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The N400 in Processing Repeated Name and Pronoun anaphors in Sentences and Discourse

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Abstract

We report two EEG/ERP experiments that examined processing of repeated name (e.g., *Bill*, Experiment 1) and pronoun (e.g., *he*, Experiment 2) subject anaphors to single antecedents (e.g., *Bill*) and to antecedents embedded in a conjunction (e.g., *Bill and Mary*) within sentences and discourses. Experiment 1 replicated previous reports of repeated references to single antecedents eliciting greater N400 negativity than repeated references to conjoined antecedents within sentences, and extended these results to cross-sentence (discourse) references. Experiment 2 found that pronouns also elicited greater N400 negativity following single than conjoined antecedents. In both experiments, references to conjoined antecedents elicited greater frontal negativity than references to single antecedents in both sentences and discourse. Our results indicate that, in processing subject anaphors, the N400 is an index of reference predictability rather than a marker of the fit between antecedent salience and reference form, and that frontal negativity marks referential ambiguity elicited by conjoined phrases.

Keywords

anaphor; reference; repeated name penalty; sentence; discourse; N400; LAN

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Introduction

Coherent discourse often consists of multiple sentences that are linked to one another by repeated reference to the same entities. Repeated reference involves the use of *anaphoric expressions*, i.e., expressions that refer to an *antecedent*, which is an earlier mention of the *referent*. Due to the prevalence and importance of anaphoric reference in discourse and text, considerable research has explored the psychological mechanisms that underlie the use and processing of these expressions (e.g., Almor, 1999; Ariel, 1990; Gernsbacher, 1989; Gordon, Grosz, & Gilliom, 1993). A general finding of this research is that the salience¹ of a given referent in memory affects the choice and comprehension of an anaphoric expression such that greater salience is associated with the preferential use of reduced anaphoric expressions such as pronouns (Ariel, 1990). The use of reduced anaphoric expressions is pervasive in discourse, and an individual's reading time will typically slow if, when referring to the most salient referent in the discourse, a repeated proper name anaphor is used in the subject position instead of a reduced anaphor. Gordon et al. (1993) first demonstrated that this effect, dubbed the Repeated Name Penalty (RNP), occurs with repeated proper names (e.g., *Daniel*), and subsequent research reported a similar effect with repeated definite descriptions (e.g., *the man*; Almor, 1999).

Although the earliest demonstrations of the RNP were restricted to behavioral studies in which the dependent measure was the reading speed of sentences and sentence fragments, subsequent studies employing ERP methodology demonstrated that the RNP is also reflected in a more negative N400 (Camblin, Ledoux, Boudewyn, Gordon, & Swaab, 2007; Ditman, Holcomb, & Kuperberg, 2008; Ditman, Nieuwland, & Kuperberg, 2009; Ledoux & Camblin, 2008; Ledoux, Camblin, Swaab, & Gordon, 2006; Ledoux, Gordon, Camblin, & Swaab, 2007; Swaab, Camblin, & Gordon, 2004). These studies contrasted the ERPs evoked by repeated proper name anaphors (e.g., *Daniel*) in different contexts. One group of studies (Camblin et al., 2007; Johns, Gordon, Long, & Swaab, 2014; Ledoux, Gordon, Camblin, & Swaab, 2007; Swaab, Camblin, & Gordon, 2004) contrasted antecedents appearing as single noun phrases with antecedents that were embedded in conjoined noun phrases, as in the following example (the contexts and anaphors are underlined):

Single noun phrase context: *At the office Daniel moved the cabinet because Daniel needed room for the desk.*

Conjoined noun phrase context: *At the office Daniel and Jane moved the cabinet because Daniel needed room for the desk.*

Over a series of studies, these researchers observed that when the antecedent was a single noun phrase, repeated name anaphors elicited a larger N400 than pronouns (Swaab, Camblin, & Gordon, 2004) and that the N400 elicited by repeated name anaphors was comparable to the N400 elicited by mentioning a new name (Camblin et al., 2007). Following Gordon et al. (1993), they argued that the difference between the single and conjoined noun phrase conditions mostly affects the salience of the antecedent such that the

¹The term "salience" is used in different ways in the literature. Here we use this term to mark the accessibility of the referent in the discourse representation, and generally distinguish between the most salient referent, which in simple declarative sentences is typically the grammatical subject and topic, and less salient referents, which typically occupy other positions.

antecedent is more salient in the single noun phrase condition than in the conjoined noun phrase condition. While these studies provide promising evidence for the existence of an ERP equivalent of the RNP, they have so far only examined anaphoric reference within sentences, whereas most behavioral studies of the RNP have used inter-sentence discourse anaphors (Almor, 1999; Gelormini-Lezama & Almor, 2011; Gordon, Grosz, & Gilliom, 1993; Yang, Gordon, Hendrick, & Wu, 1999). Indeed, there is reason for concern about the timing of integrative reference effects within sentences. For example, Greene, McKoon, and Ratcliff (1992) showed that readers often delay pronoun reference resolution until the end of sentences. These investigators argued that pronominal reference resolution can occur at different points in processing as a function of available resources and readers' goals. This suggests that some anaphors may not be fully interpreted as they are encountered within sentences and that reference processing within and across sentence boundaries may differ. One goal of the present research was therefore to extend the previous ERP studies to inter-sentence discourse reference. Throughout the rest of the paper we will refer to inter-sentence discourse anaphors as simply 'discourse anaphors' and to within-sentence anaphors as 'sentence anaphors'.

The identification of ERP components related to the RNP has several important theoretical implications. First, it will help complete our understanding of the electrophysiology of discourse reference processing, which has so far not examined subject anaphors in great detail, in particular with respect to the relation between anaphor form and the salience of the antecedent. The importance of distinguishing between these factors has been highlighted by the work of Kehler and colleagues in the framework of Bayesian modeling (Kehler, Kertz, Rohde, & Elman, 2008; Kehler & Rohde, 2013; Rohde & Kehler, 2014). Although there have been several reports of N400 associated with discourse anaphor processing, these studies only looked at anaphors that did not appear in the subject position (e.g., Burkhardt, 2006; Ditman, Nieuwland & Kuperberg, 2009) or at anaphors whose antecedents did not appear in the subject position of the previous sentence (e.g., Burkhardt, 2006; Ditman, Nieuwland & Kuperberg, 2009; Schumacher & Hung, 2012; Yang, Perfetti & Schmalhofer, 2007; Wang & Schumacher, 2013). None of these cases is therefore likely to elicit the same kind of RNP reported in self-paced reading studies, which only occurs for anaphors in subject or fronted positions when their antecedent is in the subject position of the previous sentence (Gordon, Grosz, & Gilliom, 1993). Thus, while previous research suggests that the N400 marks the difficulty of identifying an antecedent in situations that do not give rise to the RNP (see Schumacher & Hung, 2012 for a review), the understanding of how processing is influenced by the relation between antecedent salience and reference form, necessary for a complete view of the electrophysiology of reference processing, requires that we examine whether, and if so how, the N400 responses are changed in contexts that elicit the RNP.

A second theoretical implication is that finding an ERP marker of the RNP in discourse would imply that the processes underlying the RNP occur rapidly and are not delayed. This has bearings for theories of reference processing that differ with respect to the order and timing of different aspects of reference processing. A third theoretical implication is that identifying ERP components such as the N400 and the LAN (left anterior negativity) that are associated with the RNP would suggest that the cognitive processes associated with these components play a role in the RNP. Finally, a fourth theoretical implication is that the

similarities and differences between the ERP responses elicited by sentence and discourse anaphors can provide additional information about the underlying processes. For example, finding ERP responses for discourse anaphors similar to the ones reported for sentence anaphors (Swaab et al., 2004) would support the theoretical claims of Gordon and Hendrick's (1998) Discourse Prominence Theory (DPT), which considers the processing of anaphoric expressions to be similar within and across sentences. Finding different effects for discourse and sentence anaphors would be informative about the underlying reasons for the differences in processing the two kinds of anaphors, especially with respect to memory processes that are marked by distinct ERP components. Before we discuss these ERP components in detail, we address the neural basis as well as relevant aspects of the time course of processing an anaphoric reference.

The neural basis of reference processing

The fine level processing time information provided by ERP is crucial for placing recent evidence about the neural basis of the RNP in the broader context of reference processing. Another important type of evidence is provided by fMRI studies that can further help identify the brain regions that participate in these processes. Most relevant to the current study, Boiteau et al. (2014) previously showed that, in multi-sentence texts, plural reference to a conjoined discourse entity leads to greater bilateral parietal activity relative to single reference to a single discourse entity. An earlier study from our lab (Almor et al., 2007), looking more specifically at the RNP (inter-sententially), also found greater involvement of parietal regions bilaterally in repeated vs. pronoun conditions. We have interpreted these findings as showing that parietal regions, especially in the superior part, are involved in the formation, maintenance, and manipulation of the multiple representations of referents during discourse comprehension.

Another fMRI study (Nieuwland, Petersson, & Van Berkum, 2007) found that ambiguous references evoked activity in fronto-parietal regions including the superior parietal lobes and the dorsolateral prefrontal cortex, which may reflect either introduction of new entities into the discourse model or the decision making processes involved in resolving ambiguous reference. Similarly, McMillan, Clark, Gunawardena, Ryant, and Grossman (2012) showed that processing ambiguous referents evoke more frontal activity (the dorsolateral prefrontal cortex in particular) than processing non-ambiguous ones. While our focus in this paper is on the time course and ERP components involved in reference processing, we consider the implications of these various findings for the neural bases of reference processing in the general discussion.

Time course and integrative processes

Several theories of anaphor resolution (e.g., Almor & Eimas, 2008; Almor & Nair, 2007; Duffy & Rayner, 1990) distinguish between multiple stages, with the lexical identification of the referent occurring in the initial stage, followed by the integration of the anaphor into the discourse model. Consistent with this view, some behavioral studies have demonstrated the RNP with measures that are likely to tap integrative processing but not with measures that index only immediate processing (Almor & Eimas, 2008; Nair & Almor, 2006). For example, Nair and Almor (2006) found the RNP when they presented the items from

Gordon et al. (1993) as whole sentences but not when they presented the same items word by word. Nair and Almor attributed this difference to reduced sensitivity of the word-by-word self-paced reading paradigm to integrative processes. Further evidence for the delayed nature of anaphor resolution comes from eye-tracking measures of reading that have shown the RNP only in text regions following the repeated name anaphors or in regressive eye movements to the anaphor, but not in initial fixation times or gaze durations on the anaphor itself (Ledoux et al., 2007). These results suggest that when readers control their own reading pace they may move on to process subsequent words before completing the discourse integration of anaphoric expressions and delay the integration to a later point. Similar effects were demonstrated in spoken language comprehension. Almor & Eimas (2008) showed that the RNP affected the resulting memory representation of the discourse but not response times in a lexical decision task, and more recently, using the visual-world eye-tracking methodology, Peters, Boiteau and Almor (2016) showed that the RNP occurs following an initial processing of the anaphoric expression, and that the RNP likely reflects the activation of other information in memory.

In contrast to the delayed effect suggested by self-paced reading and eye tracking studies, the results of previous ERP studies (Burkhardt, 2006; Camblin et al., 2007; Ledoux et al., 2007; Schumacher & Hung, 2012; Streb et al., 2004; Swaab et al., 2004; Van Berkum, Brown, & Hagoort, 1999) suggest that the integration of an anaphor with prior discourse context occurs rapidly enough to be reflected in ERP waveforms such as the N400. The N400 has traditionally been associated with lexical-semantic processes as well as sentence/discourse level processes (e.g., St. George, Kutas, Martinez, & Sereno, 1999). Several investigators have argued that, in sentence processing, the N400 reflects the predictability of the next word in the sentence (e.g., Kutas & Hillyard, 1984; Van Berkum et al. 2005; Van Petten & Luka (2012); for recent reviews see Kuperberg, 2016, and Kutas & Federmeier, 2011). In the area of reference processing, the N400 was found to reflect the difficulty of referent identification in anaphor resolution (e.g., Ledoux et al., 2007; Swaab et al., 2004; Van Berkum, Brown, & Hagoort, 1999). Streb et al. (2004) have demonstrated that referent salience modulates the N400 in response to proper names and pronouns, suggesting that the N400 may index the ease with which the referent is identified and integrated with prior context. In contrast, Schumacher and colleagues have argued that the N400 indexes the difficulty of linking an anaphor with its antecedent rather than either the lexical semantic processing of the anaphor (Burkhardt, 2006; Schumacher & Hung, 2012) or the complete integration of the anaphor with the representation of the discourse (Wang & Schumacher, 2013). Overall then, previous findings suggest that, during anaphor processing, the lexical processing of the anaphor, its referent identification, and its integration into the discourse representation may all overlap, and that any of these processes may affect the N400.

Of particular interest here are findings of an interaction between anaphor form and referent salience in the N400 time window, which suggest that the RNP may show as early as 300 ms after reading an anaphoric expression (Camblin et al., 2007; Ledoux et al., 2007; Swaab et al., 2004). This would suggest that the N400 reflects not merely the ease of identifying an antecedent, but instead a more complex discourse process. However, it is not yet known whether the same results would hold for discourse anaphors, which have been the focus of most work on the RNP. In particular, the processing of sentence anaphors is more likely to

be affected by syntactic constraints (e.g., Chomsky, 1981), and the processing of discourse anaphors is more likely to be affected by the memory processes that are involved in the maintenance and updating of discourse representations over longer periods of time (Garrod & Sanford, 1994). Although there is evidence that the N400 associated with processing referential relations within sentences disappears for references across sentence boundary (e.g., Burkhardt & Roehm, 2007), this evidence pertains to co-reference between grammatical object antecedents, and anaphors that were the grammatical subjects of embedded clauses but not for co-reference between grammatical subject antecedents and anaphors that are the grammatical subjects of the matrix verb. Since the RNP only occurs for anaphors that appear as grammatical subjects of the matrix verb (or fronted topics) when they refer back to a subject antecedent (Gordon et al. 1993), the results of Burkhardt and Roehm still leave unclear whether the RNP will occur similarly for sentence and discourse anaphors.

While Burkhardt and Roehm's findings do not necessarily indicate the absence of an N400 effect for all repeated discourse anaphors, their results are in accord with research on memory and reading. Most importantly, during text comprehension, readers may postpone certain processes to the end of the sentence. Such processes may include the resolution of any remaining ambiguities within the sentence, matching anaphors with their antecedents, and inter-clause integration (Just & Carpenter, 1980). In support of the existence of such effects, Just and Carpenter (1980) showed that memory for recently comprehended text decreases after a sentence boundary, which they attributed to the combination of needing to maintain textual information while a sentence is still processed and the demands of integrative processing at the end of the sentence. There is therefore a good reason to expect differences between sentence and discourse anaphors in memory demands, which in turn may affect the timing of the waveforms elicited by the underlying processes. To address these questions, the present research looked at both sentence and discourse anaphors, with special attention to specific ERP markers of memory processes, which we review below.

In addition to these open questions about the discourse processes underlying the RNP, there are reasons to question whether the N400 would be the right ERP component to mark this phenomenon. As mentioned above, recent research has shown that the N400 most strongly reflects the extent to which a word violates the predictions made during comprehension (Lau, Holcomb, & Kuperberg, 2013; Kuperberg, 2016). In the area of reference processing, such predictions could reflect the likelihood that a certain referent will be mentioned or the likelihood that a specific form will be used to refer to a referent. It is only the latter type of prediction which has to be based on the fit between reference form and referent salience that could explain the RNP. Because Swaab et al. (2004) did not observe any N400 effects for pronouns, it is unclear whether the N400 differences they found for repeated names truly represent the RNP. If they did, pronouns should have elicited complementary N400s to those shown by repeated names. A possible explanation for the lack of pronoun effects is that the predictability differences between the different pronoun conditions were too small in comparison to the predictability differences between the repeated name conditions, resulting in a weak and statistically underpowered difference in the pronoun conditions. In the research we report here, we made several changes to the experimental design used by Swaab et al. to address this issue. Most crucially, we tested repeated names and pronouns in

separate experiments so as to make the predictability differences between the conditions for each form independent of the other form. A complementary N400 result for the pronoun conditions in this alternative design would support Swaab et al.'s attribution of the N400 effects to the RNP.

Memory and anaphoric processing

There are other ERP components besides the N400 that have proved useful in studies of reference processing. Most relevant here, ambiguous anaphoric expressions are associated with negative waveforms at anterior electrodes (Nieuwland & Van Berkum, 2007; Camblin, Ledoux, Boudewyn, Gordon, & Swaab, 2007; Van Berkum, 2009; Van Berkum, Brown, & Hagoort, 1999). Van Berkum et al. (1999) asked participants to read Dutch sentences in which a definite noun phrase anaphor referred to an antecedent either in a single referent story or embedded in a two-referent story. The anaphors were non-ambiguous in the single referent story and ambiguous in the two-referent version. Referentially ambiguous anaphors were associated with larger amplitudes and longer latencies of the negative waveform as well as a shift towards frontal regions. Because this waveform was modulated by the referential properties of the noun, Van Berkum et al. suggested that this negativity could be classified as a *referential negativity* (Nref), a component that marks the memory retrieval of the antecedent and that is distinct from the N400.

Nieuwland & Van Berkum (2007) further investigated the Nref and found that it was elicited only when two possible antecedents for a pronoun were equally plausible but not when one was more plausible than the other. Camblin et al. (2007) examined spoken sentence anaphors with single noun phrase antecedents and observed that repeated name anaphors elicited an increased frontal negativity in the 200–300 ms time window relative to new names, an effect which may be an early manifestation of the Nref. Camblin et al. suggested that the Nref reflects the initial interpretation of a repeated reference as a 'new' entity, which is then compared against the representation already existing in the discourse model. In line with DPT, Camblin et al. suggested that, when the referent is salient, this comparison is harder to complete because the search for a correct referent proceeds sequentially in increasing order of salience. Camblin et al.'s interpretation is in agreement with Nieuwland's (2014) argument that the Nref observed for pronouns that do not have a morpho-syntactically agreeing antecedent reflects the creation of a representation of a new referent. Overall, previous studies suggest that frontal negativity is observed in situations where referent identification is difficult, either due to the difficulty in matching the anaphor with the correct antecedent that could lead to the formation of a representation of a new referent (Camblin, et al., 2007; Nieuwland, 2014) or due to the presence of multiple possible antecedents that are both equally plausible and simultaneously active in working memory.

The LAN is also associated with the working memory requirements of processing anaphoric reference. Coulson, King, and Kutas (1998) tested the ERPs elicited by reading grammatical pronouns as in the sentence "Ray fell down and skinned *his* knee" and pronouns with an ungrammatical case as in "Ray fell down and skinned **he* knee." They found a left anterior negativity between 300 and 500 ms after the onset of both grammatical and ungrammatical pronouns. However, pronouns with ungrammatical case showed greater frontal negativity

compared to grammatical pronouns. Coulson et al. interpreted this finding as showing that the processing of the pronoun ‘*he*’ led to a search for a matching referent in working memory. Anderson and Holcomb (2005) also found a LAN effect when comparing the electrophysiological responses of coreferential noun phrases to non-coreferential noun phrases, attributing this effect to the increased working memory load of reference assignment, and specifically with integrating the coreferential entity with the previously mentioned referent already in the discourse model. While it is unclear whether the LAN found by Coulson, King, and Kutas in response to morphosyntactic violations reflects the same working memory processes found by Anderson and Holcomb and the Nref studies in response to referential difficulties that do not result in ungrammaticality, previous research shows that an Nref/LAN response is commonly found when referential processing increases working memory demands.

In summary, in addition to the N400, the Nref and LAN ERP components may index the memory processes underlying anaphor resolution (Anderson & Holcomb, 2005; Burkhardt and Roehm, 2007; Coulson et al., 1998; Swaab et al., 2004; Van Berkum, 2009; Van Berkum et al., 1999). In the current experiments, we investigated the circumstances in which the referential processes involved in processing repeated name and pronoun anaphors elicit these ERP components in both sentences and discourses. Overall, the objective of our study was twofold. First, we aimed to extend the N400 found in previous research to discourse anaphors (e.g., Camblin et al., 2007; Ledoux et al., 2007; Swaab et al., 2004). A similar finding in a discourse context would reinforce these authors’ claim that the N400 is a marker of the referential processes that underlie the RNP both within and across sentence boundaries and that these processes commence very rapidly. Second, we also examined ERP markers of memory processes associated with anaphor processing within and across sentences. Given that, like the previous ERP studies that we aimed to extend (and, indeed, like most ERP studies on language), our conditions likely differed in their acceptability, our focus was on the specific conditions under which these differences would affect the two ERP responses. We thus followed a strong a-priori approach in which we examined the two components of interest using the strict criteria established by Picton et al. (2000), in which, in addition to the task that likely elicits them (which is the focus of our paper), components are defined by their time window and electrode scalp location.

We used the materials from Swaab et al., but in order to independently assess the referential processes underlying the processing of each form in different contexts, we recorded event-related waveforms evoked by repeated name and pronoun anaphors in two separate experiments. More generally this addressed any possible confounds due to differences between pronouns, which are high frequency closed class words, and repeated names, which are open class lower frequency words. Our design thus allows for a cleaner comparison of the effect of the different antecedent types on each kind of reference. Experiment 1 examined the processing of repeated names and Experiment 2 examined the processing of pronouns.

Experiment 1

Experiment 1 contrasted the processing of repeated name anaphors in discourse and in sentences with single and conjoined noun phrase antecedents. Specifically, this experiment examined negativity in the anterior frontal (Nref/LAN), and central and posterior areas (N400). The following possible outcomes were of particular interest:

N400—A larger negativity during the 300–500 ms time window in central and posterior areas in response to repeated name anaphors referring to a single noun phrase antecedent, relative to the conjoined condition, would replicate previous findings in the sentence conditions, and extend these previous findings to the discourse conditions. Finding similar effects in the sentence and discourse conditions will support the interpretation of the N400 found in previous studies as constituting an ERP marker of the RNP.

Nref and the LAN—A larger negativity during the 300–700 ms time window in the frontal areas in the single noun phrase relative to the conjoined conditions may indicate the need to resolve a temporary referential ambiguity. This is because in the single noun phrase condition the target repeated proper name may be initially interpreted as a new reference (Gordon & Hendrick, 1998). In contrast, a larger negativity during this time window in the frontal areas in the conjoined relative to the single noun phrase conditions may indicate that referring to an antecedent that is embedded in a conjoined phrase requires more effort than referring to a single antecedent. This could reflect the availability of multiple possible antecedents. Indeed, previous research has shown that conjoined noun phrases can lead to the formation of multiple referents in the discourse representation corresponding to the representations of each of the conjoined NPs, the plural conjoined NP, or a complex reference object, in which both the individual and conjoined referents are represented (e.g., Albrecht & Clifton, 1998; Boiteau et al., 2014; Moxey, Sanford, Sturt, & Morrow, 2004; Patson & Warren, 2011).

A larger negativity during the same time window in the discourse relative to the sentence condition would indicate that processing multiple sentence discourses requires more memory resources than processing single sentences.

Method

Participants—Twenty-one right handed participants (aged 18 to 30 years, 5 males and 16 females) participated in Experiment 1. All participants were native speakers of English, with normal or corrected-to-normal vision and were recruited from the student population at the University of South Carolina. Participants were also screened for neurological and medical disorders. Participants provided informed consent before the study and received course credit as incentive for participation.

Materials—A total of 160 test items and 80 filler items were constructed such that each item could be assigned to one of four conditions (single noun phrase/sentence, conjoined noun phrase/sentence, single noun phrase/discourse, and conjoined noun phrase/discourse) by manipulating the noun phrase and structure. In the single noun phrase condition, the

antecedent of the repeated name anaphor was a single noun phrase, and in the conjoined condition it was embedded in a conjoined noun phrase. The sentence version of each item was the original item from Swaab et al. (2004) and the discourse version was created by breaking the original sentence stimulus into two separate sentences. All items were matched with a yes/no comprehension question that targeted information from any part of the stimulus. Each item had four versions corresponding to the four experimental conditions. Filler items consisted of both sentences and discourses of similar length to the experimental items and had various syntactic constructions with proper name and pronoun references to either one, two or three persons. This reduced the likelihood of item-specific confounds. Table 1 shows a sample item in all conditions. The assignment of items and conditions to individual participants were counterbalanced using a Latin square design such that each participant saw each item in only one condition but each item appeared in all four conditions within a group of four consecutive participants. Each participant saw a total of 160 test items and 80 filler items presented in a random order. Filler items, similar to test items, had one or two proper name characters, but differed with respect to the type of syntactic constructions used.

Procedure

Stimulus presentation: Each participant was tested individually in a moderately lit, electrically shielded sound-attenuating room. Participants sat at about 100 centimeters from a 29-inch color video computer monitor (NEC Multisync XM29) displaying at 1280 horizontal and 1024 vertical pixels. The experiment started with a short practice session of 10 items followed by 8 blocks with 30 items per block. Each item was presented word by word at the rate of 300 ms per word and an inter-word interval of 200 ms. Words were presented in the center of the computer screen as white letters against a black background in lowercase 14 point Tahoma font. The first word was presented with a capital letter, and the last word of a sentence was presented together with a period. After silently reading every item, subjects pressed a button on a hand-held button box to answer yes/no to a question pertaining to that sentence. Participants were asked to refrain from blinking, and to minimize movements as much as possible during trials and encouraged to blink during the blank screen that came up after every question.

Recording and segmenting of ERPs: The electroencephalogram (EEG) was recorded using a 128 channel Geodesic sensor net (GSN 200) with the EGI system (Electrical Geodesic Inc., Eugene, OR; Tucker, Liotti, Potts, Russell, & Posner, 1994). A schematic diagram of the sensor net used in the experiment is shown in Figure 1. The net was positioned according to its anatomically marked locations. The EEG signal was referenced to the vertex (Cz). Individual sensors were adjusted until impedances were less than 100 k Ω , and the signal was amplified with the EGI “NetAmps” that consist of high impedance amplifiers and a PowerPC-based computer system. The EGI “Netstation” computer program was used to control zero and gain calibrations for each participant’s impedance calibration, A/D sampling (250 Hz), and EEG data storage. Band pass filters were set at .01 to 100 Hz with 20K amplification. A second computer was time-synchronized with the PowerPC running the Netstation computer program so that timing and trial information were stored with the EEG recordings. Trial presentation was controlled by E-prime (Schneider, Eschman, &

Zuccolotto, 2002) which also sent event information to the Netstation recording system. The data were segmented offline using a 100 ms baseline prior to the onset of the critical anaphor until 1000 ms post-stimulus period. This segmenting was with respect to the onset of the critical word (i.e. the repeated name). Trials that contained eye movements (amplitude greater than 70 μ V) or more than 15% bad channels (average amplitude over 100 μ V or differential amplitude over 50 μ V) were eliminated from the analyses. Each trial was visually inspected and excluded if artifacts were observed. The data for two participants with less than 50% remaining data were eliminated from the study. For the remaining 19 participants, less than 15% of the trials was eliminated. Data were average referenced off-line and baseline corrected using the 100 ms pre-stimulus interval and low pass filtered to 30 Hz. Average referencing was chosen because it is more appropriate for large electrode montages than referencing to one or two chosen electrodes. For each participant, average ERPs were then computed over artifact-free trials for the critical repeated name anaphors in all four conditions.

Data Analysis: ERP data were analyzed using repeated measures analysis of variance (ANOVAs) performed on the mean amplitude of the ERPs to the critical words in the 300- to 500-msec (N400) and 300–700-msec (LAN) epochs at selected average electrode sites. To facilitate comparison of our results with previous ERP studies of reference we focused on the twelve electrode sites that correspond to F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O3, Oz, and O4 (Luu & Ferree, 2000). To increase the reliability of this method, the potential value at each of these electrode sites was calculated as the average of the closest electrodes as determined by Luu and Ferree. For clarity, we label these average electrodes in the rest of the paper using a nomenclature of *l*, *z*, and *r* rather than *3*, *z* and *4*. Figure 1 shows the actual electrodes averaged to generate each of the twelve target electrodes. To detect any broad differences across the scalp, we started our analysis of each waveform with an Omnibus ANOVA across the relevant electrodes for each component in the time window of interest. For the N400 the factors in this omnibus analysis were Construction (Sentence, Discourse), Salience (Single, Conjoined), Laterality (Left, Mid, Right) and Anteroposteriority (Central, Parietal, Occipital). For the Nref/LAN, factors in the omnibus analysis were Construction (Sentence, Discourse), Salience (Single, Conjoined), and Laterality (Left, Mid, Right), and only the frontal electrode sites were included. To the extent any of these omnibus ANOVAs found significant main or interaction effects that involved more than two means, these effects were further explored by subsequent analyses. The results of all ANOVAs are reported after a Greenhouse-Geisser correction for non-sphericity.

Results

Below we discuss the results by the ERP components of interest. Figure 2 shows the topographic maps of potentials from all 129 electrodes in the four conditions in 100 ms time windows. Figure 2 also shows topographic maps of the potential difference between the Single and Conjoined conditions in the Discourse and Sentence items. Figure 3 shows the ERP waveforms in the twelve average electrode sites in the Sentence (3a) and Discourse (3b) conditions.

N400 (300–500 msec)—Figure 4a shows the average potentials in the nine relevant electrode sites in the 300–500 ms time window following the target reference. The omnibus ANOVA found an effect of Laterality, $F(2, 36) = 5.402$, $p = .009$, an effect of Anteroposteriority, $F(2, 36) = 7.133$, $p = .002$, and no effects of Construction, $F < 1$, or Salience, $F(2, 18) = 2.438$, $p = .136$. There was also a significant three-way interaction between Construction, Salience and Laterality, $F(2, 36) = 3.519$, $p = .04$. There were no other significant interaction effects (F s > 1.9 , except for the interaction between Construction and Laterality, $F(2, 36) = 2.218$, $p = .12$, Construction and Anteroposteriority, $F(2, 36) = 2.435$, $p = .102$). To explore the basis of the three-way interaction between Laterality, Construction and Salience, we conducted three separate Construction by Salience ANOVAs for the left, middle and right electrode sites. In the analysis of the left sites (Cl, Pl, Ol), the main effect of Construction was not significant, $F(1, 18) = 3.033$, $p = .099$, there was no effect of salience, $F < 1$, and the interaction between the two factors also failed to reach significance, $F(1, 18) = 3.063$, $p = .097$. In the analysis of the central sites (Cz, Pz, Oz), both main effects and the interaction effect were not significant, all F s < 1.2 . Finally, while the analysis of the right sites (Cr, Pr, Or) found no significant main effects of either Construction, $F(1, 18) = 3.033$, $p = .099$, or Salience, $F < 1$, their interaction was significant, $F(1, 18) = 4.998$, $p = .038$.

As indicated by these analyses and shown in Figures 2–4, the three-way interactions between Construction, Salience, and Laterality was most prominent in the parietal sites and reflected greater negativity in the Single than in the Conjoined conditions in the Sentence conditions on the Left, and for the Discourse conditions on both the Left and Right. Thus, in the 300–500 ms time window, intra-sentence RNP was reflected in more negativity over left electrode sites while the discourse RNP was reflected in more negativity bilaterally. In addition, repeated names resulted in more negativity on the left than on the right.²

Nref/LAN (300–700 msec)—Figure 4b shows the average potentials in the three frontal electrode sites in the 300–700 ms time window following the target reference. An ANOVA of these electrodes with factors Construction (Sentence, Discourse), Salience (Single, Conjoined) and Laterality (Left, Mid, Right) found significant main effects of Laterality, $F(2, 36) = 9.358$, $p = .004$, and Salience, $F(1, 18) = 6.204$, $p = .023$, but no effect of Construction, $F(1, 18) = 1.318$, $p = .27$. None of the interactions were significant (all F s < 1 , except for the interaction between Construction and Laterality, $F(2, 36) = 2.447$, $p = .119$, and between Construction, Salience and Laterality, $F(2, 36) = 1.864$, $p = .18$).

These analyses therefore indicate that, as is shown in Figures 2–4, there was greater negativity on the left, consistent with the LAN, and that Conjoined conditions elicited

²Because the N400 has been argued to index the predictability of the next word in the context of the sentence (e.g., Kuperberg, 2016; Kutas & Federmeier, 2011; Kutas & Hillyard, 1984; Van Berkum et al. 2005; Van Petten & Luka, 2012), we wanted to assess to what extent the N400 effects we observed reflected the building up of expectations during the experiment. We therefore repeated the N400 analysis using only the first third of the trials from each participant and, separately, from the last third of the trials. Given the much smaller number of trials and, consequently, the much reduced power of these analyses, we do not consider their results in detail but only note that the main effect of interest, reflected in the three-way interaction between Laterality, Construction, and Salience, was present in both early and late trials, although in both cases it was embedded in a four-way interaction that included Anteroposteriority such that the interaction between Construction and Salience was similar, but its localization on the scalp may have shifted throughout the experiment.

greater frontal negativity than the Single conditions for both Sentence and Discourse references.

Baseline check (–100–0 msec)—To confirm that there were no a priori differences in the critical word in the four conditions, we performed an omnibus analysis on a 100 millisecond time-window, starting from 100 milliseconds before the onset and extending up to the onset of the critical word. This analysis found no significant main or interaction effects, $F's < 1.41$.

Discussion

The results of Experiment 1 replicate and extend previous research in several ways. We discuss these for each of the ERP components that we examined.

N400—The larger N400 in the Sentence conditions for repeated name references with single NP antecedents supports the previous interpretation of this effect as a manifestation of the RNP. In particular, this finding supports the claims of DPT (Gordon & Hendrick, 1998), which argues that the RNP occurs for within-sentence references. According to this theory, in both sentences and discourse, repeated name anaphors lead to the construction of a new semantic entity in the discourse model. The difficulty in processing the repeated reference stems from an additional step required for establishing equivalence between the new representation generated by the repeated reference and the representation of the referent that already exists in the discourse model. This difficulty may manifest as the N400 observed in ours and in previous studies (Boudewyn et al., 2012; Camblin et al., 2007; Ledoux et al., 2007; Swaab et al., 2004). However, although the claims of DPT are supported by our and by previous research's N400 findings for sentence anaphors, there is one aspect of our results that is problematic for this theory. Although we observed N400 reflections of the RNP for both sentence and discourse anaphors, the scalp distribution of this effect was different in the two cases: the RNP was left lateralized for the sentence anaphors and bilateral for the discourse anaphors. According to DPT, sentence and discourse anaphors are processed similarly and should therefore elicit similar ERP responses. Our results, on the other hand, indicate that the processes underlying the N400 response to repeated name anaphors are not identical within sentences and in discourse. Finally, our post hoc analysis of the first and last third of trials revealed that the effects we found are not a reflection of expectations that were built up by participants during the experiments.

Nref/LAN—Repeated names elicited greater negativity in frontal sites in the Conjoined than in the Single conditions. This anterior negativity was more pronounced on the left electrode sites but was not different for sentence and discourse anaphors. We observed a similar waveform here that was more negative in the conjoined conditions. One possible interpretation of the results of this experiment is that the N400 marks the RNP (albeit a different RNP for sentences and discourse), whereas the LAN marks the difficulty of referring to a referent within a conjoined expression. However, before settling on this interpretation, it is important to examine the ERP evoked by pronoun references to the same referents. If the N400 truly marks the RNP, then this effect should disappear or even reverse when pronoun references are used instead of repeated names (Gordon & Hendrick, 1998).

This is indeed the result that was obtained by Swaab et al. (2004) who did not find any differences between the ERPs evoked by pronouns referring back to single vs conjoined antecedents within sentences. Moreover, if the LAN truly marks the processing effort related to referring to a referent embedded within a conjoined expression, this effort should be present for pronoun references just as for repeated names. Experiment 2 therefore tested the ERPs evoked by pronouns.

Experiment 2

Experiment 2 contrasted the processing of pronoun anaphors in discourse and in sentences with Single and with Conjoined noun phrase antecedents. Given the results of the previous experiment, the effect of interest here was the difference in waveforms elicited by the pronouns in the Single versus Conjoined antecedent condition in the Sentence and Discourse conditions. Smaller negativity in the Central and Parietal areas in response to pronouns in the Single condition relative to the Conjoined condition would demonstrate a facilitative effect of using a pronoun to refer to a salient antecedent and would support the interpretation of the N400 observed in previous research and in Experiment 1 as reflections of the RNP. Smaller negativity in frontal electrodes in the Single than in the Conjoined condition, similar to Experiment 1, would reinforce the interpretation of the LAN as indexing the effort related to processing reference to a referent embedded in a conjoined phrase.

Method

Participants—Eighteen different right handed participants (aged 18 to 30 years, 4 males and 14 females) participated in Experiment 2. All participants were native speakers of English, with normal or corrected-to-normal vision and were recruited and screened using the same procedure as in Experiment 1.

Materials—The same materials were used as in Experiment 1 except that the critical references in the experimental items were changed from repeated names to pronouns (see Table 2 for an example item).

Procedure and Analyses—The procedure and analyses were the same as in Experiment 1.

Results

Below we discuss the results by the ERP component of interest. Figure 5 shows the topographic maps of potentials from all 129 electrodes in the four conditions in 100 ms time windows. Figure 5 also shows topographic maps of the potential difference between the Single and Conjoined conditions in the Discourse and Sentence items. Figure 6 shows the ERP waveforms in the twelve electrode sites in the Sentence (6a) and Discourse (6b) conditions respectively.

N400 (300–500 msec)—Figure 7a shows the average potentials in the nine relevant electrode sites in the 300–500 ms time window following the target reference. The omnibus ANOVA found an effect of Laterality, $F(2, 38) = 7.341$, $p = .002$, and Salience, $F(2, 19) =$

5.084, $p = .036$. No other main or interaction effects were significant, F 's < 1.7 (except for the interactions between Construction and Laterality, $F(2, 38) = 2.628$, $p = .085$, and between Salience and Laterality, $F(2, 38) = 2.339$, $p = .110$).³

Overall, this analysis indicates (also see Figures 5–7) that in the 300–500 ms time window, pronouns elicited greater negativity on the left than on the right, and that pronouns in the single conditions elicited greater negativity than in the conjoined conditions.

Nref/LAN (300–700 msec)—Figure 7b shows the average potentials in the three frontal electrode sites in the 300–700 ms time window following the target reference. The ANOVA of these electrodes with factors Construction (Sentence, Discourse), Salience (Single, Conjoined) and Laterality (Left, Mid, Right) found a significant main effect of Salience, $F(1, 19) = 5.675$, $p = .028$, but no effects of Laterality, $F(2, 38) = 2.163$, $p = .145$, or Construction, $F < 1$. None of the interactions were significant, F 's < 1.22 .

These analyses therefore confirmed that, as is shown in Figures 5–7, the conjoined conditions elicited greater frontal negativity than the single conditions for pronouns in both sentences and discourse. Although this effect was numerically larger on the left than on the right, the difference in laterality was not significant.

Baseline check (–100–0 msec)—To confirm that there were no a priori differences in the critical word in the four conditions, we performed an omnibus analysis on a 100 millisecond time-window, starting from 100 milliseconds before the onset and extending up to the onset of the critical word. This analysis found no significant main or interaction effects, F 's < 1.2 .

Discussion

We discuss the results of Experiment 2 for each of the ERP components that we examined.

N400—In contrast to the predictions of DPT (Gordon & Hendrick, 1998), the N400 evoked by the pronouns in this experiment was mostly similar to (as opposed to a complementary image of) the N400 evoked by the repeated names in Experiment 1. A critical prediction of DPT stems from the role it assigns to referent salience in anaphor processing. In particular, it utilizes Centering Theory's notion of "order of prominence", whereby linguistic entities are ordered according to *attentional* salience (Grosz, Joshi, & Weinstein, 1995). Attentional salience can be affected by syntactic as well as word order factors. According to DPT, when a repeated name is used, referents are searched in an ascending order of salience, whereas in the case of pronouns, a search for a suitable referent proceeds in a descending order of salience. When the referent is the most salient entity in the discourse and a repeated reference is used, this search requires extra time, leading to the RNP. DPT therefore predicts

³We again wanted to assess to what extent the N400 effects we observed reflected the building up of expectations during the experiment and therefore, as in Experiment 1, repeated the N400 analysis using only the first third of the trials from each participant and, separately, from the last third of the trials. Given the much smaller number of trials and, consequently, the much reduced power of these analyses, we do not consider their results in detail but only note that the main effect of interest, reflected in the main effect of Construction was present in both early and late trials, although in the early trials it interacted with Anterior-posteriority, and in the late trials it interacted with laterality, showing that while it had a consistent effect throughout the experiment, the localization of this effect on the scalp may have shifted throughout the experiment.

an inverse relation between the processing of pronouns and the processing of repeated names for both salient and non-salient antecedents. In line with this view we expected to find a difference in the N400 elicited by pronouns in the Single and in the Conjoined conditions, with a reduced N400 in the Single relative to the Conjoined condition. However, we found that pronouns, like repeated names, elicited larger negativity in the Single relative to the Conjoined condition. This suggests that the N400 is not an ERP correlate of the RNP but instead reflects other factors. We discuss this question in detail in the general discussion. The fact that this experiment did not find a main or interaction effect involving Construction, suggests that the N400 effects in this study do not indicate a simple factor such as an expectancy of a null form, which perhaps could have been present in the Sentence conditions but not in the Discourse conditions.

Nref/LAN—Like the repeated names in Experiment 1, the pronouns in this experiment elicited greater negativity in frontal sites in the Conjoined than in the Single conditions. However, unlike the repeated names in Experiment 1, which evoked an overall greater negativity of the left side of the scalp, for the pronouns in this experiment, this effect was not lateralized. With the exception of this laterality difference, we thus observed a similar LAN effect for both repeated names and pronoun anaphors both within sentences and across sentence boundaries. This suggests that this effect reflects processes that are specific to referring back to a conjoined antecedent regardless of reference form and sentence boundaries. We discuss the further implications of this finding in the general discussion.

Finally, we should note that while the results of Experiment 1 are consistent with previous research, the results of Experiment 2 are not. In particular, Swaab et al. (2004), after which we modeled our experiments, did not find any differences in the N400 evoked by pronouns with single and conjoined antecedents. We believe that there are several factors that can explain the different results. First, we chose to test repeated names and pronouns in separate experiments so as to avoid confounds related to baseline differences between the two forms. As we explained in detail in the introduction, it could be that in an experiment that used a mix of these two expressions, differences between two conditions involving pronouns would be washed out by the much stronger differences between the two word forms and between the different conditions of the repeated names. Our design may simply allow for a cleaner comparison of the effect of the different antecedent types on each type of reference separately. A second difference between our study and Swaab et al.'s is in the system used for recording the EEG response. While Swaab et al. used a 30 electrode system we used a system with 129 electrodes that could provide an overall more sensitive measure of the ERP evoked by pronouns. A third and related difference is the fact that we used the centermost electrode (vref) as a physical reference and then re-referenced our data using the average over all the electrodes while Swaab et al. used the left mastoid as a physical reference and then used an average of the left and right mastoid electrodes for re-referencing. This difference could have made our setup more likely to capture subtle differences, especially in sites near the mastoids, where we had indeed observed the N400 effects.

A possible concern is that our study resulted in greater predictability of items than in Swaab et al.'s (2004). In particular, each condition in Swaab et al.'s study was half as frequent as the same condition in our experiments. Lau, Holcomb, & Kuperberg (2013) showed that the

N400 is highly sensitive to the predictability of a word in the experimental context, such that a strong N400 occurs when a word violates a strong prediction. It may therefore be that the clearer N400 effect for the pronouns in our Experiment 2 reflects stronger predictions made by our participants in comparison to Swaab et al., in which the conditions eliciting the N400 were less frequent, and thus, from the perspective of the participant, less predictable. However, our post hoc separate analyses of the first and last third of trials in each experiment suggest that this was not the case as the main differences we found occurred both early and late in our experiments.

General Discussion

Following several previous studies (e.g., Gordon et al., 1999; Swaab et al., 2004), we employed the single versus conjoined noun phrase contrast as a way to manipulate the salience of the antecedent. In line with this previous research, we found that subsequent repeated name subject anaphors evoked a greater N400 when referring to a single antecedent than when referring to an antecedent in a conjoined noun phrase. Experiment 1 replicated previous research by showing this effect for intra-sentential repeated name anaphors and extended previous research by showing a similar effect for inter-sentential (discourse) repeated name anaphors. Despite the finding of N400 for both sentence and discourse subject anaphors, there were topographical differences in the scalp distribution of the N400 for sentence anaphors and discourse anaphors, indicating that the processes indexed by the N400 are not identical for the two types of anaphors. In addition, Experiment 1 also revealed an increased Nref/LAN for repeated names referring to conjoined antecedents than to single ones and this effect was not different for sentence and discourse anaphors. In contrast to previous studies, our Experiment 2 found N400 differences for pronoun anaphors as well. Pronouns referring to a single antecedent elicited an increased N400 than pronouns referring to an antecedent embedded in a conjoined phrase. Indeed, the pronouns in this experiment elicited ERP responses that were similar to the responses elicited by the repeated names in Experiment 1 with the exception that, for the pronouns, there were no differences in the N400 scalp topography between the sentence and discourse conditions. Similar to Experiment 1, in Experiment 2 there was also a stronger Nref/LAN response for pronouns referring back to an antecedent in a conjoined phrase than to pronouns referring back to single antecedents. Unlike the N400 results, the differences in frontal negativity between the conditions had similar bilateral topographical distribution in both experiments.

A potential concern related to our Experiment 1 and the earlier studies by Swaab and colleagues (Camblin et al., 2007; Johns, Gordon, Long, & Swaab, 2014; Ledoux, Gordon, Camblin, & Swaab, 2007; Swaab, Camblin, & Gordon, 2004) is that the single antecedent condition with a repeated name in the sentence conditions induces a violation of Binding Theory's principle C (Chomsky, 1981), which states that referring expressions such as the repeated names we used in Experiment 1, should not have an antecedent in the syntactic position they did in our experiment and in the earlier studies. The N400 observed in our sentence conditions and in the previous studies could perhaps reflect a violation of this principle, which much more than other syntactic principles, has been controversial and violable in many contexts (e.g., Gordon & Hendrick, 1997), and may thus evoke an N400 rather than the P600 more often seen in cases of syntactic violations. However, the facts that

we also observed an N400 in the discourse conditions of Experiment 1 and that we observed an N400 effect for the pronouns in Experiment 2, which did not violate this principle, means that the only possible effect of violating Principle C could be in the N400 scalp distribution differences between the sentence and discourse conditions in Experiment 1. Given that there are no reports in the literature suggesting that a syntactic violation results in a shift in the scalp location of an N400, we do not find this a plausible explanation of the differences in the scalp distribution of the N400 in the sentence and discourse conditions of Experiment 1.

There are three general conclusions that we can draw from these results. First, the differences we saw in Experiment 1 between the sentence and discourse conditions in the scalp distribution of the N400 suggest that the underlying processes resulting in the N400 are different for sentence and discourse repeated name anaphors. If Swaab et al. (2004) were correct in arguing that the N400 reflects the RNP, then this result would be inconsistent with theories such as DPT (Gordon and Hendricks, 1998), which attribute the RNP to the same underlying process within and across sentences. According to DPT, anaphor processing is governed by a set of construction rules that operate in the same way for both sentence and discourse anaphors. Our results suggest that this may be an oversimplification and that the processing of sentence and discourse anaphors is differentially affected by the underlying memory processes. Crucially, the processing of within-sentence dependencies likely occurs as part of the incremental construction of the representation of the sentence. In contrast, the processing of inter-sentence discourse dependencies involves accessing and manipulating the already constructed representations of previous sentences. Thus, the processing of sentence and discourse anaphors could occur at different stages with respect to the identification and integration of the antecedent. Sentence anaphors may be processed before the representation of the antecedent has been fully integrated into the representation of the discourse, and discourse anaphors are likely to be processed after the representation of the antecedent has been consolidated into the representation of the discourse. This means that relative to the processing of sentence anaphors, the processing of discourse anaphors may be more strongly affected by memory factors related to the activation, retrieval, and manipulation of antecedent information.

The second conclusion is that, together, the results of our two experiments are in fact incompatible with previous claims that the increased N400 in the single than in the conjoined conditions reflects the RNP (Swaab et al. 2004). If these claims were correct, the pattern of N400 responses elicited by the repeated names in Experiment 1 and the pronouns in Experiment 2 should have been complementary, rather than similar.

The third conclusion is that the increased frontal negativity in the conjoined than in the single conditions, which we observed for both sentence and discourse references in both experiments, suggests that there is some effort involved in referring to an antecedent that is embedded in a conjoined noun phrase and that this effort is similar for sentence and discourse anaphors. This conclusion is compatible with Boiteau et al.'s (2014) fMRI study which revealed greater activation in parietal regions associated with the processing of references to conjoined antecedents.

We now turn to discuss the broader implications of our findings for the interpretation of N400 and the Nref/LAN in studies of reference processing.

N400 in reference processing

Our findings call into question the previous interpretation of the N400 as an ERP marker of the RNP, as was originally proposed by Swaab et al. (2004). Critically, unlike Swaab et al., who found no N400 differences for pronouns in the single and conjoined conditions, we found a clear difference that resembled the differences we found for repeated names, a difference which we attribute to the increased sensitivity in our experiments due to the testing of repeated names and pronouns in separate experiments, and our use of a high density electrode montage which may have been more sensitive to subtle effects.

Given the recent focus on the N400 as a marker of the predictability of a word in its sentence context (e.g., Kuperberg, 2016; Kutas & Federmeier, 2011; Kutas & Hillyard, 1984; Van Berkum et al. 2005; Van Petten & Luka, 2012), it may be that, rather than marking the fit between reference form and antecedent salience, the N400 elicited by anaphors reflects instead reference predictability. Before considering this possibility in more detail it is necessary to distinguish between different aspects of predictability that are relevant to the processing of anaphoric expression. As described by Kehler and his colleagues' Bayesian framework (Kehler, Kertz, Rohde, & Elman, 2008; Kehler & Rohde, 2013; Rohde & Kehler, 2014), comprehenders form probabilistic predictions about which referent is likely to be re-mentioned in the following discourse on the basis of the content of prior discourse. Once they encounter an anaphor, comprehenders update their prediction of which is the referent by integrating their initial predictions (priors) with the referential bias (evidence) provided by the form of the anaphor: pronouns are associated with a strong subject bias and fuller references are associated with biases towards less salient antecedents. This framework would therefore explain our findings as suggesting that the N400 may reflect the prior probability of making a reference to the antecedent regardless of which form is used to make this reference and would suggest that the referents in our experiments were more predictable as antecedents in both sentences and discourse when they were embedded in a conjoined phrase rather than when they appeared as a single noun phrase.

Although, without further research, we can only speculate on the reason for these differences in predictability, we believe that they may reflect a difference between the items in the single and conjoined condition in the amount of information they contain and therefore in the expectations they engender for subsequent information. The single conditions describe a single agent engaged in a relatively simple event, possibly making readers expect more information about the event. The conjoined conditions describe two agents participating in an event, possibly making readers expect either information about the event or on the relative roles of each of the participants, for example singling out one of the participants as being the driving force behind the action. This could make a reference to one of the participants in the event more predictable in the conjoined conditions than in the single conditions. The present data do not allow us to conclusively support this interpretation, which will therefore need to be directly addressed by future research.

Similarly, we can only speculate on the reason for the differences in scalp distribution of the N400 effects for repeated names in Experiment 1. A plausible interpretation is that the finding of a bilateral effect in the sentence conditions and a left lateralized effect in the discourse conditions indicates differences in the strengths of the expectations between the sentence and discourse contexts. While repeated name references were less likely in the single than in the conjoined conditions in both contexts, that difference could have been stronger in the sentence contexts than in the discourse contexts. The fact that, for pronouns, the scalp distribution of the N400 effects was similar in sentences and discourse shows that while both pronouns and repeated name references were more predictable in the conjoined than in the singular conditions, the mechanisms leading to these predictions were not identical for the two forms. At the same time, it is worth noting that fMRI studies of the RNP, though generally reporting bilateral parietal activity, also found stronger effects in the left angular gyrus (Boiteau et al., 2014) and left temporal lobe (Almor et al., 2007). However, these studies only looked at discourse effects and not intra-sentential reference, leaving this an open question for future research.

In summary, we believe that our results show that the N400 is not a good index for the discourse processes that lead to the RNP. This is compatible with extant theories' attribution of the RNP to integrative processing that may not occur immediately as the reference is processed. Rather, we believe the N400 can be useful as a more general marker of reference predictability, but not one that is necessarily sensitive to reference form. Indeed, this interpretation is compatible with the previous research on anaphor processing in contexts that do not elicit the RNP (e.g., non-subject anaphors or antecedents; Burkhardt, 2006; Ditman, Nieuwland & Kuperberg, 2009; Schumacher & Hung, 2012; Yang, Perfetti & Schmalhofer, 2007; Wang & Schumacher, 2013). In these studies, the N400 has consistently emerged as a marker of the effort associated with linking an anaphor to its antecedent, rather than with its overall integration with the discourse representation. This conclusion is important for the interpretation of ERP studies of reference processing. Of most relevance here, it appears that the integrative discourse processes underlying the RNP are either delayed beyond the anaphoric expression (Almor & Eimas, 2008; Almor & Nair, 2007; Peters, Boiteau & Almor 2016), or are simply not reflected in the N400 component.

Nref/LAN

Both repeated name references and pronouns elicited greater frontal negativity in the conjoined conditions than in the singular conditions. This effect was similar in both sentence and discourse contexts. Broadly interpreted, this result likely reflects an increased working memory load in the plural than in the single conditions, possibly due to the availability of multiple potential antecedents (Nieuwland, 2014). A likely reason for this is offered by previous research on plural references, which has shown that referring to a single entity in a conjoined phrase can lead to processing difficulty, and that in general, a conjoined reference is costlier to maintain in the discourse model (e.g., Albrecht & Clifton, 1998; Boiteau et al., 2014; Moxey, Sanford, Sturt, & Morrow, 2004; Patson & Warren, 2011). The differences we observed in frontal negativity suggest that rather than merely manipulating the salience of the antecedent, the single versus conjoined noun phrase manipulation results in a different number of potential antecedents in the different conditions. Importantly, while the single

noun phrase condition gives rise to only one possible antecedent, the conjoined noun phrase condition can engender three possible antecedents: the first noun, the second noun, and the conjoined noun phrase (Albrecht & Clifton, 1998). Because the Nref has been suggested to mark referential ambiguity (Nieuwland, 2014; Van Berkum et al., 1999), its presence after both repeated full names and pronouns in the conjoined conditions suggests that readers may have been uncertain about whether the repeated name anaphor would end up referring to just one of the nouns or to the entire conjoined noun phrase. Additionally, while there are important differences between the timing of the EEG and BOLD signal, as well as limitations inherent in localizing ERP components, the Nref may be related to activity in the frontal cortex that has been shown to play a crucial role in the decision-making aspect of referring and assigning new reference (Nieuwland, Petersson, & Van Berkum, 2007; McMillan et al., 2012).

Conclusion

Together with previous research, the present results suggest that many aspects of referential processing are initiated very rapidly and can be profitably studied by measuring the ERPs evoked by referential expressions. The N400 could provide a useful marker of reference predictability but not necessarily of the integrative processes involved in processing subject anaphors that give rise to the RNP. The Nref/LAN provides a useful marker of the number of competing antecedents. Our results further show differences in the scalp topography of N400 responses to repeated name anaphors in sentences and in discourse, suggesting differences between anaphor processing within and across clause boundaries. Finally, the present study shows that the single versus conjoined manipulation provides an interesting and productive way to uncover some of the memory processes underlying anaphoric resolution. However, our results also suggest that further research of effects like the RNP will need to employ more direct manipulations of antecedent salience that do not confound salience with the potential number of antecedents.

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Significance to the neurobiology of language

We show that the N400 likely reflects the predictability of reference, and not the fit between reference form and antecedent salience as was previously argued. On the other hand, the LAN likely indexes the complexity of the representations of referents in discourse. These results help advance the emerging understanding of the neural basis of reference processing. Specifically, these results reinforce the role of parietal regions in maintaining representations of referents during discourse comprehension and frontal regions in responding to referential ambiguity and failure.

Highlights

- We report two ERP experiments on pronoun and repeated name anaphors.
- Both forms elicit similar N400 but with differences in scalp topography.
- References to a conjoined antecedent elicit frontal negativity Nref/LAN.
- The N400 reflects reference likelihood regardless of reference form.
- The Nref/LAN shows that conjoined NPs introduce multiple possible antecedents.
- These results help support fMRI results about the role of parietal regions in reference tracking and frontal regions in dealing with reference ambiguity.

Figure 1.

Averaged electrode sites shown over the diagram of the EGI Geodesic Sensor Net 128 Channel V2.0 used in both experiments.

Figure 2. Topographic voltage map for Experiment 1 in 100 ms time windows. 0 marks the onset of the critical repeated name. The bottom two rows show potential differences between the single (salient) and conjoined (non-salient) conditions.

Figure 3. Experiment 1 grand-averaged waveforms to repeated names over the 12 average electrodes in the (a) sentence conditions and (b) the discourse conditions.

Figure 4.

Experiment 1 average potentials evoked by repeated names over the 12 average electrodes in the (a) N400 300–500 ms time window and (b) Nref/LAN 300–700 ms time window.

Figure 5.

Topographic voltage map for Experiment 2 in 100 ms time windows. 0 marks the onset of the critical pronoun. The bottom two rows show the potential differences between the single (salient) and conjoined (non-salient) conditions.

Figure 6.

Experiment 2 grand-averaged waveforms to pronouns over the 12 average electrodes in the (a) sentence conditions and (b) the discourse conditions.

Figure 7.

Experiment 2 average potentials evoked by pronouns over the 12 average electrodes in the (a) N400 300–500 ms time window and (b) Nref/LAN 300–700 ms time window.

Table 1

Sample item in all conditions in Experiments 1 and 2

Construction	Salience	
	Single	Conjoined
Sentence	John went to the store so that John (he) could buy some candy.	John and Mary went to the store so that John (he) could buy some candy.
Discourse	John went to the store. John (he) wished to buy some candy.	John and Mary went to the store. John (he) wished to buy some candy.

Note: Materials adapted from Swaab et al. (2004). Experiment 1 used the repeated name anaphor and Experiment 2 used the pronoun reference (shown in parentheses in the table).

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