What You Ask Affects What You Get: Task-Dependent ERPs in the Processing of Syntactically Ambiguous Sentences

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Abstract

Two experiments examined how task demands influence underlying sentence processing mechanisms, as reflected in neural responses at the disambiguating word, where reanalysis occurs. In both experiments, participants read garden-path sentences with late-closure ambiguity, such as *While the man hunted the deer ran into the woods*, and then answered comprehension questions while their brainwaves were recorded. Existing research suggests that people often interpret such sentences as meaning that the man hunted the deer and the deer ran into the woods. Previous studies also show that high "yes" erroneous responses to questions like *Did the man hunt the deer?* partly stem from inferences. In the present study, the first experiment asked questions like *Did the man hunt the deer?*, while the second experiment asked "explicit" questions such as *Did the sentence explicitly say that the man hunted the deer?*, aiming to reduce responses based on inference. Results revealed a typical P600 effect, more pronounced for ambiguous than unambiguous sentences at the disambiguating verb *ran* in Experiment 1, and an N400 effect followed by a Sustained Frontal Negativity in Experiment 2. These findings suggest that the "explicit" questions shifted the sentence processing mechanism from syntactic reanalysis, typically associated with the P600, to a more detailed evaluation of plausibility, as reflected by the N400. The Sustained Frontal Negativity likely reflects increased processing load during conflict resolution when participants must evaluate and resolve competing interpretations. This conflict resolution process likely persisted longer due to the "explicit" questions.

Keywords: sentence processing; late-closure ambiguity; ERPs, N400; P600; Sustained Frontal Negativity; plausibility

Introduction

This study examines the mechanisms underlying sentence processing across different tasks in temporarily ambiguous sentences with late-closure syntactic ambiguity, as shown in example (1) below.

(1) *While the man hunted the deer that was brown and graceful ran into the woods.*
(2) *Did the man hunt the deer?*
(3) *Did the deer run into the woods?*

Research has consistently shown that when reading sentences like (1), readers experience a slowdown at the main verb *ran.* This occurs because they initially interpret the noun phrase *the deer that was brown and graceful* as the object of the subordinate clause verb *hunted*. Upon reaching the main clause verb *ran*, the parser detects the absence of a subject and initiates reanalysis. This slowdown in reading is known as the garden-path effect. Successful reanalysis involves removing the noun phrase from its role as the object of *hunted* and reassigning it as the subject of *ran*. The parsing of garden-path sentences, such as (1), has been widely studied to differentiate among competing theories of sentence processing (e.g., Christianson et al., 2001; Ferreira et al., 2001; Ferreira & Henderson, 1990; Garnsey et al., 1997; Pickering & Traxler, 2003; Pickering et al., 2000; Trueswell et al., 1993).

Parsing sentences with late-closure ambiguity, such as (1), has been used to compare two major sentence processing theories: two-stage serial models and one-stage interactive models. Serial models, like the Garden-Path Model, propose that initial syntactic decisions are based solely on syntactic information (Ferreira & Clifton, 1986; Frazier, 1987; Frazier & Fodor, 1978; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983). The parser selects the simplest structure using principles such as Minimal Attachment and Late Closure, deferring non-syntactic information to a second stage for evaluation (Frazier & Rayner, 1982). In contrast, interactive models, such as constraint-based models, suggest that multiple structures are activated simultaneously, with both syntactic and non-syntactic information influencing parsing from the outset (Garnsey et al., 1997; MacDonald et al., 1994; McRae et al., 1998; Trueswell et al., 1993, 1994). For example, in serial models, encountering the main verb *ran* triggers reanalysis to reassign *the deer* from the object of the subordinate verb to the subject of the main clause. In interactive models, both object and subject interpretations are initially active, with *ran* prompting a re-ranking of these analyses. Despite their differences, both theories assume that the parser ultimately constructs a complete and accurate syntactic structure and interpretation by the end of the sentence.

Since the studies by Christianson et al. (2001) and Ferreira et al. (2001), growing evidence has shown that readers do not always arrive at the correct interpretation of sentences with late-closure ambiguity (e.g., Qian et al., 2018; Qian & Dell, 2024). After reading sentences like (1), readers often incorrectly answer “yes” to questions like (2) while correctly answering “yes” to questions like (3), suggesting that they interpret the sentence as meaning that the man hunted the deer and the deer ran into the woods, even though this interpretation is not supported by the syntax (Christianson et al., 2001; Christianson et al., 2006; Ferreira et al., 2001). These findings suggest that reanalysis is only partially successful: while *the deer* is correctly reattached as the subject of *ran into the woods*, it remains erroneously linked as the object of *while the man hunted*.

One possible explanation for why readers interpret sentence (1) as meaning that *the man hunted the deer* is the role of inference. Since 96% of readers arrived at the interpretation that *the deer ran into the woods* (Qian & Dell,

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2024), they may infer that, while this event is occurring and the man is hunting something, the most likely object of his hunt is the deer. The idea that inference contributes to the misinterpretation of sentences like (1) is supported by the high error rates (around 50%) observed in responses to comma-disambiguated and reverse-order disambiguated unambiguous versions of such sentences, like (4) and (5) (Christianson et al., 2001). Considering that the error rate for questions like (2) is approximately 70% (Christianson et al., 2001), the remaining 20% of errors can likely be attributed to incomplete reanalysis.

(4) *While the man hunted, the deer that was brown and graceful ran into the woods.*
(5) *The deer that was brown and graceful ran into the woods while the man hunted.*
(6) *While Anna dressed the baby who was cute and small spit up on the bed.*

To reduce the likelihood of answering comprehension questions based on inferences, another type of sentence, referred to as sentences with Reflexive Absolute verbs, such as (6), has been widely used in research (e.g., Christianson et al., 2001). In (6), *dress* functions as a Reflexive Absolute verb that takes its subject as the object if no object is explicitly mentioned. Successful reanalysis of (6) would lead to the interpretation that *Anna dressed herself*, rather than an unspecified person or object. Indeed, Christianson et al. found that readers make 20% fewer errors after reading ambiguous sentences like (6) compared to sentences like (1).

In the present study, we asked two types of questions across two experiments. The second type of question aimed to reduce the likelihood that readers would answer based on inferences. The first type of question, used in Experiment 1, was the same as (2), rewritten below as (7). The second type of question, used in Experiment 2, is shown in (8). The error rates for comprehension questions and the event-related brain potentials (ERPs) associated with processing the disambiguating word, such as *ran* in (1), were collected and compared between the two experiments.

(7) *Did the man hunt the deer?*
(8) *Did the sentence explicitly say that the man hunted the deer?*

Two ERP components, the N400 and P600, will serve as indicators to examine the underlying sentence processing mechanisms at play when readers either suppress or do not suppress making inferences while responding to questions (7) or (8). When readers refrain from making inferences, they may need to focus more on the literal meanings of the sentences. The N400 and P600 components are known to reflect semantic and syntactic aspects of language processing. The N400, a negative deflection peaking approximately 400 milliseconds after the onset of a word, indicates the ease with which the meaning of a word can be processed within its given context (Kutas & Hillyard, 1980; Kutas & Federmeier, 2011). In contrast, when the syntactic agreement is violated, the amplitude of the P600, a positive deflection peaking around 600 milliseconds after the triggering word, typically increases (Hagoort et al., 1993; Osterhout & Holcomb, 1992; Osterhout et al., 1994). The P600 may be preceded by a left anterior negativity (LAN), a negative deflection most prominent at anterior scalp sites, often more pronounced over the left hemisphere (Kluender & Kutas, 1993). Hagoort (2003) suggested that the LAN reflects the automatic detection of morphosyntactic violations during initial processing, while the P600 reflects the reanalysis or revision of these violations during later processing stages. We predict that P600 and LAN effects may be observed in Experiment 1; however, it is difficult to make predictions for Experiment 2, as there is no prior research available for reference.

Experiment 1

Experiment 1 examined the event-related brain potential (ERP) responses to the disambiguating word in temporarily ambiguous sentences with late-closure ambiguity when comprehension questions probed the initial misanalysis.[1]

Method

Participants The participants were 64 undergraduate students (29 males; mean age 19, range 18–22) from a midwestern university in the United States. All were native English speakers, strongly right-handed as determined by the Edinburgh Inventory (Oldfield, 1971), had a normal or corrected-to-normal vision, and had no history of neurological or psychiatric disorders. Data from six participants were excluded due to technical issues with data collection or excessive trial loss due to artifacts. Four additional participants were excluded because their accuracy of distractor responses was below 75%. The final analysis included data from 54 participants.

Materials and Design The experimental sentences consisted of 40 sets, each including an ambiguous version and a comma-disambiguated unambiguous version, as shown in (9). In all sentences, the ambiguous noun was followed by a relative clause containing two adjectives. Each verb was used in only one item set throughout the experiment. All sentences were taken from Christianson et al. (2001).

(9) **Ambiguous:**
While the man hunted the deer that was brown and graceful ran into the woods.
Unambiguous:
While the man hunted, the deer that was brown and graceful ran into the woods.
Question: *Did the man hunt the deer?*

The critical sentences were distributed across two lists using a Latin square design, ensuring that each participant viewed only one version from each item set and an equal

[1] The results of Experiment 1 were previously reported in (xxx, 20xx) as Experiment 3, as part of a larger project examining whether increased effort during reanalysis leads to more accurate interpretation of sentences like those illustrated in (1). These results are included here for comparison with the findings of Experiment 2.

number of sentences from each condition. Following each sentence, a comprehension question was presented to probe the initial misinterpretation.

Distractors consisted of 144 sentences across the following categories: (1) 40 ambiguous sentences where the noun immediately following a verb is interpreted as the subject of an embedded sentential complement rather than the direct object of the main clause, along with their unambiguous versions (e.g., *The naïve girl believed (that) the urban myth could teach her the real history*); (2) 50 sentences with matrix-subordinate clause order, where the noun following the main clause verb is its direct object (e.g., *The union leader implied the raise when he met with strikers*); (3) 20 sentences with subordinate-matrix clause order similar to the experimental items, but containing both a direct object and a main clause subject (e.g., *While Janis watched the fish, she cleaned the tank*); (4) 10 unambiguous sentences with matrix-subordinate clause order (e.g., *The mother served the broccoli while the kids banged the table*); and (5) 24 ambiguous and unambiguous sentences with Reflexive Absolute verbs (e.g., *While Anna dressed(,) the baby who was cute and small spit up on the bed*). Distractor types 2–4 were included to ensure that the overall proportion of trials where the noun immediately following a verb turned out to be its direct object, rather than needing to be reanalyzed as the subject of a subsequent clause, remained balanced.

Procedures Participants were seated comfortably in a dimly lit, sound-attenuated booth in front of a 23-inch LCD monitor. Each trial began with a fixation point that remained at the center of the screen for 500 ms. To avoid eye movement artifacts that could contaminate the EEG signal, sentences were presented word-by-word at the center of the screen in 26-point white Arial font on a black background, at a rate of 400 ms per word (300 ms for the text and 100 ms for a blank screen). After each sentence, a comprehension question (e.g., *Did the man hunt the deer?*) was presented, with Yes and No response choices displayed below the question. Participants indicated their responses by pressing one of two buttons on a Cedrus RB-830 response box. If no response was made within four seconds, a "Too Slow" warning appeared. No feedback was provided regarding response accuracy. Stimulus presentation was controlled using the Presentation® software package.

Each list was divided into four blocks, with participants given a short break after each block. They were instructed to minimize blinking and body movement during the sentence presentation and were encouraged to blink between trials as needed. A practice block of five trials was provided at the beginning. The recording session lasted approximately 45 minutes, and the entire session took about two hours.

EEG Recording and Data Analysis Continuous EEG were recorded from 27 Ag/AgCl sintered electrodes placed in an elastic cap (EasyCap, 10–10 system), referenced online to the left mastoid, and re-referenced offline to the average of left and right mastoids. The electrode configuration included the following sites: midline: Fz, Cz, Pz; lateral: AF3/4, F3/4, F7/8, FT7/8, FC3/4, C3/4, T3/4, CP3/4, T5/T6, P3/4, P5/6, PO7/8. A .01–30 Hz analog bandpass filter was applied during online recording. Impedances were kept below 5 kΩ.

Epochs were extracted from the continuous waveforms starting 100 ms before the onset of the disambiguating verb and extending to 1100 ms after its onset. Eye blinks and movements were detected using a moving window peak-to-peak function on the EOG channels, while non-ocular artifacts were identified with the same function applied to the EEG channels. On average, 11.5% of the data were lost due to artifact rejection, with no significant difference across conditions (ambiguous: 11.5%, unambiguous: 11.6%).

Visual inspection revealed a P600 effect, which was more positive for the ambiguous condition than for the unambiguous condition. Mean amplitudes for each channel in each condition were calculated for the 600–900 ms time window to capture the P600 component and were submitted to separate repeated-measures analyses of variance (ANOVAs) for two sets of analyses. One set included all lateral electrodes, while the other focused on midline electrodes. When interactions with electrode sites in the omnibus ANOVAs motivated further analyses, these were conducted on six regions of interest (ROIs), each consisting of four electrodes: left anterior (AF3, F3, F7, FT7), right anterior (AF4, F4, F8, FT8), left central (FC3, C3, CP3, T3), right central (FC4, C4, CP4, T4), left posterior (P3, T5, P5, PO7), and right posterior (P4, T6, P6, PO8). In cases where no interactions involved the laterality factor, it was collapsed, and analyses were conducted on three ROIs: anterior, central, and posterior. Analyses within ROIs included one within-subject factor: ambiguity (ambiguous, unambiguous). The Greenhouse-Geisser correction was applied where necessary to correct for violations of sphericity (Greenhouse & Geisser, 1959).

Results

Comprehension Accuracy Comprehension accuracy for distractors was analyzed to assess whether participants were paying attention to the sentences. Four participants were excluded from further analyses due to their response accuracy to distractors being below 75%. The average accuracy of the remaining participants was 91%. Comprehension accuracy for critical sentences was analyzed using logit mixed-effects models with the maximum random effects structure, including ambiguity as a fixed effect. The results revealed a significant main effect of ambiguity on comprehension accuracy (β=0.85, *SE*=0.21, z=4.06, p<.001), with more incorrect responses for ambiguous sentences (58%) compared to unambiguous sentences (44%).

ERPs Visual inspection revealed that the waveforms for the disambiguating verb (e.g. *ran*) were more positive during the P600 time window (600–900 ms) in the ambiguous condition compared to the unambiguous condition, as shown in Figure 1. As is typical for the P600 effect, it was centroparietally distributed. ANOVAs conducted over all lateral electrodes revealed a main effect of ambiguity, $F(1,53)=4.45$, $p<.05$, and an interaction between ambiguity and the anteriority of electrode location, $F(2,106)=11.61$, $p < .001$. This interaction occurred because the P600 effect was significant at central sites, $F(1,53)=6.58$, $p=.01$, and posterior sites, $F(1,53) =15.91$, $p<.001$, but not at frontal sites, $F<1$. ANOVAs over the midline electrodes revealed the same pattern, with a main effect of ambiguity, $F(1,53) = 5.90$, $p < .05$, and an interaction between ambiguity and anteriority, $F(2,106) = 8.18$, $p<.001$, because the P600 effect was significant at Cz, $F(1,53) = 6.72$, $p = .01$ and Pz, $F(1,53) = 11.77$, $p = .001$, but not at Fz, $F<1$. The P600 effect suggested that syntactic reanalysis took place at the disambiguation, or that readers experienced processing difficulty or confusion at the point of the disambiguating verb.

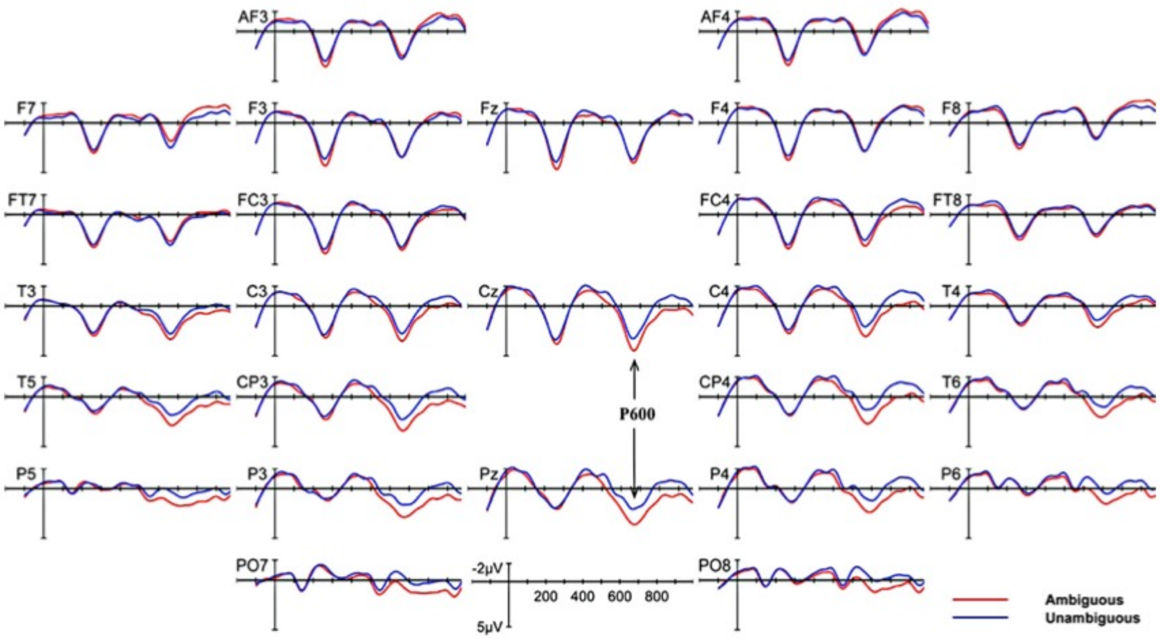

Figure 1. Grand average ERPs for the disambiguating verb at all electrodes in ambiguous and unambiguous sentences in Experiment 1, baselined on 100 ms before the onset of the disambiguating verb. The Y-axis position indicates the onset of the disambiguating verb.

Experiment 2

Experiment 2 differed from Experiment 1 only in the way the comprehension questions were asked. In Experiment 1, the comprehension questions were "non-explicit", such as *Did the man hunt the deer?*. In Experiment 2, the questions were explicit, such as *Did the sentence explicitly say that the man hunted the deer?*. This change aimed to direct the readers' attention to the literal meanings of the sentences, without the influence of inferences that may arise during the comprehension of this type of sentence.

Method

Participants Participants were 42 undergraduate students (24 males; mean age=19.3, range=18–23) from a midwestern university in the United States. All were native speakers of English, strongly right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971), had normal or corrected-to-normal vision, and had no neurological or psychiatric disorders. All participants gave written informed consent and received course credits or payment for their participation. Data from three participants (1 male) were excluded from analysis due to technical problems with data collection or excessive loss of trials due to artifacts.

Materials and Design As in Experiment 1, the critical sentences included both ambiguous and unambiguous versions of garden-path sentences. There were 60 items in total: 40 from Experiment 1 and an additional 20 items from Maxfield et al. (2009). Distractors consisted of 234 sentences, 144 of which were the same as in Experiment 1, with an additional 90 distractors added to Experiment 2. These new distractors were unambiguous sentences in which the noun immediately following the verb was the direct object, included to increase the number of unambiguous sentences across the experiment. An explicit question was asked at the end of each sentence. Among the 90 newly added distractors, the correct response to 66 was "yes" and 24 was "no." The inclusion of more "yes" than "no" correct responses to distractors was intended to balance the "yes" and "no" responses across the experiment, as readers tended to give more "no" responses to critical sentences when explicit questions were asked.

Procedures The procedures were identical to those in

Experiment 1. The total of 294 sentences was divided into six blocks, each containing 49 sentences. A practice block of six sentences was provided at the beginning. The recording session lasted approximately 75 minutes, and the entire session lasted between 2 to 2.5 hours.

EEG Recording and Data Analysis EEG recording and data analysis procedures were the same as in Experiment 1. Artifact rejection resulted in a 4% data loss, with no significant difference between the ambiguous and unambiguous versions (ambiguous 4.5%, unambiguous 4.3%). Visual inspection of the waveforms suggested that there might be effects other than the P600, so mean amplitudes were measured for the N400 (300-500 ms) and P600 (600-900 ms) time windows to capture potential N400, P600, and Sustained Frontal Negativity effects.

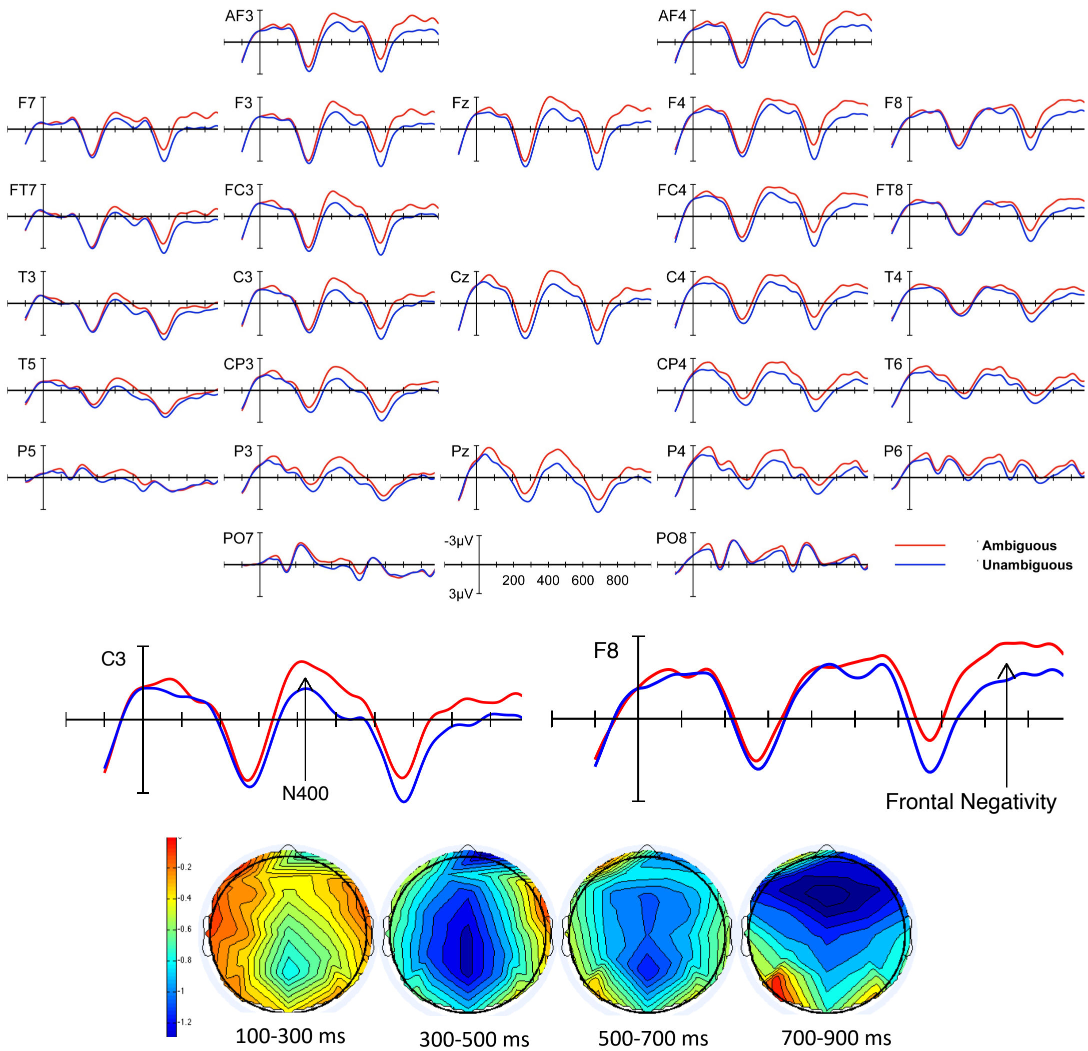

Figure 2. Grand average ERPs for the disambiguating verb at all electrodes in ambiguous and unambiguous sentences in Experiment 2, baselined on 100 ms before the onset of the disambiguating verb. The Y-axis position indicates the onset of the disambiguating verb. Topographical voltage maps of the ambiguity effect show that the scalp distribution of the effect changes over time.

Results

Comprehension Accuracy The average question response accuracy to distractors was 88%, with a range of 75% to 98%. Question response accuracy to critical sentences was analyzed using logit mixed-effect models, which included ambiguity as a fixed effect. Results revealed a main effect of ambiguity on response accuracy (β=1.22, *SE*=0.26, *z*=4.73, *p*<.001), with more incorrect responses to ambiguous than unambiguous sentences (50% vs 32%). This suggests that asking "explicit" questions reduced the likelihood of answering the questions based on easily drawn inferences by approximately 10% for both ambiguous and unambiguous conditions.

ERPs Visual inspection showed that contrary to expectation, there was no P600 effect elicited by the disambiguating verb. Instead, there was a broadly distributed negativity beginning in the N400 time window and persisting throughout the epoch that was larger for the ambiguous than the unambiguous condition, as illustrated in Figure 2. These observations were confirmed by statistical analyses. For the N400 time window measure, ANOVAs over all lateral electrodes revealed a main effect of ambiguity, $F(1,38)=11.03$, $p=.001$, but no interaction between ambiguity and anteriority, $F<1$. Analysis over midline channels showed the same pattern: a main effect of ambiguity, $F(1,38)=15.37$, $p<.001$, but no interaction with anteriority, $F<1$. Consistent with the absence of an interaction, analysis of individual ROIs showed that the ambiguity effect was significant over all ROIs: Left Frontal, $F(1,38)=8.68$, $p<.01$; Right Frontal, $F(1,38)=4.44$, $p<.05$; Left Central, $F(1,37)=10.08$, $p<.01$; Right Central, $F(1,38)=6.90$, $p<.05$; Left Posterior, $F(1,38)=5.26$, $p<.05$; Right Posterior, $F(1,38)=4.83$, $p<.05$.

For the 600-900 ms time window measure, ANOVAs over all lateral electrodes showed that the ambiguity effect persisted in this time window, $F(1,38)=12.37$, $p<.001$, but that it was modulated by an interaction between ambiguity and anteriority, $F(2,76)=4.56$, $p<.05$ because the scalp distribution of the difference changed over time. The ambiguous condition remained more negative than the unambiguous condition at the Frontal, $F(1,38)=14.68$, $p<.001$, and the Central Regions, $F(1,38)=10.04$, $p<.01$, but not at the Posterior Region, $F(1,38)=1.16$, $p>.1$. The ANOVA over midline channels also showed a main effect of ambiguity, $F(1,38)=10.08$, $p<.01$, and a marginal interaction between ambiguity and anteriority, $F(1,38)=2.48$, $p=.09$, which was caused by the ambiguous condition being more negative than the unambiguous condition at Fz, $F(1,38)=15.54$, $p<.001$, and Cz, $F(1,38)=5.56$, $p<.05$, but only marginal at Pz, $F(1,38)=2.77$, $p=.10$. The topographical maps in Figure 18 show how the scalp distribution of the ambiguity effect changed over time. During the N400 time window, the maximum difference was in the centroparietal region but by 700-900 ms it had shifted to a frontal maximum.

Discussion and Conclusion

In Experiment 1, the expected P600 ambiguity effect was elicited by the disambiguating verb when the question asked *Did the man hunt the deer?*. However, in Experiment 2, when an explicit question was asked after the same sentences (e.g., *Did the sentence explicitly say that the man hunted the deer?*), what was elicited at the disambiguating verb appeared to be an N400 effect followed by a sustained negativity with a frontal maximum, rather than P600.

The goal of the explicit questions was to encourage people to respond based on what the sentence actually said had happened, rather than on inferences that could easily be drawn from the sentence, with the idea that discouraging inference-based responding would lead to a tighter link between the online processing measures and the question responses. The questions seemed to have the desired effect because incorrect question responses declined from Experiment 1 to Experiment 2. However, another likely consequence of the explicit questions was that they encouraged people to be generally more careful in deciding on a response. In ambiguous sentences such as *While the man hunted the deer ran into the woods*, when it becomes clear at the disambiguating verb (*ran*) that the deer has to be its subject, that leaves *hunted* with no specified object. There is no automatic replacement of the object with the verb's subject as in sentences like *While Anna dressed the baby spit up on the bed*. Under these circumstances where the sentence does not say what the man hunted, the explicit question seems to have triggered a more thorough analysis of the plausibility of the deer as the object of *hunted*, given that no other object is available, and that led to an increase in the amplitude of the N400 component instead of P600.

Thus, tasks can determine which ERP component is observed. In Experiment 2, it was N400 that was elicited rather than P600 because people tried to use the plausibility of a noun as the object of a verb as the basis for answering the explicit question.

A sustained frontal negativity was observed in response to the disambiguating verb. It began during the N400 time window and had the centroparietal maximum scalp distribution that is typical of the N400 at that point, but then it persisted and shifted to a frontal maximum scalp distribution. The change in scalp distribution over time provides some justification for considering it to be two different but temporally overlapping effects. Sustained Frontal Negativity has been interpreted as reflecting the processing load occasioned by the need to resolve conflict among competing alternatives. It seems possible that the Sustained Frontal Negativity arose in Experiment 2 because the explicit questions caused people to evaluate more carefully both possible answers, with the result that more conflict between the two possible answers persisted longer.

To conclude, the results of Experiments 1 and 2 demonstrate how tasks can influence the ERP components observed during sentence processing. Experiment 1 elicited a P600 effect at the disambiguating verb, consistent with the resolution of syntactic ambiguity. In contrast, Experiment 2 elicited an N400 effect followed by a sustained frontal negativity. The shift from a P600 to an N400 effect reflects the impact of the explicit questions, which encouraged participants to prioritize the explicit content of sentences rather than relying on inferences. This task manipulation reduced incorrect responses and led to a deeper evaluation of the plausibility of nouns as verb arguments, as evidenced by the increased N400 amplitude. In addition, the sustained frontal negativity observed in Experiment 2 likely reflects the heightened processing load and conflict resolution associated with carefully weighing competing interpretations of the sentence. These findings underscore the role of task demands in shaping the sentence processing mechanisms involved in interpreting even the same sentence.

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