N400 BUT NO P600 WITH SEMANTIC ANOMALIES

N400 BUT NO P600 WITH SEMANTIC ANOMALIES

By

ELOJIKA THAVENDRAN, H.Ba.,

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of Requirements

for the Degree

Master of Science

McMaster University

© Copyright by Elojika Thavendran, August 2012

MASTER OF SCIENCE (2012) McMaster University

(Linguistics and Languages) Hamilton, Ontario

TITLE: N400 BUT NO P600 WITH SEMANTIC ANOMALIES

AUTHOR: Elojika Thavendran, B.A. (McMaster University)

SUPERVISOR: Dr. Elisabet Service

NUMBER OF PAGES: XIVIII

Abstract

N400 BUT NO P600 WITH SEMANTIC ANOMALIES

Elojika Thavendran
Bachelor of Arts
Department of Linguistics and Languages
McMaster University
2012

Event-related potentials (ERPs) have been used extensively in the scientific research of cognitive processing such as language comprehension. Specific responses, such as the negativity called N400 (Kutas & Hillyard, 1980), have in the literature typically been associated with semantic violations in sentences. Another electrophysiological response, the positive P600 waveform, has mostly been associated with syntactic and morphological violations. However, recently, the P600 has been reported also in connection with semantic violations (Kuperberg et al, 2003; van Herten, 2004; Osterhout, 2004). The present research further explores the neurophysiological correlates of processing sentences with semantic and morpho-syntactic violations. It tests the functional interpretations of the P600 component, which has been proposed to reflect syntactic error detection, context updating, or syntactic reanalysis or repair. I contrasted semantic and syntactic possessive violations. The semantic violation conditions (i.e. *The mother borrowed the* ***car's daughter*** *for work yesterday*), morphosyntactic violations (i.e. *The mother borrowed the* ***daughter car*** *for work yesterday)* and double violation sentences (i.e. *The mother borrowed the* ***car daughter*** *for work yesterday)* were derived from the control condition, (i.e. *The mother borrowed the* ***daughter's car*** *for work yesterday).* I explored whether the P600 component may index more general processes than ones related to syntactic error detection. An N400 was seen to our semantic manipulation, i.e. *The mother borrowed the* ***car's daughter*** *for work yesterday.* However, none of the conditions produced a P600.

Acknowledgements

I would like to thank my supervisor Dr. Elisabet Service for her immense support, patience and guidance. I would like to express my very great appreciation to my committee members Dr. John Connolly and Dr. Anna Moro. I wish to acknowledge the moral support provided by Dr. Stroinska and Dr. Colarusso. Advice given by previous students and my fellow colleagues has been a great help in completing this paper. I would like to express my very great appreciation to my grandmothers, my parents (Santhakumari Thavendran and Sellathurai Thavendran), sister (Kajalaxy Thavendran), and my significant other (Ashish Goel). I would also like to thank the Goel family (Nisha Goel, Nitish Goel, Renu Goel and Bhupinder Goel and of course Rolly Goel. I am grateful for the assistance given by all those I've lost this past year. I wanted to finish this in part for them.

Contents

List of Tables

List of Figures

1. Introduction

The hypothesis that there are qualitatively different syntactic and semantic processing mechanisms is difficult to test with simple reaction time paradigms. The rules of syntax govern the order in which sentence elements appear and the grammatical roles they play, whereas the need for meaningful coherence restricts the selection of words at a semantic and pragmatic level (Osterhout & Holcomb, 1992). Although linguistics considers syntactic rules as distinct from semantic constraints, it is not certain whether these restrictions also index different psychological processes. This is because there is a lack of direct evidence suggesting a different response to syntactic as opposed to semantic anomaly. Neuroimaging techniques, such as the recording of electroencephalograms (EEG) and its derivative measures, event-related potentials (ERPs), could help in exploring this distinction at the level of brain responses (Osterhout & Holcomb, 1992). Distinct brain waveforms that reflect semantic versus syntactic anomalies would facilitate such an investigation. The present study explores the neurophysiological correlates of the online processing of anomalous possessive sentences to determine whether the brain distinguishes between two types of violations: syntactic possessive violations vs. semantic possessive violations. Specifically, it explores two electrical brain responses that have been claimed to be respective signatures of syntactic and semantic processing.

Event-related potentials are a measure that might more effectively discriminate between syntactic and semantic anomaly during language comprehension. ERPs are patterned voltage changes in the ongoing electroencephalogram that are time-locked to the onset of a sensory, motor or cognitive event. This is apparent when minute variations of electrical potentials between two points in relation to some reference point pattern differently to a stimulus (e.g., the presentation of a word on a computer screen) to reveal an ERP distinct from the pre-stimulus baseline activity. ERP components recorded at the scalp reflect the summation of electrical activity from a large number of neurons acting synchronously, primarily in the neocortex (Rodden & Stemmer, 2008). Such components have polarity (positive and negative voltage) and latency. These are taken into account when labeling the components. The letter N is used to denote a negativity and P a positivity depending on the peak polarity. This is combined with a number stating the approximate peak latency of the component in milliseconds (e.g., N100 denotes a negativity peaking approximately 100 ms after stimulus onset). Over the years, various language relevant ERP components have been reported, including the ELAN, LAN, N400, and P600 (Kutas & Van Petten, 1994). These components will be described in more detail below.

There are three major goals of using neuroimaging techniques in language processing research: 1) to unfold 'where' and 2) 'when' language is processed in the brain as well as 3) 'how' the different levels of linguistic processing occur and unfold. The second and third goal are precisely why ERPs have been so closely affiliated with language comprehension research. ERPs can help resolve debates concerning models of language processing, such as the division of labour between domain general and domain specific cognitive processing, and whether structure building targets several words in parallel or is a strictly serial process.

An advantage of EEG-based research compared to traditional reading and reaction time paradigms is the multidimensional character of the event-related brain measures. This is because ERP components can be distinguished by such characteristics as latency, amplitude, polarity and scalp distribution (Osterhout & Holcomb, 1992). *Amplitude* is defined as the difference between the mean prestimulus baseline voltage and the largest (positive or negative going) peak of the ERP waveform within a time window determined by stimulus modality and task conditions (Polich, 2012). The *latency* is typically defined as the time from stimulus onset to the point of maximum (positive or negative) amplitude within this same time window (Polich, 2012). This multidimensional character of the ERP signal provides a number of ways to test hypotheses regarding qualitative differences in processing information at different representational levels, such as syntax vs. semantics. For example, consider the amplitude of an ERP component. This reflects the activity of more than one generator. This is because post-synaptic electrical fields are volume-conducted to the scalp. Under this assumption, when volume-conducted electrical fields intersect, they have an additive effect. These additive amplitude effects on scalp-recorded activity are likely to be a reflection of independent generators (Helmholz's Law of Superposition) (Coulson, King & Kutas, 1998).

The independence of the representational levels of syntactic and semantic processing can be tested by experimentally manipulating variables thought to engage different sorts of processing to see if this gives rise to additive effects. These additive effects affect the amplitude of ERP components. Furthermore, under the assumption that cognitively distinct processes are sub-served by anatomically distinct brain areas, one might expect different ERP components (with different generator sets) to index syntactic versus semantic processing. Thus, similar to the existence of ERP components specific to language, supporting the assumption of the modular nature of the language processor, representation-specific ERP components would support the independence of syntax and semantics (Coulson, King, Kutas, 1998). An additional method to distinguish between representational levels is to analyze the scalp distribution of an ERP response. This is because distinct scalp topographies strongly suggest some difference in underlying neural generators. However, without a model of the neural generators responsible for a given set of ERP data, only crude assumptions about which brain regions are responsible for the generation of an ERP component can be made.

Frequently replicated ERP components at the scalp are assumed to reflect specific neurocognitive processes (Hillyard & Picton, 1987). For example, one well established language relevant ERP component is the N400 (Kutas & Hillyard, 1980), generally assumed to reflect semantic processing (Coulson, King, Kutas, 1998). Similarly, researchers have argued that the P600 is an indicator of coping with pure syntactic violations (amongst other syntactic interpretations). The present study used a violation paradigm to challenge this interpretation of the P600. Violation paradigms are the most common way of studying the ERP correlates of morpho-syntactic processing. The underlying notion here is that violations should disrupt (or increase) the workload of the brain systems involved.

Below, I will discuss the relevant language comprehension ERPs. First, two ERP components repeatedly identified as markers of two stages of syntactic processing will be described. These two components have been labeled the early left-lateralized anterior negatively (ELAN) and the left-lateralized anterior negatively (LAN). Subsequently, the P300 component and its functional interpretation is reviewed. Next, the N400 is discussed with regards to representing something fundamental about the processing of meaning (meaningful vs. nonmeaningful dimension). I will then delve into the P600 and outline previous functional interpretations.

1.1 Language-related ERP components

1.1.1 Early Left Anterior Negativities (ELAN)

The earliest sentence-level ERP component discussed in the literature is the early left anterior negativity (ELAN) (Friederici, 2002). The ELAN is thought to correlate with the identification of the syntactic category of a word, such as noun, verb or preposition. Thus ELAN, occurring at 120–200 ms after word onset (or after the part of the word which provides the word category information) may be sensitive to word category violations. The earliness of this component was originally attributed to the ease with which word category information can be extracted from the stimulus (Friederici, 2011).

Patients with circumscribed brain lesions have allowed researchers to infer where in the brain this initial ELAN process takes place. The left frontal cortex has been reported to play a crucial role in generating the ELAN, as patients with left frontal cortical lesions did not show this component when compared to patients suffering from only left basal ganglia (frontal sub-cortical) lesions (Friederici, 2011). Additionally, the left frontal and left anterior temporal cortex have been proposed to be involved with the early structure building process because the presence of the ELAN is also affected in patients with lesions in the left anterior temporal lobe, but not in patients with lesions in the right temporal lobe (Friederici, 2011). The magnetic equivalent to the EEG, magnetoencephalography (MEG), provides better topographic resolution than electrical measures. With the use of MEG, the ELAN effect has been localized in the anterior temporal cortex and the inferior frontal cortex, or solely in the temporal cortex for auditory language experiments (Friederici, 2011).

In a number of studies, the ELAN may have reflected violations of phonological or orthographic expectations (related to word categories) rather than being an automatic response to syntactic violations (Friederici, 2011). In the absence of phonological/orthographic markers, however, word category violations have been reported to elicit a somewhat later response, one that researchers have dubbed as the left anterior negativity (LAN) because of its latency around 300–500 ms (Hagoort, 2003). Friederici (2003) conducted two similar German probe verification studies that yielded LAN effects when the stimuli were presented visually as opposed to ELAN effects when they were presented in the auditory modality. It is speculated by Steinhauer & Connolly (2008) that the ELAN is distinct from the later occurring LAN in that it reflects interruptions of highly automatic processes during the very first phase of building up a phrase structural representation. Additionally, the ELAN has been reported to be uninfluenced by the proportion of violations in the stimulus set. This could be because ELANs are present independent of processing strategies. Currently, word category violations are most frequently associated with ELAN responses, whereas other grammatical anomalies such as morphosyntactic violations are thought to usually evoke a LAN (Martin-Loeches et al., 2006).

In psycholinguistics, the early latency of the ELAN, has served as strong empirical support to 'syntax first' models. 'Syntax first' models aim to preserve the notion of an initial autonomous phase for syntactic parsing as opposed to interactive (syntax, semantics & pragmatic simultaneously) models. Interactive models or constraint-based models propose that syntactic ambiguities trigger the parallel activation of all analyses consistent with the grammar (Trueswell & Tanenhaus, 1994). Overall, researchers claim, violations syntactic in nature share a common pattern: they produce anterior negativities (ELAN and LAN) (Martin-Loeches et al., 2006).

1.1.2 Left Anterior Negativities (LAN)

Neurolinguistic models assume that the assignment of grammatical relations takes place after the initial structure building processing stage (Friederici, 1995). This includes not only understanding semantic features (i.e. animacy), but also syntactic features such as subject-verb-agreement and case marking. Two ERP components have been reported during this stage: the LAN (occurring 300–500 ms from word onset) is found for syntactic processes, whereas semantic-thematic violations elicit the N400 (Neville, 1991). Earlier research reported LANs primarily for outright syntactic violations and not for structure ambiguities. LANs were reported for word category violations (Neville, 1991) and violation of number agreement in English. The ELAN only appeared to violations of expected speech sounds or orthographic patterns in particularly constrained structural environments (Friederici, 2011). Hence, it was later linked to the highly automatic initial build up of local phrase structure (Friederici, 2011). Steinhauer & Connolly (2008) suggest that the later LAN more directly reflects structural/syntactic processes because of its presence with over-generalizations in morpho-phonology (i.e. childs instead of children). LAN is also associated with the interruption of proceduralized cognitive operations such as rule based sequencing. (Steinhauer & Connolly, 2008).

A specific violation can affect more than one aspect of language. One such case is a grammatical violation affecting semantics. Consider a gender violation between a pronoun and its antecedent. This grammatical violation jeopardizes meaningfulness (semantic domain) (Kutas & Federmeier, 2011). Morphosyntactic information provided by verb's inflection (i.e. number and person) is also essential for the assignment of grammatical roles in a sentence (especially in languages with free word order). Violations of subject-verb agreement (i.e. singular vs. plural) in an inflecting language induce a LAN between 300–500ms. Within the interpretative framework that the ELAN reflects interruptions of highly automatic processes between 100–300ms, the later occurring LAN (300–500ms) is thought to reflect other morphosyntactic operations affecting agreement features or verb arguments (Friederici, 2011). This is because the likelihood of the LAN appears to increase with the amount of morphosyntactic markings in a given language (Friederici, 2007). LAN is also present when the morphosyntactic information is crucial for the assignment of syntactic roles. In Hebrew, gender agreement between subject, noun and verb is essential. A violation of this morphosyntactic marking produces a LAN. Thus, currently the LAN is understood as sensitive to violations of morphosyntactic marking that is crucial for the assignment of grammatical relations in a sentence (Friederici, 2011).

1.1.3 P300a and P300b

The P300 (sometimes called the late positive component 'LPC') was first reported by Sutton, Braren, Zubin & John (1965). Sutton et. al. manipulated stimulus information to see how the brain responds to infrequent stimuli among a series of frequently presented auditory tones. Stimulus manipulation via such oddball paradigms allowed the P300 to be functionally understood as related to stimulus probability and task relevance effects. This is because a large P300 was seen to the deviant conditions. Over the years, the P300 has been functionally interpreted a number of ways from context updating, to resource (attentional) allocation and even as an index of recall memory. Currently, the phenomenon is considered to reflect an information-processing cascade associated with attentional and memory mechanisms (Polich, 2012).

The typical experimental paradigms in which the P300 is observed are of three kinds. In a single-stimulus oddball procedure an infrequent target is presented with no other stimuli, whereas in the traditional oddball two-stimulus task an infrequent target is presented against a background of frequent "standard" stimuli (Squires, Squires & Hillyard, 1975). The three-stimulus task presents an infrequent target against a background of frequently occurring standard stimuli with infrequently occurring distractor stimuli. In all three of these procedures, participants show a P300 to the target stimulus (Polich, 2012). Like many other ERP waveforms, the P300 is measured by examining the amplitude (positive going), the peak latency (approximately at 300 ms) and the scalp distribution of the response. The P300 is characterized as an amplitude change over the middle electrodes, increasing from frontal to parietal electrode sites (Polich, 2012). The P300's latency is thought to index the time required to detect and process a target item (shorter over the frontal compared to parietal areas).

The names P3a and P3b denote distinct subcomponents of the P300. The two-stimulus paradigm mentioned above produces a positive-going waveform called the P3a in the absence of a task. Its task-relevant counterpart P3b is produced during target stimulus processing (Squires, Squires & Hillyard, 1975). P3a typically has a central/parietal maximum with a short peak latency. Research on patients with lesions has helped with localizing the neural generators of these components. For example, in one study (Polich, 2012), patients with frontal lobe lesions showed a significant reduction of the P3a amplitude, whereas parietal P3b amplitude remained at a typical level. Likewise, patients with focal hippocampal lesions produced a reduced P3a, but normal P3b components (Polich, 2012). This indicates that the frontal lobe and hippocampus are essential in generating the P3a. The P3b (a positive going component) with centro-parietal maxima is known to reflect: 1) the resolution of prior uncertainty and 2) the task relevant surprise value of the deviant stimulus (Polich, 2012). Its amplitude is inversely related to the eliciting item's subjective probability of occurrence (the less probable an event, the larger the P3b) (Kutas & Federmeier, 2011).

The review above has described how each of the ERP waveforms discussed so far (ELAN, LAN P3a & P3b) have their own signatures. It is in understanding the unique composition of each one of them that we begin to discern the underlying meaning of these ERPs. Below we discuss the P600 component, often studied in sentence processing experiments. Although, it has been suggested to be the main brain signature for syntactic processing,there exists at present no consensus on its exact functional interpretation.

1.1.4 The lexico-semantic integration: The N400 component

Kutas and Hillyard (1980, 1984) illustrated that contextually anomalous words appearing at the end of a sentence or embedded within a sentence produce a negative going ERP component that peaks at approximately 400 ms after word onset. This N400 response is thought to reflect semantic congruity. Decades worth of papers published on semantic processes in different languages show this centro-parietal N400. The N400 was originally observed to violation of semantic expectancies before it was realized that each word in a sentence produced a N400. Its amplitude is inversely related to cloze probability of a word (usually terminal word) in a sentence context. Thus, the amplitude of the N400 appears to be a function of the semantic fit between the target word and previous context (Kutas & Federmeier, 2011). Its amplitude is said to increase when a word does not have lexical access, for example, when non-words and pseudo-words are processed. A prominent N400 can also be observed when the second word of a word pair does not fit the first word semantically (Kuperberg, 2007) or when the selectional restrictions of a verb-argument relation is violated (Kuperberg, 2007).

There are also situations in which the amplitude of the N400 is said to decrease (Friederici, 2011). For example, as a sentence unfolds, each word provides constraining contextual and pragmatic cues that increase predictability. This facilitates sentence-level meaning processing and decreases the amplitude of the N400. Currently, the N400 is understood as an indicator of lexical processes, lexical-semantic processes, semantic contextual predictability and predictability due to world knowledge. It reflects processes at different levels that are thought to be related to language comprehension. However, N400 amplitude is not a function of pure language processing as it is also sensitive to violations of world knowledge.

In localizing the semantic N400 effect, both at the word and sentence level, researchers have used methodologies such as MEG recording to pinpoint the main generators of the N400 in the vicinity of the auditory cortex (Friederici, 2011).

Within the domain of language, the N400 is correlated with semantic information carried by content elements such as nouns, adjectives as well as verbs. Verbs provide selection restriction information from the semantic domain. A verb's selection restriction information indicates what semantic features the related noun arguments must have. For example, the verb 'eat' requires a noun with the feature of "edible" (as in *eat the cheese* not *eat the table*, which produces a N400). The syntactic domain considers both number and type of arguments. This includes agreement violations (e.g. *The spoiled child throw the toys on the floor.*) and word order violations (e.g. *the expensive very tulip*). The N400 followed by a late positivity (*P600*), has been observed to a verb's syntax related information such as how many arguments a verb can take (intransitive vs. transitive verb). Verbs not only restrict the number the arguments that can be taken, but also the type of arguments (i.e. direct object, indirect object or subject). Violations of number and type of arguments, defined as part of the syntactic domain, elicit a biphasic N400/P600 pattern. However, violations of selection restrictions defined as semantic processing only show a N400 (Friederici, 2011). The biphasic N400 response has, yet, to be investigated in terms of where in the brain these processes take place. It is important to note that further research must show whether the N400 observed in the violation of semantic information (selection restriction) is different from the biphasic N400/P600 pattern found for the syntax-related information is a unitary component or one that varies according to information type.

1.1.6 Syntactic processing: the P600/SPS

The P600 (also referred to as the syntactic positive shift, *SPS*) is an ERP waveform typically seen to syntactic violation. It is a positive deflection that peaks approximately at 600 ms after presentation of target stimuli. Topographically, it is seen centrally with largest amplitudes in the parietal regions. Where in the brain specifically this process takes places remains unclear because the P600 has not been localized using time-sensitive neuroimaging measures. The few published MEG studies have localized the P600 in the middle temporal gyrus and the posterior portion of the temporal cortex (Friederici, 2011). Additionally, lesion studies have implicated the basal ganglia as part of the circuit supporting processes reflected in the syntax-related P600 (Friederici, 2011). A debate since the 90's concerns the underlying cognitive processes driving the elicitation of the P600. Even today, the full functional interpretation of the P600 is unclear. It is also important to note that the P600 is difficult to differentiate from the LAN or N400 in fMRI studies due to all of these waveforms occurring in close vicinity (Friederici, 2011).

The SPS ERP measure was originally taken to reflect syntactic processes in general (Hagoort, Brown & Groothusen, 1993) for sentences such as, "*The spoilt child throw the toys on the floor*," where the presence of the SPS, they concluded, as the difficulty the parser experiences assigning the preferred (already built) structure to the future incoming string of words. This led to the conclusion that the SPS might have a robustness in the domain of syntactic computations similar to the N400 in the domain of semantic computations. Around the same time, a component named the P600 was independently reported to specifically represent syntactic reanalysis and repair (Osterhout & Holcomb, 1992) when processing garden path sentences (*The horse ran past the barn fell;* Osterhout & Holcomb, 1992). These and similar results found by Osterhout et al. (1994), led the researches to argue that the P600 response reflects the cost of reprocessing or reanalyzing the sentence when a syntactic anomaly is detected.

Coulson, King and Kutas (1998) have suggested an alternative interpretation. Because the P600 shares various topographic characteristics with the P300, they concluded that the P600 is a) a member of the P300 family and b) a response to the violation of one's expectation that a sentence is grammatical. This conclusion fell in line with the understanding of the P300, which is observed in response to the presentation of unexpected attended stimuli or stimuli that violate expectations. However, this interpretation has been questioned due to the appearance of the P600 in the absence of task demands. Osterhout et al.'s (1996) stimuli discounted the theory of the P600 as a member of the P300 family. This was because the subject-verb agreement violation (*The doctors believes the patient will recover.)* elicited the P600, while the expectancy violation (*The doctors BELIEVE the patient will recover*.) evoked a P300.

Another interpretation proposed by Kaan et al (2000) using syntactically complex, yet grammatical, sentences proposed the P600 as an indicator of syntactic integration costs. The findings led Kaan et al. (2000) to conclude that although they do not discount syntactic reanalysis, their view certainly emphasizes the relationship between reanalysis and integration. Until recently, the P600 was thought to vary as a function of purely syntactic variables (Friederici, 2011). Later studies showed the P600 to interaction of syntactic and semantic anomaly at the sentence level, which led to the interpretation that it must reflect sentence-level integration processes of syntactic and semantic information (Kuperberg, 2006). Most recently, however, this has been challenged by studies reporting a P600 effect to sentence-level semantic violations (Kuperberg et al., 2003; van Herten, Kolk, Chwilla, 2004; Kim, Osterhout, 2005).

Kuperberg et al., (2003) tested how the brain responded to two types of semantic violation: a thematic role animacy violation (*For breakfast the eggs would only eat toast and jam.)* and a non-thematic role pragmatic violation (*For breakfast the boys would only bury toast and jam.*). They found the expected N400 response to only the pragmatic condition, but an unexpected P600 to the thematic role animacy violation condition. Their conclusion was that the P600 is sensitive to thematic structure violations. Specifically, if the animacy information used to build the thematic structure encounters information that contradicts the built structure, a P600 is produced.

van Herten et al. (2004) also reported P600s to semantic anomalies. In an experiment with Dutch sentences that were semantically unacceptable but morphosyntactically agreed in number (*The fox [sg] that hunted [sg] the poachers [pl]stalked through the woods*.) or that failed to agree in number (*The fox [sg] that hunted [pl] the poachers [pl] stalked through the woods*), .the semantically unacceptable conditions evoked a P600. The authors interpreted this as signifying a conflict monitoring process where the parser simultaneously uses semantic and syntactic information to build a plausible and grammatical structure. Encountering conflicting information from either stream (semantic or syntactic) triggers a P600 effect. This hypothesis could also be used to interpret the results attained by Kuperberg et al. (1993), i.e. that a P600 was produced when animacy information that falls within the domain of semantics did not match with the presented syntactic structure.

1.1.6 Current Experiment

The current experiment was motivated by recent works such as Kuperberg (2003) and van Herten et al. (2005) for the unexpected presence of a P600 to semantic anomalies. The present study examined event-related potential (ERP) responses to visually presented sentence-embedded morphosyntactic, semantic, and double violations. We aime to study what cognitive process the P600 represents and in doing so how the semantic and syntactic constrains are implemented during sentence processing, i.e. whether these domains are independent and serial versus interactive and parallel. We propose that neither of the two responses (N400 or P600) need to be specific to a single level of language processing. We agree with the consideration that the N400 is sensitive to how well a critical word is anticipated and integrated to the previous context. However, we propose that the P600 is a more general component that is sensitive to overall predictable pattern in violations (whether syntactic or semantic). This view is different from the traditional syntax versus semantic theories. Observing how the N400, LAN (ELAN) and P600 change in the double violation compared to the single violations allows for conclusions about the interplay between syntax and semantics during sentence comprehension. We hypothesized syntactic violations to elicit a LAN, followed by the late centroparietal positivity (P600). Semantic anomalies should elicit an N400 as well as a P600. Thus, if a P600 is seen in response to semantic anomalies, then the current functional interpretation of the P600 is limited. Kuperberg (2003) and van Herten et al. (2005) used stimuli comprised of semantically unacceptable sentences that violated syntactic rules, as well. In this study, the semantic condition does not violate any syntactic rules and is purely semantic in nature.

The latency and different morphology of the P600 response to morphosyntactic violations compared to semantic anomalies can indicate to some extent that the responses are functionally different. This can help with suggesting when different levels of processing occur (i.e. if morphosyntactic information is processed prior to lexical-semantic information), which lends itself to the serial vs. parallel debate (syntax first models). This can also help with narrowing the current P600 debate in cognitive. Because previous research have illustrated a P600 with various violations (syntactic and semantic in nature), uncovering many of the conditions under which the P600 is evoked can help with re-examining a more accurate picture of what the P600 functionally represents.

The aims of this paper are as follow: 1) produce a P600 to semantic anomaly. This will show that previous studies interpreting the P600 as an indicator of pure syntactic anomaly are limited. Additionally, it will illustrate that the P600 is unlike the N400 in that it is not always elicited to one type of stimuli. 2) Its appearance to both semantic and syntactic anomaly proposes it might represent a more general activation of recognition processes within episodic memory.

2 Method

2.1 Participants. A total of 17 (15 females and 2 males) undergraduates from McMaster University aged 20–24 (mean = 21.5) participated in the study. Three participants' data were rejected because of an insufficient number of trials without artifacts. All participants were right-handed. Selection criteria required all participants to have normal or corrected-to-normal vision (glasses) and to be native speakers of English. Participants were asked to fill out a short questionnaire to verify native language, handedness and alertness. Written consent was obtained from all subjects before participation according to the guidelines of the McMaster University Research Ethics Board.

2.2 Construction of stimuli. A total of 60 sentence stimulus sets were created. Each set contained 4 conditions to yield 240 stimulus sentences (see APPENDIX). Each sentence exemplar consisted of the following sequence: subject NP made up of determiner + noun, verb, object NP made up of determiner + possessive phrase (animate possessor and item being possessed) and a prepositional phrase (PP: preposition and NP). There were four variants within each set: grammatically and semantically acceptable control sentence, semantically anomalous sentence, morphosyntactically anomalous sentence and a sentence that contained both violations (semantic and morphosyntactic) (see Table 1). All sentences consisted of 9 words with the 5th and 6th word as the critical region for comparison. Each of the anomalous sentences was derived from an acceptable control sentence. The words preceding and following the critical region remained the same within a set. The set of 60 sentences were closely matched. Only the violation regions (5th and 6th word) differed between the conditions. These experimental sentences were randomly divided into 3 blocks with a 1:1 ratio of filler sentences. The list consisted of a total of 360 sentences (180 experimental sentences and 180 filler sentences) evenly split into three blocks. Table 1 provides an example of the grammatically correct and anomalous conditions. The crucial regions are underlined. The entire set of experimental materials is presented in the APPENDIX.

Table 1. Examples of Sentence Types

Control	*The mother borrowed the <u>daughter's car</u> for work yesterday.*
Semantic violation	*The mother borrowed the <u>car's daughter</u> for work yesterday*
Syntactic violation	*The mother borrowed the <u>daughter car</u> for work yesterday.*
Double violation	*The mother borrowed the <u>car daughter</u> for work yesterday.*

2.3 Ratings of stimuli. In order to help with stimulus selection, a pre-experiment was conducted. The primary goal of this pre-experiment was to survey both the grammaticality and plausibility of all the constructed stimulus sentences for the EEG study. An online survey was created and recruited different participants than those participating in the EEG paradigm. The survey asked participants to judge both the grammaticality and plausibility of a list of 240 possible stimulus sentences (see APPENDIX). Using the online-subject pool of the Department of Linguistics and Languages, 97 native English speakers were recruited from McMaster University to rate the sentences' grammaticality and plausibility on 5-point scales (5 indicating ungrammatical or implausible and 1 indicating grammatical or plausible) in exchange for 1% course credit. Participants rated the control sentences as acceptable/grammatical 89% (SD = 2.3) of the time, the sentences with mophosyntactic violations 5% (SD = 2.8), the sentences with a double violation 4% (SD = 2.7) and the sentences with a semantic violation 3% (SD = 1.3) of the time.

2.4 Procedure. Participants were tested in a single session lasting 2 h (including 30 min of experimental preparation). Each participant sat in a comfortable chair facing a computer screen in a dimly lit room separate from the experimenter. Sentences were visually presented on a computer screen in a word-by-word fashion (rapid serial visual presentation). Each participant was instructed to read as normally as possible and try to understand the sentences. Each trial consisted of the following events: a fixation cross appeared in the centre of the screen for 500 ms, after which the stimulus sentence was presented. Each word appeared in the centre of the screen for 350 ms with an interstimulus interval (ISI) of 300 ms (SOA = 650 ms). For 1/3 of the trials, a 2000-ms interval followed each sentence. The prompt, 'Was that grammatical?' appeared asking participants to decide if the preceding sentence was grammatical. The prompt remained on the screen until the subject responded to the question. Participants were instructed to answer using "Y" or "N" on the keyboard. Subjects that responded within the allotted time were given a 500-ms delay before the fixation cross reappeared. This delay was designed to reduce any contamination of the ERP waveform by any response-sensitive brain activity. For those that failed to respond, a fixation cross appeared immediately after the 2-sec response window. The 1/3 of the trials for the grammaticality verification task were randomly chosen within the blocks to increase the likelihood of participants attending to the stimuli. For the remaining 2/3 of the trials, a 1000-ms black-screen interval followed the end of each sentence.

2.5 Data acquisition and analysis. The EEG was recorded from 64 Ag/AgCl electrodes held in place on the scalp by an elastic cap. The electrodes were placed in standard International 10–20 Systems locations. Thirty-two channels covered the scalp over the left hemisphere (A1-A32) and 32 channels over the right hemisphere (B1-B32). Reference electrodes were placed on the left and right mastoid (EXG2 and EXG3, respectively) as well as on the tip of the nose (EXG1). Vertical eye movements and blinks were monitored by means of two electrodes. One was placed above the right eye and the other to the right of the right eye. All 64 electrodes were referenced offline to the left and right mastoids. The EEG signal was recorded online with a bandpass of 0.1-100 Hz and was continuously sampled at 512 Hz by an analog to digital converter. It was then sampled offline with a bandpass of 0.1-30 Hz. ERPs, time-locked to the onset of a target stimulus (5th and 6th word) were averaged off-line within each sentence type (control, semantic violation, morphosyntactic violation and double violation) for each subject at each electrode site. Grand averages were then created by averaging the event-related responses of all participants.

ERP components of interest were quantified as mean voltage within a time window of activity. After visual inspection of the data, the following windows were employed: 300–500 ms (N400), 700–800 ms (P600). Repeated measures analyses of variance (ANOVAs) were performed on the above dependent measures. Bonferroni correction was used to counteract the problem of multiple pairwise comparisons. A two-way 4 x 9 ANOVA was conducted on the 5th word (the first word in the critical region). This design crossed the four levels of condition type with nine levels of electrode position. A three-way 2 x 2 x 9 ANOVA model was used for analysis on the 6th word (the critical word in the violations). This design crossed two levels of morpho-syntactic sentence acceptability (morpho-syntactically acceptable vs. morpho-syntactic violation) and two levels of semantic sentence plausibility (plausible vs. implausible) with nine levels of electrode position. These 9 sites are as follows: midline (Fz, Cz, Pz), right of midline (F4, C4, P4) and left of midline (F3, C3, P3). Significant main effects were followed by t-tests.

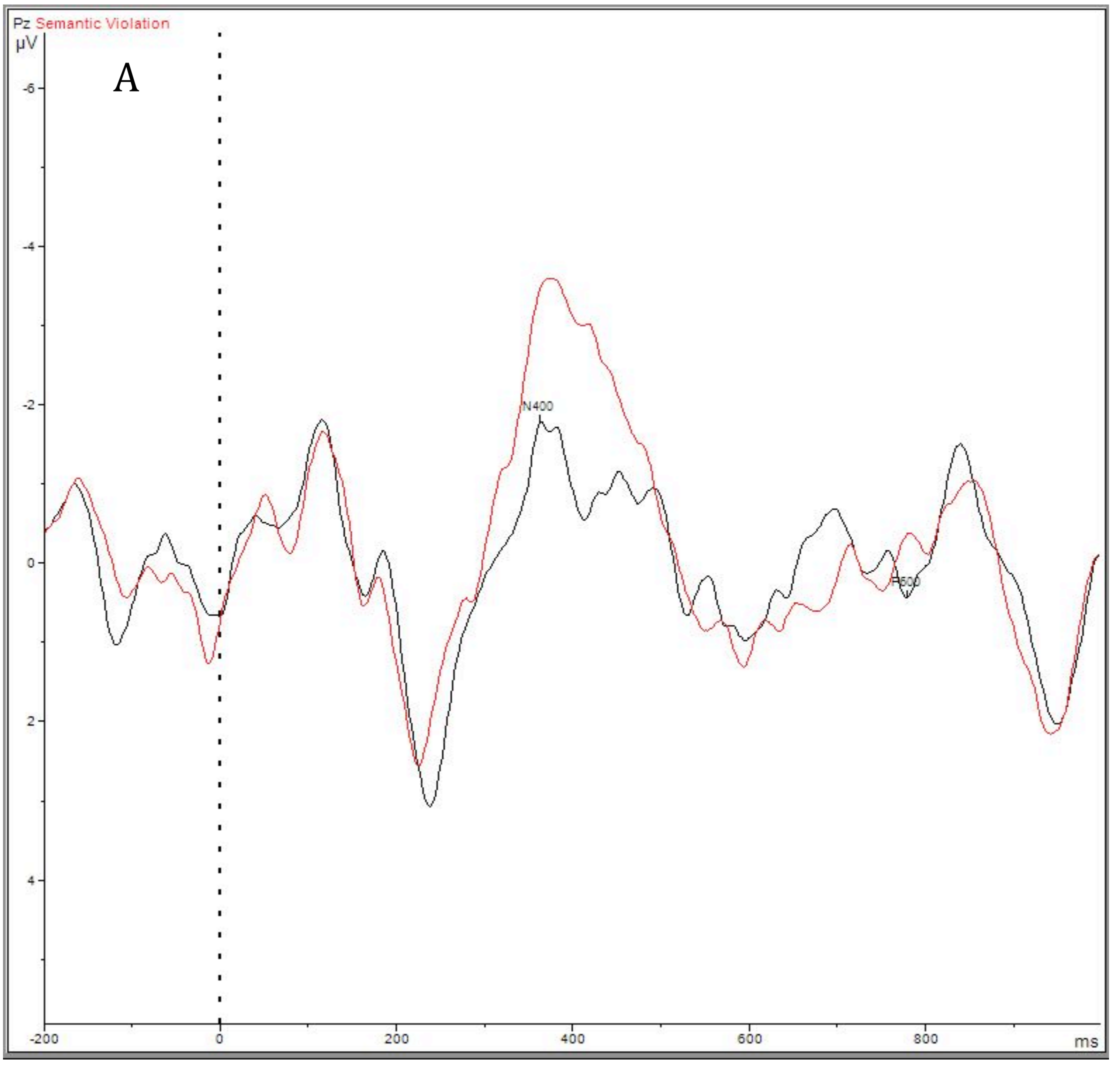
3 Results

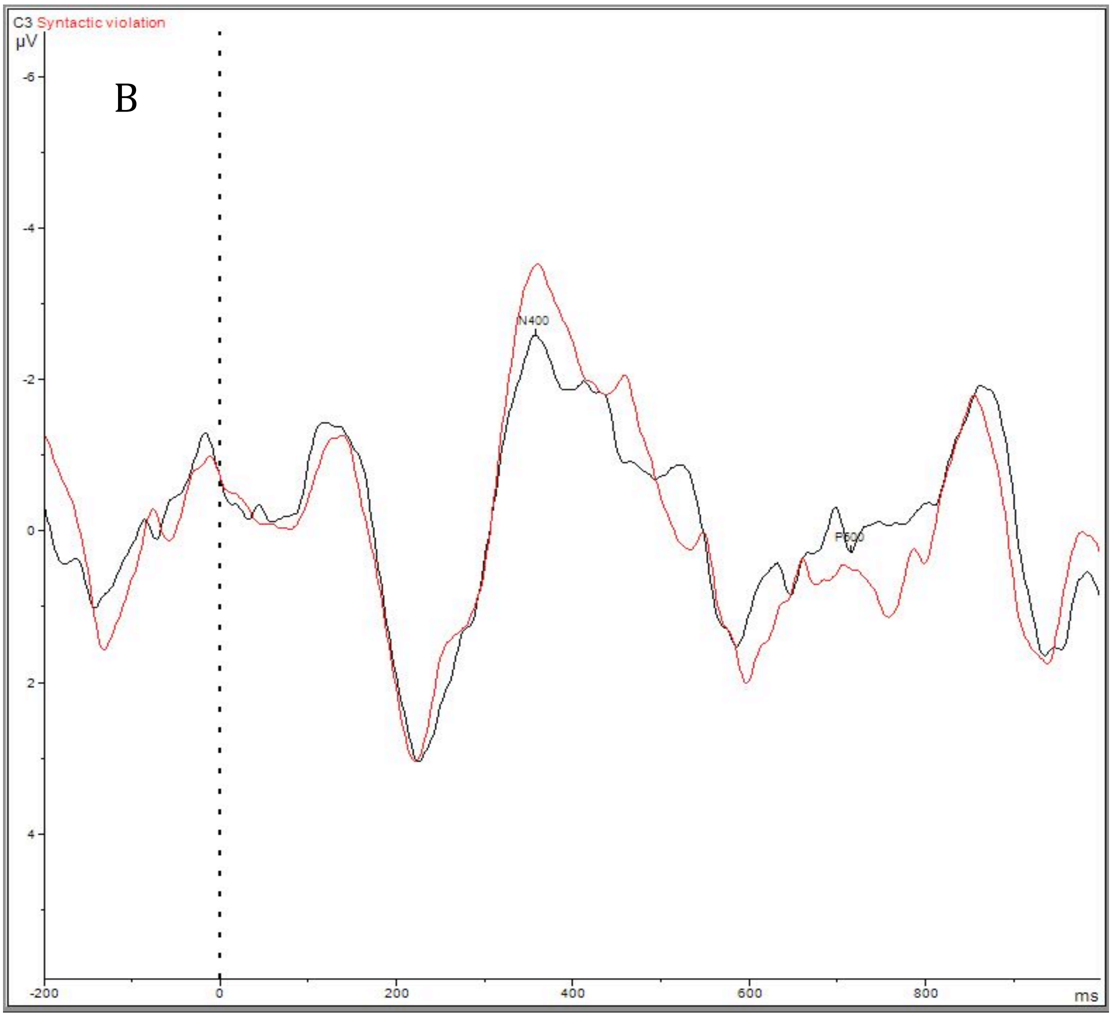
3.1 ERPs. Grand-average ERPs to the critical words (5th and 6th word) in each sentence type are shown in Fig. 1 & 2, respectively. Note that selected single sites that revealed an interaction with condition are shown. Fig. 1A compares the semantic violation condition with the control condition for the 5th word, preceding the critical 6th word, Fig. 1B compares the morphosyntactic violation condition with the control condition and Fig. 1C compares the double violation with the control condition at the 5th word. ERP responses to the critical 6th word that determined the sentence type are presented in Fig. 2. Fig. 2A compares the semantic violation condition to the control condition. Fig. 2B compares the morphosyntactic violation to the control condition. Fig. 2C shows the double violation with the control condition.

In these figures the general shapes of the waveforms are consistent with previously reported language-relevant ERP components (Osterhout & Kim, 2004). A clear negative-going component (N400) was present between 300 and 500 ms following word onset. This potential was followed by a positive component (P600) within 600–800 ms. This pattern is in line with what researchers have called the biphasic N400/P600 response sequence (Kuperberg, 2007).

Note that the best fitting 5th words in the RSVP procedure are the nouns in the double violation condition (e.g., *car*) whereas the noun in the control condition is in the less frequent possessive form (e.g., *daughter's*). Inspection of the 5th word in Fig. 1 shows that the ERP response to the violation conditions (e.g., *car's*, *car*, *daughter*) was dominated by a negative deflection (N400) relative to the control condition (e.g., *daughter's*), beginning at about 300 ms after word onset. Between 700 and 800 ms, the ERP response to the semantic violation (e.g., *car's*) conditions, with a less frequent combination of noun and possessive form, was dominated by a positive deflection relative to the control condition. This positive deflection is similar in latency and scalp distribution to the previously reported P600 response to syntactic anomalies (Kim & Osterhout, 2004).

ANOVAs for the 5th word in the 300–500 ms window revealed a main effect of condition, $F(3,11) = 4.147$, $p = .034$, showing a larger negative response for the nouns (e.g., *car's, car*) in the two semantic violation conditions than the nouns in the control and morpho-syntactic violation conditions (e.g. *daughter's, daughter*). There was also main effect of site, $F(8,6) = 15.89$, $p = .002$. Pairwise comparisons revealed parietal sites as having a larger negative deflection for both the semantic violation condition. The double violation condition at sites P3 $t(1,13) = 2.75$, $p = .016$, Pz $t(1,13) = 3.31$, $p = .003$ and P4 $t(1,13) = 3.20$, $p = .007$ produced a larger N400 in amplitude compared to the control. The semantic violation condition at sites Pz $t(1,13) = 2.66$, $p = .020$ and P4 $t(1,13) = 2.46$, $p = .028$ produced a larger N400 compared to the control condition.




C3 Syntactic violation
µV
B
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms

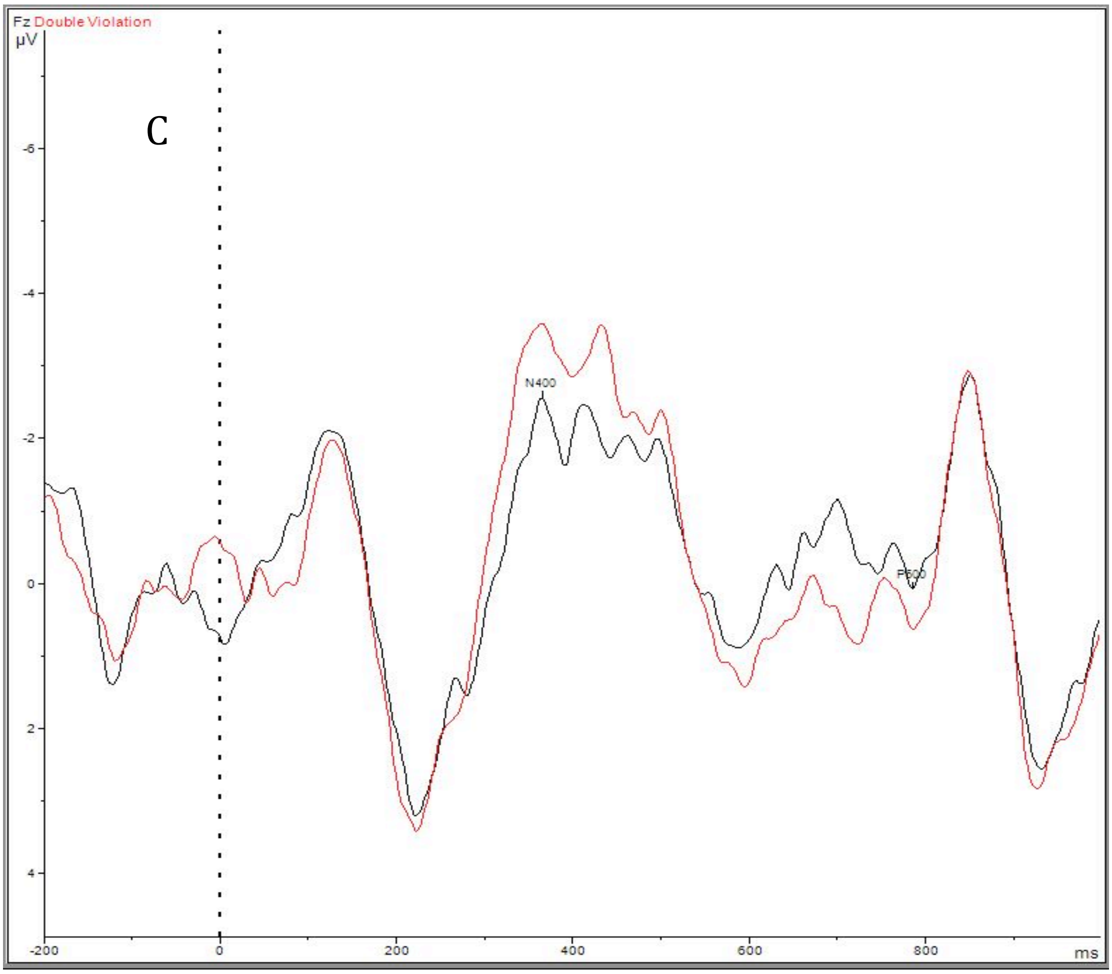


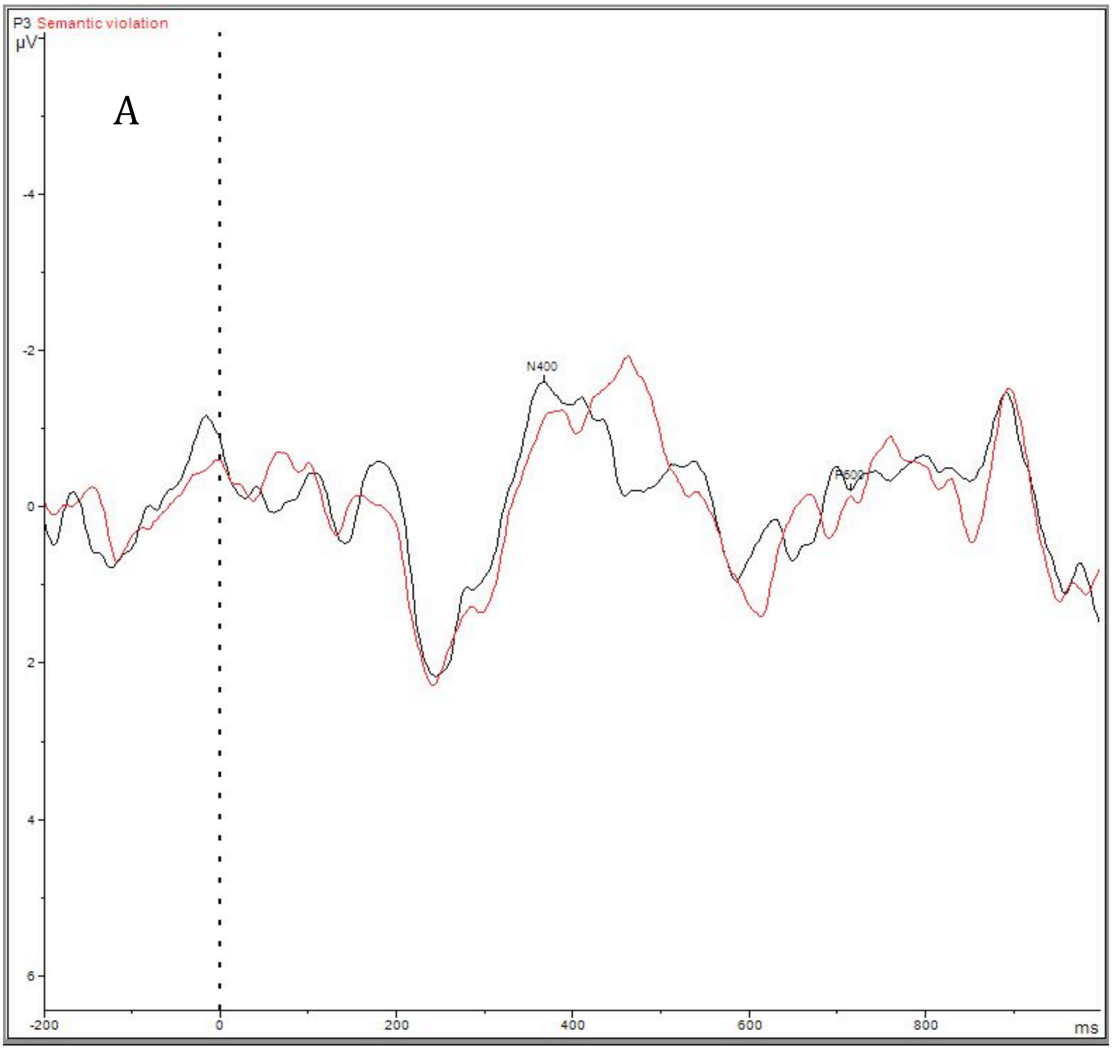
Fig. 1 ERP response at word 5. (A) Grand-average ERPs at site Pz comparing the control condition (black line; ...*borrowed the daughter's*...) to the semantic violation condition (red line; …*borrowed the car's*…). (B) Grand-average ERPs at site C3 comparing the control condition (black line) to the syntactic violation condition (red line; …*borrowed the daughter*…). (C) Grand-average ERPs at site Fz comparing the control condition (black line) to the double violation condition (red line; … *borrowed the car* …).

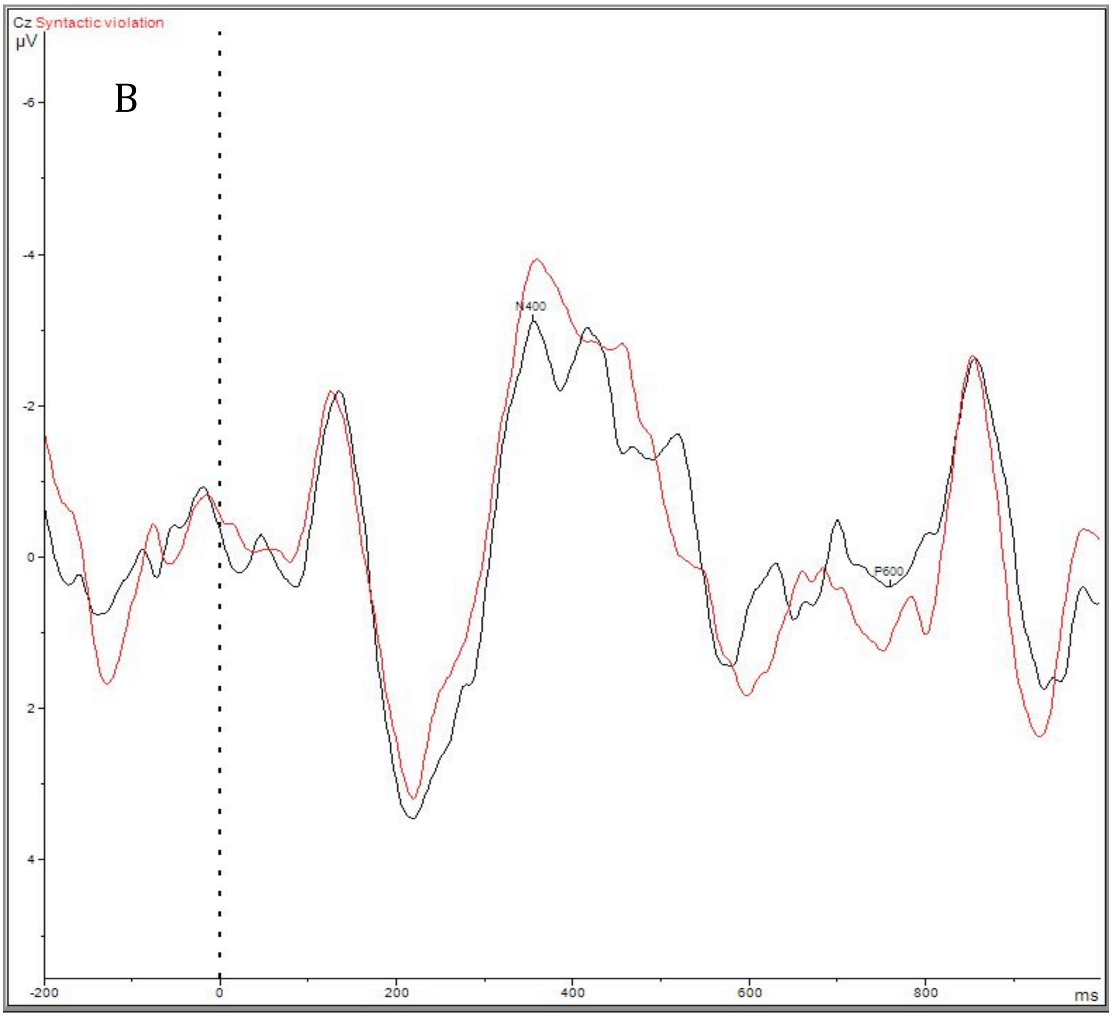
Inspection of the brain responses to the 6th word in Fig. 2 shows that the ERP to the violation conditions did not significantly differ from the control condition in either the 300–500 ms window or the 700–800 ms window. ANOVAs for the 6th word within the 300–500 ms window revealed only a significant main effect of site, $F(8, 6) = 12.76$, $p = .003$. Pairwise compairson within this time window showed a greater negative deflection centroparietally. Overall, central sites traveling towards the posterior region showed the largest deflection in amplitude (compared the frontal sites) for the control condition (C3&P3 $t(1,13) = -3.96$, $p = .002$, C4&P4 $t(1,13) = -2.63$, $p = .021$) and semantic violation condition (C3&P3 $t(1,13) = -4.69$, $p = .000$, C4&P4 $t(1,13) = -3.68$, $p = .003$, C4&P4 $t(1,13) = -2.52$, $p = .025$ (

ANOVAs on peak latencies in the 300–500 ms time window revealed a latency interaction between the two language factors (morphosyntactic and semantic), $F(1,13)$

= 11.36, *p* = .005. Visual inspection revealed that the morphosyntactic violation conditions (e.g., *daughter car*; *car daughter*) affected the latency differently in the condition where there was also semantic implausibility.

In the 700–800 ms time window peak analysis, a main effect of site was seen, *F*(6, 8) = 5.81, *p* = .023. ANOVAs also revealed an interaction between morphosyntactic acceptability and site, *F*(8, 6) = 15.16, *p* = .002. The morphosyntactically anomalous condition shows a greater positive deflection at parietal (Pz) and (Cz) central sites, *t*(1,13) = 2.20, *p* = .046 . This supports the interpretation that the positivity is a P600. To pinpoint when this positive deflection was greatest, an area analysis was performed based on the area under a curve within a specified time period. The area analysis was conducted within the 700-800 ms window because the main effect was seen within this time frame. The area analysis revealed an interaction between morphosyntactic acceptability and site within only the 700–750 ms window , *F*(8,5) = 6.55, *p* = .027. Pairwise comparisons revealed left (F3 and C3: *t*(1,12) = 2.21, *p* = .047 and central sites (Fz and Cz: *t*(1,12) = 2.95 , *p* = .012. The control condition was not different from the violation condition in this time window.




Cz Syntactic violation
µV
B
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms

C

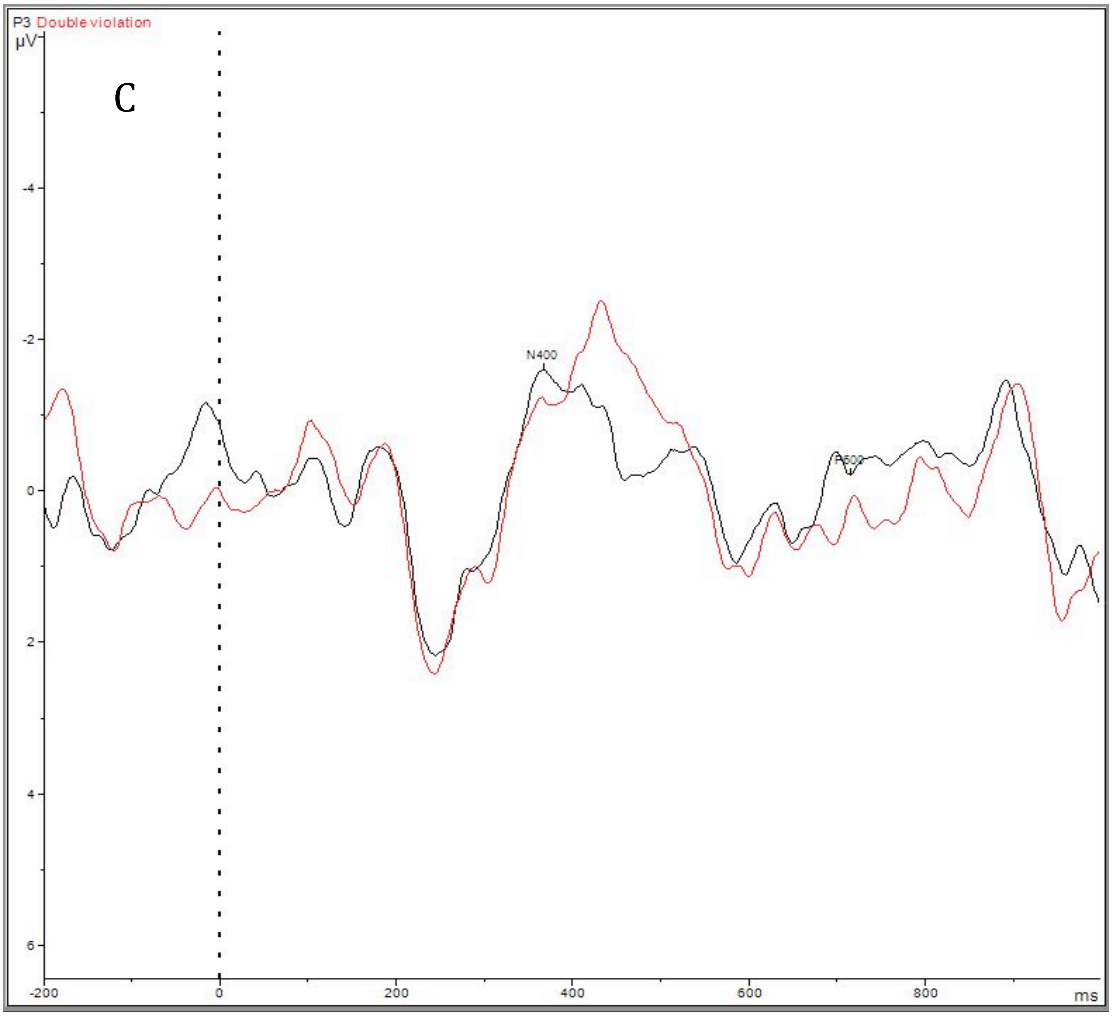


Fig. 2 ERP responses at word 6. (A) Grand-average ERPs at site P3 comparing the control condition (black line; …*borrowed the daughter's car*…) to the semantic violation condition (red line; …*borrowed the car's daughter*…). (B) Grand-average ERPs at site Cz comparing the control condition (black line) to the morphosyntactic violation condition (red line) (C) Grand-average ERPs at site P3 comparing the control condition (black line) to the double violation condition (red line)

4 Discussion

The present experiment was designed to explore whether repeated violations of semantic expectancies in possessive NPs could elicit a P600, usually seen in response to syntactic or morpho-syntactic violations. We expected the syntactic violations (e.g. *daughter car*) to elicit a LAN, followed by the late centroparietal positivity (P600). We also hypothesized that the semantic anomalies in our paradigm (e.g. *car's daughter*) would elicit an N400 as well as a P600 to the second word in the NP. However, we were only able to detect here a significant effect of our manipulations at the 5th word (e.g. for *car's* in *The mother borrowed the car's daughter for work yesterday*). A robustly greater negativity peaking at 300–500 ms after stimulus onset was elicited to *car's* compared to *daughter's*. This suggests the conclusion that syntactic cues, such as word order, rather than morphological cues, ultimately seemed to determine combinatory analysis as even clear morpho-syntactic violations, such as *car daughter* and *daughter car* did not elicit a significant P600 at the critical word compared to the control condition.

Similar to Osterhout et al. (2005), the P600 effect here cannot be attributed to an outright syntactic violation. This is because the 6th word in the semantically anomalous condition (e.g. *daughter in car's daughter*) is syntactically well-formed, but produced a P600. The presence of large N400 effects suggests that the syntactically supported but semantically dispreferred structure (e.g. *car's* in *car's daughter* was pursued by the participants. However, this may be in part due to many of our stimuli containing less frequent possessive forms (e.g., *car's*).

Bates & MacWhinney (1982) have described a concept known as *competence-to-perform*. We believe this contributed to the overall reduced P600 results seen here. According to these researchers, semantic, pragmatic and perceptual strategies must be directly represented in the grammar. For example, English is a non-agglutinative word order language with an unmarked order of SVO (subject-object-verb). English marks the verb to agree with the subject in person and number. English's limited verb morphology system leads to more ambiguity than the richer and less ambiguous Italian system. For example, English only marks third-person singular as distinct (e.g. I buy, you buy vs. s/he buys) and almost always relies on subject pronouns. Because English is limited in morphology, speakers of the language do not seem to rely on disambiguating cues from verb morphology. This suggests that word order in English may be the primary vehicle for indicating basic grammatical relations (Bates & MacWhinney, 1982). Thus, English speakers rely less on morphological markers and are more competent with noticing word order violations.

The participants may have relied on the compulsory order in English possessive noun phrases. In English, the possessor (whether animate or inanimate) always precedes the entity or item being possessed. The participants may have analyzed the double violation condition (*daughter car*) as *daugther's* car despite the fact it is did match the fine-grained information (lack of a possessive marker). Futhermore, Mitchell (1995) proposes that initial parsing decisions in cases such as ours are based largely on course-grained records of previous attachments in the past. This explains participants favouring the possessive attachment despite the lack of a possessive marker in cases such as *daughter car*. This *competence-to-perform* concept helps explain why the P600 may not have been as robust as we had expected. Our stimuli relied heavily on using the morphological possessive marker in two of the four conditions. Word order was violated in the morphosyntactic condition. If English speakers do not feel bound to agreement or morphological cues, this could explain why our stimuli did not elicit robust P600s.

Additionally, two other factors may have contributed to these results. The participant population was primarily undergraduate students at the end of the semester. It is entirely possible these were not highly-motivated individuals. Additionally, our experimental paradigm relied heavily on noticing these less frequent possessive forms (e.g. *car's*) as opposed the noun (e.g. *car*). Bates and MacWhinney (1982) point out these possessive markers are not salient features in the English language (compared to word order). This in combination with unmotivated participants may have contributed to less robust P600s

In explaining the presence of a reduced P600, but robust N400 I considered the performance of an explicit acceptability judgment task. Kuperberg (2007) suggested acceptability judgments such as grammaticality verification tasks may bias the participants to pay particular attention to the plausibility of the syntactic role? theta role? assignments. The participants seemed to pay particular attention towards potential plausibility driven by semantic associative relationships (e.g. semantic associations between the main verb and its arguments). This seemed to be the case with some of the stimulus sentences. Consider, the control sentence, *The mother borrowed the daughter's car for work yesterday* where the syntactic assignment between the verb and the object (e.g. *The mother borrowed the daughter*) challenges the semantic association (Mitchell et. al., 1995). There appears to be conflict between the thematic roles that are syntactically assigned by the verb to its argument and coherent semantic associations between the verb and its argument. Our experimental paradigm with a grammaticality task may have biased participants away from syntactic rules and towards plausibility.

The P600 has been noted to vary along a number of different parameters including latency, duration, amplitude and scalp distribution. Poeppel (2010) suggested an account that reflects these variations. The retrieval of syntactic elements, creation of syntactic elements and destruction of syntactic relations can all be processes that underlie the P600 in our findings here (Poeppel, 2010). The latency of the P600 reflects the time needed for retrieval of the elements, especially with our semantic manipulations (*car's daughter*).

Additionally, the semantic violation (e.g. *car's daughter*) and syntactic violation (e.g. *daughter car*) conditions violated animacy constraints. Kuperberg (2007) has suggested that the syntactic assignment of thematic roles by a verb to its NP arguments that violate animacy constraints is often associated with P600 effects. This may explain the presence of a P600 effect even if participants did not actively attend to (or failed to notice) the morphological possessive marker ('). The verb in this example (e.g. *The mother borrowed the daughter car for work yesterday*) requires an inanimate instrument rather than the semantically implausible patient (*daughte*r). Studies by Kolk et al., (2003) and van Herten et. al., (2005) showed P600 effects when the semantically violated critical verbs were preceded by inanimate subject NP arguments. In these studies and in ours the inherent thematic structure that arises because of the animacy constraint imposed by a verb on its arguments is violated by the animacy of that argument.

Johnson (2009) states that there are two central questions surrounding the nature of possessives. The first is whether possessives have a single unit of meaning or a variety of different relations. The second attempts to tackle if possessives are actually part of the denotation of the noun (Barker, 2010). Understanding this can help with the strategies participants may use to disambiguate our semantic violation condition (*car's daughter*). Johnson (2009) suggests that what "possession" means varies somewhat and varies with the head noun involved. He explains, in some cases, the role played by genitive DPs, such as in (1a-c), is not determined by the meaning of the noun or the head noun that follows. In (1b) and (1c) the relation the genitive bears on the rest of the DP is constant, and Johnson (2009) points out that it is still a possession relation involved. He calls this, '*Poss'* and considers this to be responsible for the possession relation that holds between the argument and in its Specifier NP that follows. This very same relation in found in all cases in which the noun refers to an object. Our stimuli can be represented in line with this because the majority of the stimuli dealt primarily with nouns and objects (e.g *daughter's car*). In (1) the subject has the role that is identical to that which would be given to the external argument of the verb from which the head noun derives (Johnson & Johnson, 2009). For example, in (1f) *Jerry's dancing*, *Jerry* has the same role as it would in *Jerry dances*. Thus, Johnson (2009) believes that it is ultimately the same semantic relation for both the noun and the verb. Fig. 3 illustrates the D-structure (deep structure) for this construction.

(1) a. Sean's opinion
b. Gary's novel
c. Sandy's picture of Sean
d. Mary's discussion of poi
e. Mary's invasion on Jupiter
f. Jerry's dancing
g. Sean's running.
h. Mary's discussion

For cases such as (1b) and (1h), which is more closely in line with our stimulus sets Grimshaw (1990) proposes attempts to force the genitive to bear a theta role from the

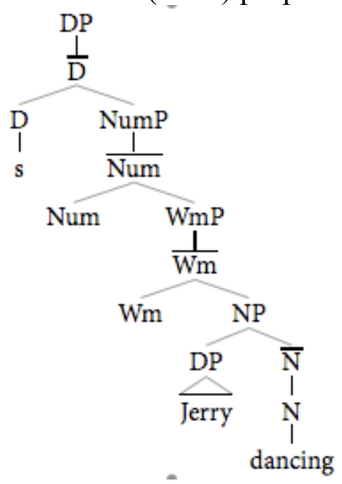


Fig. 3. D-structure of (1f). The surface form is achieved by moving *Jerry* into the Specifier of DP to meet Case filter's requirements.

noun and then determine if the result is grammatical depending on whether the object also appears.. Baker (2010) offers the same conclusion through inverse scope and points to an example by Ruys (2000) in constructing, *Every celebrity's siblings resent her fame.* Ruys (2000) offers the explanation that if A can bind to B, and A contains C, and C can take scope over B then C can bind to B. In this example, A is the subject (e.g *her*) and DP *every celebrity's sibiling* and B is her,

Although this experiment cannot distinguish exactly what process is indexed by the P600, there are several possibilities that may fit with the current results. One previously introduced notion is the P600's sensitivity to violations of generalizable rules (Holcomb et. al., 1998). This would include the recent findings with (thematic violations Kuperberg, 2007) and animacy violations (van Herten et. al., 2002). This is in line with our current paradigm where animacy information only seems to have a real impact after the critical verb

Our data appears to be consistent with syntax first models of sentence comprehension (Altmann, 1999). Although, this is probably due to the way in which the stimuli were constructed. The less frequent possessive forms were not salient compared to the noun forms. This forced the participants to rely heavily on word order? as a disambiguation strategy. Kuperberg (2007) has argued however that the fact that the N400 can be modulated by both sentence and discourse level contexts, regardless of semantic associations suggests that the N400 can be influenced by the outcome of syntactically-driven combinatorial processing that determines the build-up of components. This can be applied to our study. If participants relied heavily on word order as a parsing strategy, then the N400 seen for the 5^{th} word may reflect a syntactically-driven system.

REFERENCES

Barker, C. (1995). Possessive Description. Standford: CSLI Publications

Bates, E., McNew, S., MacWhinney, B., Devescovi, A., & Smith, S. (1982). Functional constrains on sentence processing: a cross-linguistic study. Cognition, 11, 245-299.

Broadbent, D.E., & Broadbent, M.H.P. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics*, *42,* 105-113.

Chow, W., & Phillips, C. (in press). No semantic illusions in the “semantic P600” phenomenon: ERP evidence from Mandarin Chinese. 1-29.

Coulson, S., King, J., & Kutas, M. (1998). Except the unexpected: event-related brain responses to morphosyntactic violations. *Language and Cognitive Processes*, 13, 21-58.

Donchin, E., Ritter, W., & McCallum, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, & S. Koslow (Eds.), *Brain-event-related potentials in man* (pp. 349-411). New York: Academic Press.

Faustmann, A., Murdoch, B.E., Finnigan, S.P., Copland, D.A. (2005). Event-related brain potentials elicited by semantic and syntactic anomalies during auditory sentence processing. *Journal of the American Academy of Audiology, 16*, 708-25.

Fischler, I., Bloom, P., Childers, D., Roucos, S., & Perry, N., (1983). Brain potentials related to stages of sentence verification. *Psychophysiology,* 20, 400-9.

Friederici, A.D. (2011). The brain basis of language processing: from structure to function. *Physiol Rev*, 91, 1357-1392.

Friederici, A.D., & Weissenborn, J. (2007). Mapping sentence onto meaning: the syntax-semantics interface. *Brain Res.,* 46, 50-58.

Friederici, A.D., Gunter, T.C., Hahne, A., & Mauth, K. (2004). The relative timing of syntactic and semantic processes in sentence comprehension. *NeuroReport, 15,* 165-169.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (sps) as an erp measure of syntactic processing. *Lang Cogn Proc* 8, 439-483.

Hillyard, S.A., Picton, T.W. (1987). Electrophysiology of cognitive. In F. Plum (Ed.), *Handbook of physiology. higher functions o the nervous system. Section 1: The nervous system.* (Vol. 1, pp. 519-584). Washington, DC: American Physiological Society

Hoen, M., & Dominey, P.F. (2000). ERP analysis of cognitive sequencing: a left anterior negativity related to structural transformation processing. *Neuroreport*, 11, 3187-3191.

Jackendoff, R. (1968). Possessive in English. In: S. Anderson, R., Jackendoff & S.J. Keyser (Ed.). *Studies in Transformational Grammar and Related Topics.* Waltham, MA: Brandeis University Press

Johnson, K. (2009). *Introduction to Transformation Grammar*.

Lau, E.F., Poeppel, D., & Phillips,C. (2008). A cortical network for semantics: (de)constructing the N400. *Nature Reviews Neuroscience*, 9, 920-30.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration difficulty. *Lang Cogn Proc,* 15, 159-201.

Kuperberg, G.R., Caplan. D., Stinkikova, T., & Holcomb, P. J. (2003). Electrophysiological distinction sin processing conceptual relationships within simple sentences. *Cog Brain Research,* 17, 117-129.

Kuperberg, R.G. (2007). Neural mechanisms of language comprehension: challenges to syntax. *Brain Research, 1146*, 23-49.

Kuperberg, G., Kreher, D.A., Stinikova, T., Caplan, D., & Holcomb, P. (2007). The role of animacy and thematic relationship in processing active English sentences: Evidence from event-related potentials. *Brain and Language,* 100, 223-238.

Kutas, M., & Hillyard, S.A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207, 203-5

Kutas, M., & Federmeier, K.D. (2011). Finding Meaning in the N400 component of the event-related brain potential (ERP). *Annu. Rev. Psychol., 62, 621-47*

Kutas, M., & Van Petten, C.K. (1994). Psycholinguistics electrified: event-related brain potential investigations. In: MA. Gernsbacher (Ed.), *Handbook of Psycholinguistics* (pp. 83-143). San Diego, USA: Academic Press

Knight, R.T. (1996). Contribution of human hippocampal region to novelty detection. *Nature,* 383, 256-259

Mitchell, D.C., Cuetos, F., Corley, M.M.B., & Brysbaert, M. (1995). Exposure-based models of human parsing: evidence for the use of coarse-grained (nonlexical) statistical records. *Journal of Psycholinguistic Research, 24,* 469-488.

Näätänen, Risto. (1988). Implications of ERP data for psychological theories of attention. *Biological Psychology*, 26, 117-163.

Neville, H, Nicol, J.L, Barss, A., Froster, K.L., & Garrett, M.F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience,* 3, 151-165.

Osterhout, L., & Hagoort, P. (1999). A superficial resemblance does not necessarily mean you are part of the family: counterarguments to Coulson, King and Kutas (1998) in the P600/SPS-P300 debate. (1999). *Language and Cognitive Processes*, 14, 1-14

Osterhout, L., & Kim, A. (2004). The independence of combinatory semantic processing: Evidence from event-related potentials. *Journal of Memory and Language*, 52, 205-225

Osterhout, L., & Holcomb, P. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, 31, 785-806.

Polich, J. (2012). Neuropsychology of P300. In S.J. Luck & E.S. Kappenman (Eds.), *Handbook of event-related potential components,* (pp. 159-188), New York: Oxford University Press.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118, 2128-2148

Service, E., Helenius, P., Maury, S., & Salmelin, R. (2007). Localization of syntactic and semantic brain responses using magnetoencephalography. *Journal of Cognitive Neuroscience, 19*, 1193-1205.
Squires, N. K., Squires, K., & Hillyard, S. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology, 38,* 387-401

Steinhauer, K., Connolly, J. (2008). Event-related potentials in the study of language. In B. Stemmer & H. Whitaker (Eds.) *Handbook of the neuroimaging of language* pp. 91-104). Canada: Academic Press

Stemmer, B., Rodden, F. (2008). A brief introduction to common neuroimaging techniques. In B. Stemmer & H. Whitaker (Eds.) *Handbook of the neuroimaging of language* (pp. 57-67). Canada: Academic Press.

Sutton, S., Braren, M., Zubin, J., & John, E.R. (1965). Evoked potential correlates of stimulus uncertainty. *Science, 150,* 1187-1188.

Trueswell, J.C. & Tanenhaus, M.K. (1994). Toward a lexicalist framework for constraint-based syntactic ambiguity resolution. In: Clifton, Frazier & Rayner (Eds.). Perspectives on Sentence Processing, 155-179. Hillsdale, NJ: LEA Press.

vanHerten, M., Kolk, H.J.H., Chwilla, J.D. (2004). An ERP study of P600 effects elicited by semantic anomalies. *Cognitive Brain Research, 22*, 241-255.

APPENDIX

1. The babysitter cleaned the girl's sweater in hot water.
The babysitter cleaned the sweater's girl in hot water.
The babysitter cleaned the girl sweater in hot water.
The babysitter cleaned the sweater girl in the hot water.

The mother borrowed the daughter's car for work yesterday.
1. The mother borrowed the car's daughter for work yesterday.
The mother borrowed the daughter car for work yesterday.
The mother borrowed the car daughter for work yesterday.

The child broke the player's arm at the game.
The child broke the arm's player at the game.
1. The child broke the player arm at the game.
The child broke the arm player at the game.

The girlfriend saw the bartender's face in the pub.
The girlfriend saw the face's bartender in the pub.
The girlfriend saw the bartender face in the pub.
1. The girlfriend saw the face bartender in the pub.

1. The mother sold the man's land at the auction.
The mother sold the land's man at the auction.
The mother sold the man land at the auction.
The mother sold the land man at the auction.

The girl cracked the teacher's window in the parking lot.
1. The girl cracked the window's teacher in the parking lot.
The girl cracked the teacher window in the parking lot.
The girl cracked the window teacher in the parking lot.

The alligator attacked the fisherman's leg in the boat.
The alligator attacked the leg's fisherman in the boat.
1. The alligator attacked the fisherman leg in the boat.
The alligator attacked the leg fisherman in the boat.

The motorcyclist stole the woman's heart at the rally.
The motorcyclist stole the heart's woman at the rally.
The motorcyclist stole the woman heart at the rally.

1. The motorcyclist stole the woman heart at the rally.

1. The neighbour left the sister's stuff on the porch.
The neighbour left the stuff's sister on the porch.
The neighbour left the sister stuff on the porch.
The neighbour left the stuff sister on the porch.

The fraternity crashed the classmate's wedding at their house.
1. The fraternity crashed the wedding's classmate at their house.
The fraternity crashed the classmate wedding at their house.
The fraternity crashed the wedding classmate at their house.
The pilot flew the man's plane over the Alps.
The pilot flew the place's man over the Alps.
1. The pilot flew the man plane over the Alps.
The pilot flew the plane man over the Alps.

The grandmother visited the sister's house in the village.
The grandmother visited the house's sister in the village.
The grandmother visited the sister house in the village.
1. The grandmother visited the house sister in the village.

1. The paparazzi leaked the president's photo to the magazine.
The paparazzi leaked the photo's president to the magazine.
The paparazzi leaked the president photo to the magazine.
The paparazzi leaked the photo president to the magazine.

The tenant sublet the landlord's apartment to her brother.
1. The tenant sublet the apartment's landlord to her brother.
The tenant sublet the landlord apartment to her brother.
The tenant sublet the apartment landlord to her brother.

The landlord fixed the building's tap with a wrench.
The landlord fixed the tap's building with a wrench.
1. The landlord fixed the building tap with a wrench.
The landlord fixed the tap building with a wrench.

The wife cleaned the husband's junk in the garage.
The wife cleaned the junk's husband in the garage.
The wife cleaned the husband junk in the garage.
1. The wife cleaned the junk husband in the garage.

1. The doctor examined the boy's lip in the office.
The doctor examined the lip's boy in the office.
The doctor examined the boy lip in the office.
The doctor examined the lip boy in the office.

The shark bit the man's foot in the ocean.
1. The shark bit the foot's man in the ocean.

The shark bit the man foot in the ocean.
The shark bit the foot man in the ocean.

The optometrist checked the woman's eye at the clinic.
The optometrist checked the eye's woman at the clinic.
1. The optometrist checked the woman eye at the clinic.
The optometrist checked the eye woman at the clinic.

The student exchanged the roommate's book for class notes.
The student exchanged the book's roommate for class notes.
The student exchanged the roommate book for class notes.
1. The student exchanged the book roommate class notes.

1. The father held the child's hand in the park.
The father held the hand's child in the park.
The father held the child hand in the park.
The father held the hand child in the park.

The salesman entered the supervisor's office in a hurry.
1. The salesman entered the office's supervisor in a hurry.
The salesman entered the supervisor office in a hurry.
The salesman entered the office supervisor in a hurry.

The hairdresser trimmed the senior's hair at the salon.
The hairdresser trimmed the hair's senior at the salon.
1. The hairdresser trimmed the senior hair at the salon.
The hairdresser trimmed the hair senior at the salon.

The sister heard the brother's voice in the woods.
The sister heard the voice's brother in the woods.
The sister heard the brother voice in the woods.
1. The sister heard the voice brother in the woods.

1. The wife paid the husband's bail at the station.
The wife paid the bail's husband at the station.
The wife paid the husband bail at the station.
The wife paid the bail husband at the station.

The surgeon repaired the victim's wound in the OR.
1. The surgeon repaired the wound's victim in the OR.
The surgeon repaired the victim wound in the OR.
The surgeon repaired the wound victim in the OR.

The coyotes surrounded the ranger's scooter in the forest.
The coyotes surrounded the scooter's ranger in the forest.
1. The coyotes surrounded the ranger scooter in the forest.
The coyotes surrounded the scooter ranger in the forest.

The musician signed the fan's chest at the concert
The musician signed the chest's fan at the concert
The musician signed the fan chest at the concert
1. The musician signed the chest fan at the concert

1. The burglar broke the resident's television in the basement.
The burglar broke the television's resident in the basement.
The burglar broke the resident television in the basement.
The burglar broke the television resident in the basement.

The witness found the perpetrator's weapon in the garbage.
1. The witness found the weapon's perpetrator in the garbage.
The witness found the perpetrator weapon in the garbage.
The witness found the weapon perpetrator in the garbage.

The father fixed the son's truck in the garage.
The father fixed the truck's son in the garage.
1. The father fixed the son truck in the garage.
The father fixed the truck son in the garage.

The snake bit the scout's neck at the campsite.
The snake bit the neck's scout at the campsite.
The snake bit the scout neck at the campsite.
1. The snake bit the neck scout at the campsite.

1. The bumblebee stung the carpenter's shoulder at the carnival.
The bumblebee stung the shoulder's carpenter at the carnival.
The bumblebee stung the carpenter shoulder at the carnival.
The bumblebee stung the shoulder carpenter at the carnival.

The farmer watered the mother's plant in the pot.
1. The farmer watered the plant's mother in the pot.
The farmer watered the mother plant in the pot.
The farmer watered the plant mother in the pot.

The girl delivered the man's package for a fee.
The girl delivered the package's man for a fee.
1. The girl delivered the man package for a fee.
The girl delivered the package man for a fee.

The man ignored the girl's tears during the fight.
The man ignored the tear's girl during the fight.
The man ignored the tear girl during the fight.
1. The man ignored the girl tear during the fight.

1. The daughter took the father's phone for her date.
The daughter took the phone's father for her date.
The daughter took the father phone for her date.

The daughter took the phone father for her date.

The raccoon ate the girl's present in the car.
1. The raccoon ate the present's girl in the car.
The raccoon ate the girl present in the car.
The raccoon ate the present girl in the car [?]

The professor invited the student's dog to the barbecue.
The professor invited the dog's student to the barbecue.
1. The professor invited the student dog to the barbecue.
The professor invited the dog student to the barbecue.

The widow donated the husband's liver to the girl.
The widow donated the liver's husband to the girl.
The widow donated the husband liver to the girl.
1. The widow donated the liver husband to the girl.

1. The artist painted the grandmother's ruby at the fair.
The artist painted the ruby's grandmother at the fair.
The artist painted the grandmother ruby at the fair.
The artist painted the ruby grandmother at the fair.

The microbiologist analyzed the shark's blood for the infection.
1. The microbiologist analyzed the blood's shark for the infection.
The microbiologist analyzed the shark blood for the infection.
The microbiologist analyzed the blood shark for the infection.

The analyst took the teacher's computer to the lab.
The analyst took the computer's teacher to the lab.
1. The analyst took the teacher computer to the lab.
The analyst took the computer teacher to the lab.

The gymnast outperformed the coach's technique at the competition.
The gymnast outperformed the technique's coach at the competition.
The gymnast outperformed the coach technique at the competition.
1. The gymnast outperformed the technique coach at the competition.

1. The police investigated the brother’s murder at the scene.
The police investigated the murder’s brother at the scene.
The police investigated the brother murder at the scene.
The police investigated the murder brother at the scene.

The divorcee put the husband’s estate under her name.
1. The divorcee put the estate’s husband under her name.
The divorcee put the husband estate under her name.
The divorcee put the estate husband under her name.

The son ran the father’s market everyday at noon.

The son ran the market's father everyday at noon.
1. The son ran the father market everyday at noon.
The son ran the market father everyday at noon.

The uncle found the boy's shoe under the couch.
The uncle found the shoe's boy under the couch.
The uncle found the boy shoe under the couch
1. The uncle found the shoe boy under the couch.

1. The schoolgirl purchased the father's gift at the shop.
The schoolgirl purchased the gift's father at the shop.
The schoolgirl purchased the father gift at the shop.
The schoolgirl purchased the gift father at the shop.

The infant grabbed the mother's toe on the bus.
1. The infant grabbed the toe's mother on the bus.
The infant grabbed the mother toe on the bus.
The infant grabbed the toe mother on the bus.

The father gambled the son's money at the casino.
The father gambled the money's son at the casino.
1. The father gambled the son money at the casino.
The father gambled the money son at the casino.

The brothers stole the father's beer in the fridge.
The brothers stole the beer's father in the fridge.
The brothers stole the father beer in the fridge.
1. The brothers stole the beer father in the fridge.

1. The wife enjoyed the husband's sandwich in the cafeteria.
The wife enjoyed the sandwich's husband in the cafeteria.
The wife enjoyed the husband sandwich in the cafeteria.
The wife enjoyed the sandwich husband in the cafeteria.

The plane carried the president's coffin to the funeral.
1. The plane carried the coffin's president to the funeral.
The plane carried the president coffin to the funeral.
The plane carried the coffin president to the funeral.

The dog took the cat's yarn to his brother.
The dog took the yarn's cat to his brother.
1. The dog took the cat yarn to the brother.
The dog took the yarn cat to the brother.

The cat scratched the dog's paw at the park.
The cat scratched the paw's dog at the park.
The cat scratched the dog paw at the park.
1. The cat scratched the paw dog at the park.

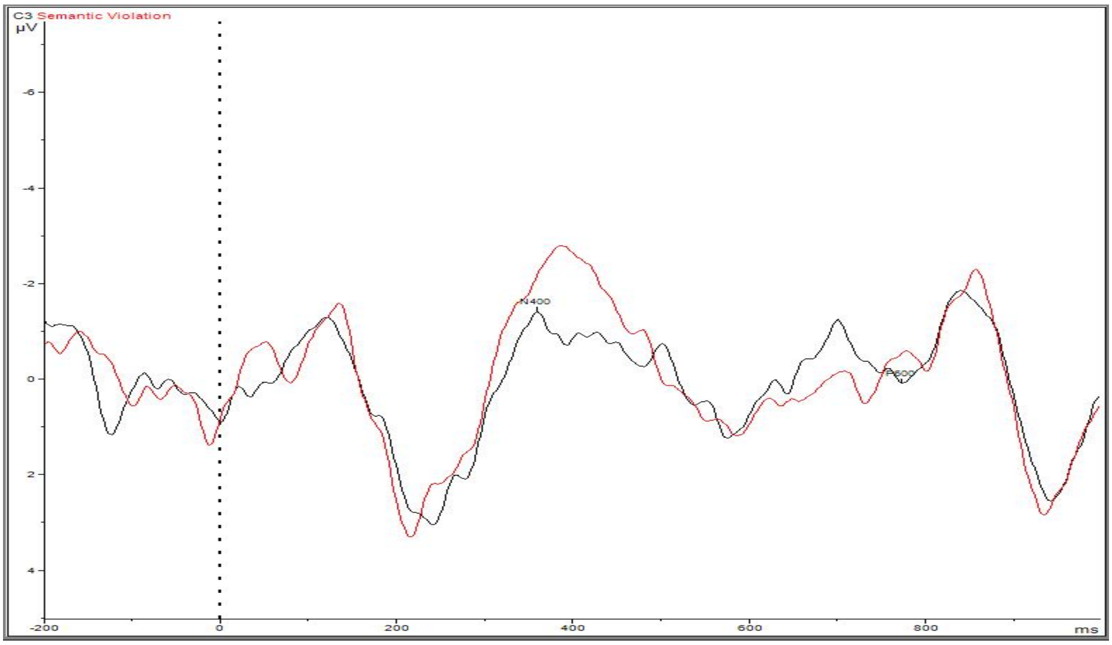
1. The veterinarian examined the bird's wing at the zoo.
The veterinarian examined the wing's bird at the zoo.
The veterinarian examined the bird wing at the zoo.
The veterinarian examined the wing bird at the zoo.

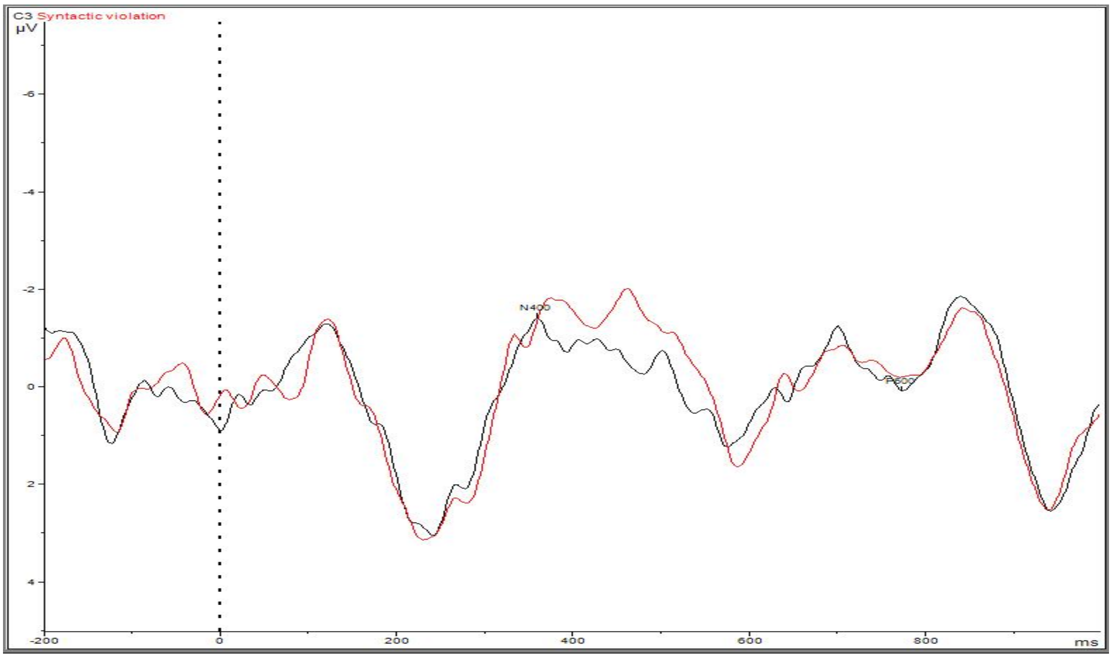
The investigator inspected the celebrity's apartment for any evidence.
1.The investigator inspected the apartment's celebrity for any evidence.
The investigator inspected the celebrity apartment for any evidence.
The investigator inspected the apartment celebrity for any evidence.

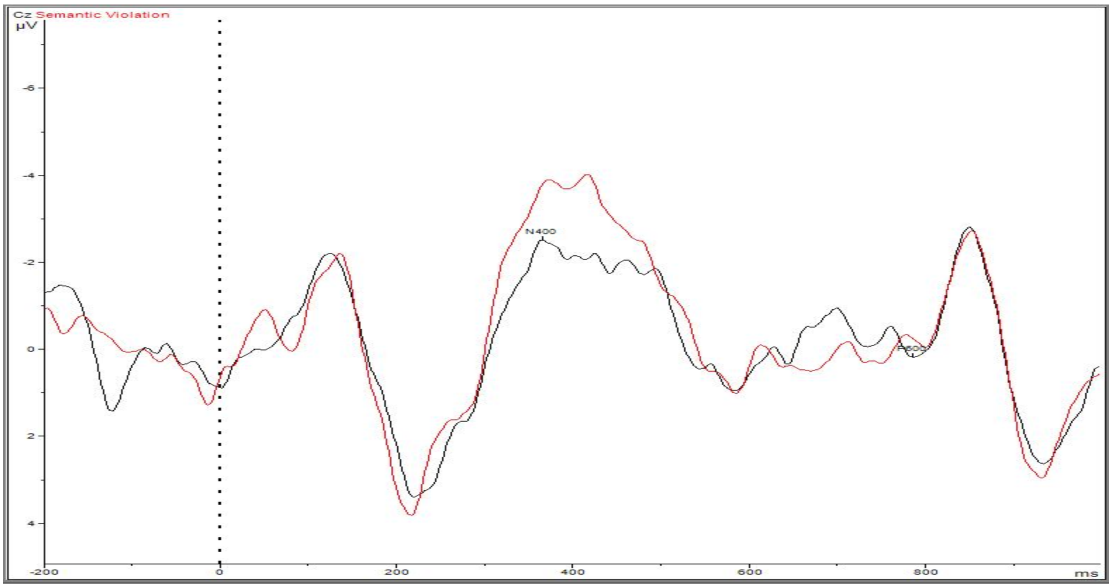
The attorney approached the judge's bench with the crown.
The attorney approached the bench's judge with the crown.
1. The attorney approached the judge bench with the crown.
The attorney approached the bench judge with the crown.

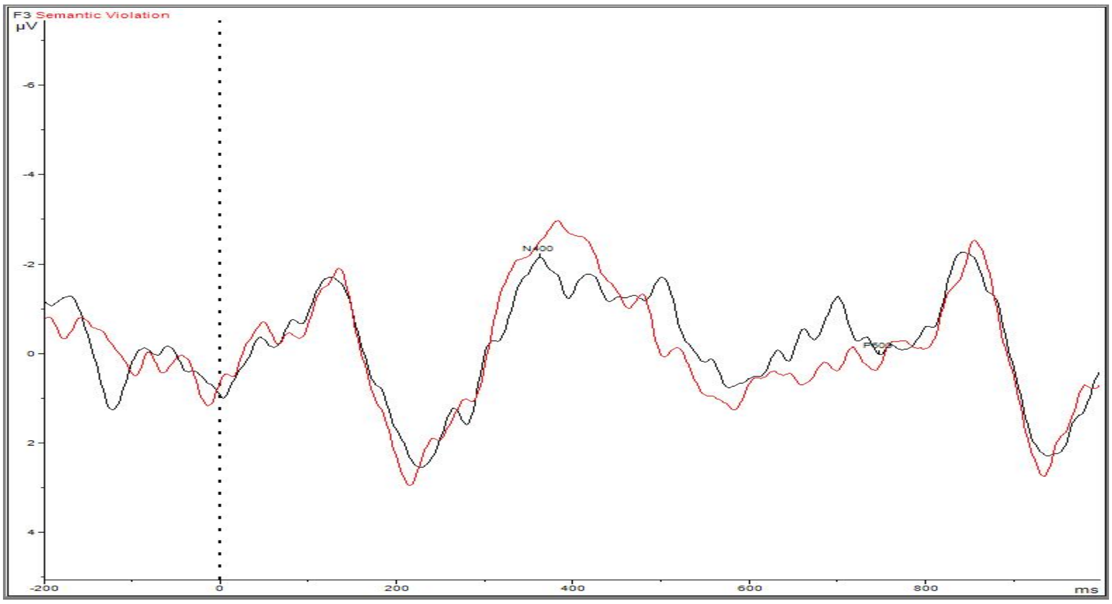
The chef prepared the customer's beef on the grill.
The chef prepared the beef's customer on the grill.
The chef prepared the customer beef on the grill.
1. The chef prepared the beef customer on the grill.

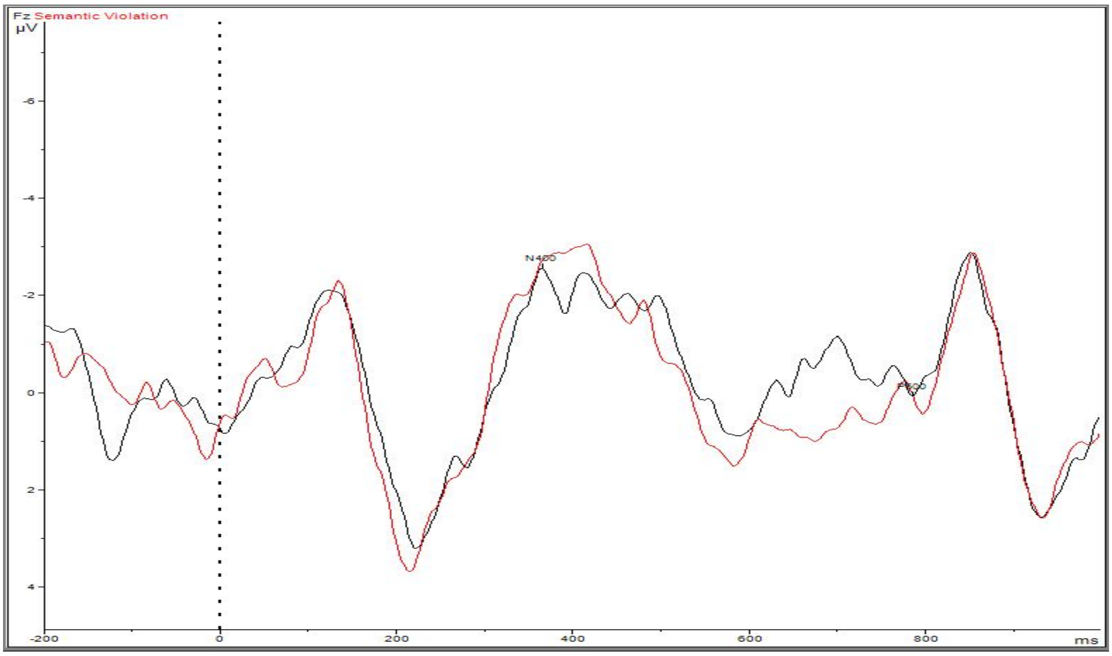
TRIGGER 5 WAVEFORMS

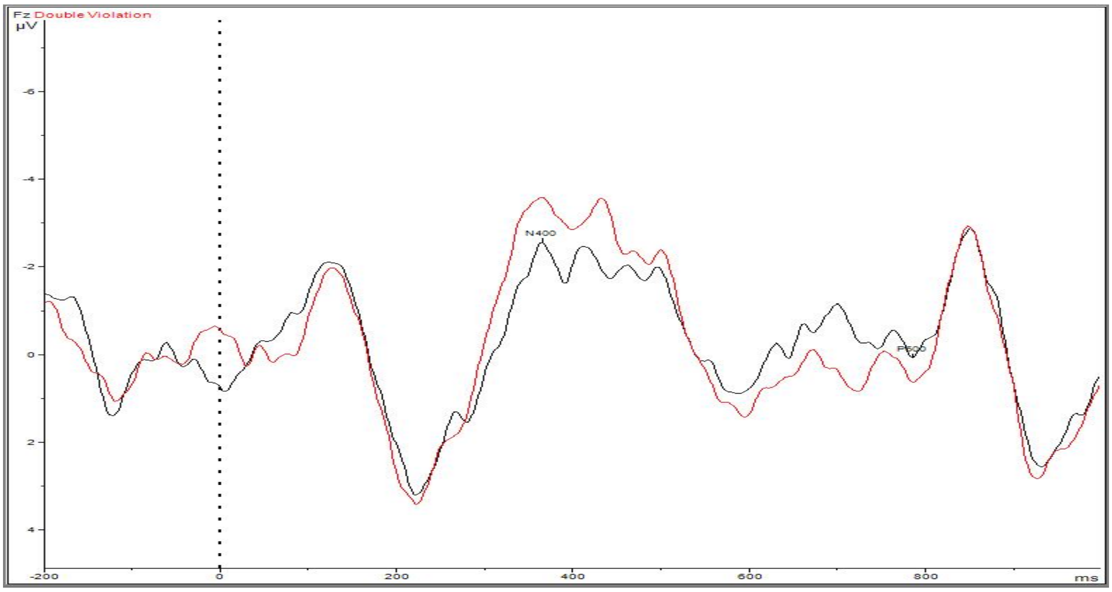


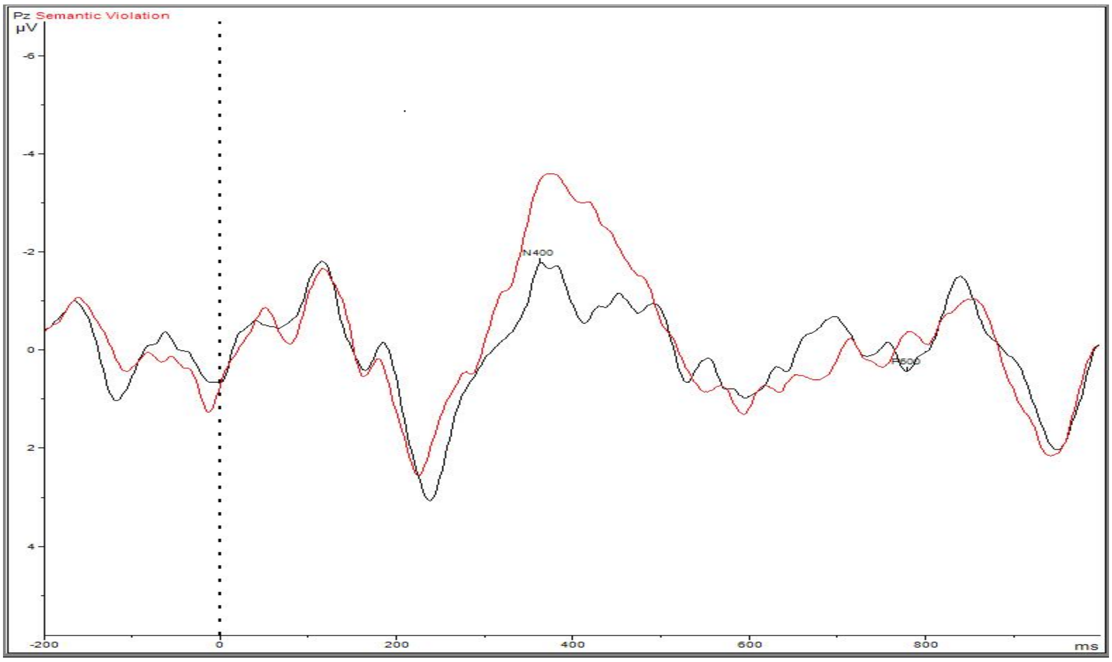

C3 Syntactic violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms


Cz Semantic Violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms

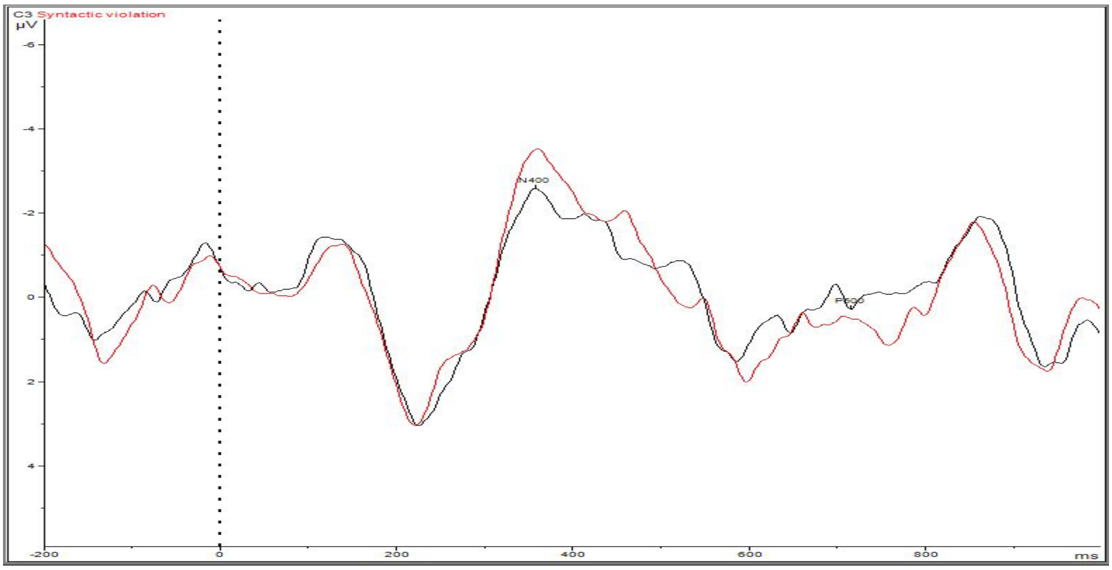

F3 Semantic Violation
µV
-6
-4
-2
0
2
4
N400
-200
0
200
400
600
800
ms

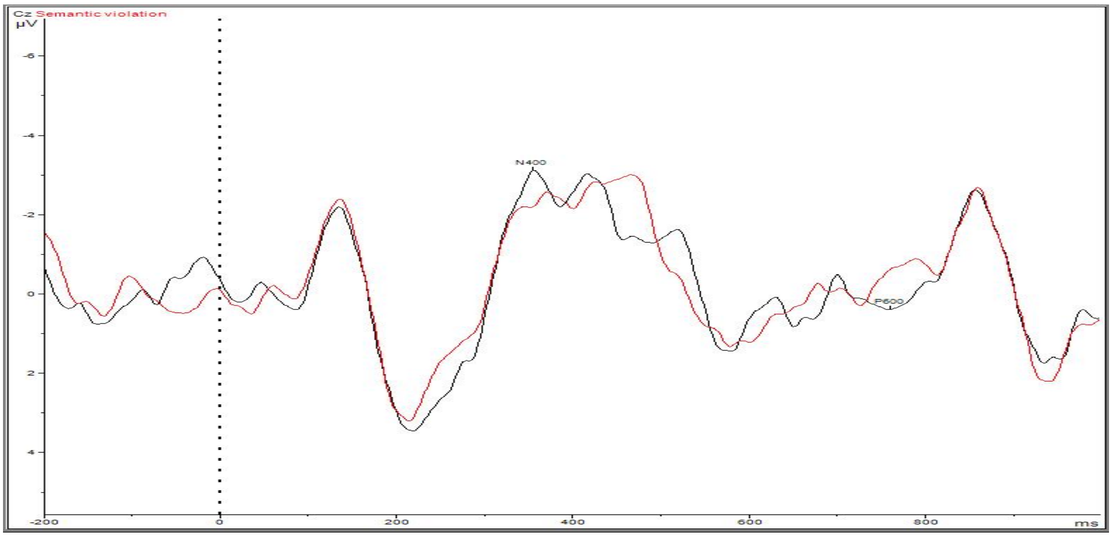

Fz Semantic Violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms

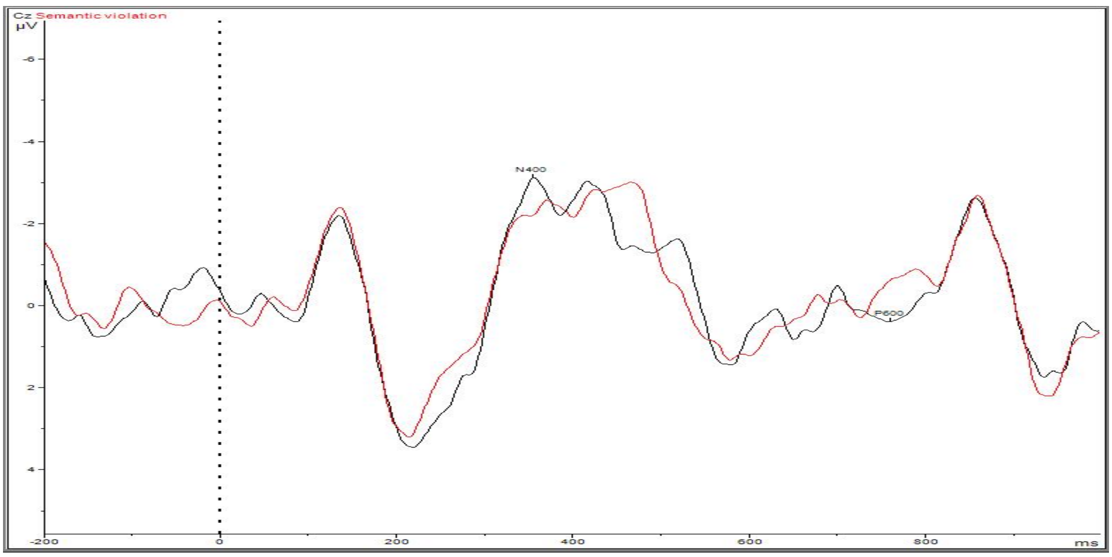


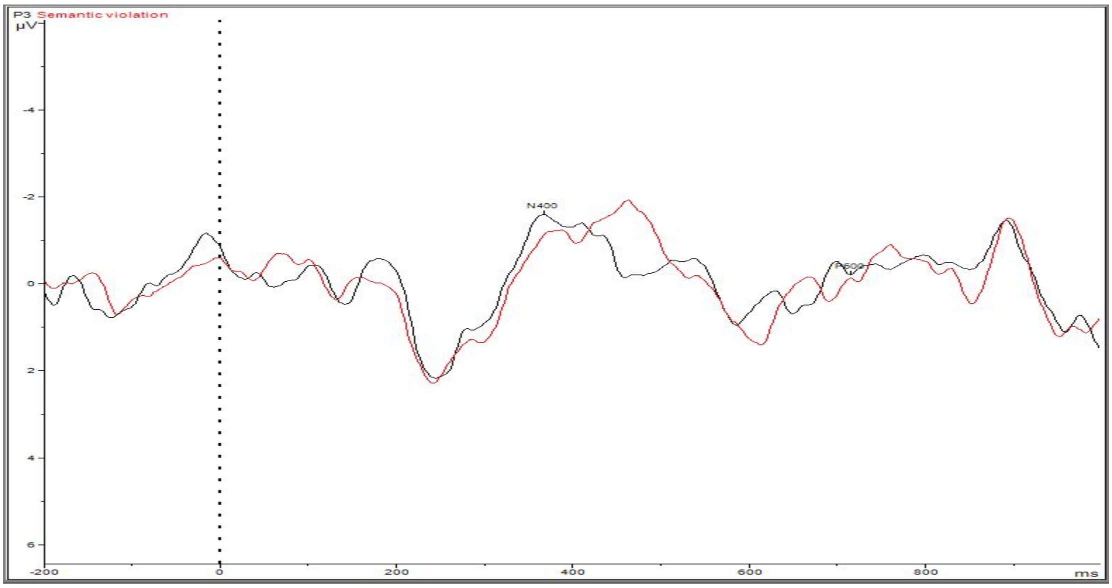


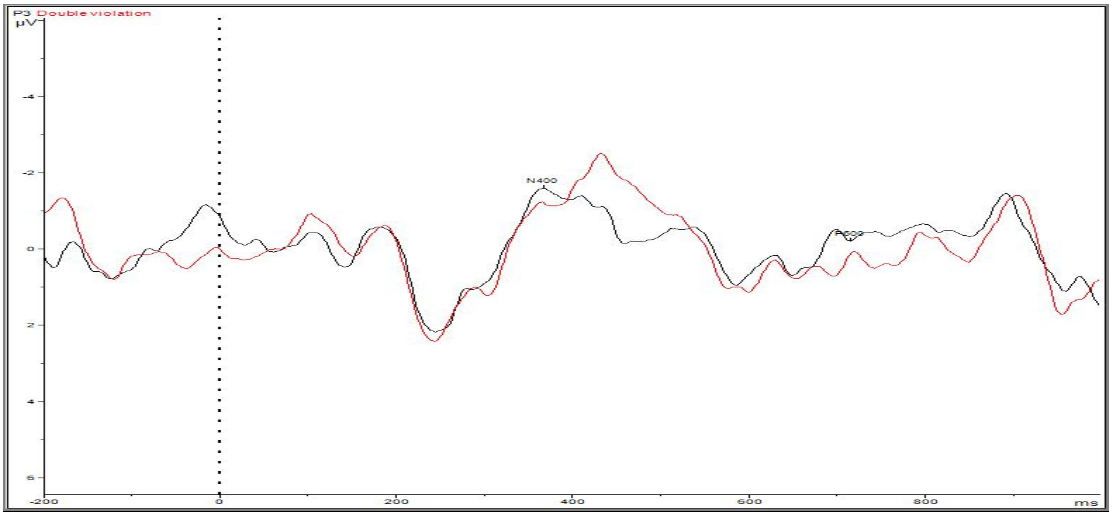
TRIGGER 6 WAVEFORMS

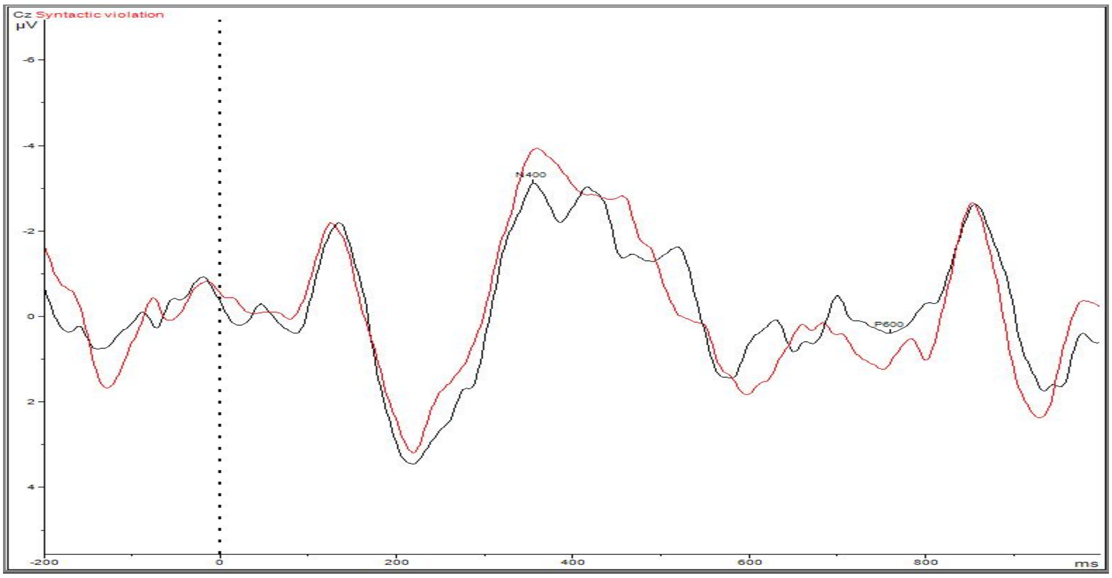

C3 Syntactic violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms


Cz Semantic violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms


Cz Semantic violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms


P3 Semantic violation
µV
-4
-2
0
2
4
6
N400
P600
-200
0
200
400
600
800
ms


P3 Double violation
µV
-4
-2
0
2
4
6
N400
P600
-200
0
200
400
600
800
ms


Cz Syntactic violation
µV
-6
-4
-2
0
2
4
N400
P600
-200
0
200
400
600
800
ms