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Electrophysiological response to omitted stimulus in sentence processing

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The current study provides evidence that the absence of a syntactically expected item leads to a sustained cognitive processing demand. Event-related potentials were measured at the omission of a syntactically expected object argument in a speech sequence. English monolingual adults listened to paired sentences. The first sentence in the pair established a context. The second sentence provided a response to the first sentence that was either grammatically correct by containing an overt object argument in the form of a pronoun, or was syntactically unacceptable by omitting the expected object pronoun. Event-related potentials measured at the omission of the object argument showed a prolonged positivity for 100–600 ms with a broad scalp distribution, and for 600–1000 ms with a focus in the anterior region. This observed omitted stimulus potential may contain characteristics of the P300 component, associated with the detection of the deviation of an expected stimulus, and the classical P600 related to syntactic reanalysis. Further, the late anterior P600 may indicate an increased memory demand in sentence comprehension. Thus, this linguistic omitted stimulus potential is a cognitive indicator of language processing that can be used to investigate the organization of linguistic knowledge. *NeuroReport* 25:1169–1174 © 2014 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

In the pioneering studies of human electrophysiological response to an omitted stimulus, Klinke *et al.* [1] observed that the omission of a stimulus in a sequence of electric somatosensory stimulations evoked a distinct event-related potential (ERP), characterized by a large amplitude positive-going wave that plateaued around 340–370 ms. This omitted stimulus potential (OSP) has also been observed in other sensory modalities. For example, when visual (e.g. flashes of light) or auditory (e.g. tones) stimuli were presented in sequence, a positivity was observed when a stimulus was randomly omitted using the oddball paradigm [2–6].

The OSP observed in response to the omission of stimuli in various modalities appears to share the same underlying mechanisms as the P300 [4]. The P300 is also a positive deflection with latency around 300 ms. It is typically evoked by a deviant, yet physically existing stimulus in a sequence of stimuli, using the oddball paradigm. The P300 is deemed to reflect the process of updating a representation of a perceptual event with new information [6], and/or a purely perceptual sensory response to a low probability timing deviation. That is, a deviation that is unlikely to be encountered within a typical context [4,7–9].

A P300-like OSP response has been observed when the presentation of the expected final words of familiar proverbs and idioms were artificially delayed in natural speech [10]. While the expectancy violation in the oddball paradigm relies on a newly learned temporal sequence stored in short-term memory, expectancy violations in language comprehension derive from long-term memory since the recognition of a grammatical violation requires comparisons with previously learned knowledge. The proverb study contained two possible violations: the abrupt discontinuation in speech prosody before the delayed words, which might have evoked the P300-like OSP; and the syntactic violation associated with the perceived omission of the delayed final words. Syntactic violation has been shown to elicit ERP components such as the P600 or the late positive component (LPC) [11–14].

In the current study, we investigate the nature of the OSP evoked by a stimulus omission in language comprehension in the case where there is no prosodic violation. There is an expectation in English grammar that object arguments in the transitive subject–verb–object structure are obligatorily overt except for limited contexts [15]. In the situational context, 'Your dinner was awesome. How did you prepare the fish?' the following response sentence must have an object argument that is

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explicitly expressed, usually in the form of a pronoun, 'I marinated it.' The omission of the final pronoun (hereafter referred to as the 'null object' or the 'ø'), will create an expectancy violation and may evoke an OSP. Here we investigate whether the omission of an object argument that violates a syntactic rule elicits the OSP. Of particular interest is to examine the extent to which this component appears more similar to the P300 or P600.

Materials and methods

Participants

Participants were 10 monolingual native speakers of English (six female; *M* = 21 years; range = 18–23 years). Written informed consent was obtained before the experiment. The Saint Mary's College of California's Institutional Review Board approved this study.

Stimuli

Sixty-six pairs of context and target sentences were created in which pronoun usage in the target sentences was manipulated across two conditions. In the pronominal condition, a target sentence ended with an object pronoun with the referent in the preceding context sentence. In the null condition, the object pronoun was omitted. For example:

Context: 'The apples on the tree are ripe now.'

Target: 'We should pick **them**' (Pronominal).

'We should pick **ø**' (Null).

The difference in grammatical acceptability of the sentence pairs in the two conditions was validated in an offline judgment task administered to a different set of participants. A total of 180 distractor pairs were also created that contained semantic or syntactic violations, but not null arguments. Distractor pairs were included to ensure that participants could not predict the pattern of errors, and were not analyzed.

The sentences were read by native speakers of English and were digitally recorded (44,100 Hz, 16 bit, Sound Forge, Sony). Special attention was given to prosody for the target sentences in the null condition. The speaker read the sentences with null objects as if they were grammatically acceptable. Thus, the verbs followed by null objects contained falling pitch, indicating the end of the sentence. The average durations of recorded stimuli are as follows: context sentences 2603 ms, SD = 955 ms; pronominal target sentences 1201 ms, SD = 415 ms; and null target sentences 1157 ms, SD = 425 ms.

Trigger placement

ERP triggers were placed at the object argument onset in each of the target sentences. To place a trigger at the onset of a null object, the interval between the offset of the verb and onset of the pronoun in each of the target sentences in the pronominal condition was measured. The average interval was 23 ms (range = 3–121 ms, SD = 20 ms). The same time interval was used to place the trigger after offset of the verb in the target sentence in the null condition.

Procedure

Participants listened to stimuli sentences through closed-ear headphones. The stimuli were organized with the Latin square design. Context-target paired sentences were divided into three blocks, each with 66 test sentences and 60 distractor sentences. Participants completed all blocks.

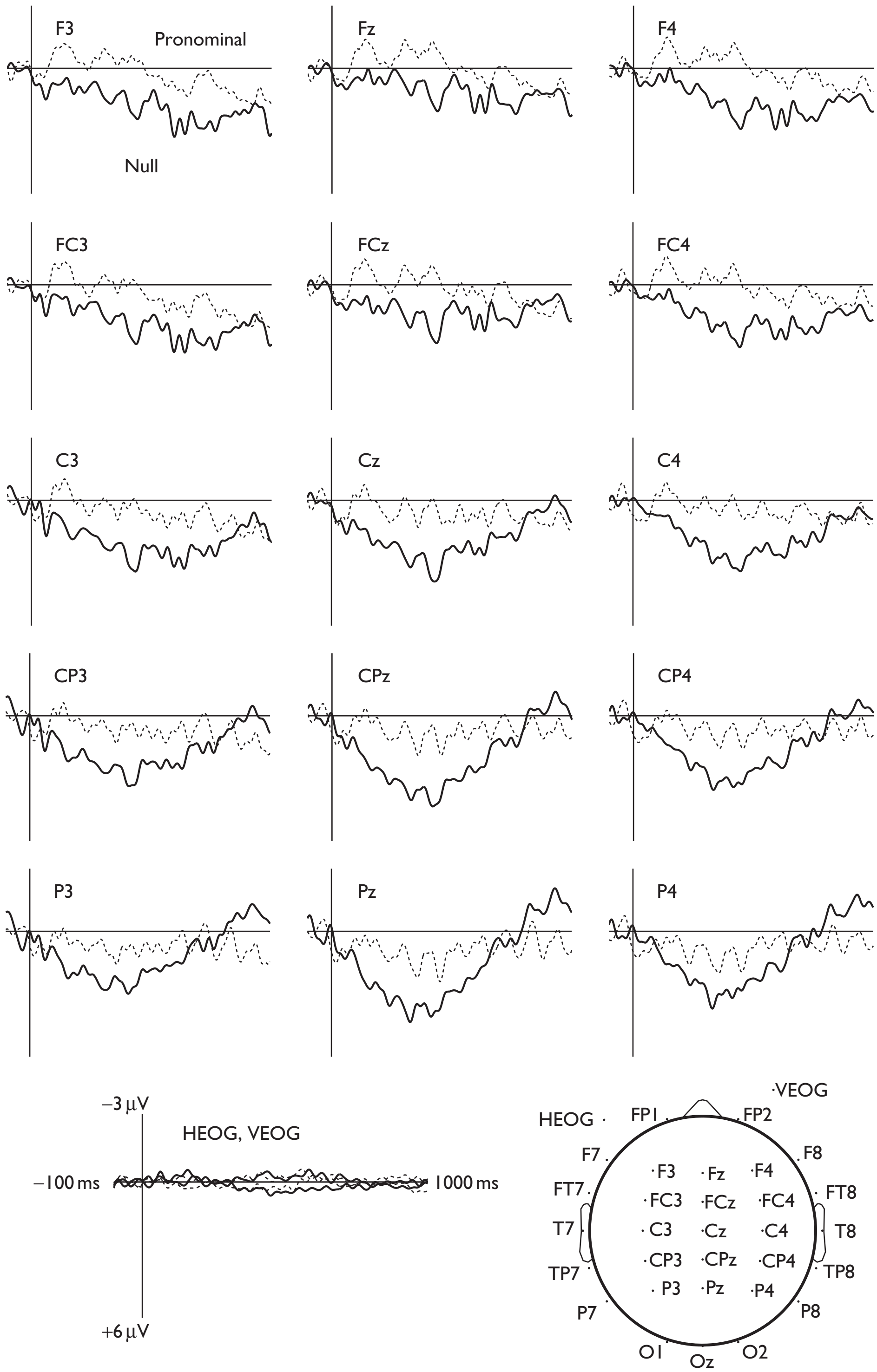
Each trial began with a fixation cross displayed for 500 ms on a monitor positioned 1.0 m in front of the participant. The fixation cross remained visible during the auditory presentation of the stimuli, and for an additional 1000 ms after the offset of the sentence. To ensure participants' engagement in the tasks a written comprehension probe question (e.g. 'Did James like the fish at dinner?') was presented for 20.6% of the stimuli. Participants were asked to respond as quickly and accurately as possible by pressing a 'yes' or 'no' button on a keyboard. The average percent correct for responses to the comprehension probes was 91.9% (range = 83.1–96.1%).

Electroencephalogram recording and analysis

Electroencephalogram (EEG) was recorded from 32 electrodes (sintered Ag/Ag/Cl), mounted in an elastic cap (Neuroscan 32 QuickCap, Compumedics, Charlotte, North Carolina, USA). Electrodes were referenced to linked right and left mastoid bones. To monitor eye movements and blinking, electrodes were also placed on the left and right outer canthi, and below and above the left eye. Impedances were kept below 5 kΩ. The EEG signal was band pass filtered with cutoffs at 0.01 and 200 Hz, and digitized online at a sampling rate of 1000 Hz (Neuroscan SynAmp I, Compumedics, Charlotte, North Carolina, USA).

EEGLAB (UCSD, San Diego, California, USA) was used for EEG data analysis. Data were resampled to 320 Hz for offline processing. Artifact correction was performed on the continuous data by applying a joint probability method to remove segments with nonstereotyped artifacts, and using independent component analysis [16] to identify components related to blinks, eye movement, and muscle activity. Epochs were extracted from the artifact corrected continuous data, starting 100 ms before stimulus onset (baseline) and ending 1000 ms after stimulus onset. The correction procedures resulted in rejecting 8.3% of the pronominal and 7.2% of the null epochs. Average ERPs were computed over trials for the object argument in both conditions. Mean amplitude of ERPs was subjected to statistical analyses.

Fig. 1



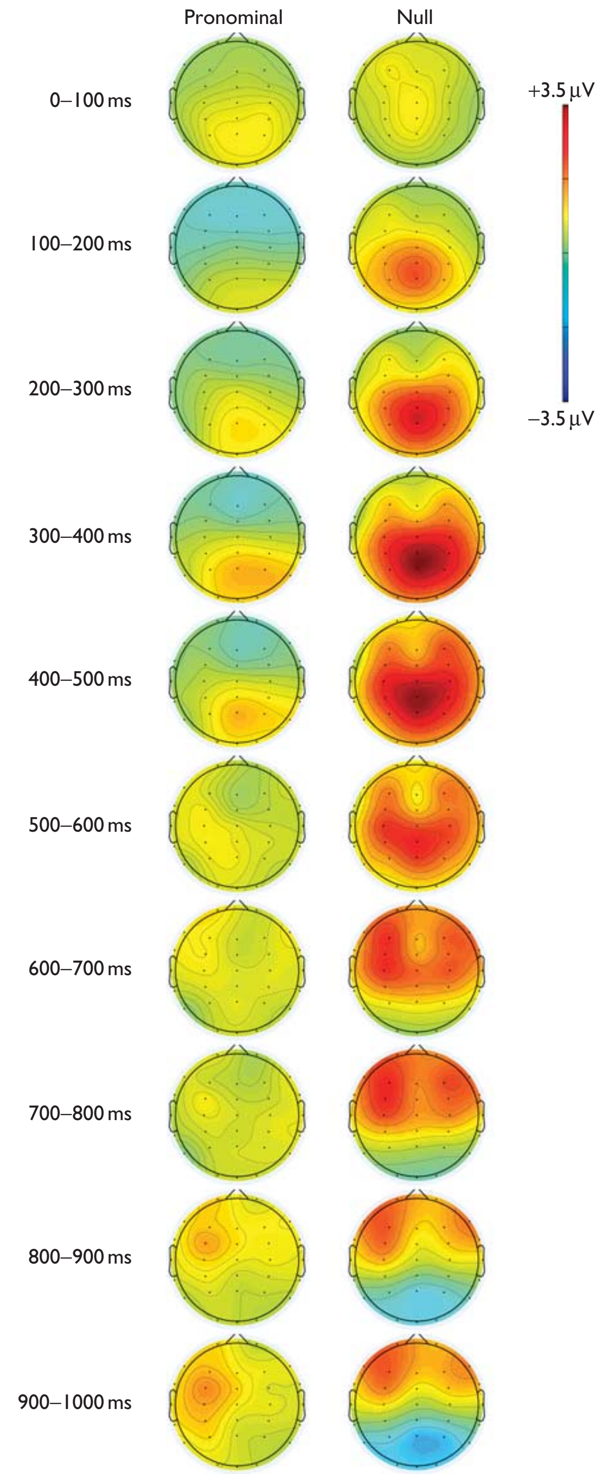
Event-related potential (ERP) patterns for F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, and P4 electrodes. Horizontal and vertical electrooculograms (HEOG, VEOG) and electrode sites are also shown.

Results

Figure 1 shows grand average ERPs of pronominal and null conditions measured at the onset of the object argument. The ERP for the null condition has a prolonged positive deflection, starting early and lasting for several hundred milliseconds, compared with the pronominal condition. A two-way repeated measures analysis of variance (ANOVA) with argument type (pronominal and null) and electrode sites (30 sites) with the Greenhouse–Geisser corrections were performed on the mean amplitudes within the 100–600-ms time interval. The ANOVA yielded a main effect of argument type [$F(1.0, 9.0)=11.139$, $P=0.009$], a main effect of electrodes [$F(3.1, 27.1)=5.056$, $P=0.006$], and no significant interaction [$F(2.4, 21.5)=2.498$, $P=0.098$]. The null condition elicited greater positivity (i.e. OSP) than the pronominal condition.

The topographic distribution of the ERP patterns over time in 100-ms increments showed that the positivity shifts from centroparietal sites toward anterior sites for the null condition after 600 ms (Fig. 2). To investigate this topographic shift, a three-way ANOVA was performed for the 600–1000-ms time interval with argument type (pronominal, null), region (anterior, posterior), and electrode sites as repeated factors. The main effects of argument and electrodes were significant [$F(1.0, 9.0)=7.078$, $P=0.026$ and $F(2.1, 18.6)=9.225$, $P=0.002$, respectively]. There was a significant interaction of argument type by region [$F(1.0, 9.0)=7.593$, $P=0.022$]. Post-hoc analyses using the Least Significant Difference Test (LSD-T) revealed the anterior region showed greater positivity than the posterior region in the null condition [$t(9)=4.416$, $P=0.002$]. A region difference was not found in the pronominal condition. In the anterior region, a larger positivity was elicited by the null condition compared with the pronominal condition [$t(9)=2.673$, $P=0.026$]. In the posterior region, there was no difference between conditions (Fig. 3).

Fig. 2



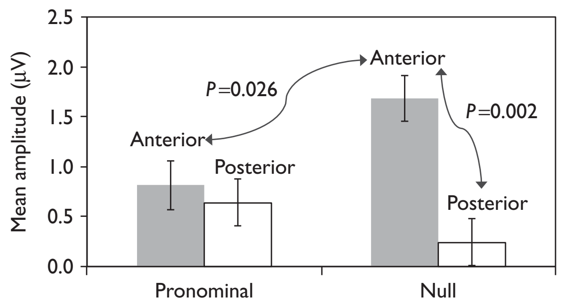
Scalp distribution of the ERP patterns. Each distribution represents a time average over 100-ms increments for pronominal and null conditions.

Discussion

For the null condition, the omitted argument elicited an electrophysiological response in the form of a prolonged positive-going wave. Thus, the OSP was indeed elicited by the omission of a syntactically expected object argument. In this study, verbs in the null condition were read as if they were sentence-final to minimize effects of perceptual surprise, suggesting that the observed OSP was derived from pre-existing syntactic knowledge stored in long-term memory. The underlying mechanisms of this linguistic OSP, therefore, differ from those of the perceptual OSP evoked in the oddball paradigm.

We further observed that the linguistic OSP was comprised of distinct scalp distributions: a widely distributed positivity for the 100–600-ms time window; and an anteriorly distributed positivity for 600–1000 ms. The early positivity may reflect the detection of deviation from an expected syntactic sequence stored in long-term memory, that is, conceptual surprise as opposed to perceptual surprise. For example, Osterhout *et al.* [17] observed a P300 elicited to a verb printed in uppercase letters in a sentence printed in lowercase letters. The P300 effect was enhanced when the typeface violation was combined with a syntactic violation. In the current study, thus, the omission of an expected pronominal object provoked this type of conceptual surprise. In addition, the prolonged positivity may reflect further

Fig. 3



ERP mean amplitudes for anterior (F3, Fz, F4, FC3, FCz, and FC4) and posterior (CP3, CPz, CP4, P3, Pz, and P4) regions during the 600–1000-ms time window.

reanalysis of the syntactic anomaly. It is well documented that violations of syntax such as phrase structure rules or agreement rules elicit the LPC including the P600 with a broadly or centroparietally distributed positivity [11–14]. Our observation of a late positivity in the time window of 100–600 ms is in accordance with the LPC latency and distribution, suggesting that participants encountered a need for syntactic reanalysis that was triggered by the omitted object pronoun.

The process of syntactic reanalysis seemed to continue past 600 ms, with the distribution of the OSP shifting toward frontal locations for the 600–1000-ms time window. Kaan and Swaab [13] propose that the distribution of the P600 reflects different characteristics of syntactic processing: the posterior P600 is related to syntactic reanalysis, consisting of revision and/or repair, whereas the frontal P600 is associated with an increase in discourse level complexity. With our data, it is possible that the system initially encountered a need for syntactic reanalysis. Then, after 600 ms, it faced the need to perform further complex operations. For example, to repair the grammatical error and understand the null argument sentences, participants needed to first retrieve either the exact context sentence or the discourse content, then fill in the missing information using the retrieved material. The memory retrieval and syntactic repair operations created an increased conceptual demand, which elicited increased frontal positivity. Late frontal positivity has also been reported with nonlinguistic materials, such as complex mnemonic memorization tasks [18] and memory retrieval tasks of graphical stimuli [19]. Our observed anterior LPC may belong to this set of processes that involve conceptually complex memory operations, which are not strictly linguistically based.

An alternative explanation of our results is that the observed positivity during 100–600 ms might be part of a closure positive shift (CPS), which is a broadly distributed positive shift starting 400–500 ms after onset of a prosody cue that indicates phrasal closure [20,21]. With our material, CPS is expected at phrasal closures in both conditions: at the object noun for the pronominal condition, and at the verb for the null condition. Thus, the early onset of positivity in the null condition at the object noun may be a carryover CPS elicited at the verb. If the positivity in the null condition is CPS, a similar CPS-based positivity is expected in the pronominal condition at the object noun. However, the positive deflection in the null condition is distinctly more pronounced than the pronominal condition, suggesting that the null positivity reflects more than a carryover CPS. The prosody–syntax mismatch in the null condition called for syntactic reanalysis, which might have also elicited a LPC. This is consistent with previous studies that have shown such a mismatch evokes LPCs such as P600 [21].

Our results suggest that the OSP is a neurocognitive indicator of language processing with characteristics of both P300 and P600. In fact, a recent finding from Japanese monolinguals showed that Japanese null object sentences failed to elicit an OSP [22] because the omission of object arguments is grammatically acceptable in Japanese. This linguistic OSP can be a valuable tool in investigating how this knowledge develops during language acquisition, as well as in examining whether the organization of grammatical knowledge in English–Japanese bilinguals differs from monolinguals.

Conclusion

The omission of a syntactically expected item from complex linguistic material elicited an OSP, characterized by an early and prolonged positivity with a broad distribution and a late positivity with an anterior distribution. This finding provides evidence that linguistic OSPs reflect long-term memory based surprise in response to omission of an expected object argument, followed by syntactic reanalysis, which involves processes of memory retrieval and the resolution of the omitted item.

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Conflicts of interest

There are no conflicts of interest.

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