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Processing new and repeated names: Effects of coreference on repetition priming with speech and fast RSVP

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Abstract

Previous research has shown that the process of establishing coreference with a repeated name can affect basic repetition priming. Specifically, repetition priming on some measures can be eliminated for repeated names that corefer with an entity that is prominent in the discourse model. However, the exact nature and timing of this modulating effect of discourse are not yet understood. Here, we present two ERP studies that further probe the nature of repeated name coreference by using naturally produced connected speech and fast-rate RSVP methods of presentation. With speech we found that repetition priming was eliminated for repeated names that coreferred with a prominent antecedent. In contrast, with fast-rate RSVP, we found a main effect of repetition that did not interact with sentence context. This indicates that the creation of a discourse model during comprehension can affect repetition priming, but the nature of this effect may depend on input speed.

Keywords

Language comprehension; ERP; Coreference; Repetition priming

1. Introduction

Understanding spoken and written language presents unique challenges to the comprehension system. For example, when trying to comprehend spoken input, we cannot control the rate at which words are presented, nor can we stop the speech stream to replay earlier portions of the utterance should comprehension difficulty arise. In contrast, with normal reading, we must plan saccades to carry us through the text. While this places an additional demand on the reader, it also gives him/her control over the input, thereby lessening working memory demands. The outcome of this control during reading usually produces rates of input for linguistic material that are much faster than when listening to speech: college students on average can read five words a second while for speech the average rate is three words a second. Despite these differences, the ultimate goal of integrating the input to form a cohesive discourse representation is the same for both modalities. Distilling the message from language input imposes processing demands above those required for understanding words in a context devoid of linguistic structure, like word lists, and this message-level computation may modulate simple interlexical effects of context. However, the differences inherent in decoding speech and

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written text may result in differences higher up in this integration process. In the studies described here, we used event related potentials (ERPs) to extend our previous research in examining how the higher level process of establishing coreference affects basic repetition priming using natural speech and reading in an RSVP paradigm that more closely replicates natural reading speeds.

ERPs give us a window into the neural correlates of real-time language processing, without requiring study participants to do more than simply read or listen for comprehension. This method also provides high temporal resolution, which is of great advantage when studying the rapid integration process. The systematic modulation of ERP components by language factors has informed our theories of semantic organization and comprehension processes (e.g., Kutas and Federmeier, 2000; Osterhout and Holcomb, 1995). This method has also been used to examine referential and coreferential processing on-line (Anderson and Holocomb, 2005; Hammer et al., 2005; Harris et al., 2000; Osterhout and Mobely, 1995; Streb et al., 1999; Van Berkum et al., 1999a,b; Van Berkum et al., 2003a,b, this issue).

However, this method does have some limitations. For example, many researchers have argued that the classic language components do not reflect initial stages of lexical access (Sereno and Rayner, 2003). Beyond this possible limitation, which could apply to both written and spoken language comprehension, there are specific methodological constraints for studying reading. When using ERPs to study reading, the words must be presented one-at-a-time to avoid eye movements. This introduces an unnatural element, as participants now lack the input control that is a hallmark of natural reading. In addition, in order to better resolve the ERP components, words are usually presented at comparatively slow rates (e.g., one word every 500–800 ms), which may also influence normal reading strategies. In the studies presented here, we examine the impact of these methodological constraints by using more natural presentation methods (speech and faster RSVP).

2. Repetition priming

Repetition priming is perhaps the most fundamental effect of context: word processing is facilitated for words on their subsequent presentations. While the exact mechanism for this facilitation is debated, this phenomenon is very robust and has been shown with a variety of measures (Jacoby and Dallas, 1981; Rugg, 1985; Scarborough et al., 1977).

With ERPs, repetition priming has been shown to affect two components: the N400 and the Late Positive Complex (LPC). The N400 is a negative-going wave that usually peaks around 400 ms after the onset of a word (Kutas and Hillyard, 1980). The amplitude of the N400 is thought to be sensitive to lexical integration, such that words that are easier to integrate produce reduced N400s (Brown and Hagoort, 1993; Holcomb, 1993; Van Petten and Kutas, 1991). Facilitation due to repetition priming produces smaller amplitude N400s. The LPC component is a positive deflection occurring between 400 and 900 ms after word onset. Unlike the N400, LPC amplitude increases for repeated words in lists (Paller et al., 1995; Rugg, 1985; Swick and Knight, 1997). Modulation of this component has been linked to explicit recall of the word's prior presentation, as well as memory updating (Olichney et al., 2000; Paller and Gross, 1998; Van Petten et al., 1991).

While most studies examining the effects of word repetition have used word lists, modulation of these ERP components has also been found for words embedded in more natural text. For example, Van Petten et al. (1991) looked at ERP repetition effects for content words and proper names using excerpts from the Readers Digest. In that study, a reduction in N400 amplitude was found for repetition of both word types. However, differential effects were found in the LPC time window. The LPC was decreased for repeated content words and increased for repeated proper names. LPC amplitude may decrease for repeated content words because

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explicit recall of the prior presentation is not required and the memory updating demands are low. In contrast, the authors argue that when names are repeated the memory updating demands will increase, because during subsequent presentations, the reader has more information to link with the previously unknown person to which the name refers. This illustrates that names may not evoke standard repetition priming effects. However, as the referent of the repeated name had often been out of discourse focus for some time at the point of the repetition in the Van Petten et al. (1991) study, these were cases of reinstatement (O'Brien et al., 1995) and not local coreference, which is the process examined here.

3. Coreferential processing and the repeated name penalty

Two linguistic expressions are said to be coreferential if they refer to the same semantic entity. The process of establishing coreference between expressions is critical to extracting a message-level representation. For example, take the following passage:

> After Karen saw the flyer advertising free kittens, she and Mike discussed getting a new pet. Mike thought it was a wonderful idea.

To comprehend that passage, one must understand that "she" in the second clause refers to the same woman introduced in the first clause, and that the Mike referred to in both sentences is the same person. This example illustrates that coreference can occur with full expressions (as in the two instances of Mike) and reduced expressions like pronouns. In addition, coreference can occur within or across sentences.

Some theories of coreferential processing build directly upon basic memory phenomena, suggesting that the same effects found in word lists will be, for the most part, unchanged for words appearing in richer context (Greene et al., 1992; Gernsbacher, 1990, 1996). For example, the structure building theory predicts that word repetition will aid processing of coreferential expressions regardless of context, just as it facilitates processing in word lists (Gernsbacher, 1990). This can be contrasted with models like Gordon and Hendrick's discourse prominence theory (Gordon and Hendrick, 1998), which suggests that the ease or difficulty of establishing coreference with a repeated full expression (like a name) will depend on the surrounding context.

The discourse prominence theory specifies constructions rules, by which referential noun phrases (NPs) are interpreted. According to this model, reduced expressions like pronouns trigger a search for a suitable antecedent, thus starting the process of establishing coreference. In contrast, full expressions, like names, prompt the construction of a new semantic entity in the discourse model. With repeated names this results in an error, as two distinct entities are being predicated on the same name. Therefore, in order to establish coreference with repeated names, additional processes must be performed to establish equivalence between the two instances of the same name. The difficulty of these processes is dependent on discourse-level factors, such as the prominence of the first occurrence of the name (i.e., the antecedent). Specifically, according to the discourse prominence theory, when the antecedent is prominent the difficulty of establishing coreference with a repeated name is increased relative to when the antecedent is less prominent in the discourse representation. This phenomenon has been termed the repeated name penalty (Almor, 1999; Garrod et al., 1994; Gordon et al., 1993, 1999, 2004; Swaab et al., 2004).

The repeated name penalty is specific to coreferential repeated names and therefore would not apply to cases wherein different presentations of the name refer to separate semantic entities. For example, in a sentence like "Scott worked in the yard while his friend Scott watched television" a repeated name penalty would not be expected as the reader or listener does not

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need to establish equivalence between the two instances of the same name. It is the coreferential process that prompts the repeated name penalty and not simply name repetition.

4. Repeated versus new names

In a previous paper (Ledoux, Gordon, Camblin, and Swaab, in press), we tested the predictions of the discourse prominence theory by comparing the processing of new and repeated names. In parallel ERP and eye-tracking studies, we examined the effect of context on establishing coreference, using new names as a baseline. As can be seen in the sample stimuli (presented in 1), two factors were orthogonally varied: the sentence context (i.e., the noun phrase in the first clause) and the critical name type (repeated or new).

(1)

- **a.** Singular noun phrase/repeated name At the office *Daniel* moved the cabinet because **Daniel** needed room for the desk.
- **b.** Singular noun phrase/new name At the office *Daniel* moved the cabinet because **Robert** needed room for the desk.
- **c.** Conjunctive noun phrase/repeated name At the office *Daniel and Amanda* moved the cabinet because **Daniel** needed room for the desk.
- **d.** Conjunctive noun phrase/new name At the office *Daniel and Amanda* moved the cabinet because **Robert** needed room for the desk.

While the coreferential interpretation of the repeated name seems straightforward in sentences like 1c, it is crucial to note that repeated names in contexts like 1a are also being interpreted coreferentially. Although a pronoun is the preferred vehicle for coreference in cases like 1a, readers do ultimately interpret these repeated names as referring to the same semantic entity. In a stimulus pretest (reported in Ledoux et al., in press), participants were asked to paraphrase sentences like those in 1a–d. Over 90% of the responses for sentences like 1a used ellipses or pronouns, indicating the presence of only one referent and thus a coreferential interpretation of the repeated name.

As described above, according to the discourse prominence theory, a repeated name penalty will be incurred when establishing coreference between a repeated name and a prominent antecedent. One way to manipulate antecedent prominence is through linguistic embedding. A name that is embedded in a conjunctive noun phrase will be less prominent than a name that stands alone in a singular noun phrase. Therefore, according to the discourse prominence theory, it should be more difficult to establish coreference in case 1a than in 1c. To examine how this context manipulation might affect repetition priming, repeated names could be compared to the processing of new names in the same contexts. For both Conjunctive Noun Phrases (CNPs) and Singular Noun Phrases (SNPs), repeated names could benefit from repetition priming not afforded the new names (1a versus 1b and 1c versus 1d), but for the SNPs the facilitation of repetition priming may be countered by the repeated name penalty that may also occur in that context.

As predicted, we found an interaction between critical name type and sentence context (Ledoux et al., in press). With ERPs, this was evidenced as modulation of the N400 component. Pairwise analyses of mean N400 amplitude revealed significant repetition priming only for the CNP conditions (1c versus 1d), but not for the SNP conditions (1a versus 1b). This was an intriguing finding, as the difficulty in establishing coreference eliminated repetition priming even though the prime was presented only seconds earlier. Additionally, we found direct evidence of a repeated name penalty; that is, the integration of the repeated names (as evidenced by the amplitude of the N400) was more difficult following an SNP relative to a CNP (a difference

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that was not found for the new names). In the later time window of the LPC, there was an effect of sentence context for repeated names, such that repeated names following CNPs elicited larger LPCs. This was interpreted as an increased updating cost for repeated names in this case where there is a larger memory load. Importantly, for neither of these time windows was there a main effect of repetition priming.

In the eye-tracking study, in contrast, we found robust repetition priming on the critical name independent of the type of preceding sentence context (SNPs and CNPs). This priming was found for first fixation duration and gaze duration, both measures of early processing. An interaction between sentence context and name type was not significant until rereading of the post-target region. For this measure, there was a crossover interaction with longer reading times for the new name with CNPs and repeated names for SNPs. In other words, evidence of a repeated name penalty was only found for a measure of later processing, downstream of the critical word. Therefore, both studies showed an interaction between name type and sentence context, supporting the discourse prominence theory. However, the eye-tracking study also showed a main effect of repetition priming on the critical names, not found with ERPs. Therefore, in the eye-tracking study, repetition priming was found for both sentence types, and the modulating effect of context did not come on-line until the post-target region.

As described above, there are basic methodological differences between ERPs and eye tracking that may have lead to these differential results. In particular the differences in the method and rate of presentation in the two studies may have influenced the findings. To examine reading with ERPs, words must be presented one word at a time, in the center of the screen. This enables the experimenter to eliminate eye movements, which would contaminate ERP traces. However, this is undeniably an unnatural mode of presentation. In addition, words were presented at a rate of 2 words a second in the ERP study, while in eye-tracking readers generally average 5 words a second. This slow rate allows for better resolution of the ERP components, but this prolonged duration may prompt the reader to engage in interpretive processes that would take place over a region of several words in normal reading.

In order to examine the locus for our differential ERP and eye-tracking findings, we performed two additional ERP studies, using the same stimuli from Ledoux et al. (in press). In the first study, we used auditory presentation to examine the possibility that the naturalness of the input affected the results. In the second study, we used a faster RSVP rate to more closely mimic the natural reading rate.

5. Experiment 1

Unlike reading, understanding speech is a nearly universal skill. Its long history has exposed spoken language to evolutionary pressures, in a way that has not yet been possible for the comparatively juvenile written language. Nevertheless, a majority of language comprehension studies have utilized written text, often with the implicit assumption that spoken and written language processes differ only at early sensory stages, but for the most part are largely overlapping. In support of this view, in an fMRI study of lexical processing, Booth et al. (2002) only found modality-specific activity in sensory association cortical areas, while both spoken and written words activated the left inferior frontal gyrus (IFG) and the left middle temporal gyrus. From this, the authors argue that lexical recognition occurs in the same area regardless of input modality. This is in contrast to an fMRI study by Michael et al. (2001) that found effects of input modality outside of these sensory association cortical areas during sentence comprehension. In their study, auditory input and written input produced activity in different areas of the IFG. In addition, listening to speech produced more bilateral frontal activity than reading. These findings suggest that differences in input modality can have effects at higher levels of processing.

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Evidence from ERP studies also indicates some differences in auditory and written language comprehension. While qualitatively similar results have been found across modalities (Holcomb and Neville, 1990; Federmeier and Kutas, 1999; Federmeier et al., 2002; Van Berkum et al., 1999a,b, 2003), the onset of the N400 effect has been shown to occur earlier with auditory presentation (Diaz and Swaab, this issue; Holcomb and Neville, 1990; Van Berkum et al., 2003a,b; Van Petten et al., 1999), diverging 200 ms or less after the onset of the word. In addition, spoken language may have a longer lasting N400 effect than that found with written stimuli (Holcomb and Neville, 1990; Van Berkum et al., 2003a, b). ERP differences across modalities are not limited to aspects of timing, as N400 scalp distribution also differs for auditory and written input: the N400 has a central parietal maximum for visually presented words and a more even distribution across the head for words presented auditorily (Domalski et al., 1991; Holcomb and Neville, 1990). This indicates that while the auditory N400 and visual N400 may have the same functional significance, they are not produced by completely overlapping neural generators (Kutas and Federmeier, 2000).

This experiment will examine whether the repeated name penalty found with various reading paradigms will also emerge with auditory input. It will also address the concern that the lack of a main effect of repetition priming in Ledoux et al. (in press) was due to the unnatural processing involved in RSVP reading. The N400 onset with spoken language occurs well within the time range of the early repetition effects found with eye tracking in Ledoux et al., in press. Perhaps this early onset of the N400 will allow us to discern a main effect of repetition priming with spoken language stimuli that was not found with visual presentation. Also, unlike our previous findings, we may see that the interaction between sentence context and name type extends into the LPC time window due to the increased duration of the auditory N400 effect.

5.1. Methods

5.1.1. Participants—Eighteen healthy volunteers recruited from UC Davis took part in the study. All participants were right-handed, native speakers of English and none reported any psychiatric or neurological disorder. Participants received course credit or payment as compensation.

5.1.2. Materials—The stimuli were taken from Ledoux et al. (in press). There were 160 experimental sentence sets. Each set included four versions of the sentence, where sentence context (single or conjoined NP) and critical name type (new or repeated) were orthogonally varied. These sentence sets were divided into four lists such that no subject saw more than one sentence from each set. The subject of the sentence was introduced within the first clause as either a single or conjunctive noun phrase. The second clause started with a temporal or causal connective, which was followed by a name that was either coreferential to the first character introduced in clause one (repeated), or introduced a new character (new). The average duration of the critical names was 490 ms, ranging between 289 ms and 815 ms, and each name occurred only once within a stimulus list. Off-line tests conducted on these materials in Ledoux et al. (in press) assured that new names were not deemed less plausible than their repeated name counterparts and that repeated names were being processed coreferentially.

The experimental sentences, the fillers and the practice sentences were all spoken by an experienced female speaker, with normal intonation at a normal speaking rate, and were recorded onto a computer using a Schoeps U.S. Edition Microphone Set in one recording session. Visual and auditory inspection was used to determine the onset of the second clause, and stimuli were spliced at this time point using the speech editing program MeV, part of the BLISS digital speech analyzer from Brown University. In this way, the same tokens of the first clause (one SNP and one CNP) were used for both the repeated and new names conditions and

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the same tokens for the second clause (one repeated name and one new name) were used for both the single and conjunctive noun phrase conditions.

5.1.3. Procedure—Participants were tested in an electrically shielded, sound-attenuating booth. The stimuli were presented via a computer through Beyerdynamic headphones on a computer equipped with Presentation software (www.neurobehavioralsystems.com). Trials began with a white fixation cross that became visible 100 ms before the onset of auditory stimuli and remained on the screen until 1800 ms after the offset of the auditorily presented sentence. Participants were instructed to keep their eyes fixated on this cross and were asked to move as little as possible and to refrain from blinking and other eye movements when the auditory sentences were presented and as long as the fixation cross was visible. This was done to minimize eye movements and other artifacts in the EEG signal. The fixation cross was replaced with a true/false comprehension question which remained on the screen until the subject selected a response (i.e., pressed a button in a game pad). The participants' response to the true/false question immediately triggered the onset of the next trial. The experiment began with a practice block containing 10 filler items to familiarize participants with the task. Following this warm-up block, the 160 experimental sentences were presented mixed with 80 filler items. These were divided into 8 blocks. Blocks were presented in random order. Participants had short breaks between each block.

5.1.4. ERP Recording and data analysis—The electroencephalogram (EEG) was recorded with an Electro-Cap with 29 embedded electrodes. Eye movements and blinks were monitored via additional electrodes placed on the outer canthi and below the left eye. Electrode impedances were kept below 5 kΩ for the eye electrodes and below 3 kΩ for all the other electrode sites. On-line the EEG was referenced to the right mastoid, and off-line the EEG was re-referenced to the algebraic average of both mastoids. The EEG was amplified by NeuroScan amplifiers, sampled at 250 Hz, and filtered with a bandpass of 0.01–30 Hz.

Visual and auditory inspection of the digitized speech stream was used to determine onset of the critical word (the new or repeated name). ERPs were averaged over a 1200-ms epoch for the critical name in all conditions, beginning 200 ms before the word onset. Trials were screened for eye movements, electrode drift, and electrode blocking; contaminated trials were not included in the analysis.

5.2. Results

5.2.1. Comprehension questions—Comprehension scores ranged from 86 to 100%, with an average of 94%. This indicated that the participants were attending to the spoken stimuli.

5.2.2. ERPs—ERP traces time-locked to the onset of the critical word are shown in Figs. 1 and 2. Early sensory components are hard to discern due to the continuous quality of naturally connected speech. All conditions show a negative trend in the ERP traces starting by 200 ms. This negativity is greatest for repeated names in sentences with a prominent NP1 (i.e., single noun phrase) and new names in sentences with a non-prominent NP1 (i.e., conjunction noun phrase).

ANOVAs were performed on the mean amplitude of the ERPs during three latency ranges: the onset of the N400 (200–300 ms), the classic N400 window (300–500 ms), and the LPC (500–800 ms). The Greenhouse–Geisser correction was applied to *F* tests with more than one degree of freedom in the numerator. The traces were analyzed with a 100 ms prestimulus baseline.[1]

[1]Because the traces diverged so rapidly after word onset, separate analyses were also performed with a 100 ms post-stimulus baseline. With this altered baseline, the critical interaction remained significant for both the 200–300 and 300–500 ms analyses.

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5.2.2.1. 200–300 ms: In this time window, there was a significant interaction between sentence context and name type, but neither main effect was significant (Table 1). Pairwise analyses of repetition (Table 2) showed that this interaction was due to repetition effects in the SNP conditions, which were not found for CNPs. However, the direction of this effect was opposite from that expected by repetition priming, as repeated words following single noun phrases were more *negative* than new names in the same context during this time window. This inverse repetition effect was more frontal in its distribution than the standard auditory N400 effect, which tends to have a central maximum (Fig. 5).

Pairwise analyses of prominence (Table 3) revealed that for the coreferential repeated names the ERPs were significantly more negative in this time window following SNPs as compared to CNPs. This was not found for new names, where an interaction between sentence type and electrode resulted from a greater positivity for the new names in the SNP condition.

5.2.2.2. 300–500 ms: In this classic N400 time window, there was a significant interaction between sentence context and electrode, indicating that critical words in the CNP conditions were more positive than critical words in the SNP conditions over posterior electrodes. There was also an interaction between sentence context and name type in this time window. Pairwise analyses of repetition revealed significant N400 repetition priming only for the CNP conditions, with repeated names producing smaller (i.e., more positive) N400s.

Pairwise analyses of prominence looked very similar to those found in the earlier time window. For repeated names, there continued to be a greater negativity for the SNP condition, whereas an interaction between sentence type and electrode reflected a greater negativity for the CNP condition with new names.

5.2.2.3. 500–800 ms: The interaction between sentence context and name type remained significant in this final time window. As in the earlier time window, pairwise analyses showed an effect of repetition only for words following CNPs, where new names remained more negative than repeated names. Pairwise analyses in this time window again showed a significant effect of repetition for the CNP. In addition, the pairwise comparisons of prominence continued to show a cost of processing a repeated name when preceded by an SNP.

5.3. Discussion

These results are very similar to those found with standard RSVP in our previous study (Ledoux et al., in press). No main effect of repetition was found and in the N400 time window repetition priming was only found for words in the CNP conditions. For these repeated words, coreference was felicitous according to the discourse prominence theory as the antecedent was not prominent in the discourse model. Repetition priming was not found for repeated words in sentences where only one person had been introduced in the discourse. In these cases, where the antecedent was prominent and the discourse prominence theory would predict a repeated name penalty, the repeated names were not easier to integrate than lexically-matched new names. In addition, we find a greater negativity for the repeated names in the SNP condition as compared to the CNP condition, indicating that coreference is more difficult with a prominent antecedent. In contrast to the repeated names, the new names were more positive in the SNP condition. As predicted, the interaction between name type and sentence context persisted into the LPC time window, where repetition priming was also only evident for the CNPs.

The critical interaction between sentence context and name type was also found in the 200- to 300-ms time window. The earlier onset of this effect is consistent with previous ERP studies of speech comprehension. However, in contrast to the effect in the classic N400 window, the effect here was driven by an increased negativity for repeated words in the SNP condition. This

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is arguably even stronger evidence for the repeated name penalty, as difficulty arises when processing a repeated name with a prominent antecedent even before repetition priming emerges in the CNP condition. The very frontal distribution of this effect leaves open the possibility that this is not a modulation of the N400, per se. This may be an early manifestation of the Nref component described by Van Berkum and colleagues that has been linked to reference ambiguity (see Van Berkum et al., this issue for a review). Regardless, it seems to indicate increased difficulty for repeated names relative to new names in the prominent NP1 sentences.

In the N400 time window, there was also an interaction between sentence context and electrode where names following CNPs produced smaller N400s than names following SNPs. Because the names in the CNP conditions were necessarily in a later sentence position than names in the SNP condition, this is consistent with previous findings showing that words appearing later in the sentence tend to produce smaller N400s than words in an earlier sentential position (Van Petten, 1995).

In sum, the repeated name penalty was found when participants were listening to naturally produced speech, illustrating the importance of the sentential context when establishing coreference with repeated names. These results indicate that the absence of a main effect of repetition priming was not due to the unnatural mode of presentation in the previous ERP study, and they lend further support to the discourse prominence theory.

6. Experiment 2

Experiment 1 revealed a repeated name penalty when participants listened to naturally produced connected speech. This finding replicates our previous findings with ERPs and RSVP, where a repeated name penalty was also observed on the coreferentially repeated name. However, this leaves open the possibility that under normal reading conditions, the effects of discourse prominence do not emerge until after the critical name, just as we observed with our eye-tracking study, because of fast input speed in normal reading on the one hand, and reduced input speed with standard RSVP and speech on the other hand. The input speed of the critical repeated name in the present auditory study was 490 ms (on average) which is very similar to the RSVP rate of one word every 500 ms in the Ledoux et al. (in press) study, but slower than what is observed under natural reading conditions (~5 words per second). Studies have shown that lexical integration with speech occurs early as the speech signal unfolds, and N400 effects have been observed prior to the point at which the acoustic signal of the input can be uniquely distinguished from other lexical items in the language (Van den Brink et al., 2006; Van Petten et al., 1999). Therefore, the amount of time subjects have to integrate the critical word before receiving more linguistic input is similar for Experiment 1 and for our previous ERP study (Ledoux et al., in press). It is possible that these differences in input speed have led to the divergent patterns of results that we have observed. When the input speed is high, as with natural reading in eye tracking, effects of repetition are observed on the critical repeated name, and effects of discourse prominence do not occur until words downstream from the manipulation. But when input speed is slower, as with RSVP rates of one word every 500 ms and in spoken language, more time can be devoted to integration processes at the critical repeated name itself, and effects of discourse prominence occur at this point in time.

Therefore, while it is not possible to determine if input control, per se, was the crucial factor in producing the main effect of repetition priming on the critical coreferential repeated names in our eye-tracking study (Ledoux et al., in press), we can examine the influence of a related variable: input speed.

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Similar to the eye-tracking experiment presented in Ledoux et al. (in press), many studies have shown effects of manipulations on eye movements in the post-target spillover region. For example, effects of plausibility and congruence that affect the N400 to the manipulated word in ERPs can elicit effects in the post-target region in natural reading (Camblin et al., in press; Rayner et al., 2004). This may be due to the increased input speed that is produced by normal reading. Therefore, in this second experiment, we wanted to more closely replicate natural reading speed in an RSVP paradigm, to determine if effects of repetition would emerge on the N400 to the critical names themselves as in our previous eye-tracking study.

6.1. Methods

6.1.1. Participants—Thirty-eight healthy volunteers who did not take part in Experiment 1 were recruited from the UC Davis campus. All participants were right-handed, native speakers of English and none reported any psychiatric or neurological disorders. Participants received course credit or payment as compensation.

6.1.2. Stimuli—Printed versions of the same experimental sentences and fillers as in Experiment 1 were used.

6.1..3. Procedure—The procedure was identical to Experiment 1, except that the stimuli were presented in RSVP format on a computer screen. The computer screen was approximately 100 cm in front of the participants, who were asked to silently read the sentences presented. Experimental and filler sentences were presented at a rate of one word every 300 ms, with a 50 ms ISI. Characters appeared as white letters against a dark background in Tahoma, 14-point font. Stimuli were presented in standard sentence-case with a period accompanying the final word. After each of these sentences a true or false question appeared on the screen in its entirety, and remained on the screen until the participant responded with a button press.

6.1.4. ERP Recording and data analysis—These parameters were the same as those used for Experiment 1.

6.2. Results

6.2.1. Comprehension questions—Comprehension scores ranged from 75 to 100%, with an average of 92%. While these scores were slightly lower than those in Experiment 1, participants were still scoring well above chance.

6.2.2. ERPs—ERP traces time locked to the onset of the critical word are shown in Figs. 3 and 4. Early sensory components can be seen in the traces, including a P1 peaking around 100 ms, an N1 peaking around 180 ms, and a large P2 peaking around 240 ms. These components are followed by an N400 which is larger for new names relative to repeated names. Due to the fast presentation rate, the sensory components for the following word can also be seen riding on top of this N400 component.

ANOVAs were performed on the mean amplitude of the ERPs during three latency ranges: the onset of the N400 (200–300 ms), the classic N400 window (300–500 ms), and the LPC (500–800 ms). The Greenhouse–Geisser correction was applied to F tests with more than one degree of freedom in the numerator. The traces were analyzed with a 100 ms prestimulus baseline.

6.2.2.1. 200–300 ms: As can be seen in Table 4, there were no effects in this early time window.

6.2.2.2. 300–500 ms: In the classic N400 time window, there was a main effect of name type and no interaction was found. Repeated names produced classic repetition priming, eliciting smaller N400s than their new name counterparts.

6.2.2.3. 500–800 ms: The effect of repetition did not persist into the LPC time window. In this latency window, there was only a main effect of noun phrase with names following CNPs eliciting more negative ERPs.

6.3. Discussion

In the present study with a fast RSVP rate of one word every 300 ms, we found a main effect of repetition priming for repeated coreferential names. Repetition priming did not interact with sentence structure and therefore was not influenced by the embedding of the antecedent. This effect replicates our previous findings with eye tracking, but is different from the findings of our previous ERP studies, where we did not observe a main effect of repetition on the critical name. Therefore, when input speed more closely resembled that found in natural reading, a main effect of repetition priming emerged with ERPs. In addition, there was no evidence of a repeated name penalty at the manipulated word.

While these findings on repetition priming dovetail nicely with our previous eye-tracking data, there are certain caveats to keep in mind when interpreting these results. Participants in this study often complained that these sentences were very difficult to comprehend due to the fast presentation rate. It is important to remember that while this rate is still slightly longer than normal self-controlled rates, readers here did not have the ability to backtrack or slow down if comprehension difficulty arose making this mode of presentation more demanding. Therefore, even though comprehension rates were still high, it is possible that participants were performing only minimal integration on-line, because the comprehension system was so taxed by the demanding mode and speed of presentation. Also, due to methodological issues, it is difficult to determine if the repeated name penalty would occur downstream of the critical word in the fast-rate ERP study, as they did with eye tracking. The large effect of repetition on the critical name makes it difficult to determine an appropriate baseline for examining effects on the next word, so it is unclear whether a repeated name penalty would emerge.

In addition, due to the fast presentation rate the next word in the sentence was presented at the onset of the N400 time window for the critical name. While it is possible that this overlap contributed to the differential ERP results found with the auditory and fast RSVP study, it should be noted that this word (as well as the remainder of the sentence) was identical across conditions. Therefore, any systematic differences in the very early processing of this word that may have influenced the N400 epoch for the critical word would also be a result of the experimental manipulation.

An effect of noun phrase was evident in the LPC time window with words following CNPs producing more negative ERPs. This is counter to what would be predicted if the LPC were gauging memory demands, as the CNP conditions necessarily require the reader to keep track of more discourse entities than the SNP conditions. However, this time window does partially overlap with the N400 epoch for the word following the critical word. It is possible that the longer and more complex CNP sentences may cause a nontrivial increase in integration difficulty when this very fast presentation rate is employed. Thus producing larger N400s in the CNP conditions, particularly for words appearing later in the sentence. However, it is hard to determine if this is an N400 effect, as both N400 and LPC components have similar distributions across the scalp and it is difficult to find an appropriate baseline for analyzing effects on the word following the critical name. While we can only speculate as to the exact nature of this effect, the important finding is that effects of sentence context did not interact with name type. Therefore, similar to the eye-tracking data in Ledoux et al. (in press), none of the analyses of the critical name resulted in an interaction.

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These results suggest that the main effect of repetition found with eye-tracking may be related to its faster input rate, and not a lack of sensitivity in ERPs, per se, as with similar presentation speeds ERPs can also provide evidence of this facilitation.

7. General discussion

The context in which a word is presented can have profound effects on its processing. Effects of context can spring from simple word-word relationships as well as the overall discourse model. The studies presented here found ERP evidence of repetition priming for repeated names using both natural speech and fast RSVP. In addition, with natural speech, we found that this basic repetition priming effect could be overridden by manipulations of discourse context (Fig. 5).

Using natural speech in Experiment 1, we found repetition priming as evidenced by smaller N400s for repeated versus new names. However, this was only the case for the CNP sentences. In these sentences, the embedding of the antecedent in the conjoined subject made it less prominent in the discourse. Therefore, establishing coreference with a repeated name in these CNP sentences was felicitous due to the antecedent's non-prominent status. In contrast, repetition priming was not found for SNP sentences. For these sentences, the difficulty of establishing coreference with a prominent antecedent negated facilitation due to repetition. These results in the N400 epoch are very similar to those we had found with standard-rate RSVP (Ledoux et al., in press), suggesting at least some overlap in the process of establishing coreference in both input modalities. Thus, results comparing coreferential and new names as a function of discourse structure have supported conclusions drawn from previous work comparing coreferential names and pronouns using ERPs (Swaab et al., 2004) and purely behavioral measures (Garrod et al., 1994; Gordon et al., 1993, 1999).

In addition to the similar effects in this N400 latency window, there were some differences between the results found here and those we found with ERPs elicited by reading at standard (500 ms) RSVP rates. The interaction between sentence context and name type started earlier and extended longer with speech. This is in-line with previous research using speech input that found an earlier onset and longer duration of the N400 effect (Holcomb and Neville, 1990; Van Berkum et al., 2003a,b). While the broader temporal aspect of the interaction could be expected, the cause of the interaction in the early time window was surprising. In the early N400 window (200–300 ms), there was no effect of repetition for the CNP condition and a reversed repetition effect for SNPs. So, the difficulty incurred when establishing coreference with a prominent antecedent came on-line before repetition priming was found with a non-prominent antecedent. It is possible that the coreferential effects preceded repetition effects because the physical nature of the stimuli necessarily differed across the first and second presentation of the repeated name. With words presented visually the physical tokens of the repeated names are identical, allowing effects of repetition to emerge in the same time window as effects of coreferential processing (Ledoux et al., in press). In contrast, the differences in the speech signal across repetitions may have delayed repetition effects further along in the integration process.

With speech, we also found that repeated names were more difficult to process when they appeared in an SNP sentence context as compared to a CNP context. That is, processing of repeated names was more difficult (i.e., produced more negative N400s) when the name coreferred with a prominent subject in the discourse. Importantly, this difference was not found with the new name controls. This is direct evidence of the repeated name penalty that has been found previously with both ERPs and behavioral studies of reading. However, we believe this to be the first study showing evidence for the repeated name penalty with spoken language input.

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In our second experiment, we tried to more closely match the speed of normal reading in a fast-rate RSVP study. With the faster rate, we found a main effect of repetition priming on the critical name. There was no evidence of an interaction between sentence context and name type and the large number of participants included in this study, rules out the possibility that the absence of an interaction was due to a lack of statistical power. Repeated names were easier to process than new names, regardless of antecedent prominence. While this is in contrast with our other ERP studies (Experiment 1, Ledoux et al., in press), it does echo our eye-tracking data for reading of the critical name in the same experimental manipulation.

The input rate for the critical name in the auditory and standard-rate RSVP studies were very similar, 490 ms and 500 ms, respectively. In contrast, with normal reading people spent an average of only 200 ms on the word before making a saccade to a different part of the text. In our fast-rate RSVP study, words were presented at an SOA of 300 ms, which is much faster than the speed normally used in ERPs studies and a closer approximation to the time spent on the critical name in normal reading. At this faster RSVP speed, we were able to replicate the main effect of repetition priming with ERPs that was found in the eye movement study. This suggests that the absence of a main effect of repetition in our previous ERP studies may reflect differential comprehension strategies employed by participants based on input speed. When input speed is fast (as in the fast RSVP study and natural reading), the integration process of establishing coreference may be spread over many words, thus temporally smearing repeated name penalty effects. This could be seen in an examination of the verb phrase following the repeated name in eye tracking (Ledoux et al., in press), but with our ERPs, it was not possible to adequately test for N400 effects following the critical name due to baselining issues. The delay on integration processes with fast input speed also allowed effects of repetition priming to emerge regardless of sentential context. Therefore, when participants do not have the time to fully engage in integration processes at the word, bottom-up repetition priming initially dominates processing.

To conclude, in the studies presented here, we examined the processing of new and repeated names in sentential contexts. In both of these studies, we found evidence of repetition priming. With fast-rate RSVP, a robust main effect of repetition priming emerged. This effect did not interact with sentence context, indicating facilitation regardless of antecedent prominence. However, when participants were listening to natural speech the repetition effect was mediated by higher level context: repetition priming was only found when the antecedent of the repeated name was not prominent in the discourse. In addition, a direct comparison of repeated name processing showed that repeated names were easier to process when they coreferred with non-prominent antecedents. Taken together with our previous work (Ledoux et al., in press), this indicates that (1) the discourse model can have a powerful influence on basic repetition priming, and (2) the nature of this influence may be dependent upon the speed of language input.

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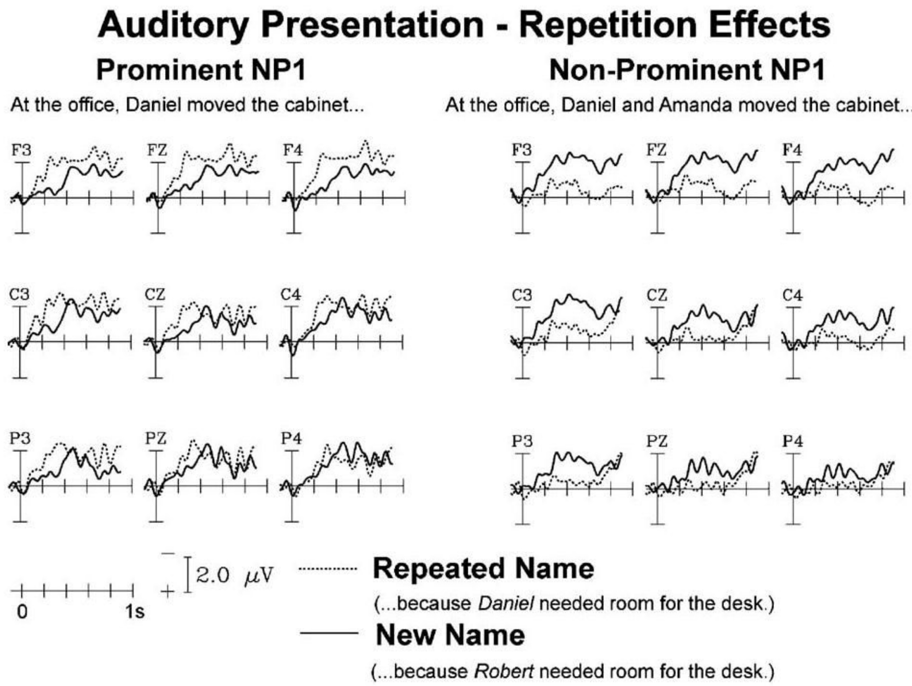

Fig. 1.

The effect of repetition following prominent (left panel) and non-prominent (right panel) noun phrases in Experiment 1. The ERPs are grand averages across all participants, recorded from frontal (F3, Fz, F4), central (C3, Cz, C4), and posterior (P3, Pz, P4) sites. ERPs were time locked to the critical name in the second clause (in italics).

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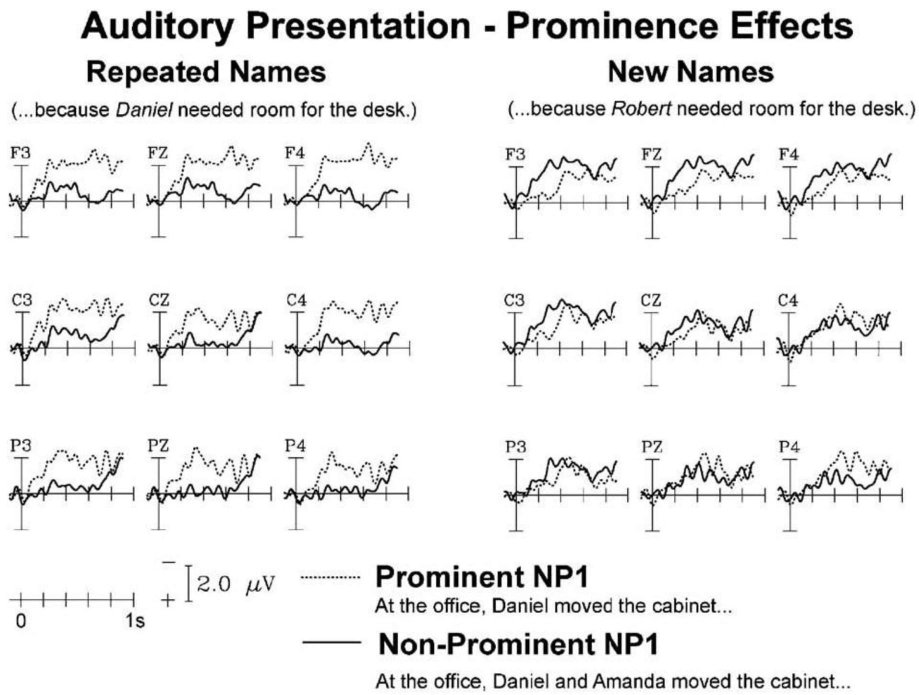

Fig. 2.

The effect of prominence for repeated names (left panel) and new names (right panel) in Experiment 1. The ERPs are grand averages across all participants, recorded from frontal (F3, Fz, F4), central (C3, Cz, C4), and posterior (P3, Pz, P4) sites. ERPs were time locked to the critical name in the second clause (in italics).

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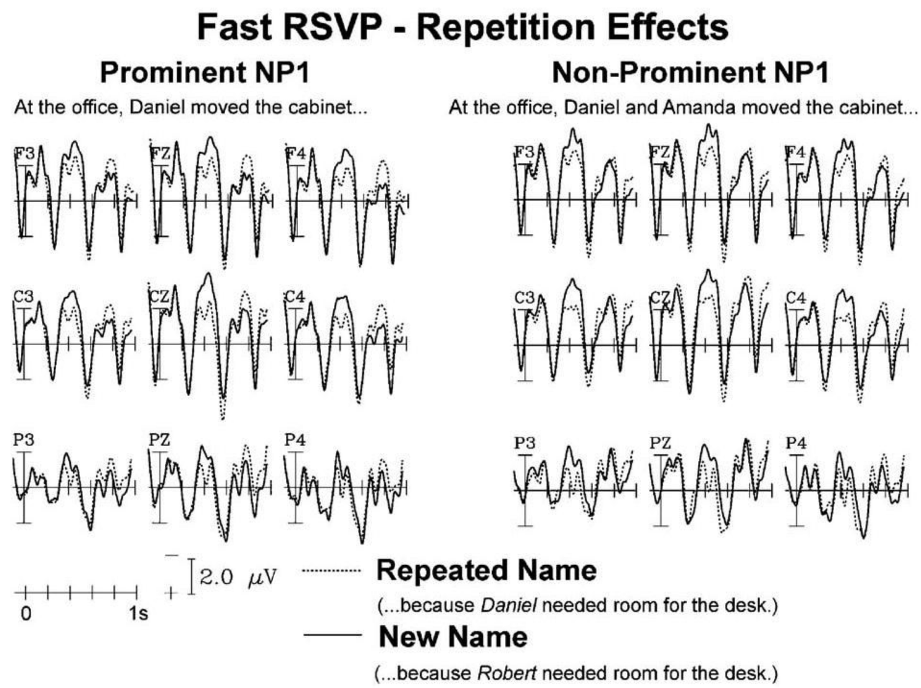

Fig. 3.

The effect of repetition following prominent (left panel) and non-prominent (right panel) noun phrases in Experiment 2. The ERPs are grand averages across all participants, recorded from frontal (F3, Fz, F4), central (C3, Cz, C4), and posterior (P3, Pz, P4) sites. ERPs were time locked to the critical name in the second clause (in italics).

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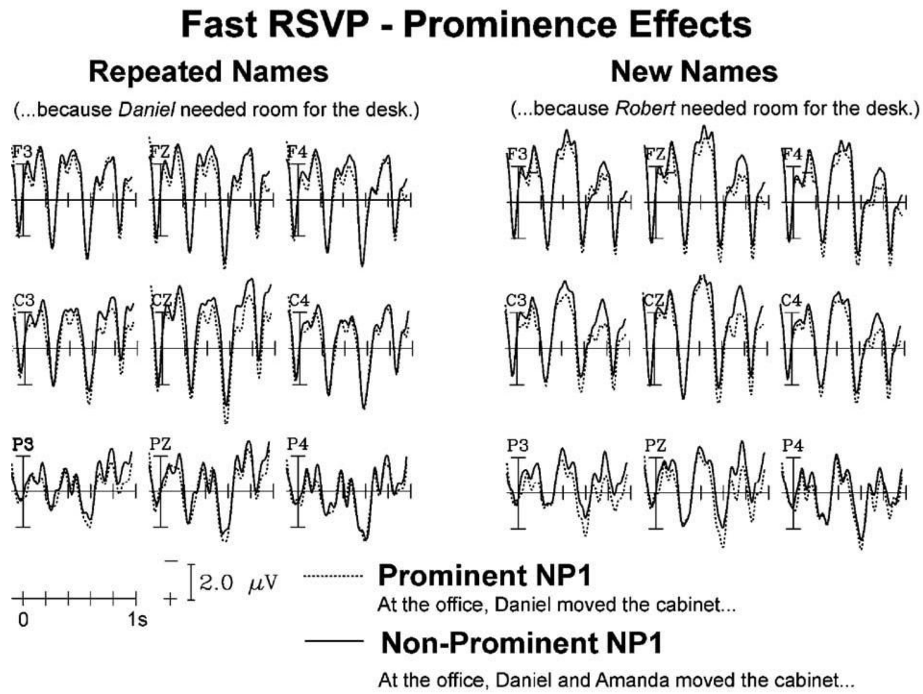

Fig. 4.

The effect of prominence for repeated names (left panel) and new names (right panel) in Experiment 2. The ERPs are grand averages across all participants, recorded from frontal (F3, Fz, F4), central (C3, Cz, C4), and posterior (P3, Pz, P4) sites. ERPs were time locked to the critical name in the second clause (in italics).

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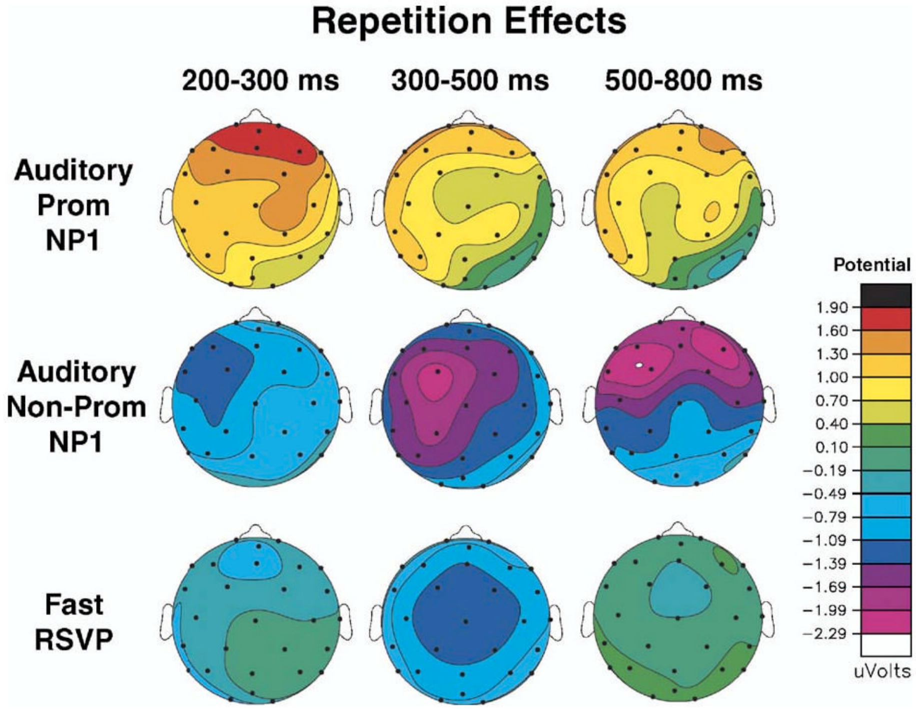

Fig. 5.

Topographic distribution of the difference waves for repeated and new names in the latency windows tested. Difference waves were created by subtracting the mean voltage of ERPs elicited by repeated names from that elicited by new names. Therefore, negative voltages in the voltage map correspond to more negativity in new name conditions. Repetition effects are shown separately for prominent and non-prominent NP1 conditions in the auditory study as sentence context interacted with repetition effects.

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Table 1

Main effects and interactions for Experiment 1

	df	Sentence context		Name type		Interaction	
		F	***p***	**F**	***p***	**F**	***p***
200 – 300 ms							
Overall	1,17	1.65	22	<1		7.90	0.01
X Electrode	28,476	1.94	13	<1		1.38	0.25
300 – 500 ms							
Overall	1,17	2.55	0.13	<1		7.41	0.02
X Electrode	28,476	2.89	0.03	<1		1.25	0.30
500 – 800 ms							
Overall	1,17	3.22	0.09	<1		4.84	0.04
X Electrode	28,476	<1		<1		2.20	0.10

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Table 2

Pairwise analyses of repetition for Experiment 1

	df	SNP (Prom. antecedents)		CNP (Non-Prom. antecedents)	
		F	*p*	F	*p*
200 – 300 ms					
Overall	1,17	8.95	0.01	1.95	0.18
X Electrode	28,476	1.31	0.27	<1	
300 – 500 ms					
Overall	1,17	2.18	0.16	5.73	0.03
X Electrode	28,476	1.47	0.22	<1	
500 – 800 ms					
Overall	1,17	<1		5.89	0.03
X Electrode	28,476	1.52	0.21	1	

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Table 3

Pairwise analyses of prominence for Experiment 1

	df	Repeated names		New names	
		F	*p*	F	*p*
200 – 300 ms					
Overall	1,17	8.12	0.01	2.61	0.13
X Electrode	28,476	<1		3.15	0.02
300 – 500 ms					
Overall	1,17	6.26	0.02	<1	
X Electrode	28,476	<1		3.18	0.02
500 – 800 ms					
Overall	1,17	5.67	0.03	<1	
X Electrode	28,476	1.80	0.12	1.32	0.28

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Table 4

Main effects and interaction for Experiment 2

	df	Sentence context		Name type		Interaction	
		F	***p***	**F**	***p***	**F**	***p***
200 – 300 ms							
Overall	1,37	1.50	0.23	<1		<1	
X Electrode	28,1036	<1		<1		1.95	0.11
300 – 500 ms							
Overall	1,37	3.56	0.07	11.96	0.001	<1	
X Electrode	28,1036	<1		2.06	0.11	<1	
500 – 800 ms							
Overall	1,37	5.08	0.03	<1		1.76	0.14
X Electrode	28,1036	<1		<1		<1	