2 as proficiency increased, as outlined in the RHM. These results thus confirm the RHM model as less proficient L2 learners showed mostly word form interference and the more proficient L2 learners showed a decrease in word form interference and an increase in semantic interference compared to less proficient L2 learners as they transition into more conceptual processing in the L2.

The adaptions of Talamas et al. (1999) became the basis of many studies looking at proficiency related effects in adult L2 learners to further investigate the link between semantic interference and proficiency (for a review, see Van Hell and Kroll, 2013). Fewer studies used this paradigm to investigate the degree of conceptual activation in and child beginning learners (Comesaña, Perea, Piñeiro & Fraga, 2009; Poarch et al., 2015). Guo, Tam and Kroll (2012) and Brenders et al. (in revision) additionally measured event-related brain potentials (ERPs) to further investigate the time course of these effects. These studies will be discussed in more detail below.

Comesaña et al. (2009) investigated semantic interference effects in fluent child Basque-Spanish bilinguals and Spanish child learners of L2 Basque. Participants in this study performed the translation recognition task. Key word pair sets contained Spanish and Basque words that were incorrect translations but semantically related and incorrect unrelated controls. . Results demonstrated semantic interference in Spanish-Basque bilinguals when processing in their L2. The semantic interference effect was also found in early beginning learners of Basque. These findings contradict the Revised Hierarchical Model of second language acquisition because according to the model, learners in the early stages should rely on word form relations and should not develop conceptual connections until L2 proficiency increases. This study demonstrated that processing at a conceptual level can occur early in L2 acquisition in children.

Poarch et al. (2015) investigated whether children in the early stages of second language acquisition map a word in their second language directly to the concept or meaning. In this study, Dutch speaking children with eight months of classroom instruction in English (about 1 hour per week) performed a translation recognition task and a translation production task. In the translation recognition task, longer reaction times and decreased accuracy for semantically related pairs relative to incorrect controls suggest that semantic activation was present when processing in the L2. This evidence supports the idea that children can directly access the meaning of L2 words, even in the very early stages of L2 acquisition.

Guo et al. (2012) also used the translation recognition task to investigate the predictions of the RHM, but they tested fluent adult Chinese-English bilinguals. Replicating Talamas et al. (1999), semantic and orthographic relatedness of the two words were manipulated to investigate the degree of conceptual and L1 lexicon activation when processing in the L2. Based on the behavioral and EEG/ERP data, Guo et al. (2012) found semantic and word form interference when processing in the L2. This evidence suggests that when fluent bilinguals process L2 words, both concepts and L1 words are active. The RHM predicts that in fluent bilinguals concept is directly activated when processing words in the L2. However, it does not predict that the L1 lexicon is active, as these results suggest.

Building on the findings of Guo et al. (2012), Brenders et al. (in revision) replicated the investigations of interference using fluent adult bilinguals and extended the study with the addition of child beginning second language learners. The children were fifth and sixth grade Dutch elementary school students learning English in a classroom setting. Fifth grade students had received English lessons for five months. The sixth grade students had received English lessons for 16 months.

The study consisted of three experiments: an off-line behavioral translation recognition study, an on-line behavioral translation recognition study and an Event-Related brain potentials translation recognition study. In Experiment 1, errors showed semantic and word form interference in the two groups of beginning child L2 learners and adult proficient bilinguals. Experiment 2 replicated these effects with the addition of reaction times providing converging evidence that both conceptual and lexical representation were active in all three age groups. The ERP data collected in Experiment 3 further supported this same conclusion. The ERP results showed a significant N400 effect present in all groups in reaction to both types of distracters. The N400 is a negative-going effect that reaches peak amplitude around 400ms after stimulus onset and is typically associated with lexico-semantic processing. The amplitude of the N400 was smaller in reaction to stimuli that are more closely semantically related. and this effect was found in both beginning L2 learners and adult bilinguals.

Brenders et al (in revision) presented evidence that child beginning learners process second language words similarly to fluent adult bilinguals. Additionally, the child beginning learners in this study showed an N400 effect similar to the adult bilinguals, providing neurocognitive evidence that child beginning learners process more like the proficient bilingual adult. This contradicts the predictions of the RHM which states that fluent bilinguals process L2 words using direct L2 word to concept mappings while early learners rely on mediation of the L1 lexicon to access meaning. However, this study is the first to provide physiological evidence that this may not be the case in child beginning learners.

A continued debate in the literature exists about the RHM. Furthermore, studies testing the RHM are highly varied in the population of use and type of manipulation. Guo et al. (2012) found that bilinguals can access their conceptual system directly, supporting the RHM. However, Brenders et al. (in revision) found neural and behavioral evidence that early child learners access their conceptual system during L2 processing. Further research collecting more EEG data during the translation recognition task would be beneficial as there are few papers out using EEG to investigate conceptual activation. Additionally, Brenders et al. (in revision) was the first to perform this task with children while recording EEG so further ERP data still needs to be collected on children to provide converging neural evidence for this effect in children.

Importantly, the early child learners in the Brenders et al. (in revision) study, living in the Netherlands, were also exposed to at least some English outside of the classroom setting through popular media (e.g., popular music, television) and the internet. Therefore, the children tested in this study not be true novice L2 learners, and may have had exposure to English in addition to their L2 English language classes. Therefore, the current study will explore early L2 learners with little L2 exposure outside of classroom instruction, who can be qualified as true novice L2 learners.

The present study will extend Brenders et al. (in revision) by utilizing the translation recognition task with children and adults in the early stages of L2 learning. This study is the first to systematically compare two groups of L2 learners who differ in age but share comparable proficiency. This study will record continuous EEG to investigate L2 lexical processing as it relates to the RHM.

The RHM predicts that both child and adult beginning learners will show no effect of semantic interference due to their novice learner status. In the adult beginning learners, we expect to find patterns consistent with the predictions of the RHM. It is predicted that the adult learners will show no difference in N400 effects between the semantically related and unrelated pairs because the RHM predicts that in the early stages of L2 learning, L2 form to concept mappings are not formed yet and L2 processing relies on L2 form to L1 form mappings to access concept.

According to the RHM, children should show no effect of semantic interference; however recent evidence contradicts this prediction. Alternatively, if children have already built L2 form to concept mapping at the early stage of L2 learning, it is predicted that they will show an effect of the semantic interference. If so, the effect will be evident in the ERP data such that a smaller N400 to semantically related incorrect pairs will be detected in comparison to the unrelated incorrect translation controls. These alternative results would suggest L2 word form to concept mappings in novice L2 child learners.

Methods

Design

This study was a one factor within subjects design with the independent variable translation type such that there were three types of word pairs (correct, incorrect semantically related, incorrect unrelated). The materials consisted of correct translations (PERRO (*dog*) – DOG), incorrect translations with the second word semantically related to the correct translation (PERRO (*dog*) – CAT) and incorrect translations with the second word unrelated to the correct translation (PERRO (*dog*) – TABLE). Event-related potentials (ERPs) time locked to the second word in the pair were used as the dependent measure.

Participants

The participants included adult L2 learners from two colleges in central Pennsylvania and kindergarten L2 learners from a local elementary school. Participants in both groups were right-handed and from English speaking homes. The adult participants did not acquire a second language until college and the children began learning Spanish in Kindergarten. We tested both groups of participants after approximately 20-25 hours of classroom instruction in Spanish.

Procedure

Following the procedure of Brenders et al. (in revision), participants were presented with word pairs, the Spanish word followed by the English word, on a monitor with a black background with letters in white Arial font. Each trial began with a fixation sign at the center of the computer screen for 500ms, followed by a 500ms pause. Next, the L2 word was presented for 350ms in the visual presentation and 500ms to 1200ms depending on the length of the word for auditory presentation. A blank screen was presented for 1000ms followed by the L1 word with timing the same as the L2 word timing. Following the pair presentation, there was a 3000ms pause until a screen appeared asking the participant if the word pair was a good or bad translation.

The participants responded using a button box to indicate whether they thought the pair was a correct or incorrect translation. This jittered time interval and the delayed decision procedure was used to prevent motor artifacts associated with pressing the buttons entering the EEG signal. After the participant responded, a smiley symbol appeared for 3 seconds, indicating to the participant that they were allowed to blink and swallow at this time if needed. All communication and directions during the experiment were in English.

EEG Recording and Data Analysis

Participants were tested in a mobile van with modifications to control for interference with EEG recording. Data was collected on-site, at the participants' school where the van was parked for the duration of testing. The EEG system was a mobile ActiCHAMP system with 30 active scalp electrodes configured to the international 10-20 system and two eye-electrodes (vertical and horizontal) to track eye movement and blinks. EEG was continuously recorded across the entire scalp of the participants. We recorded data at a sampling rate of 500 Hz with a band pass filter of 0.1 to 40Hz Impedances at each electrode site were maintained below 15kohms. Electrodes referenced online to the left mastoid electrode were later re-referenced off-line to an average of the left and right mastoid electrodes. The EEG continuous data was filtered offline at 30Hz with an offline low-pass filter and at 0.5Hz with an offline high-pass filter. ERPs were averaged offline for each participant at each electrode site for each of the three experimental conditions, relative to a 200ms pre-stimulus baseline. Trials found to contain eye artifacts were identified and rejected from inclusion in analyses.

ERP Analysis

In line with research on earlier L2 learners (e.g. Brenders et al., in revision; Tokowicz & MacWhinney, 2005), all trials were included in the analysis, regardless of whether the participant correctly determined whether the translations were correct or incorrect. EEG was time-locked to the onset of the second word (English word) in the pair. Analyses examined mean amplitudes with a pre-stimulus baseline of 200ms prior to the onset of the word. In accordance with prior research on the N400, the epoch of 300ms to 500ms was selected for analysis. Preprocessing and the measurement of the ERP data were done in ERPlab.

Two repeated measures analyses of variance (ANOVA) compared conditions by examining scalp distribution of the ERP effect. An ANOVA was performed for midline electrodes with a factor of electrode group (Fz, Cz, and Pz). Another ANOVA was conducted focusing on a factor of anteriority (anterior, posterior) and laterality (right, left hemisphere). Analyses examined if mean amplitude between 300ms and 500ms differed significantly by condition (correct, incorrect semantically related, incorrect unrelated).

Results

Adult Data

Preliminary results from the 10 adult participants tested at the time of analysis are reported. Additional data will be collected and analyzed in the future. Visual inspection of the waveforms indicated a visually detectable difference between the two types of incorrect conditions between 300ms and 500ms, such that the unrelated translation condition produced a more negative going waveform than the semantically related condition, and the two incorrect conditions produced a more negative going waveform than the correct condition in this time window (see Figure 2).

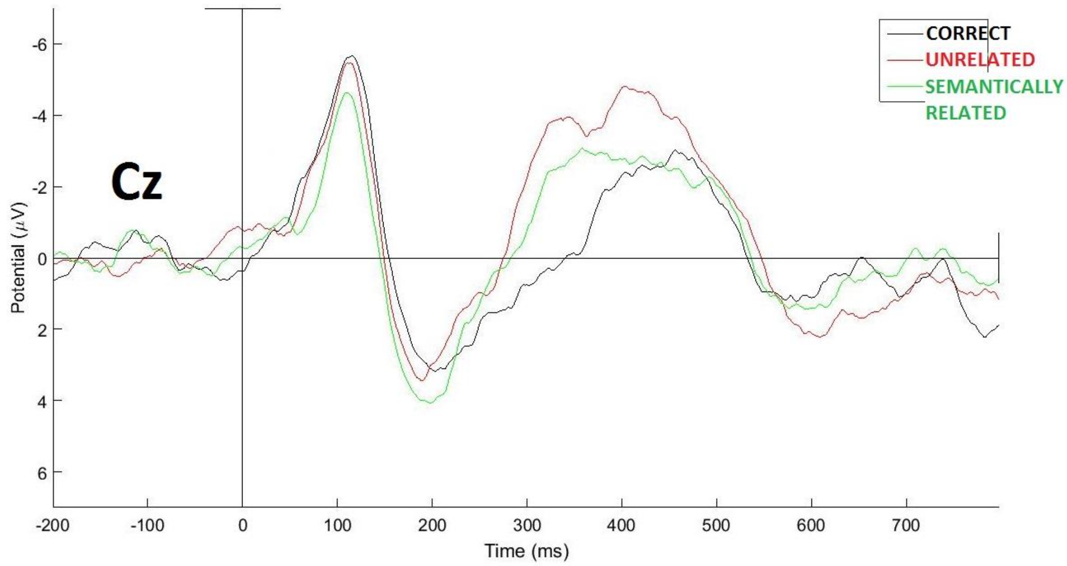


Figure 2: Adult data: Grand average event-related brain potentials at representative electrode Cz for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up. Significant difference in mean amplitude between correct translation, and both types of incorrect translations, 300ms - 500ms time window. Significant difference of mean amplitude between semantically related pairs and unrelated controls in 300ms - 500ms time window. (For additional electrode sites see Appendix A).

The analysis yielded a significant effect for translation type (correct, unrelated incorrect, semantically related incorrect) such that unrelated incorrect translation pairs produced a greater negativity than semantically related incorrect pairs which produced a greater negativity than correct pairs (midline: $F(2,18) = 9.168$, $p = .005$; lateral: $F(2,18) = 11.43$, $p = .002$).

Additionally, a significant interaction was found with topography (translation type x electrode: $F(4,36) = 4.147$, $p = .032$) such that a significant difference was found between unrelated and semantically related conditions at front and central electrode sites but not posterior sites (Fz: $F(1,9) = 6.102$, $p = .036$; Cz: $F(1,9) = 8.216$, $p = 0.056$; Pz: $F(1,9) = 2.218$, $p = .171$). A significant difference between correct and unrelated translations was found at central and parietal electrode sites Cz and Pz but no significant difference was found at frontal site Fz (Fz: $F(1,9) = 2.835$, $p = .127$; Cz: $F(1,9) = 11.7$, $p = .008$; Pz: $F(1,9) = 15.83$, p = .003). A significant difference between correct and semantically related translations was found at central and parietal electrode sites Cz and Pz but no significant difference was found at frontal site Fz (Fz: $F(1,9) = 1.236$, $p = .295$; Cz: $F(1,9) = 11.7$, $p = .008$; Pz: $F(1,9) = 2.218$, $p = .171$).

Analysis of the lateral electrodes (CP6,CP2,P8,P4,F8,F4,FC2,FC6,CP5,CP1,P7,P3,F7, F3,FC1,FC5) was performed using four regions of interest (right anterior, left anterior, right posterior, left posterior). A significant interaction was found between translation type and anteriority (anterior, posterior) $F(2,18) = 6.10$, $p = .014$). Unrelated incorrect translation pairs produced a significantly greater negativity on average in the 300ms to 500ms time window than correct translation pairs at both anterior and posterior electrode sites (anterior: $F(1,9) = 5.93$, $p = .083$; posterior: $F(1,9) = 20.76$, $p = .001$) . Semantically related incorrect translation pairs produced a significantly greater negativity than correct translations at posterior sites but not at anterior sites (anterior: $F(1,9) = 0.196$, $p = .668$; posterior: $F(1,9) = 21.87$, $p = .001$). Unrelated incorrect translation pairs produced a significantly more negative N400 effect compared to semantically relate incorrect translations at anterior sites and a marginally more negative effect at posterior sites (anterior: $F(1,9) = 8.433$, $p = .017$; posterior: $F(1,9) = 4.449$, $p = .064$).

Child Data

Preliminary results from the 10 adult participants tested at the time of analysis are reported. Additional data will be collected and analyzed in the future. Visual inspection of the waveforms indicated a visually detectable difference in the 300ms to 500ms time window between the two types of incorrect translations such that incorrect translations produced a more negative going waveform than correct translations. A marginally significant main effect for translation type was present at the midline such that semantically related translations produced the most negative going waveform, followed by unrelated translations which produced a more negative going waveform than correct translations ($F(2,8) = 5.038$, p = .054) (see Figure 3). We found no significant effect of translation type at the lateral electrodes ($F(2,8) = 3.37$, p = .127). Additionally, no significant interactions were found at the lateral electrode sites.

A significant effect of translation type was found at electrode site Fz such that semantically related translations produced on average a more negative effect than unrelated translations, followed by correct translations as least negative ($F(2,8) = 6.03$, p = .049). At electrode Fz, unrelated translations were significantly more negative than correct translations ($F(1,4) = 9.84$, p = .035) and semantically related translations were significantly more negative than correct translations ($F(1,4) = 7.30$, $p = .054$). Unrelated and semantically related translations were not significantly different at electrode Fz ($F(1,4) = 2.03$, $p = .228$).

A marginally significant effect of translations type was detected at electrode site Cz such that semantically related translation produced the most negative effect, followed by unrelated translations and then correct translations ($F(2,8) = 3.92$, $p = .082$). Additionally, a significant difference was found between correct translations and semantically related translations such that semantically related incorrect translations produced on average a more negative effect than correct translations ($F(1,4) = 8.86$, $p = .041$). No other significant differences existed at electrode site Cz (see Figure 3).

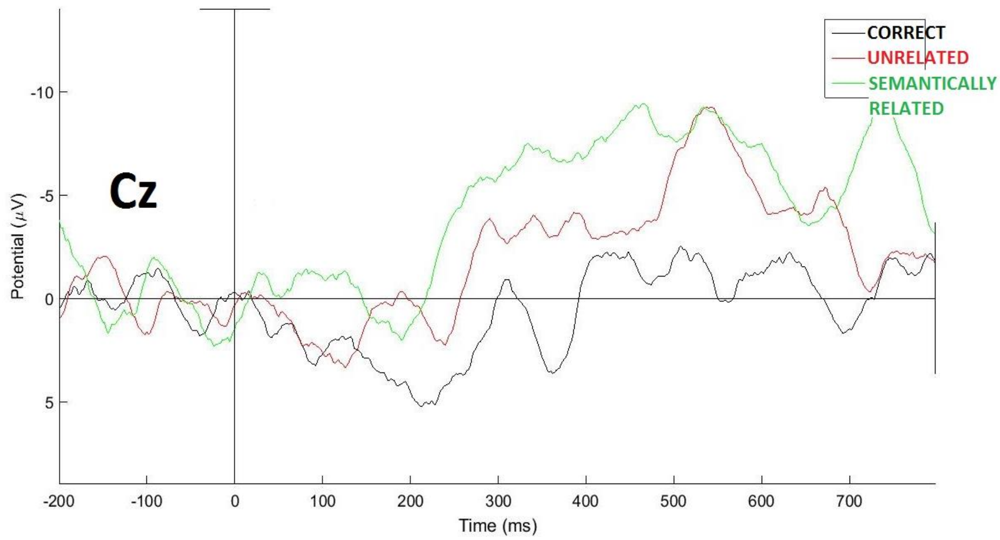


Figure 3: Child data: Grand average event-related brain potentials at representative electrode Cz for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up. Significant difference in mean amplitude between semantically related pairs and correct pairs, 300ms - 500ms time window. (For additional electrode sites see Appendix A).

No significant effect for translation type was found at posterior site Pz ($F(2,8) = 3.40$, $p = .123$). However, further comparisons reveal emerging trends that could reach significance with added participants. A marginally significant difference between semantically related and correct translations is present such that semantically related translations produced a marginally more significant negativity on average than correct translations ($F(1,4) = 6.982$, $p = .057$). Additionally, comparisons between unrelated and semantically related translations are significant such that semantically related translations produced on average more negative effect than unrelated translations ($F(1,4) = 8.855$, $p = .041$).

Discussion

The RHM predicts that beginning second language learners should not show sensitivity to the semantic manipulation during the translation recognition task. However, if beginning L2 learners do activate conceptual information when processing L2 words, then semantic interference should occur, even in these groups of beginning L2 learners. In this study, we found semantic effects in both the adult and child groups of L2 learners. Results found significant differences between the two types of incorrect translations in the 300ms to 500ms time window. This difference in N400 amplitude provides evidence for semantic interference in adults contradicting the predictions of the RHM. These results suggest that the conceptual system is active when beginning adult learners process words in their L2.

Brenders et al. (in revision) found evidence for semantic interference in beginning child L2 learners. However, it can be argued that those Dutch children were not true novice learners due to L2 English exposure outside of the classroom. The present study, testing child L2 learners in Central Pennsylvania with minimal exposure to their L2 Spanish outside the classroom, also found a semantic effect. It should be noted that the direction of the difference between semantically incorrect translations and incorrect controls (the semantically incorrect translations more negative going) differed from the direction observed in Brenders et al. (in revision) who found that semantically incorrect translation were less negative going. Because the present study included only five children, it remains to be seen to what extent this effect holds with a larger group of children. Assuming it will, a possible explanation is that the direction of the effect is related to the age difference between the two groups (5^{th} graders in Brenders et al. versus Kindergartners in the present study). Kindergartners more so than 5^{th} graders are still developing conceptual links between L1 words and their meanings, in addition to the L2 word-to-concept mappings, and this developmental difference may be reflected in the children's neurocognitive patterns. Until more Kindergartners are tested the interpretation of these results remains speculative, but generally speaking developmental differences in L1 acquisition potentially affect L2 learning and the nature of the lexical-conceptual links child L2 learners develop.

Likewise, the adult beginning learners in the present study showed a reduced N400 on trials containing semantically related incorrect pairs relative to unrelated controls, whereas the children displayed an increase N400 in reaction to these same pairs in comparison to unrelated controls. The differing patterns of results found for children and adults in this study may be related to the fact that young children are still acquiring semantic categories and may not utilize them in the same way as adults do. Adults may rely on semantic categories more than the children because the adults have fully acquired categories and can use them to their advantage when processing. However, children who are still learning words and categories in their L1 may not use semantic categories yet as a means of facilitating processing. As also noted above, this issue remains speculative until more child data are collected.

A possible explanation for the conceptual activation found in both child and adults learners at this early stage of L2 learning is the context of processing. The present study utilizes a recognition task and past studies have found that the link between concepts and L2 words in early learners is more evident in recognition tasks than production tasks (for review see Van Hell & Kroll, 2013). Furthermore, in particular later versions of the RHM (e.g., Kroll et al., 2010) do not predict an inability of novice learners to access concept but merely *weaker* L2 word to concept links. Therefore, the mixed results regarding conceptual activation suggest that the strength of this link may vary depending on the task and learner circumstances (for review see Kroll et al., 2010; Van Hell & Kroll, 2013; Poarch et al.(2015).

Additionally, ERP measures may be a more sensitive measure of conceptual activation than behavioral measures. Future analyses will also examine the accuracy data of the presently tested child and adult L2 learners. Moreover, it should be noted that Brenders et al. (in revision) is one of the very few papers, if not the only one, that examined ERP evidence related to translation recognition in L2 learners. Therefore, a wide base of empirical evidence is not yet present. However, both Brenders et al. (in revision) and the present study provide evidence for activation of conceptual information early in L2 learning.

To conclude, this study provides preliminary physiological evidence regarding semantic processing during the translation recognition task. Evidence of semantic activation was present suggesting that even in the very early stages of L2 learning, L2 form to concept mappings are available to both child and adult L2 learners. Further data collection and analysis of behavioral data recorded will provide further insights into the nature of these semantic effects. However, preliminary patterns suggest conceptual activation is possible, even in beginning L2 learners. Further research should investigate how to best revise our current theories of second language processing to accommodate these findings.

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Appendix A
Adult and Child Data: Additional Waveforms

Figure 4: *Adult data: Grand average event-related brain potentials at all scalp electrodes for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up. Significant difference in mean amplitude between semantically related pairs, unrelated pairs and correct translation pairs in 300ms - 500ms time window.*

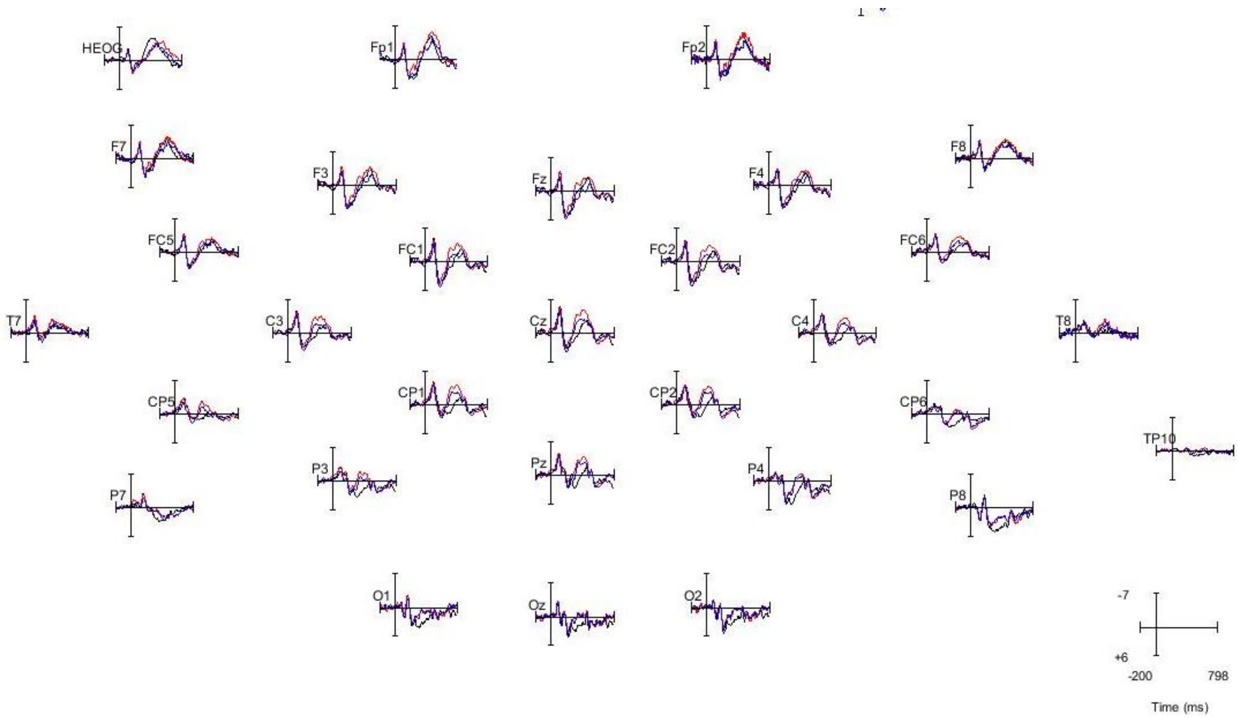


Figure 5: *Adult data: Grand average event-related brain potentials at midline electrodes Fz, Cz and Pz for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up.*

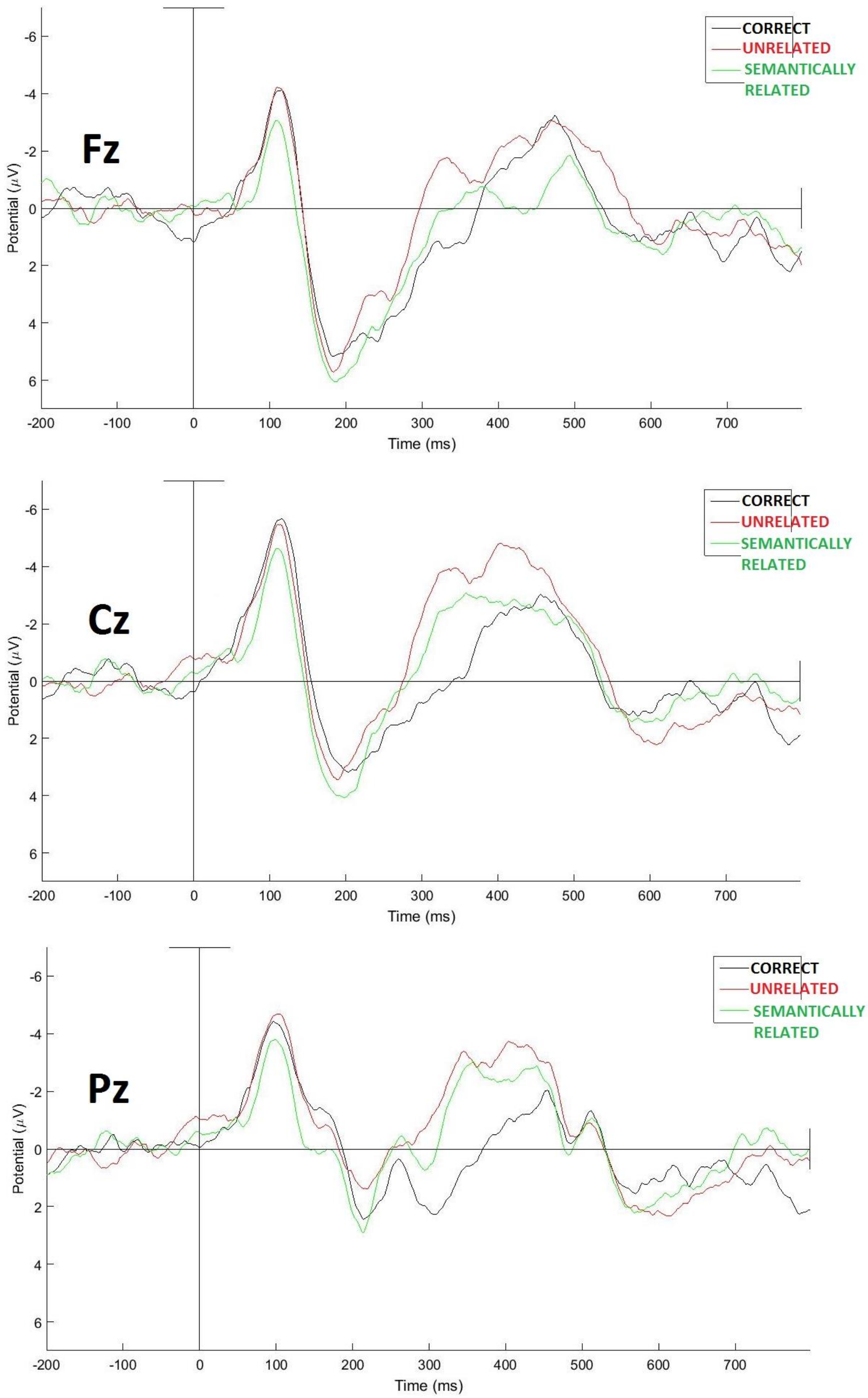
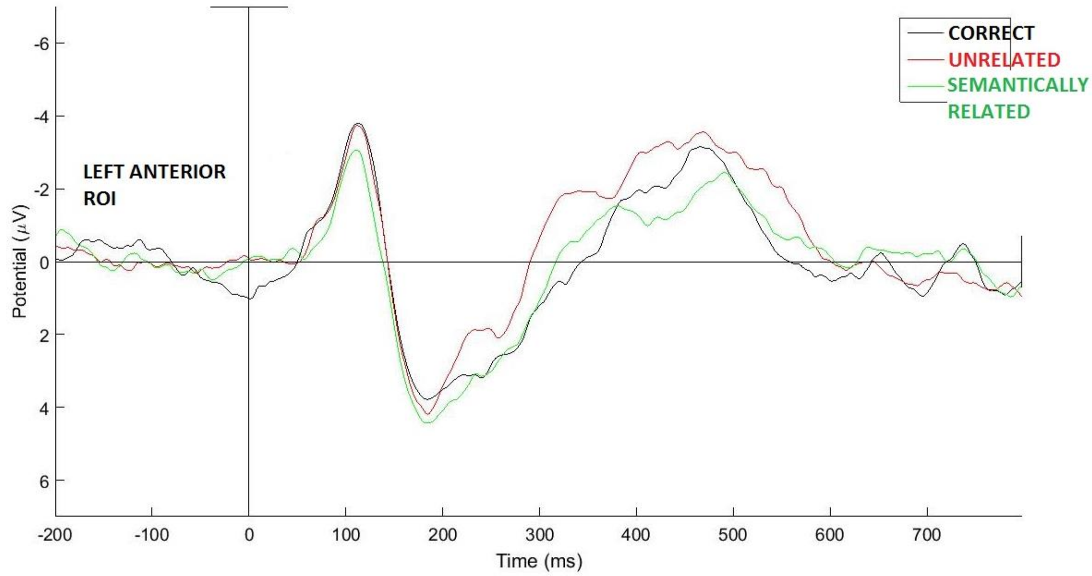


Figure 6: *Adult data: Grand average event-related brain potentials for regions of interest (left anterior, left posterior, right anterior, right posterior) for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up.*



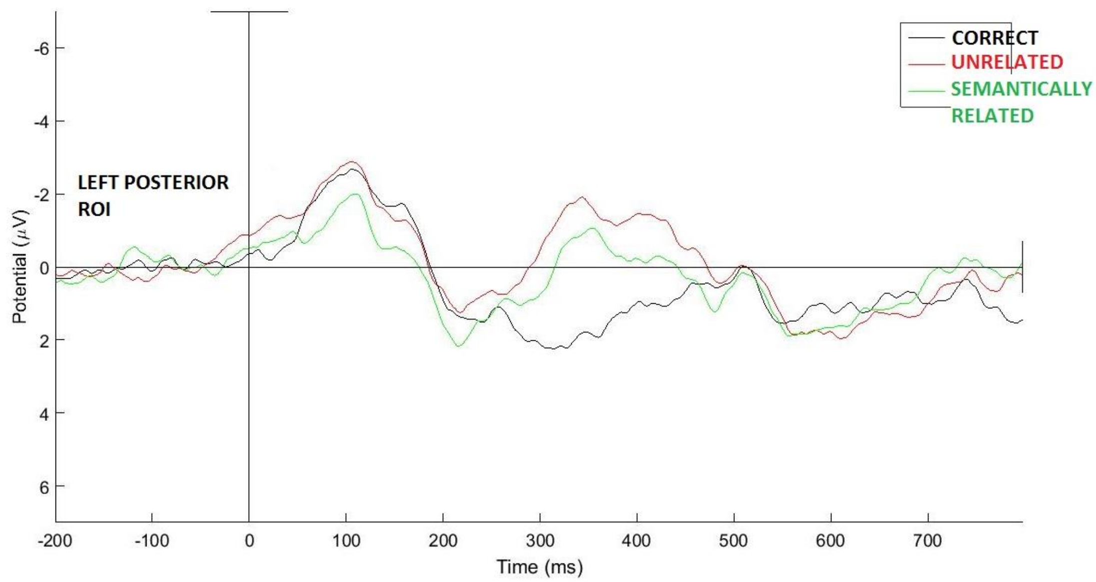
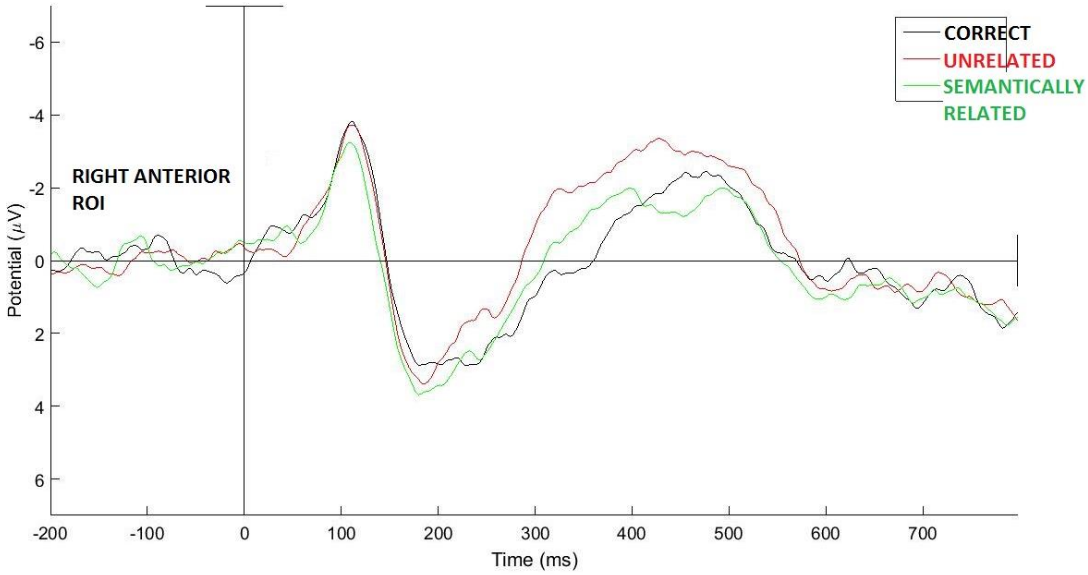


Figure 6 continued



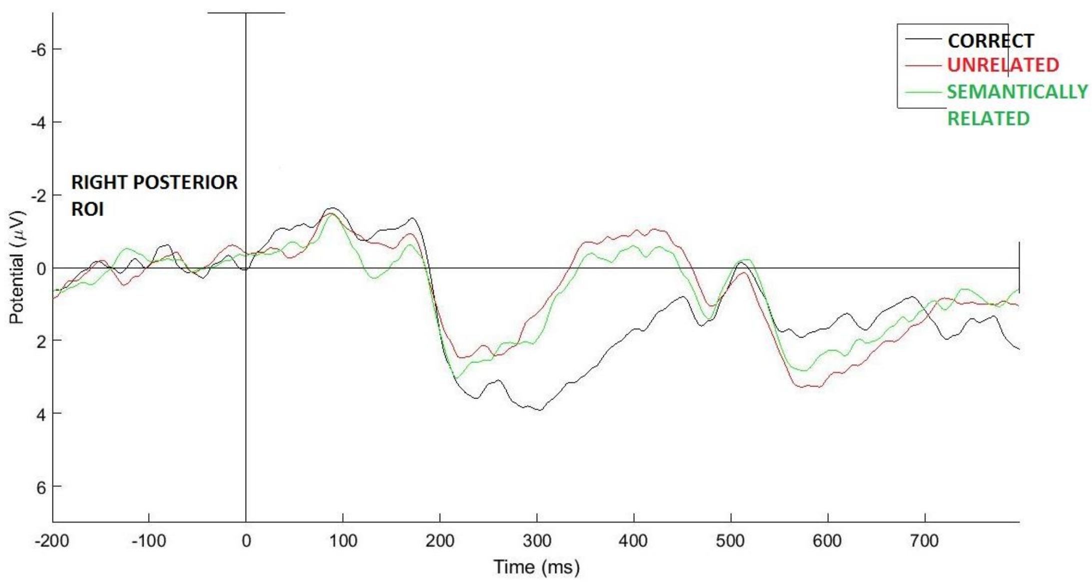


Figure 7: *Child data: Grand average event-related brain potentials at all scalp electrodes for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up. Significant difference in mean amplitude between semantically related pairs, unrelated pairs and correct translation pairs, 300ms - 500ms time window.*

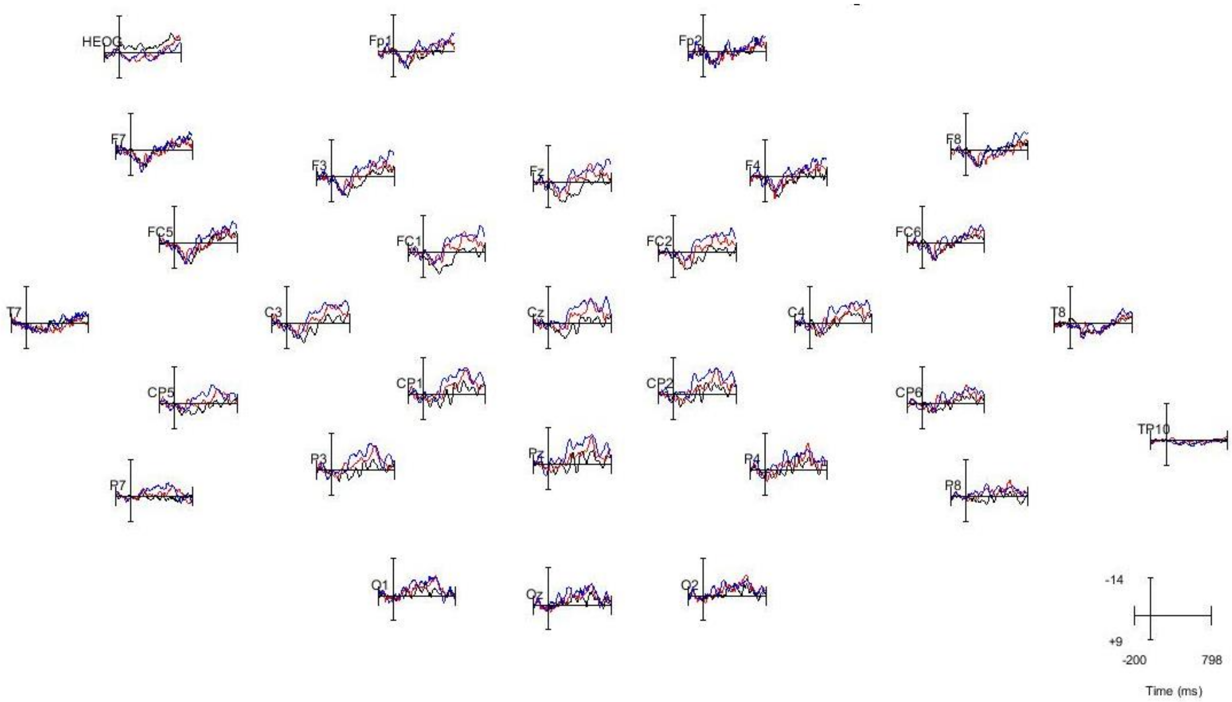


Figure 8: *Child data: Grand average event-related brain potentials at midline electrodes Fz, Cz and Pz for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up.*

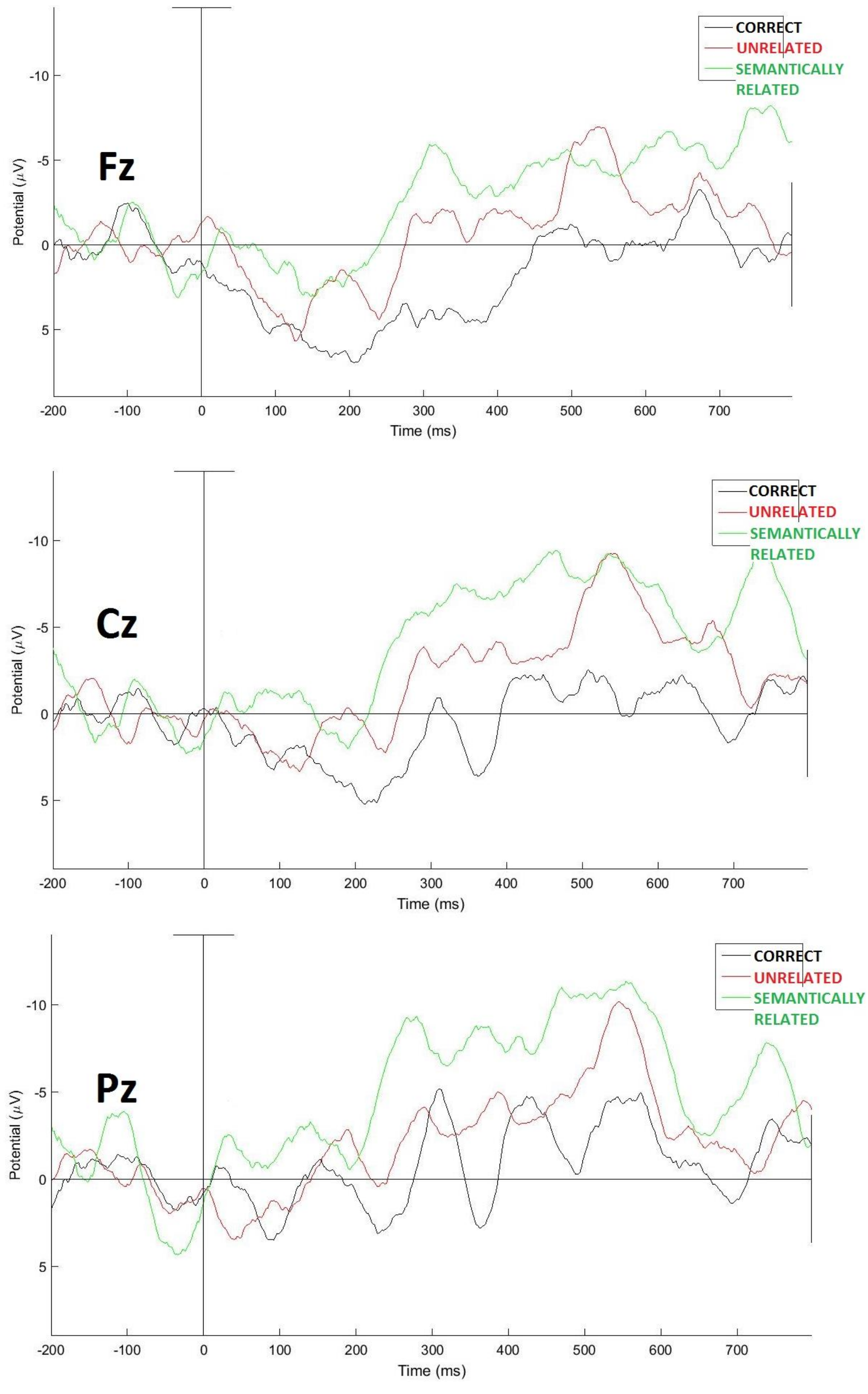
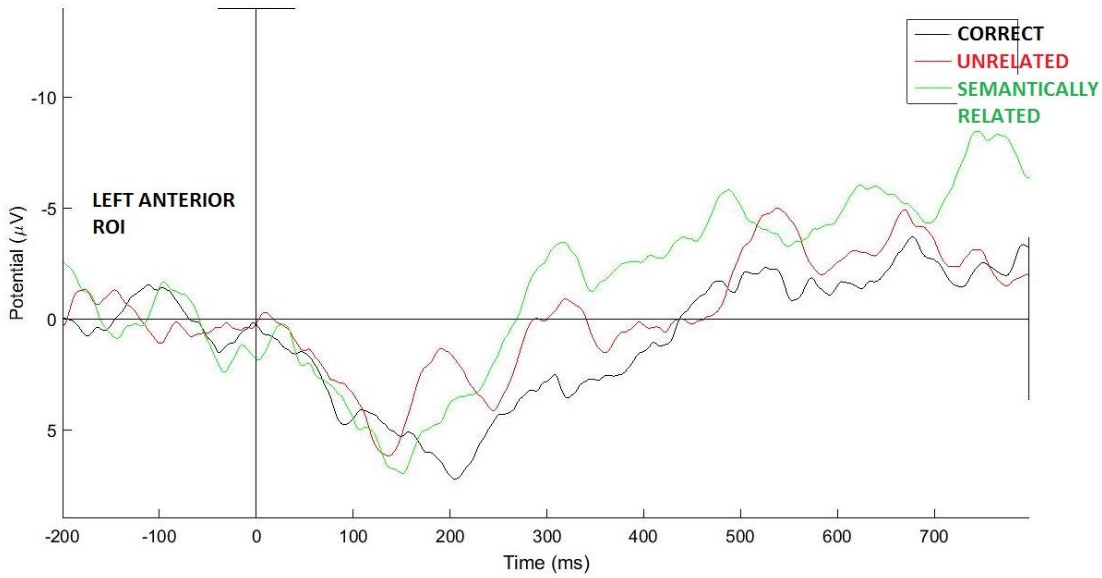


Figure 9: *Child data: Grand average event-related brain potentials for regions of interest (left anterior, left posterior, right anterior, right posterior) for correct translations (black), unrelated incorrect controls (red) and semantically related pairs (green) plotted from 200ms prior to stimuli onset to 800ms post stimuli onset. Negative is plotted up.*



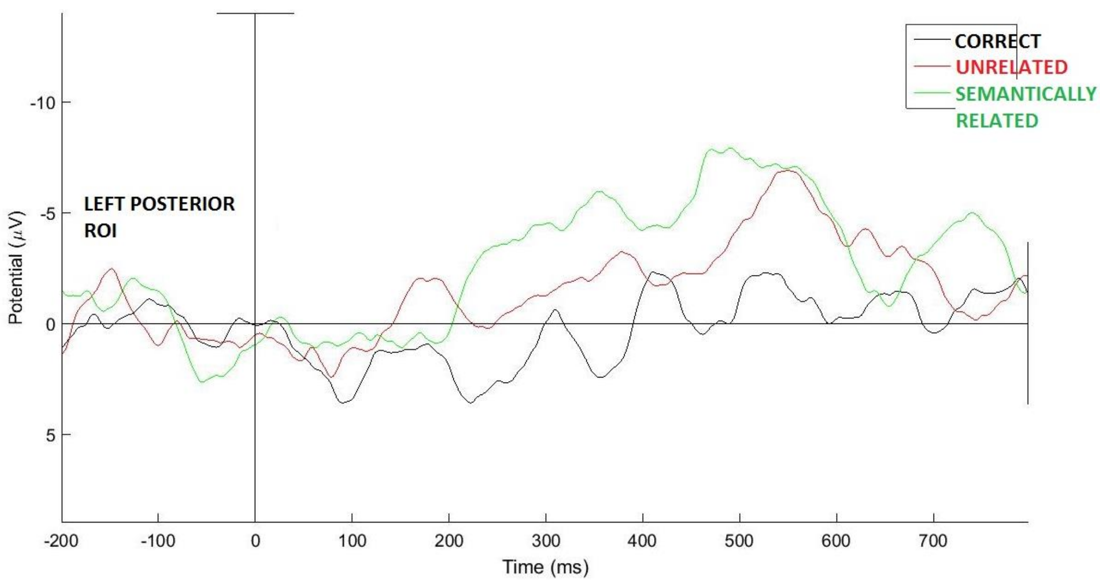


Figure 9 continued